Lake Water Quality State and Trends in Tāmaki Makaurau / Auckland 2014-2024

State of the Environment Reporting

Dr Jane Atoa (née Groom)

August 2025

Technical Report 2025/11

Lake water quality state and trends in Tāmaki Makaurau / Auckland 2014-2024

State of the environment reporting

August 2025 Technical Report 2025/11

Dr Jane Atoa (née Groom)

Environmental Evaluation and Monitoring Unit, EEMU

Auckland Council
Technical Report 2025/11

ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-991377-71-5 (PDF)

The Peer Review Panel reviewed this report
Review completed on 13 August 2025 Reviewed by two reviewers
Approved for Auckland Council publication by: Name: Paul Klinac Position: General Manager, Engineering, Assets and Technical Advisory
Recommended for approval/publication by:
Name: Dr Jonathan Benge Position: Head of Environmental Evaluation and Monitoring
Name: Sietse Bouma Position: Team Manager, Water Quality, Environmental Evaluation and Monitoring Unit (EEMU)
Date: 13 August 2025

Recommended citation
Atoa, J (2025). Lake water quality state and trends in Tāmaki Makaurau / Auckland 2014-2024. State of the environment reporting. Auckland Council technical report, TR2025/11

Cover image: Lake Wainamu. Photograph by Julia O'Grady, Environmental Specialist, Auckland Council.

Executive summary

There are approximately 108 waterbodies over one hectare in area within the Tāmaki Makaurau / Auckland region. These include natural lakes and lakes formed from human activity, such as dams, constructed or quarry lakes. Several pressures affect the health of lakes across the region including, but not limited to, catchment land cover, coarse fish, presence of invasive species, internal nutrient loading and a changing climate. Auckland Council undertakes long-term monitoring of lake water quality as part of its State of the Environment reporting. This monitoring assesses the current health of lakes in the region, detects trends in water quality and evaluates the effectiveness of council initiatives, policies and lake management strategies. The lake water quality programme started in 1988 with quarterly sampling at seven lakes across the region and expanded in 2020 to include more frequent sampling at thirteen lakes.

This report provides an overview of the current state of lake water quality (e.g. nutrients, algae and clarity) and ecology (e.g. submerged plants) at thirteen lakes and identifies trends in water quality for four lakes over the most recent 10-year period (2014-2024). Analysis includes surface and bottom waters, where available, for each of the lakes. Assessment of lake condition uses water quality parameters and ecological indicators and is graded according to the National Policy Statement for Freshwater Management (NPS-FM 2020).

Most lakes in Tāmaki Makaurau / Auckland were in poor condition (12 out of 13 lakes) according to the lake Trophic Level Index (TLI), with elevated nutrient and algae concentrations, poor water clarity and poor ecological condition of submerged macrophytes. Lake Rototoa had the best water quality in the region and was in a high ecological condition based on assessments of submerged plants (LakeSPI). Lake Keretā had the worst water quality in the region and was in a non-vegetated, algal dominated state.

Lake mixing type influences lake health. Shallow, polymictic (well-mixed) lakes were in worse health than the deeper, seasonally stratified lakes. In seasonally stratified lakes, higher nutrient concentrations in the bottom waters, coupled with persistent anoxia, suggest that internal nutrient loading (nutrient release from lakebed sediments) contributes towards nutrient enrichment in these lakes.

Trend analysis for four lakes that have data available for the 10-year trend period July 2014 – June 2024 (Lake Pupuke, Lake Rototoa, Lake Tomorata and Lake Wainamu) showed mainly degrading trends.

Lake Pupuke had elevated nutrient concentrations in the bottom waters and had a range of algae concentrations, indicating algal blooms occurring at times. Despite this, water clarity was one of the highest in the Auckland region. Degrading trends in bottom water nutrients and turbidity, and temperatures and dissolved oxygen throughout the water column show that the lake is vulnerable to declining water quality. Key drivers of declining water quality in Lake Pupuke include the presence of pest fish, the high biomass of invasive macrophytes, nutrient loading from nutrient-rich sediments within the lake and anoxic conditions that could worsen with a changing climate, fuelling further nutrient loading.

Lake Rototoa had good water quality, with high water clarity. However, degrading trends in nutrient parameters suggest declining water quality may result in adverse changes. There was evidence of internal nutrient loading due to higher nutrient concentrations in the bottom waters of the lake. Auckland Council's ongoing work on the management of pest fish, invasive macrophyte control, and kākahi conservation are helping to maintain and improve the high ecological values of the lake.

Lake Tomorata was in a poor eutrophic state with nutrient enrichment, algal blooms and poor water clarity. There were mostly degrading trends in nutrient parameters, algae and sediment parameters, suggesting lake health may worsen if there are no interventions in the lake. However, the intensive pest fish removal within the lake is promising. If fish numbers decline, zooplankton populations may increase, which consume phytoplankton, and therefore there may be reductions in algal concentrations within the lake.

Lake Wainamu had elevated nutrient and algae concentrations, high turbidity and poor water clarity. Several pest fish species were present, and no submerged vegetation, resulting in a turbid, algal dominant state. Despite the surrounding native forest catchment, the lake had poor water quality and is vulnerable to further decline. Pressures from pest fish, nutrient enrichment, recreational use of the lake and catchment erosion all contribute towards declining water quality in the lake.

The lake water quality programme expansion in 2020 has provided a more representative assessment of lake health across the Auckland region. Most lakes are in poor health, with several pressures including invasive species and nutrient enrichment. Some lakes are in a good state, but degrading trends in water quality demonstrate their vulnerability to decline in the future. Management efforts are ongoing in some lakes, including pest fish control, invasive plant eradication, biodiversity conservation, and the development of lake-specific management plans. Continued monitoring and management are needed to maintain and enhance the ecological values of Auckland's lakes.

Table of contents

1 Introduction

Lakes around New Zealand are important for their ecological, social, economic, recreational and cultural values. A healthy lake has good water quality, high ecological values (e.g., fish, submerged plants, birds) and is surrounded by a landscape that supports these values. For Māori, water is a taonga and essential to life and identity, with lakes providing great cultural significance, and opportunities for mahinga kai (e.g., kōura, kākahi and tuna).

There are approximately 108 waterbodies over one hectare in area within the Tāmaki Makaurau / Auckland region that are over one hectare in area (Schallenberg et al, 2024), excluding wastewater ponds. Of these waterbodies, 76 are classified as artificial, meaning they are formed from human activity and include dams, constructed or quarry lakes. Most naturally formed lakes in the region are dune lakes, except for Lake Pupuke, which is a deep volcanic lake.

The condition of lakes across the Auckland region is influenced by both natural factors, such as geology and seasonal variations in rainfall and temperature, and human activities, including land use changes and the spread of invasive species.

Monitoring lake water quality and ecological health is essential for gaining an understanding of the physical, chemical, and biological condition of the region's lakes. This information is used to assess their ability to support biodiversity and their suitability for recreational use.

1.1 National and regional directives

Auckland Council's lake water quality monitoring programme offers insight into the condition of the region's lake environments, tracks progress toward environmental goals and evaluates the effectiveness of management actions. The programme forms part of the feedback loop that helps evaluate whether management strategies implemented under the Auckland Unitary Plan are effectively restoring, maintaining and enhancing the values of Auckland's freshwater resources. In particular, the programme is designed to meet the following national and regional objectives:

- Fulfil Auckland Council's responsibilities under section 35 of the Resource Management Act 1991 (RMA) to monitor and report on state and trends of lakes in the Auckland region.
- Contribute to Auckland Council's ability to maintain and enhance the quality of the environment (Local Government Act 2002). Meet Auckland Council's obligations under the National Policy Statement for Freshwater Management (NPS-FM 2020), including monitoring key attributes to provide evidence of improving or declining lake health (MfE, 2024).
- Provide information to Māori that supports them in their role as kaitiaki to protect and enhance te mauri o te wai (the life supporting capacity of water).
- Inform the efficacy and efficiency of regional policy initiatives and strategies.
- Assist in identifying impacts of land use activities and on-lake activities on lake health.

- Provide baseline data to support resource consent processes and related compliance monitoring for lake environments.
- Enhance public understanding among Aucklanders of lake water quality issues in the region and promote awareness of effective management strategies.
- Contribute lake health data to support national environmental reporting initiatives.

1.2 Report purpose and objectives

The report's purpose is to assess the current state of lake health of monitored lakes across the Auckland region and to identify water quality trends over time for lakes with sufficient data.

The primary objectives of this report are to:

- Describe the current state of lake health in the region through the assessment of water quality, trophic state, ecological indicators and NPS-FM 2020 attributes.
- Identify temporal trends in key indicators for lakes that have robust long-term data.

Previous reports on the state and trends of lake water quality in seven Auckland lakes were published in 2005, covering the period from 1992 to 2005 (Barnes & Burns, 2005), and again in 2015, focusing on the period from 1992 to 2012 (Hamill & Lockie, 2015). The most recent report, published in 2021, analysed data from 2010 to 2019 for the four lakes with available data during that time (Groom, 2021). For this report, the current state of lake health is reported for 13 monitored lakes, and trends are assessed for only the four lakes where data are available across the most recent 10-year period (2014-2024).

1.3 Supporting information

This report is one of a series of technical publications prepared in support of *Te oranga o te taiao o Tāmaki Makaurau – The health of Tāmaki Makaurau Auckland's Natural Environment in 2025: a synthesis of Auckland Council State of the Environment reporting*.

All related reports (past and present) are published on the Knowledge Auckland website.

All data supporting this report can be requested through our Environment Auckland Data Portal. Here you can also view live rainfall, river flow and air quality data and use several data explorer tools including the Water Quality and River Ecology Data Explorer which provides summary statistics and interactive graphics for lake water quality data collected from July 2020 to June 2024. Readers can explore further insights through the explorer, which presents the latest information on all lakes.

2 Methods

2.1 Programme overview

Since 1988, Auckland Council has monitored water quality in seven naturally formed lakes across the region: Keretā, Kuwakatai, Rototoa, Spectacle, Tomorata, Pupuke, and Wainamu. Lake Pupuke has some earlier data, dating back to 1977. Along with water quality monitoring, periodic assessments of submerged aquatic plants (macrophytes) offer valuable insight into ecological health of each lake.

The seven lakes were initially chosen because they are naturally formed lakes, represent different lake types (dune and volcanic lakes), differed in water quality state at programme inception and are located in catchments with different land cover types.

The programme has evolved to align with shifts in management priorities. Sites have been added or removed over time (Table 1). The programme paused mid-2013 and resumed in late 2014 with a reduced site list, excluding Lake Keretā and Lake Spectacle. In late 2017, Lake Kuwakatai was removed and replaced with Lake Whatihua. Lake Kuwakatai was removed because it had been in a relatively stable, albeit degraded, state for a long time (Hamill & Lockie, 2015), and it is not publicly accessible. Lake Whatihua was added to include a lake from the Āwhitu Peninsula dune lakes series.

In 2020, the programme expanded to include 13 lakes and transitioned to monthly sampling. This expansion reintroduced some previously monitored lakes and added new ones (Table 1).

Table 1. Duration of monitoring for each lake in the Auckland Council monitoring programme.

Lake	Duration of monitoring
Pupuke	1977 – present
Rototoa	1988 – present
Tomorata	1988 – present
Wainamu	1988 – present
Kuwakatai	1988-2017 2020 – present
Keretā	1988-2013 2020 – present
Spectacle	1988-2013 2020 – present
Whatihua	2017 – present
Te Kanae	2020 – present
Ōkaihau	2020 – present
Kawaupaku	2020 – present
Pokorua	2020 – present
Slipper	2020 – present

Although some lakes have long-term quarterly datasets, changes to programme logistics complicate comparisons over time. These include changes in sampling run order (affecting timing), changes in laboratory providers, and a redesign of the sampling protocol in 2004–2005. The change in sampling protocol altered the depths at which surface and bottom water samples were taken, resulting in deeper sampling for most lakes. This change particularly affected bottom water quality results, and previously reported trends should be interpreted with caution (Hamill & Lockie, 2015). More discussion on recent changes in laboratory providers is presented in Section 2.4.1.

This report presents the current lake health status for all 13 monitored lakes. Trend analysis, however, is limited to the four lakes with available data between 2014 and 2024: Pupuke, Rototoa, Tomorata, and Wainamu.

2.2 Monitored lakes

The locations of the monitored lakes in Auckland are shown in Figure 1.

Figure 1. Lakes monitored for water quality within the Auckland region.

Table 2 presents key characteristics of all monitored lakes in Auckland. These lakes have a variety of catchment land cover, geology, depths, mixing regimes and stream connectivity. Most of the lakes are not influenced by permanent stream inflow, but are instead primarily fed by direct precipitation, overland flow, ephemeral streams, drainage channels and groundwater.

Table 2. Characteristics of lakes monitored for water quality across the Auckland region.

Lake	Area	Lake type	Max depth (m)	Mixing type	Dominant land cover category	Rock group (geology)
Rototoa	South Head	Dune	27	Seasonally stratified	Rural low	Sandstone
Kuwakatai	South Head	Dune	15	Seasonally stratified	Rural high	Sandstone
Keretā	South Head	Dune	2	Polymictic	Rural low	Sandstone
Te Kanae	South Head	Dune	18	Seasonally stratified	Rural low	Sandstone
Ōkaihau	West Coast	Dune	12	Seasonally stratified	Rural low	Sandstone
Kawaupaku	West Coast	Dune	20	Seasonally stratified	Native forest	Conglomerate
Wainamu	West Coast	Dune	15	Seasonally stratified	Native forest	Conglomerate, sandstone
Pokorua	Āwhitu	Dune	4	Polymictic	Rural high	Mudstone
Whatihua	Āwhitu	Dune	11	Seasonally stratified	Rural high	Sandstone
Pupuke	Central	Volcanic	57	Seasonally stratified	Urban	Tuff, basalt
Slipper	Te Arai	Dune	5	Polymictic	Rural high	Sandstone, greywacke
Spectacle	Te Arai	Dune	5	Polymictic	Rural high	Sandstone, mudstone
Tomorata	Te Arai	Dune	5	Polymictic	Exotic forest	Sandstone

2.2.1 Catchment land cover

Current catchment-scale land cover for each lake was determined using a desktop-based manual mapping approach based on satellite imagery from 2023-2024 (Auckland Council, 2025). Following this, land cover descriptors were assessed and aggregated according to seven broad land cover types: native forest, exotic forest, rural, urban, wetland, water and other (Figure 2).

The dominant land cover categories for each catchment in this report were determined according to the following decision criteria:

- Native forest – more than 95 per cent native forest or scrub.
- Exotic forest – more than 80 per cent within exotic forestry.
- Urban – more than 7 per cent urban land cover.

Sites not meeting the above criteria were classified as having predominantly rural land cover under the following categories:

- Rural low – rural catchment with more than 50 per cent forest cover (native and exotic).
- Rural high – rural catchment with less than 50 per cent forest cover.

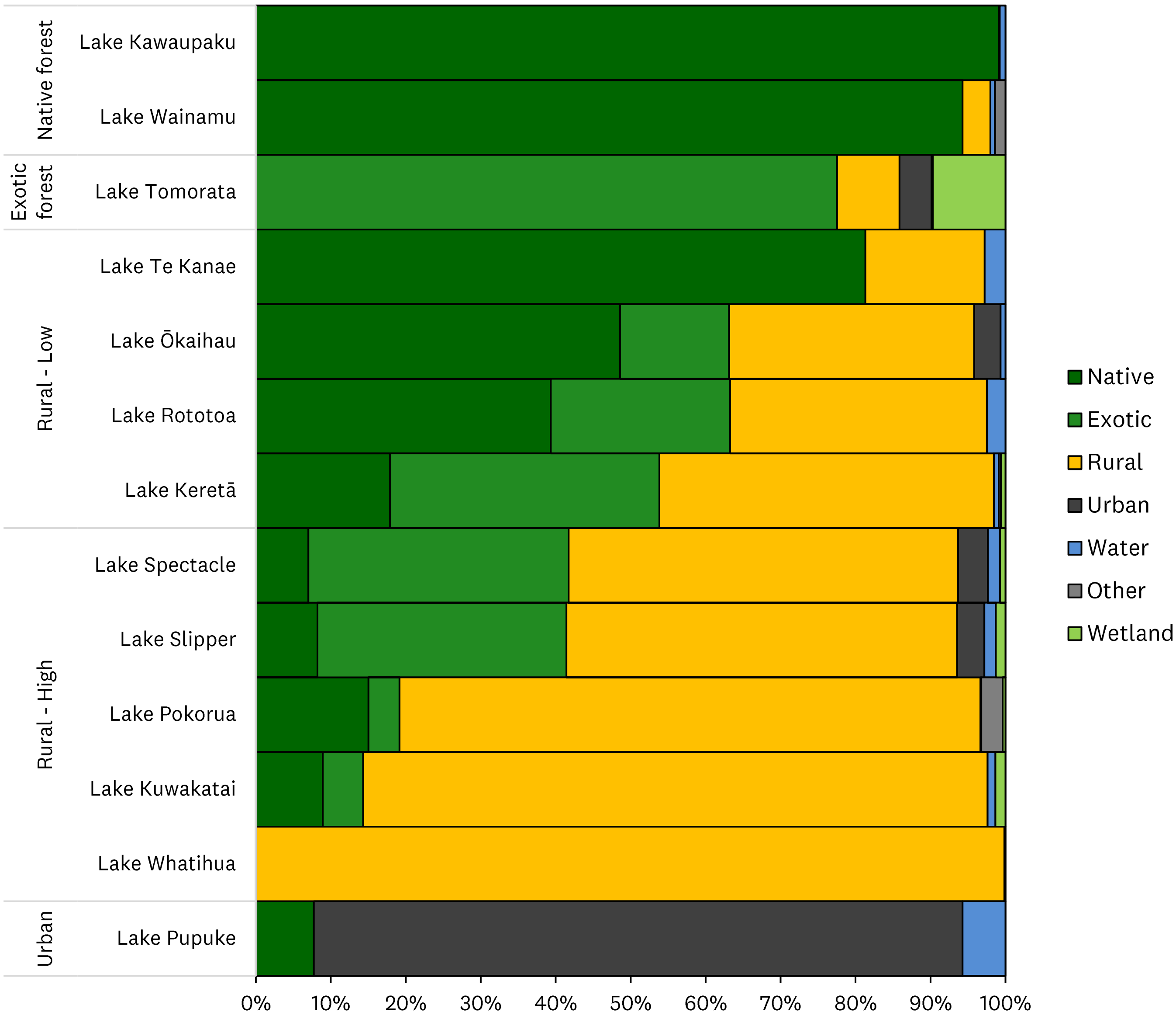


Figure 2. Land cover for monitored lakes across the Auckland region. Source: Auckland Council (2025).

2.3 Data collection

Between 2014 and 2024, the frequency of lake water quality monitoring changed over time. Before 2020, samples were taken quarterly or six times a year. Since 2020, sampling has occurred monthly. Due to the limited number of samples collected in the earlier years, a single event, such as an algal bloom, could skew the results, and seasonal patterns may not have been fully captured.

Monitoring methods were generally consistent with the New Zealand lake water quality monitoring protocols (Burns et. al. 2000). Each lake was sampled at the deepest point, permanently marked by a buoy. Vertical profiles were collected at one-metre intervals throughout the water column using an EXO Sonde, extending to the maximum depth, measuring temperature, dissolved oxygen, salinity, conductivity, pH, and turbidity. Water clarity from the surface of the lake was recorded using the Secchi disc method.

All samples were collected using a Van Dorn sampler at the appropriate depth according to the Burns et al. (2000) protocol. Shallow, polymictic lakes (less than 6 metres deep) had a single sample collected at a quarter of the maximum depth, referred to here as the surface waters. For deeper, seasonally stratified lakes, samples were collected from the epilimnion (referred to as the surface waters), and another sample was collected from the hypolimnion (referred to as the bottom waters), with depths determined by stratification status.

The temperature profile was used in the field to assess whether the lake was stratified or isothermal. A lake is stratified when the difference between the surface temperature and the bottom water temperature is greater than 3°C (Burns et. al. 2000). If the temperature difference is less than 3°C, then the lake is classified as isothermal. The classification of the lake on the day of sampling determined the depth at which water samples were collected.

When the lake was isothermal (i.e. mixed), the surface sample was taken at a quarter of the maximum depth. The bottom water sample was taken at either ¾ of the maximum depth if no anoxia is present, or at the mid-point of the anoxic zone if anoxia is present for greater than six metres. When the lake was stratified, the surface water sample was taken at the mid-point of the epilimnion or if the epilimnion is greater than five metres, a composite sample is taken from 0.2 metres, a quarter, a half and ¾ depth of the epilimnion. The bottom water sample was taken either at the mid-point of the hypolimnion if there is no anoxic layer greater than six metres, or it is taken at the mid-point of the anoxic layer (if greater than six metres in depth).

E. coli and cyanobacteria are measured as indicators of human health risks. The *E. coli* sample was taken from the surface of the lake (e.g., 10 – 20 cm depth) using a sterile bottle. The cyanobacteria sample was taken using a 5m tube to collect a composite sample of the upper five metres of surface water. Sampling at the deepest part of the lake may not reflect the exposure risk at the location used for human contact, and so a separate summer cyanobacteria surveillance programme is undertaken at the shoreline of publicly accessible locations to assess this risk further.

Nutrients, algae, suspended particles, and other chemical properties of water were all analysed in the laboratory (see Appendix 1 for summary of water quality parameters). Watercare Services Ltd. analysed samples prior to June 2017 and R.J. Hills Laboratories Ltd. analysed samples from July 2017 onwards (see Appendix 2 for information on changes in analytical methods and detection limits over time).

2.4 Data processing

All data underwent quality assurance to ensure consistency before analysis. Auckland Council adopted the NEMS quality coding (QC) framework in January 2020 (NEMS, 2020). Data collected prior to this used the IANZ-certified Auckland Council Hydrological 10-151 QC system. Earlier data met best practice standards of their respective periods. Data identified as poor quality, due to non-compliance with NEMS standards, equipment malfunctions, or erroneous values, were excluded from all analyses.

Values below the detection limit for any water quality parameter are considered 'left censored' values. To calculate state statistics, these values were replaced with imputed values generated using ROS (Regression on Order Statistics; Helsel 2012), following the procedure described in Larned et al. (2018). The ROS procedure estimates values for the censored data based on the distribution of uncensored values and can accommodate multiple detection limits.

For trend analysis, censored values were treated according to Helsel (2005, 2012, in Fraser & Snelder, 2025), using methods that are robust to changes in detection limits over time. When assessing trend direction, increases or decreases in a water quality variable were identified wherever possible. A change from a censored value of <1 to a measured value of 10 was considered an increase. A change from a censored value of <1 to a measured value 0.5 was considered a tie, as is a change from <1 to a <5, because neither can definitively be called an increase or decrease (Fraser & Snelder, 2025). When assessing trend magnitude using Sen slopes, (see Section 2.5.2 for further information) left censored values were substituted with their raw values (i.e., the numeric component of the detection limit) multiplied by 0.5. This step ensures that any values measured exactly at a detection limit are treated as being larger than values less than the detection limit (which would be the case if the raw values were not multiplied by 0.5) (Fraser & Snelder, 2025).

2.4.1 Step changes in data

As mentioned in Section 2.3, Auckland Council changed laboratory providers in July 2017. There were changes in analytical methods, and/or detection limits for several water quality parameters (see Appendix 2), which may have introduced step changes in the data. Step changes may create artificial trends that are an artefact of the laboratory change rather than a true change in the environment.

There is a clear example of step change across several lakes in dissolved reactive phosphorus, where there is a shift to lower values following the laboratory change in 2017 (Figure 3). Trend analysis over a 15-year period (July 2009 – June 2024) would indicate that dissolved reactive phosphorus is decreasing (i.e. improving). However, when the data is split for July 2009 – June 2017 (pre-laboratory change) and July 2017 – June 2024 (post-laboratory change), trends for both these time periods indicate dissolved reactive phosphorus is increasing (i.e. degrading). Therefore, reporting the trend across the laboratory change period would be reporting an artificial trend that is not a true reflection of the data. As a result, trends for this parameter across all lakes are excluded from reporting, however this parameter is included in state assessments.

In other parameters, no obvious step change is identified and therefore trends across the 10-year period are reported. However, subtle effects of the laboratory change may be present. Identifying these changes is difficult due to the quarterly sampling frequency at the time of the laboratory change. The shift to monthly sampling captures more variability in the data across several parameters, which may distort some of the trends reported here. Therefore, all trends should be interpreted with caution, as an undetected step change may still influence the results.

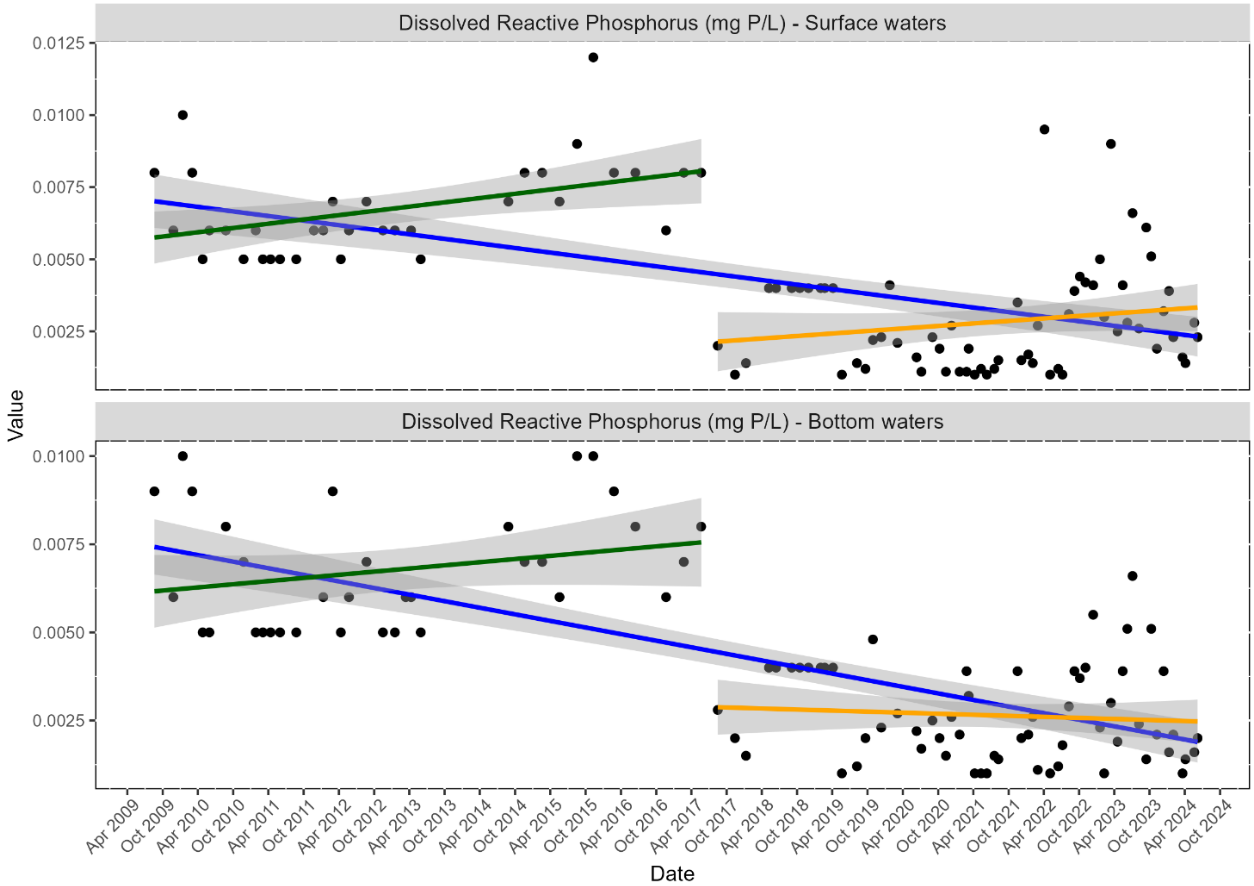


Figure 3. Evidence of step changes in dissolved reactive phosphorus in Lake Wainamu over a 15-year period. The green line is the trend line between July 2009 – June 2017 (pre-laboratory change), the orange line is the trend line between July 2017 – June 2024 (post-laboratory change), and the blue line is the trend line for the whole 15-year period.

2.5 Data analysis

2.5.1 State analysis

The current state of lake health was assessed for a five-year period where data were available (July 2019 – June 2024), or for a four-year period (July 2020 – June 2024) for lakes added to the programme more recently. Data are visualised using boxplots[1] separated into surface and bottom water groupings. Annual Trophic Level Index scores (TLI, Burns et al., 2005), the most recent Lake Submerged Plant Index (LakeSPI) ecological assessments (de Winton *et al.*, 2022; Hussain, 2025) and

[1] All boxplots and statistics are calculated/drawn using Hazen percentiles.

NPS-FM 2020 grading for water quality and human contact attributes (MfE, 2024 Appendix 2A) are also presented as described below.

2.5.1.1 Trophic Level Index

The state of lakes can be summarised using four water quality parameters that assess the life supporting capacity of a lake (see Appendix 1 for descriptions of these parameters). These are:

- Chlorophyll a
- Water clarity
- Total phosphorus
- Total nitrogen

The Trophic Level Index (TLI) is calculated using the annual[2] mean of each variable from the surface water samples only. The following regression equations were used to calculate the TLI (Burns et al. 2005):

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

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

$$TL_S = 5.10 + 2.6 \log\left(\frac{1}{SD} - \frac{1}{40}\right)$$

$$TL_C = 2.22 + 2.54 \log(Chl\ a)$$

$$TLI = \frac{(TL_N + TL_P + TL_S + TL_C)}{4}$$

Where:

TN = total nitrogen (mg/m^3)

TP = total phosphorus (mg/m^3)

SD = Secchi depth (m)

Chl a = chlorophyll a (mg/m^3)

The results of each of these parameters together produce the Trophic Level Index (TLI), as shown in Table 3. The TLI generates a number between 0 and 7, with a lower number indicating better water quality.

[2] Annual mean calculated based on the hydrological year July – June.

Table 3. Trophic Level Index descriptions (Burns et al. 2005; LAWA, 2024).

TLI	Trophic Level State	Category	Description
< 2	Microtrophic	Very good	Very low nutrient levels and algae, with very high water clarity.
2-3	Oligotrophic	Good	Low levels of nutrients and algae, with high water clarity.
3-4	Mesotrophic	Fair	Moderate levels of nutrients and algae.
4-5	Eutrophic	Poor	Elevated levels of nutrients and algae, with low water clarity.
5-6	Supertrophic	Very poor	Saturated with nutrients, high algae growth with blooms possible in summer. Very low water clarity.
>6	Hypertrophic	Very poor	Super-saturated with nutrients, very high algae growth with blooms common in summer. Very low water quality.

2.5.1.2 Lake ecology

Surveys were conducted to assess the ecological condition of lakes based on their macrophyte (underwater plant) communities. Macrophytes are useful indicators of ecological condition because of their size, ease of identification, and perennial nature.

Key features of the macrophyte community structure and composition were used to produce three indices using the LakeSPI (Submerged Plant Indicators) tool (de Winton and Burton, 2017):

- LakeSPI index – This is an overall index of the plant community (the higher the score, the better the ecological condition of the lake).
- Native condition index – This index is based on the diversity and quality of native submerged plants (the higher the score, the better).
- Invasive condition index – This index is based on the degree of impact of invasive weed species (the lower the score, the better).

The LakeSPI index enables each lake to be assigned an overall condition class using the ranges shown in Table 4.

Table 4. Descriptions of LakeSPI scores (de Winton and Burton, 2017).

LakeSPI	Condition
> 75	Excellent
50-75	Good
20-50	Fair
1-20	Poor
0	Non-vegetated

2.5.1.3 NPS-FM 2020 attributes

Auckland Council has obligations under the National Policy Statement for Freshwater Management (NPS-FM 2020) to report on the state of lakes in accordance with the National Objectives Framework (NOF, MfE 2024, Appendix 2A attributes).

The NOF identifies a core group of attributes that councils must use to assess the quality of lake surface water. State is assessed by grading attributes into specific bands using various statistical metrics. Each band (A – best, B, C, D/E – worst) includes a narrative description of the expected ecological or human contact outcome. The 'National Bottom Line' refers to the minimum acceptable state for each attribute that councils must meet, or work towards over time. The lowest (worst) band of the contributing metrics determines the overall band for that attribute state assessment.

This state assessment focuses on the best available surface water quality data recorded over the preceding five years (July 2019 – June 2024 inclusive). All statistics were calculated using Hazen percentiles. To analyse state, a minimum of 80 percent of samples for each lake, from a minimum of 80 percent of years must be available. For example, in a five-year assessment period with monthly sampling, a minimum of 48 samples is needed, and for quarterly sampling, a minimum of 18 samples is needed. This helps maintain a consistent standard for generating robust summary statistics, in accordance with the principles outlined in McBride (2016) and five-year assessment period is consistent with national reporting of lake water quality state (Whitehead *et al.,* 2021). It is not realistic to require 100% of samples, as this would not allow for missed sampling events due to unforeseen circumstances or risks to health and safety, or for the exclusion of data that do not meet quality standards.

Lakes added to the monitoring programme in 2020 are displayed as 'interim' results as they do not meet the full data requirements. This enables data from these newly established sites or parameters to be shared sooner while also providing a reasonable estimate of summary statistics (McBride, 2016).

2.5.1.3.1 Attribute specific analysis

Total ammoniacal nitrogen refers to two chemical species that are in equilibrium in water: toxic ammonia (NH_3) and the relatively non-toxic ammonium ion (NH_4^+). The proportion of the two varies, particularly in response to pH and temperature. The attribute bands in the NOF for ammoniacal nitrogen are based on a pH of 8.0 and assume a temperature of 20°C. Total ammoniacal nitrogen results are adjusted for pH following a conversion table, as prescribed by the Ministry for the Environment (MfE, 2017a) for comparison to NOF guidelines only.

For the two dissolved oxygen attributes (lake-bottom and mid-hypolimnetic), data from the vertical profiles (every one metre) throughout the water column was analysed using the rLakeAnalyzer package (Winslow *et al.,* 2022). The lake-bottom water dissolved oxygen is calculated from the maximum depth value in the vertical profile (which is taken one metre from the lake bed). The mid-hypolimnetic dissolved oxygen is calculated using the temperature profile data to determine the depth of the thermocline and depth of the hypolimnion. The dissolved oxygen value from the mid-point of the hypolimnion is then extracted for each sampling occasion. For each attribute assessment, the minimum value across the five-year state assessment period is used.

Submerged plant attributes used the two native and invasive species indices within the LakeSPI method (see Section 2.5.1.2 above).

2.5.2 Trend analysis

Trend analysis for the most recent 10-year period (July 2014 – June 2024) was completed using a purpose-written script designed for water quality trend analysis (Fraser & Snelder, 2025) using the R statistical package (R Core Team, 2023). Details of the trend method can be found in Fraser & Snelder (2025), Fraser (2023), and Whitehead *et al.* (2021), and are briefly summarised below.

During this period, the sampling frequency varied, including a shift in 2020 from quarterly sampling to monthly sampling. To maintain consistency, all trends were analysed using quarterly time steps. When there were multiple samples within a quarter, e.g., after 2020 when monthly sampling began, the median value from those samples was used for the trend analysis.

Lakes qualified for trend analysis if the minimum data requirement was met – 80 per cent of the years (i.e., the maximum possible number of quarters over the 10-year period of analysis is 40, therefore a minimum of 32 quarters is required for this analysis), in line with previous national level reporting (Whitehead *et al.,* 2021). Any sites or parameters that did not meet these data requirements were not analysed, and therefore no trends were reported.

Seasonality was assessed using the Kruskal-Wallis test to identify if seasons explain variation in the water quality variable. Monotonic trends across sites were analysed by assessing the direction of a trend (i.e., what is the likelihood the parameter is increasing or decreasing?). The confidence in the trend direction was calculated using the Kendall, or seasonal Mann-Kendall, test based on the probability that the trend was decreasing. In seasonal tests, water quality observations were compared within each quarter over time and summed for each season. In non-seasonal tests, all water quality observations were compared over time. An overarching assumption of the trend analysis was that there are always differences between observations (McBride, 2019). The calculated numerical probability was interpreted based on five categories used by LAWA (Cawthron Institute, 2024) (see Table 5).

For most parameters, a decreasing trend is interpreted as an improvement in lake water quality, and an increasing trend is a degradation in lake water quality. For parameters such as water clarity and dissolved oxygen, trends are reversed, whereby a decreasing trend is interpreted as a degradation in lake water quality, and an increasing trend is an improvement. A trend is classified as low confidence when there is insufficient evidence to determine if the data is trending in a particular direction.

Table 5. Trend confidence category levels used to determine the direction of water quality trends (Cawthron Institute, 2019).

Trend categories	Probability of improving trend (%)
Very likely improving	90-100
Likely improving	67-90
Low confidence	33-67
Likely degrading	10-33
Very likely degrading	0-10

Where water quality is found to be degrading, further assessment is critical to understand what actions may be necessary to improve water quality. This includes assessment of the likelihood of the trend, the magnitude of the trend and the risk of adverse ecological outcomes (in relation to the known current state).

The magnitude of the trend is calculated using the Sen slope estimator (SSE) (or the seasonal version (SSSE)). The SSE is the median of all possible inter-observation slopes (i.e., the difference between each measured observation divided by the time between sample dates). The seasonal variant (SSSE) calculates the median inter-observation slopes for each season and then takes the median across seasons. The 90% confidence intervals of the trend magnitude are also calculated (Fraser & Snelder, 2025).

While a trend may be very likely improving or degrading, the smaller the Sen slope, or rate of change, the longer it would take to be reflected in assessments of the current state, assuming a linear rate of change. The confidence in the direction of the trend and estimation of the magnitude of the trend decreases in reliability as the proportion of censored values increases. The Sen slope may be zero where there is a high proportion of censored data in the dataset or tied non-censored values.

3 Pressures on current lake health

There are multiple pressures on lake health across the lakes in Auckland. Further details can be found in Hussain (2025), but in summary, the primary pressures affecting most lakes are:

- Coarse fish – The presence of pest fish have a number of impacts on lake health including competing with native aquatic species, adding nutrients to the water through excrement, grazing on macrophytes and zooplankton (which disrupts the trophic cascade, reducing the grazing pressure on phytoplankton, and therefore the potential for increased algal blooms), and benthivorous feeding disturbing lakebed sediments (which can contribute to internal nutrient loading and reduced water clarity).
- Invasive weeds – Invasive macrophytes such as Hornwort and Egeria are present in most vegetated lakes. They outcompete native species and can prevent regrowth of native macrophytes. These dense macrophyte beds block light, trap fine sediment and cause anoxia, which can result in nutrient release from the sediments and create degraded littoral habitats in the lakes. When invasive macrophytes die, they release nutrients into the water which can further contribute to nutrient enrichment.
- Nutrient enrichment – Surrounding rural catchments can contribute nutrients, sediment, and pathogens to lakes, especially where riparian margins are poor. In some lakes, internal nutrient loading occurs, exacerbated by prolonged anoxia and fish disturbing the lakebed. For those lakes with ongoing algal blooms, organic matter buildup from die-off from phytoplankton and macrophytes creates a feedback loop that sustains poor conditions.
- Climate change – Increases in the number of extreme rainfall events may increase catchment erosion and increase the long-term supply of sediment, nutrients and organic matter to lakes. In seasonally stratified lakes, changes in stratification patterns may occur, resulting in more persistent periods of anoxia (low oxygen) and stress on aquatic species. Changes to water level from climate change may result in negative impacts on the aquatic plants in the littoral zone of the lake.
- Unknown groundwater connections – The influence of groundwater on lakes across the region is unknown, though it is thought connections do exist, which in some locations may influence water level, carry legacy nutrients into the lake and exacerbate nutrient enrichment.

Table 6 provides a summary of key threats identified to lake ecological health in each lake across Auckland.

Table 6. Key pressures on current lake health. Sourced from de Winton *et al.* (2022) and Hussain (2025).

Lake	Key pressures on lake health
Rototoa	• Expansion of and/or additional invasive weeds • Coarse fish • Catchment nutrient loads and internal nutrient loading
Kuwakatai	• Invasive weeds (Hornwort) • Persistent anoxia • Coarse fish • Catchment derived nutrient loads and internal nutrient loading
Te Kanae	• Invasive weeds • Catchment erosion • Coarse fish
Ōkaihau	• Internal nutrient loading • Expansion of invasive weeds • Coarse fish • Catchment land use change
Kawaupaku	• Invasive weeds • Coarse fish • Catchment landslides
Wainamu	• Lack of submerged vegetation • Presence of grass carp and other coarse fish • Catchment erosion
Whatihua	• Invasive weeds • Coarse fish • Nutrient enrichment through catchment derived nutrient loads
Pupuke	• High biomass of invasive weeds • Coarse fish • Waterfowl population • Water quality fluctuations (including internal nutrient loads)
Keretā	• Lack of submerged vegetation • Presence of grass carp and other coarse fish • Catchment derived nutrient loads • Fluctuating shallow water level
Pokorua	• Expansion and introduction of invasive weeds • Waterfowl population • Catchment derived nutrient loads • Fluctuating shallow water level
Slipper	• Catchment derived nutrient loads • In-lake organic deposition (i.e., through decomposition of algal biomass) • Lake ageing • Coarse fish

Lake	Key pressures on lake health
Spectacle	• Catchment derived nutrient loads • In-lake organic deposition (i.e., through decomposition of algal biomass) • Lake ageing • Coarse fish
Tomorata	• Water quality • Poor conditions for regeneration of macrophytes (substrate and light availability) • Coarse fish • Recreational boat use

4 Current state of lake health

The state of each water quality parameter is presented in boxplots to enable inter-lake comparisons and assess the variability in the data across the five-year period. Note that only five lakes (Pupuke, Rototoa, Tomorata, Wainamu and Whatihua) have five years of data displayed (July 2019 – June 2024); the other eight lakes have only four years of data (July 2020 – June 2024).

4.1 Nutrients and algae

Nitrogen and phosphorus are key nutrients that can stimulate the growth of algae and plants in lakes and cause eutrophication. Low nutrient concentrations (e.g., total nitrogen and total phosphorus) indicate that ecological communities are healthy and resilient, similar to natural conditions.

Plants and algae use chlorophyll a, the green pigment, for photosynthesis. Measuring how much of this pigment is in the water provides a good indication of the total biomass of microalgae in a lake. Similar to the nutrient concentrations of nitrogen and phosphorus, low concentrations of chlorophyll a indicate healthy and resilient ecological communities, similar to natural conditions. Elevated levels of nutrients and chlorophyll a indicate that excessive algal and plant growth, driven by nutrient enrichment, is affecting ecological communities. Increased algal growth in a lake reduces water clarity, affects the availability of habitat for native macrophytes (submerged plants, and decreases the availability of oxygen in deeper waters.

The highest concentrations of total nitrogen and chlorophyll a were in the surface waters of the five polymictic lakes, with the highest concentrations in the surface waters of Lake Keretā (up to 10 mg/L total nitrogen). The lowest concentrations of chlorophyll a were observed in Lake Rototoa and the lowest total nitrogen concentrations in Lake Rototoa, Lake Wainamu and Lake Pupuke.

Generally, nutrient concentrations were higher in bottom waters than the surface waters of seasonally stratified lakes, which is particularly evident in ammoniacal nitrogen concentrations (Figure 4). Higher nutrient concentrations in the bottom waters suggest that the seasonally stratified lakes may be releasing nutrients from bottom sediments. This process, known as internal nutrient loading, promotes further algal growth and can be exacerbated by prolonged anoxia and fish feeding patterns disturbing the lakebed.

Ammonia and nitrate can be toxic to sensitive aquatic species (e.g., some fish). The highest median concentrations of total oxidised nitrogen (which includes nitrate) and ammoniacal nitrogen of surface waters were in Lake Pokorua, a shallow polymictic lake (Figure 4).

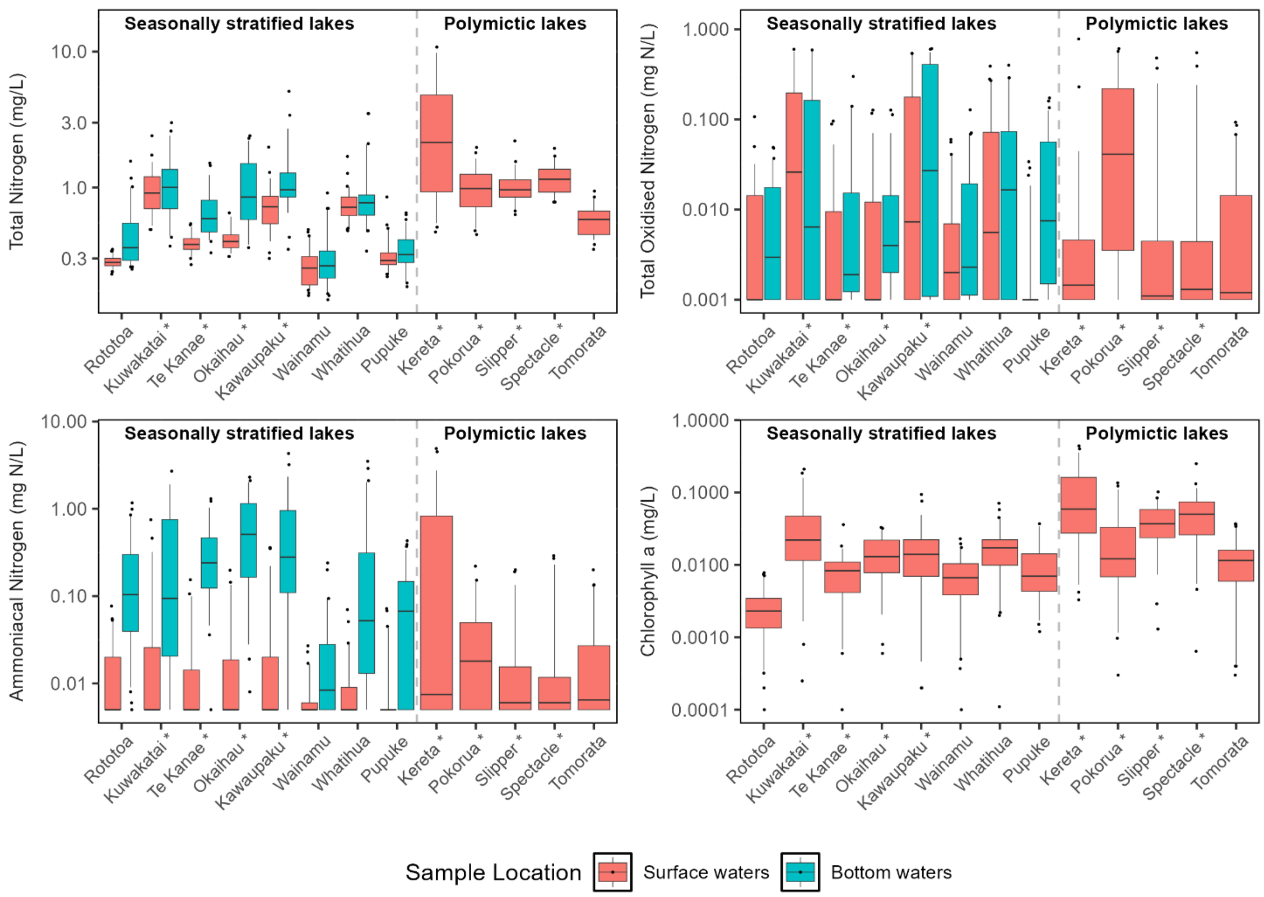


Figure 4. State of nitrogen parameters and chlorophyll a in surface waters (red) and bottom waters (blue). Sites with only four years of data are marked with an asterisk. Note the log scale for all parameters. Polymictic lakes have only surface water samples due to depth of lake. The grey vertical dashed line separates the seasonally stratified lakes from the polymictic lakes.

Effects on aquatic organisms can occur due to eutrophication effects caused by excessive phosphorus (in combination with excess nitrogen), in the bioavailable form of dissolved reactive phosphorus (DRP). Although phosphorus does not cause toxicity effects in lakes, elevated concentrations of DRP cause changes in ecological communities through nutrient enrichment and subsequent excessive primary production (e.g., algal biomass). The total phosphorus concentrations of surface waters in polymictic lakes were higher than the surface waters of seasonally stratified lakes, suggesting nutrient enrichment in polymictic lakes. The highest concentrations were measured in Lake Keretā and the lowest concentrations in Lake Rototoa and Lake Pupuke (Figure 5). Dissolved reactive phosphorus (DRP) concentrations in surface waters were highest in the polymictic Lake Spectacle but were equally high in the bottom waters of Lake Kawaupaku and Lake Kuwakatai (Figure 5).

Both total phosphorus and dissolved reactive phosphorus (DRP) were higher in the bottom waters of seasonally stratified lakes than in the surface waters, suggesting internal nutrient loading is occurring in the bottom waters of these lakes. This was most apparent for DRP, where bottom water concentrations were higher in all seasonally stratified lakes except Lake Rototoa and Lake Wainamu.

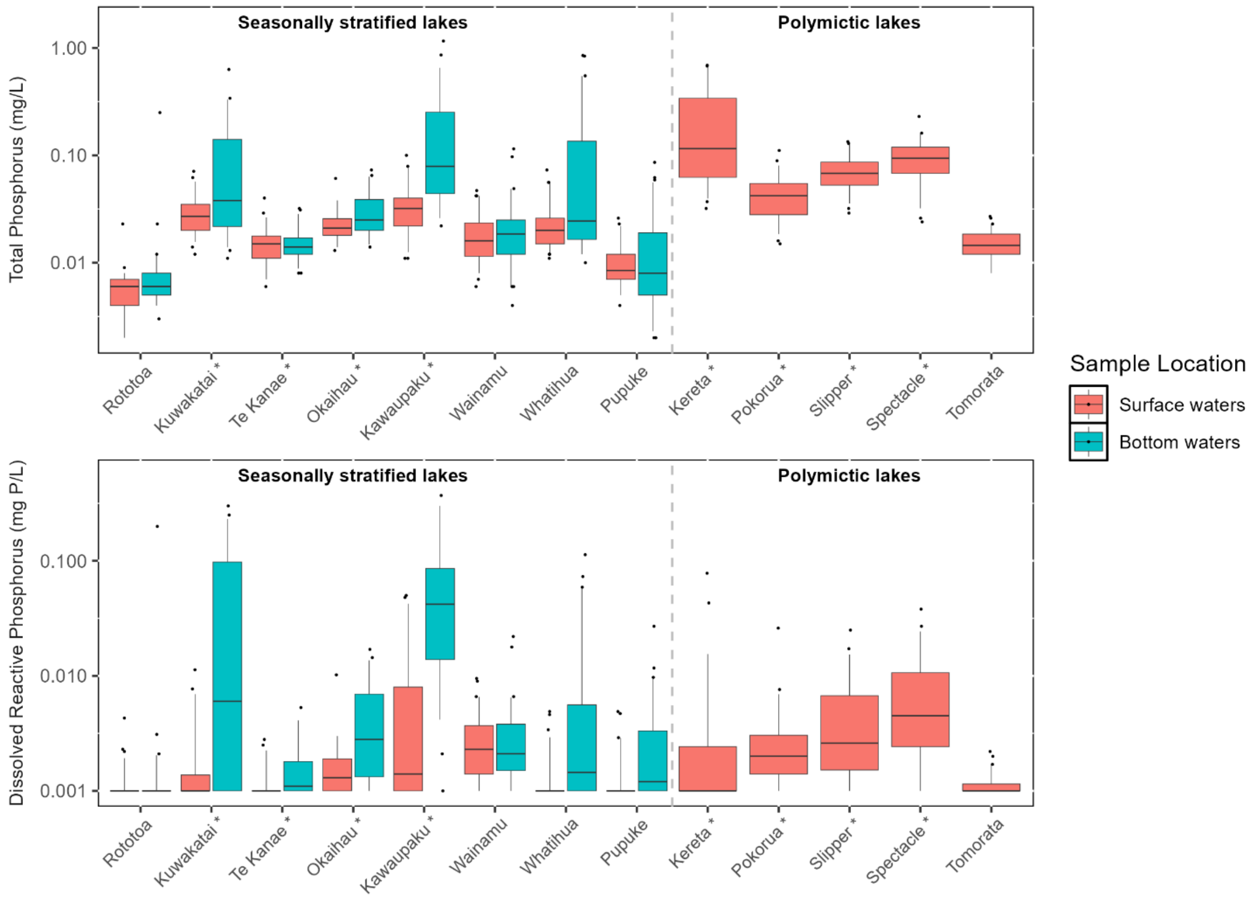


Figure 5. State of total phosphorus and dissolved reactive phosphorus in surface waters (red) and bottom waters (blue). Sites with only four years of data are marked with an asterisk. Note the log scale for all parameters. Polymictic lakes have only surface water samples due to depth of lake. The grey vertical dashed line separates the seasonally stratified lakes from the polymictic lakes.

4.2 Suspended sediment and water clarity

Suspended fine particles, including sediment, algae and organic matter, reduce the visual clarity of water which affects both amenity values and ecological communities. Reduced water clarity limits the photic zone (layer that sunlight penetrates), preventing extensive submerged vegetation growth. This can make the lake more susceptible to algal blooms and further decrease water clarity. High concentrations of particles in the water can damage respiratory and feeding structures of fish and macroinvertebrates, while sediment settling onto the lakebed can smother organisms and change the benthic habitat. Overall, these effects can alter ecological communities and increase the risk of losing sensitive aquatic species.

Generally, Total Suspended Solids (TSS), Volatile Suspended Solids (VSS) and turbidity were highest, and water clarity is lowest in the polymictic lakes (Figure 6). The highest concentrations across these sediment parameters, and the lowest water clarity was in Lake Keretā surface waters. Shallow depths in polymictic lakes may lead to higher suspended sediment levels due to wind-driven and/or anthropogenic lakebed resuspension (i.e. from recreational boating), or elevated algal biomass in these eutrophic lakes.

The lowest TSS, VSS and turbidity concentrations were in Lake Rototoa and Lake Pupuke, which are the two deepest lakes in the region. These two lakes had the highest water clarity, though there is a greater spread in the water clarity for Lake Pupuke, from less than 1 metre to up to 10 metres (Figure 6).

Some of the seasonally stratified lakes (Lakes Kuwakatai, Kawaupaku and Pupuke) had higher TSS and turbidity in the surface waters compared to the bottom waters. This suggests that surface inputs such as catchment runoff and landslides entering the lake, as well as in-lake algal biomass, have an impact on the surface waters. During the 2023 weather events, several lakes experienced landslides in the surrounding catchment, or directly into the lake, which provided a large amount of organic and non-organic matter into the lake as well as a long-term source of nutrients.

Other lakes showed higher suspended sediment and turbidity in the bottom waters (Figure 6) which may be due to sediment disturbance at the lakebed and decomposing organic matter settling onto the lakebed. Lake Ōkaihau had high TSS and VSS in both the surface and bottom waters, showing this lake had a large amount of organic matter throughout the water column.

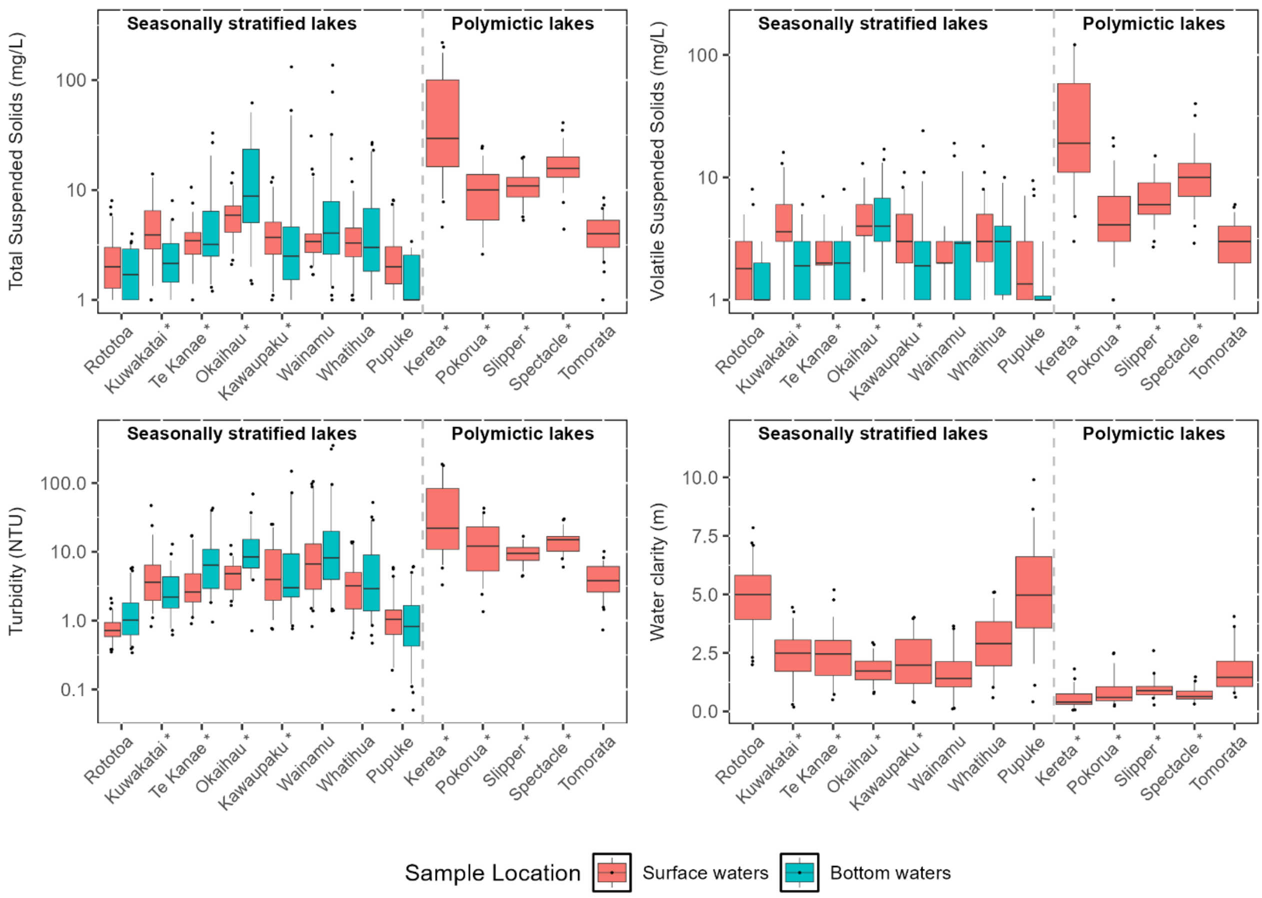


Figure 6. State of sediment parameters in surface waters (red) and bottom waters (blue). Sites with only four years of data are marked with an asterisk. Note the log scale for parameters except water clarity. Polymictic lakes have only surface water samples due to depth of lake. The grey vertical dashed line separates the seasonally stratified lakes from the polymictic lakes.

4.3 Physical water quality parameters

Median temperatures were highest in surface waters, with polymictic lakes showing the higher median temperatures, due to their shallow depths. Bottom water temperatures were lowest in deeper lakes including Lake Pupuke, Lake Kawaupaku and Lake Te Kanae (Figure 7).

Differences between surface waters and bottom waters were also evident in other physical parameters (Figure 7). Across all seasonally stratified lakes, the surface waters had higher pH than the bottom waters, likely due to photosynthesising algae and/or plants in the surface waters increasing pH and decomposition of organic matter lowering pH levels in the bottom waters. The highest median pH in surface waters was in Lake Pupuke (8.3) and the highest median pH in bottom waters was in Lake Whatihua (7.4). Increased pH can affect the accessibility of nutrients and subsequent trophic state of lakes. Experiments found that elevated pH increased the release rates of phosphorus from lakebed sediments in Lake Pupuke (Waters & Kelly, 2019). The lowest median pH in the surface waters was in Lake Slipper (6.9) and the lowest median pH in the bottom waters was in Lake Te Kanae (6.6).

Dissolved oxygen in the lake is vital for fish and other aquatic life to breathe and is released by plants and algae during photosynthesis. The surface water dissolved oxygen was similar across the lakes, with all lakes experiencing dissolved oxygen saturation that exceeded 100%, indicating periods of time with large amounts of algae and plants photosynthesising and producing oxygen. Lake Keretā had a median dissolved oxygen saturation concentration exceeding 100% (Figure 7), suggesting this lake is regularly super saturated due to large amounts of algae, which is supported by the highest concentrations of chlorophyll a in the region (Figure 4). Dissolved oxygen concentrations in the bottom waters of all seasonally stratified lakes showed greater variability compared to those in the surface waters. All bottom waters experienced periods of anoxia, with Lake Ōkaihau showing the lowest concentrations and frequently were anoxic (Figure 7 and Figure 8). When deep waters become depleted of oxygen, oxygen-sensitive species are put at risk, and anoxic conditions can trigger nutrient release from sediments, contributing to internal nutrient loading. Surface waters and bottom waters had similar within lake conductivity and salinity. Both parameters were highest in Lake Kawaupaku, and lowest in Lake Tomorata and Lake Wainamu (Figure 7).

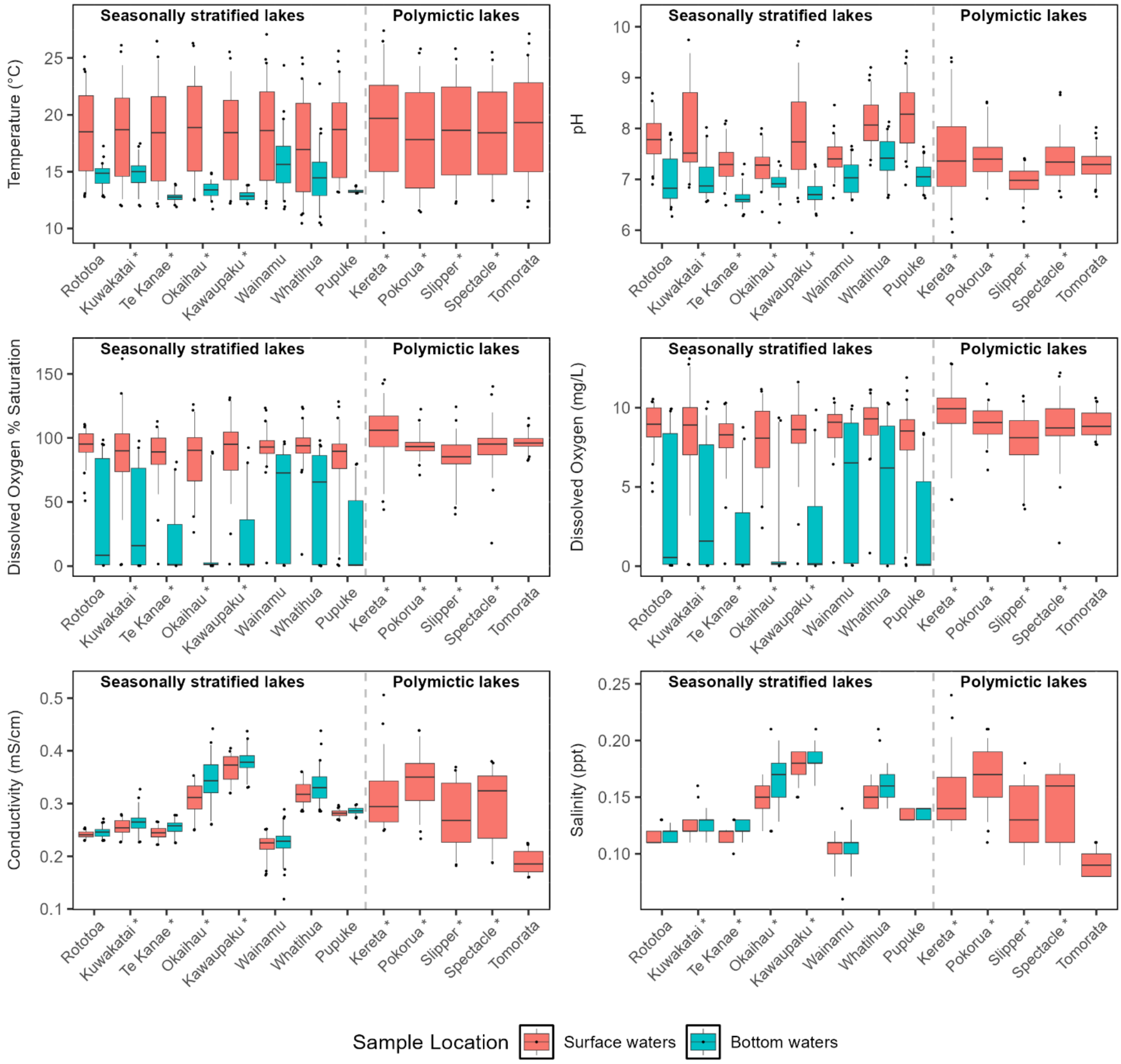


Figure 7. Physical water quality parameters for surface waters (red) and bottom waters (blue). Sites with only four years of data are marked with an asterisk. Polymictic lakes have only surface water samples due to depth of lake. The grey vertical dashed line separates the seasonally stratified lakes from the polymictic lakes.

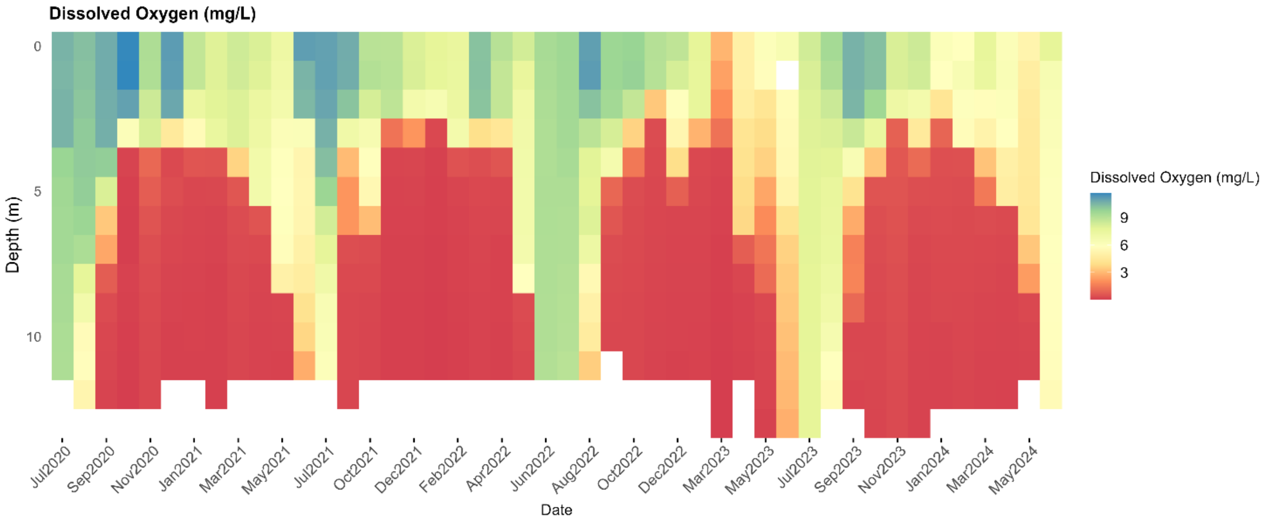


Figure 8. Depth profile of dissolved oxygen in Lake Ōkaihau between July 2020 and June 2024.

Although not shown in these boxplots, noticeable differences in these parameters were observed between stratified and isothermal periods[3], as expected when cold, dense water sinks to the lake bottom and mixing is restricted during stratification. Surface water temperatures and pH were higher in stratified periods for all seasonally stratified lakes, whilst dissolved oxygen concentrations were higher during isothermal conditions. In bottom waters, pH and dissolved oxygen concentrations were also higher during isothermal conditions in all lake bottom waters, and all lakes were anoxic (concentrations less than 3 ppm) during stratified periods. These differences can also be seen in depth profiles (example from one lake shown in Figure 8), which show the higher temperature and pH during stratification, and low dissolved oxygen, compared to more uniform profiles during well-mixed isothermal periods.

[3] See "Stratified Conditions" and "Depth profiles" tab in Lake water quality section of Water Quality and River Ecology Data Explorer.

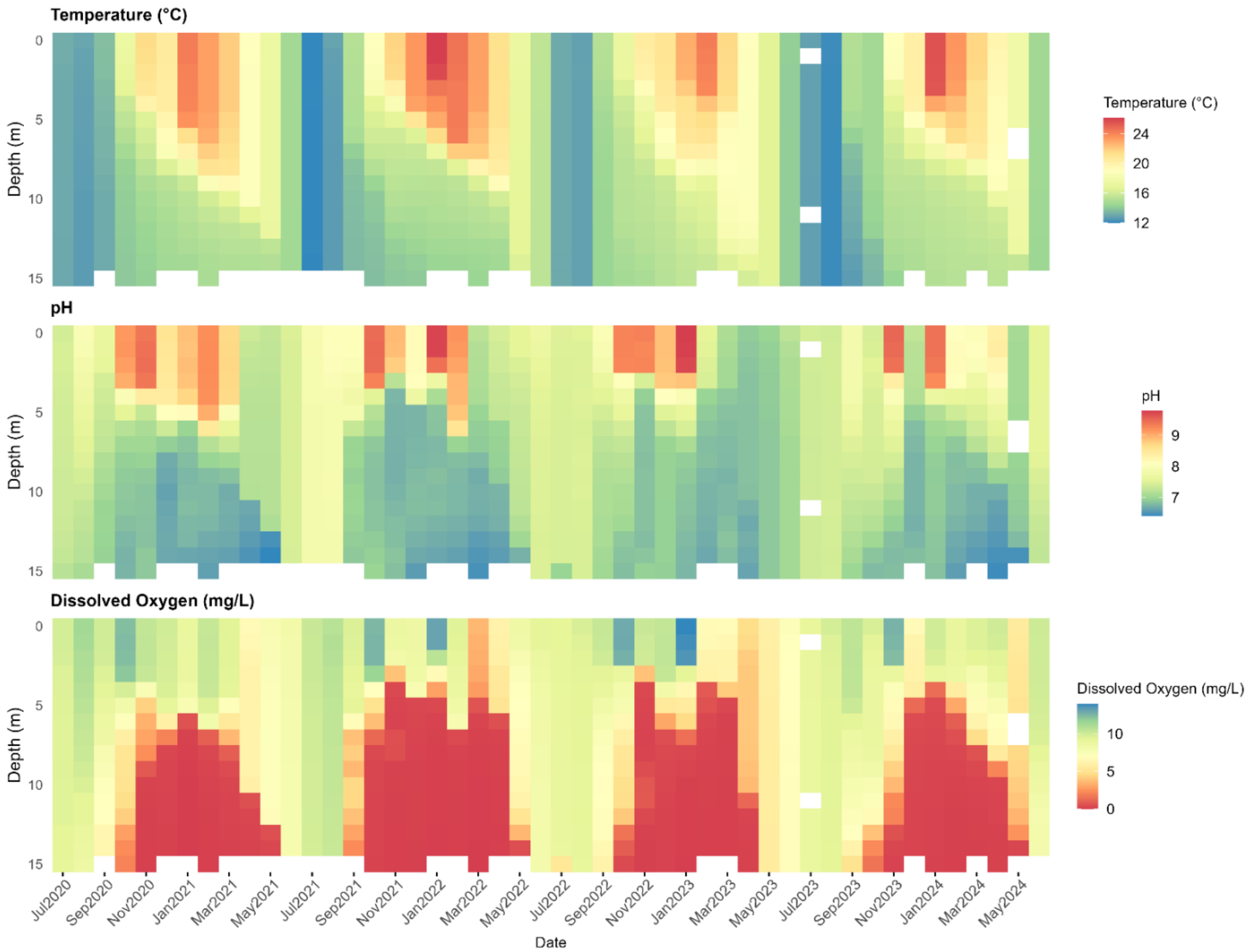


Figure 9. Depth profiles for temperature, pH and dissolved oxygen in Lake Kuwakatai between July 2020 and June 2024.

4.4 Human health indicators

Planktonic cyanobacteria (blue-green algae) naturally occur in lakes, typically in low concentrations. However, under favourable conditions such as warm temperature, low flow and elevated nutrient levels, cyanobacteria can form blooms. Whilst these blooms are a natural phenomenon, some cyanobacteria species produce toxins that can be harmful to the nervous system in humans and animals. Lower concentrations of cyanobacteria indicate a low risk of health effects from exposure during contact with freshwater. As the concentration of cyanobacteria increases, the health risks (such as respiratory effects, skin irritation and allergies) increase (MfE and Health New Zealand, 2024). In the recreational guidelines for cyanobacteria (MfE and Health New Zealand, 2024), both total cyanobacteria biovolume and cell counts for four known toxin-producing species[4] can trigger an alert that require follow up sampling and public notification.

Most lakes showed median cyanobacteria biovolumes below the recommended threshold of total cyanobacteria biovolume for an increased risk to human health (0.5 mm^3/L – amber alert; MfE and Health New Zealand (2024)) (Figure 10), with the exception of Lake Keretā and Lake Pokorua.

[4] The four known toxin-producing species of cyanobacteria in the guidelines are: *Cuspidothrix issatschenkoi, Raphidiopsis, Microcystis* and *Nodularia spumigena.*

However, most lakes occasionally exceeded the recommended threshold for total cyanobacteria biovolume, indicating cyanobacteria blooms occurred in these lakes. Several lakes that did not exceed this biovolume threshold of increased risk during the four/five years (Lakes Ōkaihau, Wainamu and Pupuke), suggest a low risk of exposure to cyanobacteria in these lakes, however, it is important to consider the cell count of known toxin-producing species as well.

Microcystis was the most prevalent known toxin-producing species across all lakes. In all lakes, but two, it was the only known toxin-producing species present. The exceptions were Lake Keretā which had all four known toxin-producing species present, and Lake Te Kanae which had both *Microcystis* and *Cuspidothrix issatschenkoi* present.

Several lakes had instances where the cell counts for *Microcystis* triggered either an amber or a red alert (Figure 10), suggesting elevated risk from toxin-producing cyanobacteria. Lake Kuwakatai was the only lake with a median *Microcystis* cell count above the amber alert level (> 500 cells/mL), despite being below the amber alert level for total cyanobacteria biovolume (Figure 10). Lakes Rototoa, Ōkaihau, Pupuke and Spectacle did not exceed the *Microcystis* cell count threshold (Figure 10), suggesting low risk of exposure to toxin-producing cyanobacteria in these lakes.

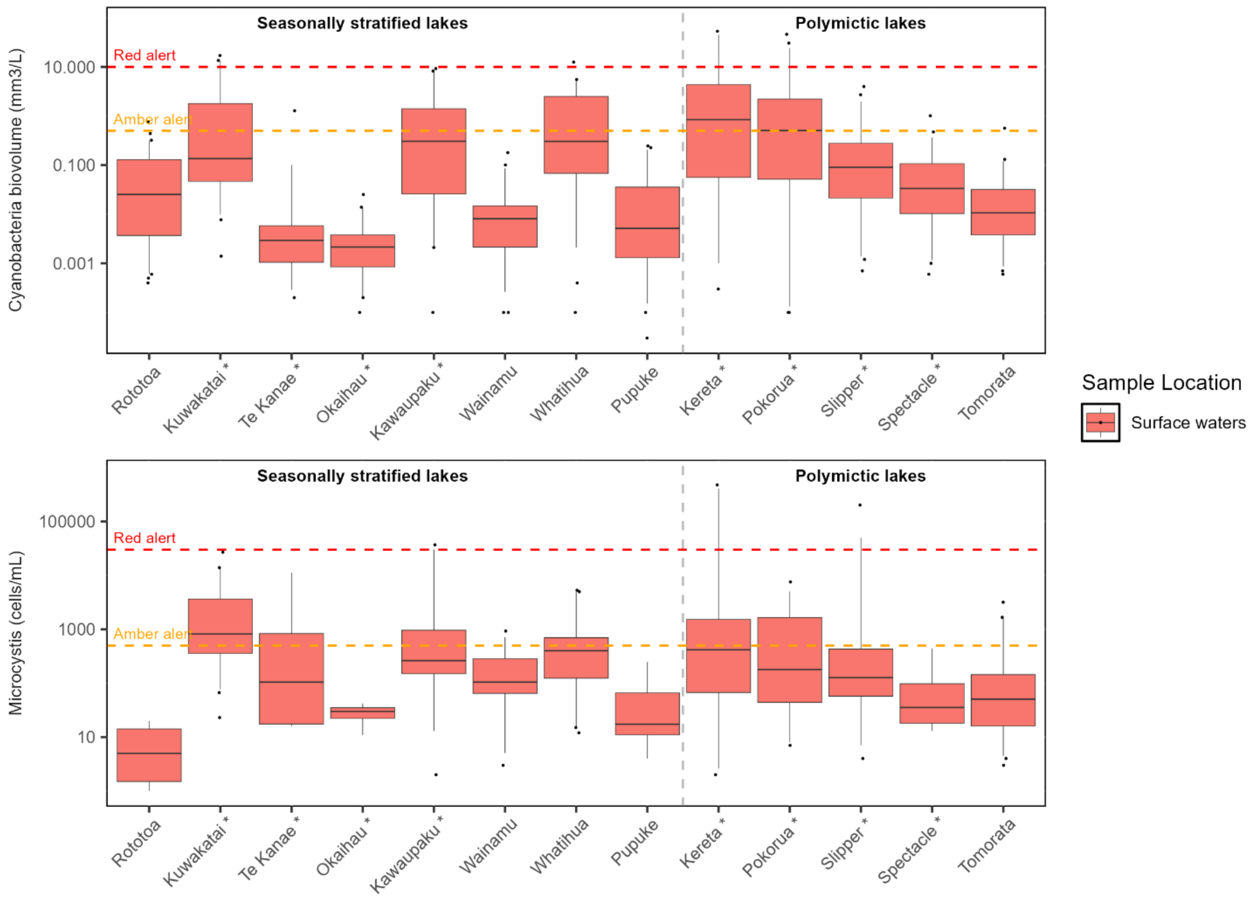


Figure 10. Cyanobacteria biovolume and cell counts for the toxin-producing Microcystis species in surface waters only. Sites with only four years of data are marked with an asterisk. Note the log scale for all parameters. Cyanobacteria alert levels have been added using dashed lines corresponding to the alert level in the MfE and Health New Zealand guidelines. The grey vertical dashed line separates the seasonally stratified lakes from the polymictic lakes.

E. coli is a faecal indicator bacterium used to indicate the risk of infection and illness from pathogens (like Campylobacter) that may also be in the water. The highest median *E. coli* concentration was in Lake Pokorua (Figure 11). This is a shallow polymictic lake that frequently had high numbers of waterfowl. Generally, *E. coli* concentrations were below levels deemed to be of higher risk for swimming in Auckland's lakes, however, most lakes had occasional spikes in *E. coli* concentrations.

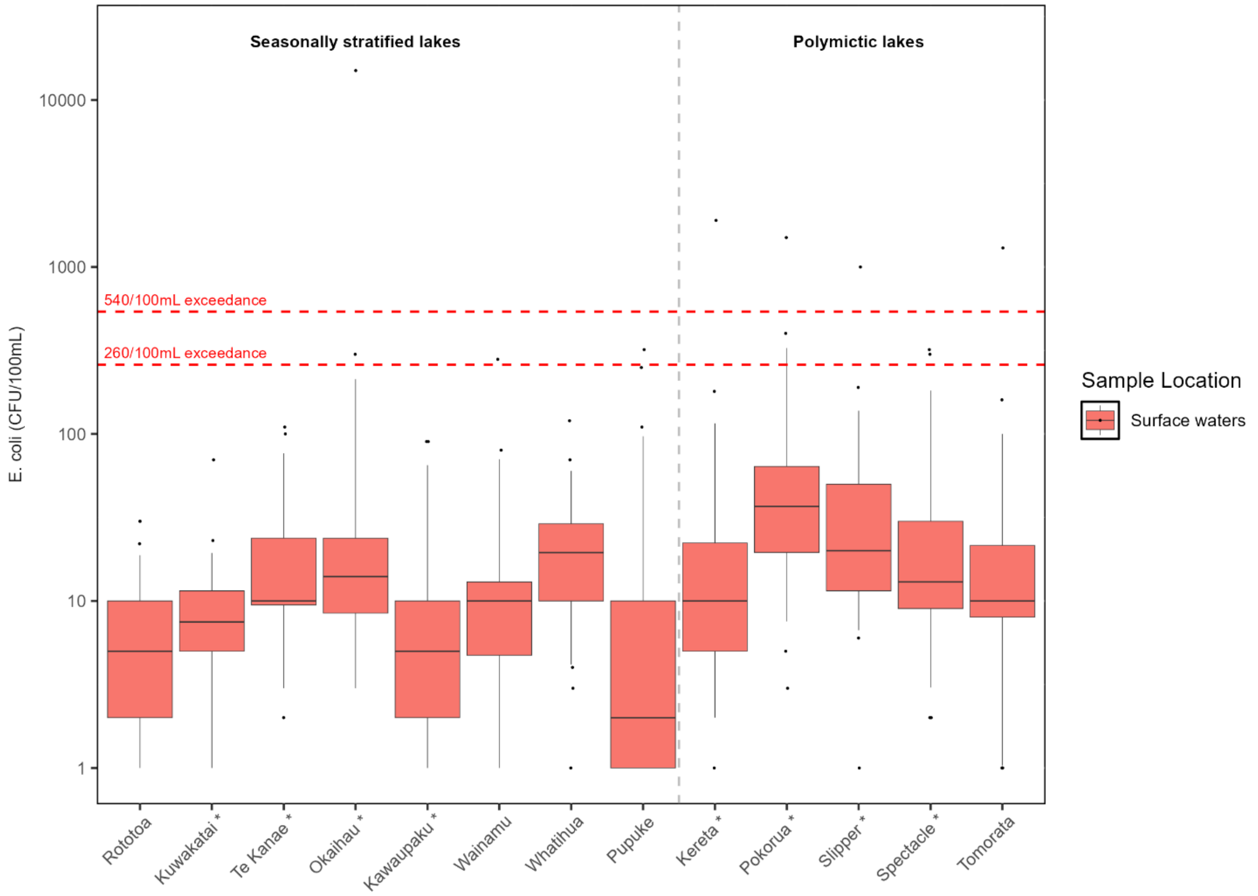


Figure 11. *E. coli* concentrations in surface waters only. Sites with only four years of data are marked with an asterisk. Note the log scale. Red dashed lines indicate the exceedance values of note in the NPSFM 2020. The grey vertical dashed line separates the seasonally stratified lakes from the polymictic lakes.

4.5 Trophic Level Index (TLI)

The health of lakes can be summarised using the Trophic Level Index (TLI, Burns et al., 2005), which incorporates four water quality parameters (total nitrogen, total phosphorus, chlorophyll a and water clarity). Figure 12 shows the variability in annual TLI scores over the past five years (July 2019 – June 2024), although some lakes only had four TLI scores available.

For the year ending 2024, 12 out of 13 lakes were in eutrophic/poor or supertrophic/very poor condition. Many of the additional lakes monitored since 2020 were in supertrophic/very poor condition (TLI >5) (Figure 12). This indicates that the expanded monitoring programme has included more lakes with poorer water quality than those monitored previously, suggesting previous lake monitoring may have been skewed towards lakes with better water quality.

Lake Rototoa had the lowest TLI scores across the five years and was classed as mesotrophic (TLI score between 3 and 4), suggesting this was the lake with the best water quality of those monitored in the Auckland region. Generally, polymictic lakes had the highest TLI scores compared to the seasonally stratified lakes in Auckland. Lake Keretā and Lake Spectacle had the highest TLI scores and were considered to have the poorest water quality across the region, classed as hypertrophic. Previous reporting indicated that Lake Spectacle had the worst water quality in the region (supertrophic), and Lake Keretā was classed as eutrophic (Barnes and Burnes, 2005; Hamill and Lockie, 2015), suggesting lake health in Lake Keretā has deteriorated during the monitoring gap from 2013 to 2020.

Some lakes (e.g., Te Kanae, Wainamu and Pupuke) had TLI scores that fluctuate between mesotrophic and eutrophic. Fluctuations in TLI scores over time highlight a caution on assigning a single annual TLI score and basing planning targets on this value; therefore, looking at the TLI across several years, as well as taking monthly samples, provides a more robust assessment of state of the lake.

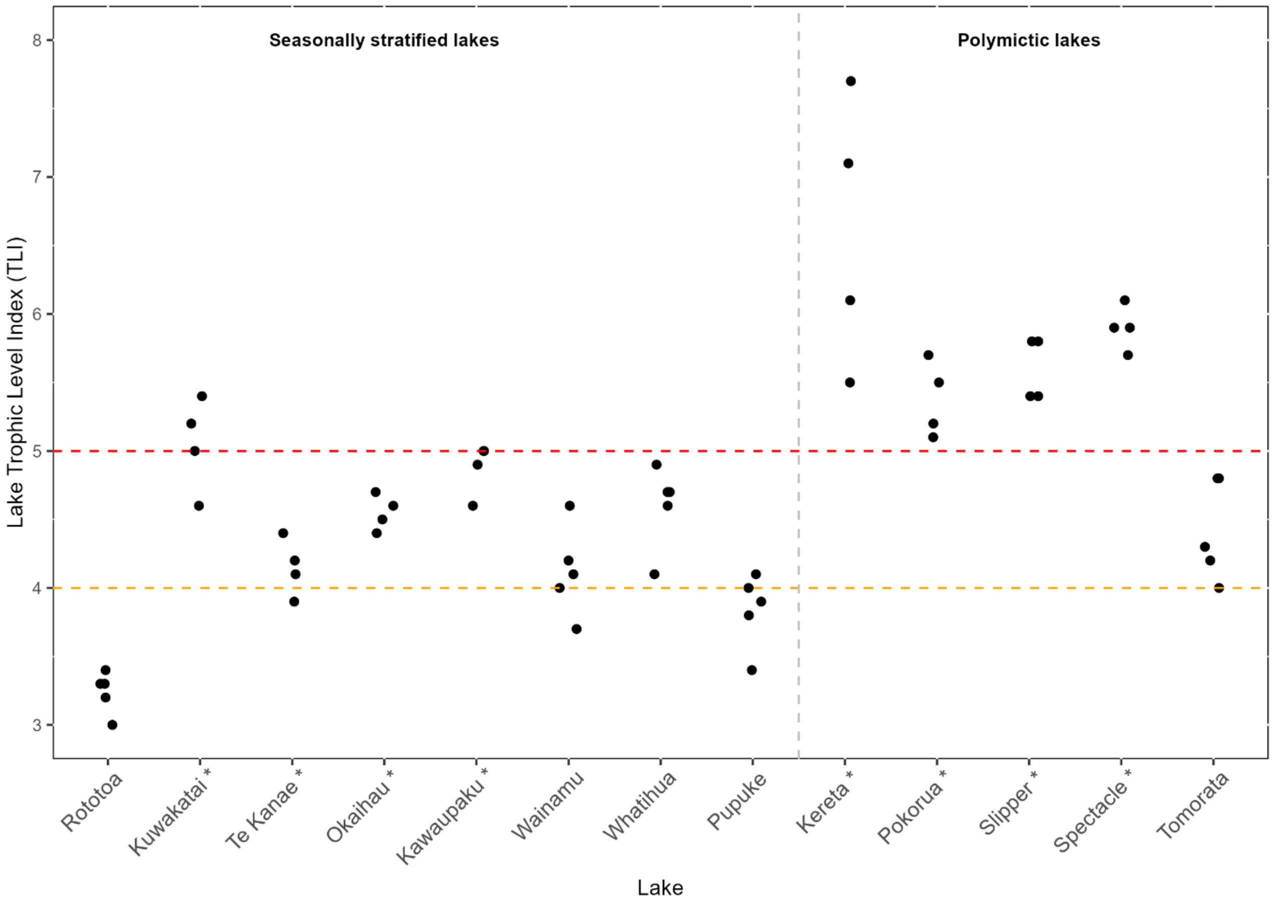


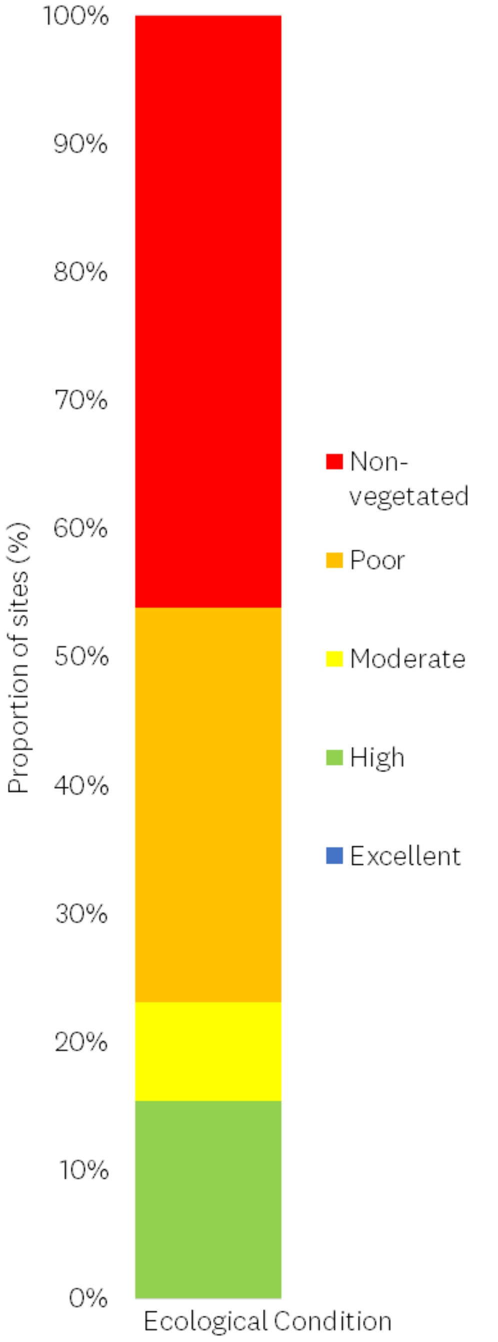
Figure 12. Annual Lake Trophic Level Index (TLI) scores. Sites with only four years of data are marked with an asterisk. Values above the yellow line indicate eutrophic/poor condition, and the values above the red line indicate super trophic/very poor condition. The grey vertical dashed line separates the seasonally stratified lakes from the polymictic lakes.

4.6 Lake ecology

In 2024, eleven lakes were surveyed to obtain a LakeSPI score (Hussain, 2025), which evaluates submerged vegetation as an indicator of ecological condition (see Section 2.5.1.2). There were no surveys in 2024 for Lakes Wainamu and Keretā, as previous surveys in 2022 indicated these lakes remained non-vegetated, due to the ongoing presence of grass carp in both lakes which were used to control submerged vegetation. LakeSPI scores cannot be ascertained until the grass carp are removed (de Winton *et al.,* 2022).

According to LakeSPI scores, the ecological health was high in two lakes (Rototoa and Pokorua) and moderate in one lake (Whatihua) (Figure 13). These lakes support native submerged vegetation and are able to coexist with invasive species, or the impact of invasive species is low. The ecological health in four of the remaining lakes was poor, indicating limited native vegetation, which is being overtaken by invasive species. Six lakes were classified as non-vegetated, either lacking vegetation entirely or having sparse coverage that does not meet the assessment criteria (i.e. < 10% coverage). The invasive species of main concern in the Auckland region are Hornwort (*Ceratophyllum demersum*) and Egeria (*Egeria densa)*.

For some lakes (e.g., Te Kanae and Tomorata), submerged vegetation may be present in areas not covered by the LakeSPI surveys (Hussain, 2025). This highlights the importance of conducting comprehensive lake-wide ecological surveys, rather than relying solely on LakeSPI data to assess the overall ecological condition of the lake.



Lake	Year of survey	LakeSPI score	Condition
Keretā	2022	0	Non-vegetated
Te Kanae	2024	0	Non-vegetated
Wainamu	2022	0	Non-vegetated
Slipper	2024	0	Non-vegetated
Spectacle	2024	0	Non-vegetated
Tomorata	2024	0	Non-vegetated
Kuwakatai	2024	4.68	Poor
Ōkaihau	2024	10.91	Poor
Kawaupaku	2024	10	Poor
Pupuke	2024	20	Poor
Whatihua	2024	26.4	Moderate
Pokorua	2024	55.43	High
Rototoa	2024	65.6	High

Figure 13. LakeSPI scores and summary of ecological condition across the lakes in 2024.

4.7 NPS-FM 2020 attributes

The following sections provide an overview of the state for all lakes as per the NPS-FM 2020 attributes, Appendix 2A and Appendix 2B. Interim state assessments are presented for those lakes that do not meet the full data requirements (see Section 2.5.1.3).

Those lakes with attributes in band A are expected to have healthy and resilient ecological communities with low risk of health effects to humans exposed to the water. Those in band B and C are slightly or moderately impacted by algal and plant growth arising from elevated nutrient concentrations. Band D is below the national bottom line for most attributes, whereby lake ecological communities have either undergone, or are at high risk of undergoing a shift to a persistent, degraded state due to elevated nutrients, with a lack of native plant communities, loss of oxygen from the bottom waters and stress on aquatic life.

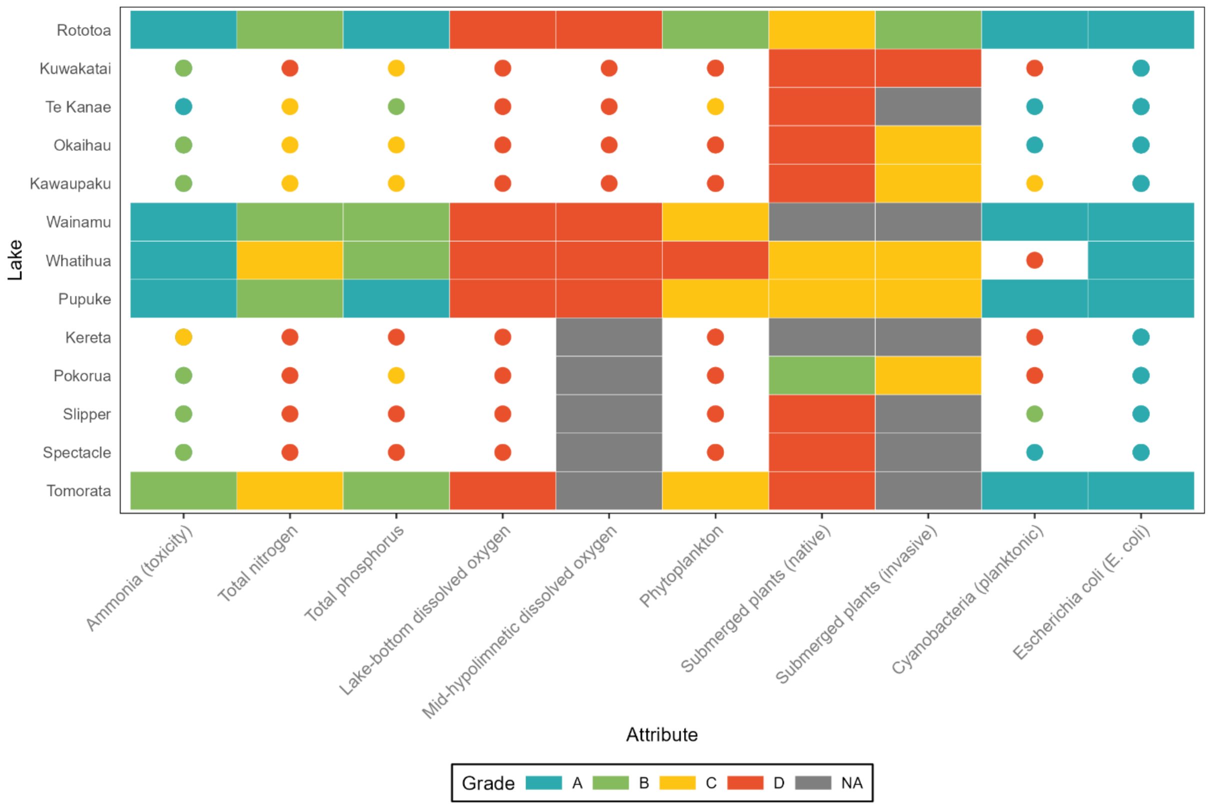


Figure 14. NPS-FM attribute grades for all attributes in Appendix 2A and 2B. Lakes with interim state assessments are presented as dots on the plot.

4.7.1 Water quality

Under the NPS-FM 2020, ammonia concentrations are used to assess the ammonia (toxicity) attribute, which indicates the level of species protection from chronic toxicity effects. Lower concentrations (i.e. band A) indicate a higher percentage of species protected and higher concentrations (i.e. band C or D) have lower species protection, with reduced survival and risk of death for sensitive species.

Five lakes were graded A for ammonia toxicity, indicating 99 per cent of all species are protected from ammonia toxicity (Figure 14). Most lakes were graded B (95 per cent species protection), with one lake graded C (Lake Keretā), which is below the national bottom line (80 per cent species protection).

Key trophic state attributes that impact ecosystem health include total nitrogen and total phosphorus, which alter the trophic state of lakes and promote plant and algal growth. For total nitrogen, three lakes were in B band, five lakes in C band, and five lakes in D band, below the national bottom line (Figure 14). Lake Pupuke and Lake Rototoa were graded B band for total nitrogen and A band for total phosphorus suggesting these lakes are healthy and only slightly impacted by elevated nutrient levels. However, four lakes were graded B for total phosphorus, four lakes were graded C, and three lakes were below the national bottom line (band D) (Figure 14). The C and D grades for these attributes suggest these lakes are moderately to severely impacted by elevated nutrient levels, which can fuel additional algal growth.

All lakes were below the national bottom line (D band) for minimum bottom water dissolved oxygen. Additionally, all eight seasonally stratifying lakes were below the national bottom line for the minimum mid-hypolimnion dissolved oxygen attribute (which does not apply to polymictic lakes) (Figure 14). Both attributes below the national bottom line for all lakes suggest there is an increased likelihood of lake-bottom biogeochemical conditions resulting in nutrient release from the sediment, and stress on aquatic species present in the hypolimnion of the deeper lakes.

4.7.2 Aquatic life

Four lakes were in band C for the phytoplankton attribute, and eight lakes were below the national bottom line (band D), suggesting ecological communities in these lakes are moderately to severely impacted by algal growth arising from elevated nutrient concentrations (Figure 14). The exception was Lake Rototoa, which was graded B, suggesting ecological communities are only slightly impacted by additional algal growth.

Submerged plant attributes (native and invasive) were measured using the LakeSPI metrics. Both attributes were not graded for Lake Wainamu and Lake Keretā due to the non-vegetated state of the lake, a result of the presence of grass carp for weed management (de Winton *et al.,* 2022). Most lakes were below the national bottom line in the D band for native submerged plants attribute (Figure 14), three in C band and one in B band (Lake Pokorua). Low grades for the native LakeSPI attribute result from a decreased percentage of submerged native plants, indicating degraded or absent submerged native plants, and poor ecological conditions in most of the lakes.

Lake Rototoa was in the B band for the invasive submerged plants attribute (Figure 14), suggesting invasive species are currently having a minor impact and are able to co-exist with native vegetation in this lake. Five of the lakes were graded C band, and Lake Kuwakatai was graded in D band (below the national bottom line), highlighting the invasive species are having a major impact on this lake and are displacing native submerged plants. Six lakes were not graded for the invasive submerged plants attribute, as a non-vegetated lake cannot be invaded or non-invaded (de Winton *et al.,* 2022).

4.7.3 Human contact

Human contact attributes, including *E. coli* and cyanobacteria, assess the risk to human health and are used to track improvements in freshwater quality for recreational use.

Seven lakes were graded A for cyanobacteria, and one lake was graded B (Figure 14), suggesting low risk to human health from cyanobacteria presence. This includes all four of the publicly accessible lakes in Auckland. Four lakes were below the national bottom line (D band) suggesting there were high health risks from exposure to cyanobacteria in these lakes. Public health authorities recommend avoiding contact with freshwater that contains high amounts of toxin-producing species of cyanobacteria (Wood et al., 2009; MfE and Health New Zealand, 2024).

All thirteen lakes were graded A for *E. coli* (Figure 14) showing a low risk of Campylobacter infection to swimmers coming into contact with lake water, despite episodic high concentrations in those lakes with high numbers of waterfowl. Of note, samples were taken from the centre of the lake rather than at any identified primary contact area (e.g., where people might likely access the lake).

5 Trends in lake water quality

5.1 Changes in water quality state over time

Three of the currently monitored lakes (Spectacle, Keretā, and Kuwakatai) were also monitored previously, with earlier reports providing state and trend information for these lakes.

Between 1992 and 2005, Lake Spectacle had the worst water quality state across the region (hypertrophic), with declining water quality trends (Barnes and Burns, 2005). The degraded water quality was reported again in data ending 2012, with the lake classified as supertrophic with degrading water quality (Hamill and Lockie, 2015). Monitoring resumed in 2020 after a seven-year gap, and findings show the lake has remained in a degraded state, continuing to display some of the worst water quality in the region (Figure 12).

Lake Keretā was classed as eutrophic between 1992 and 2005, and had the third best water quality in the region (after Lake Rototoa and Lake Pupuke) (Barnes & Burns, 2005). Previous trend analyses of data from 1992 to 2005 suggested there were probable improving trends in water quality (Barnes & Burns, 2005). However, these improving trends were not reported for data from 1992 to 2012, and whilst the lake was still classed as eutrophic, it was one of the worst lakes for water quality in the region (Hamill and Lockie, 2015). This suggests there had been a change in water quality from 2005 and 2012.

Before 2008, Lake Keretā was dominated by Hornwort, and grass carp were stocked in the lake in 2008/2009 to eradicate the invasive macrophyte (Hamill and Lockie, 2015). Addition of grass carp resulted in a complete loss of all submerged macrophytes by 2012, which corresponded to an increase in nutrient and algae concentrations (Hamill & Lockie, 2015). Whilst there are no data between 2013 and 2020, current state assessments indicate Lake Keretā has deteriorated from a eutrophic state (1992 – 2012) to a hypertrophic state (2020 – 2024), with the worst water quality in the Auckland region (Figure 12).

Data from 1992 to 2012 showed Lake Kuwakatai was one of the worst lakes in the Auckland region, classed as supertrophic, with low water clarity, high nutrient concentrations and frequent algal blooms (Barnes and Burns, 2005; Hamill and Lockie, 2015). There were no clear trends in water quality between 1992 and 2005 (Barnes and Burns, 2005), however, trends between 1992 and 2012 showed signs of degradation, particularly between 2006 and 2012. In the seven-year period (2006 – 2012), there were increasing nutrient concentrations in the bottom waters, particularly during periods of stratification (Hamill and Lockie, 2015). It was thought that the proliferation of Hornwort in Lake Kuwakatai was masking the effects of the increase in nutrients from internal nutrient loading, through the process of nutrient assimilation (Hamill and Lockie, 2015). Lake Kuwakatai was removed from the lake monitoring programme in 2017 because it had been in a relatively stable, degraded state for a long time (Hamill & Lockie, 2015). The current state of water quality in Lake Kuwakatai was the worst for seasonally stratified lakes in the Auckland region, with poor ecological condition due to the domination of invasive macrophytes. This appears to be in line with the long-term data collected between 1992 and 2012.

5.2 Ten-year trends in water quality

Ten-year trends (July 2014 – June 2024) in surface and bottom water quality were initially assessed in the four lakes with sufficient data for trend analysis: Pupuke, Rototoa, Tomorata, and Wainamu. This preliminary assessment was to determine whether similar patterns emerged across the lakes.

Figure 15 presents the proportion of degrading and improving trends for each parameter, based on combined data from surface and bottom waters across all lakes. As outlined in Section 2.4.1, trends for dissolved reactive phosphorus (DRP) are not presented due to evidence of a step change with the change in laboratory providers. Note that water clarity, *E. coli,* chlorophyll a and cyanobacteria biovolume are only available for surface waters. Trends with low confidence are excluded at the regional level (a total of 18 trends are not included in graphics but are later presented for each individual lake in Section 6).

Overall, there were a mix of degrading and improving trends across the lakes and sampling locations (surface and bottom waters). There were no degrading trends in pH and cyanobacteria. However, there were degrading trends for all other water quality parameters, including only degrading trends in total nitrogen, dissolved oxygen, ammoniacal nitrogen and *E. coli* (Figure 15). Temperature, turbidity and total phosphorus showed degrading trends at more sites than improving ones, whereas salinity, water clarity, total suspended solids and chlorophyll a were improving at more sites.

Due to the distinct internal dynamics and pressures affecting each lake, trends are examined individually for each lake and separated into surface and bottom waters (Section 6). To understand these trends further across the region, the magnitude of the trend relative to the current state is explored in more detail in the next section.

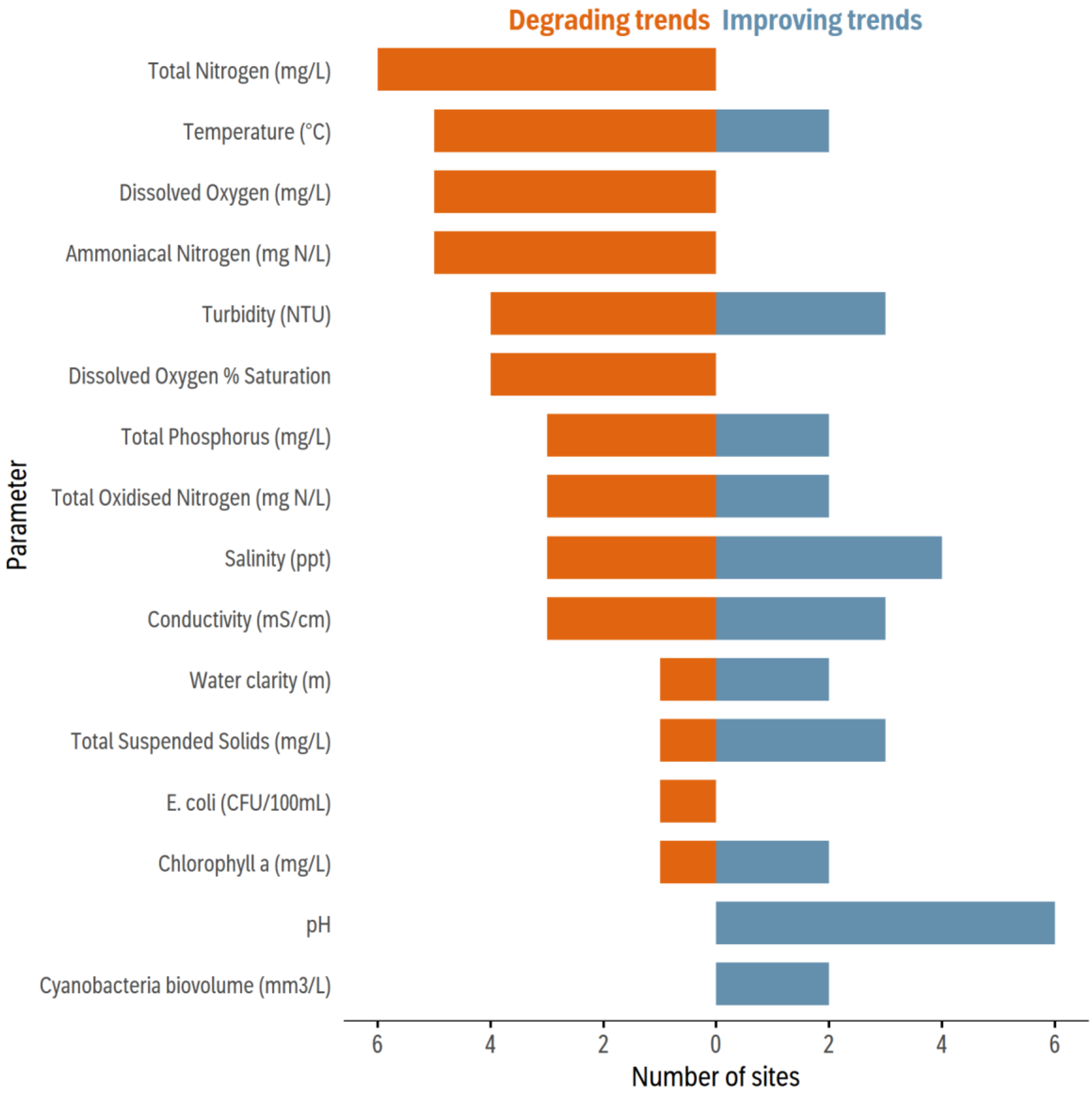


Figure 15. Number of sites with degrading and improving trends for each water quality parameter, combining surface and bottom waters across all lakes. No low confidence trends are displayed (n=18).

5.3 Trend magnitude relative to state

As outlined in Section 2.5.2, the trend magnitude (i.e., rate of change) is characterised by the slope of the trend line using the Sen slope estimator (SSE) (or the seasonal version (SSSE)). The smaller the Sen slope, or rate of change, the longer it would take to be reflected in assessments of state, assuming a linear rate of change.

Figure 16 presents the median current state of each parameter for the surface and bottom waters against the magnitude of the degrading or improving trend (no low confidence trends are displayed). Where the Sen slope is above zero, the trend is degrading, whilst negative Sen slope values indicate an improving trend. The exception for this is water clarity and dissolved oxygen, in which the trends are reversed, and a positive Sen slope indicates an improving trend. The 90% confidence intervals of both the trend magnitude and current state are displayed. Although all parameters are presented, the discussion will focus on an overview of the differences between the lakes, rather than addressing each parameter individually.

Lake Tomorata surface waters had the highest rate of degradation across the four lakes for several parameters including total nitrogen, chlorophyll a and total suspended solids. However, it also had the greatest magnitude of improvements in cyanobacteria. For most degrading parameters, Lake Tomorata was already in the poorest state among the four lakes, indicating a risk of further decline in the near future with degrading trends at the highest rate of change.

Lake Pupuke showed greater rates of improvement in water clarity compared to Lake Rototoa from similar values of high water clarity (median 5 metres). Lake Tomorata and both the surface and bottom waters of Lake Wainamu were experiencing similar rates of degradation in turbidity, starting from the poorest water quality among the four lakes. In contrast, Lake Wainamu showed the greatest rate of improvement in total phosphorus levels, despite beginning from the worst state in this parameter across all lakes.

Total nitrogen levels in the bottom waters of Lake Pupuke and Lake Rototoa were degrading at higher rates than all other lakes and sampling location, except Lake Tomorata. This aligns with the elevated rates of degradation in ammoniacal nitrogen observed in the bottom waters of these two lakes.

Overall, there was no consistent pattern across surface and bottom water trends or across lakes. However, for several parameters, Lake Wainamu had trends of the highest magnitude from the poorest state, although some were degrading (i.e., turbidity) and others improving (i.e., total phosphorus). Meanwhile, Lake Tomorata was already in a poor state and had several degrading trends with high rates of change, suggesting it is at risk of declining further over the near future. Finally, the high rates of degrading trends in ammoniacal nitrogen and total nitrogen in Lake Rototoa and Lake Pupuke bottom waters, should be considered carefully, as these were the lakes in the best state overall, and are vulnerable to decline.

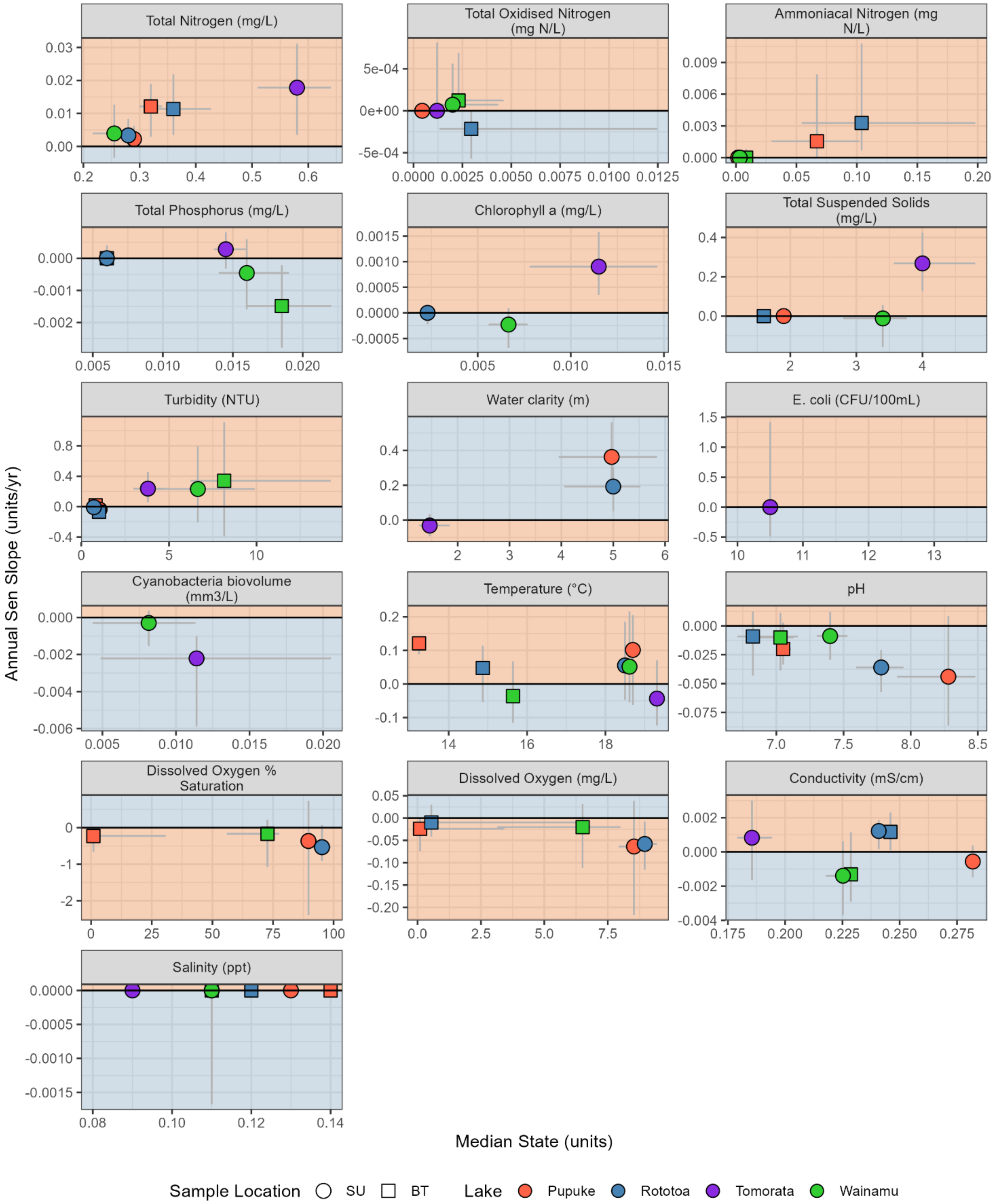


Figure 16. Magnitude of trend as Sen slope against median state for surface and bottom waters of each parameter. Note that no low confidence trends are displayed. Red shading shows degrading trends and blue shading shows improving trends. Colours represent each lake and the shape indicates sample location (surface waters as circles, bottom waters as squares). Grey bars indicate 90% confidence intervals for both the Sen slope and the median state.

6 Individual lake reports

For the four lakes with data available over the 10-year trend period, further details are provided below on in-lake characteristics, ecology, threats to lake health, water quality trends, and current management efforts. For the remaining eight lakes discussed in the current state section, information on in-lake characteristics, ecology, and threats to lake health is available in Hussain (2025).

6.1 Lake Pupuke

6.1.1 Lake characteristics, catchment land cover and biodiversity

Lake Pupuke is a 57-metre-deep, volcanic lake surrounded by an urban catchment in central Auckland (Figure 17). It is the second largest lake in the Auckland region and is used for recreational activities. There are no natural inflows into the lake, instead water levels are influenced by rainfall, stormwater, diffuse overland flow and groundwater recharge. There are no overland outflows from the lake, but underground drainage channels flow to the nearby coast.

Lake Pupuke is monomictic, meaning that while it is stratified in the summer months, it is fully mixed in winter. Despite that mixing, bottom waters can still have low oxygen throughout the year.

Figure 17. Lake Pupuke and surrounding urban catchment.

The urban catchment surrounding the lake results in limited riparian vegetation around the lake. Rather, there are private properties and public parks with mown grasses that border the lake edge (Figure 18).

Despite its urban setting, Lake Pupuke supports diverse birdlife, including black shags, pied shags, Australian coots, pūkeko, New Zealand scaup, black swans, and Canadian geese. The lake contains native fish such as shortfin eels and common bullies, along with introduced species like rainbow trout. However, several invasive species, including perch, rudd, tench, koi carp, goldfish, gambusia, brown bullhead catfish, and red-eared slider turtles are present in the lake (Chaffe, 2023; Hussain, 2025). Buried dead kākahi shell beds provide evidence that the lake previously supported populations of freshwater mussels, however they are now extinct from the lake (Hussain, 2025).

Figure 18. Lake Pupuke shoreline, by the Pumphouse Theatre.

Recent in-lake surveys found the lake to be in poor ecological condition based on the submerged vegetation present in the lake (Hussain, 2025). Invasive species dominate the submerged macrophytes, although native charophyte coverage has increased in recent years (Hussain, 2025).

6.1.2 Threats to lake health

Threats to lake health in Lake Pupuke include the high biomass of invasive macrophytes, which alter water movement, change sediment characteristics, increase water temperatures, and cause large diurnal fluctuations in oxygen and pH levels. These invasive macrophytes also create a strain on the ability of native macrophytes to regenerate, however, these species do provide ecosystem function through nutrient assimilation, lake bed stabilisation and habitat creation (Hussain, 2025).

Other threats to lake health include pest fish populations, internal nutrient loading from lakebed sediments, and shifts in stratification patterns, including prolonged periods of anoxia.

Due to the high recreational use of the lake there is also a high risk of additional invasive species being introduced to the lake, such as Hornwort, gold clam and grass carp. Surveillance for gold clam began in 2023 and is undertaken multiple times a year in Lake Pupuke and several other lakes in the region (Studholme, B. (2025), pers. comm.).

6.1.3 Water quality state and trends

Between July 2019 and June 2024, the lake fluctuated between mesotrophic and eutrophic based on annual TLI scores between 3.4 and 4.1 (Figure 12). Section 4 shows a range in algae concentrations, suggesting the lake experiences algal blooms, and higher nutrient concentrations in the bottom waters provide evidence of nutrient loading occurring (Figure 4 and Figure 5). Water clarity was amongst the highest of the lakes in the Auckland region, and overall, the NPS-FM attributes were good (except for dissolved oxygen attributes (See Section 4.7)).

Figure 19 presents a summary of the 10-year water quality trends for surface water and bottom water in Lake Pupuke. Note that there are no trends presented for volatile suspended solids and cyanobacteria due to not meeting the data requirements (see Section 2.5.2), and chlorophyll a, water clarity and *E. coli* are only measured in the surface waters.

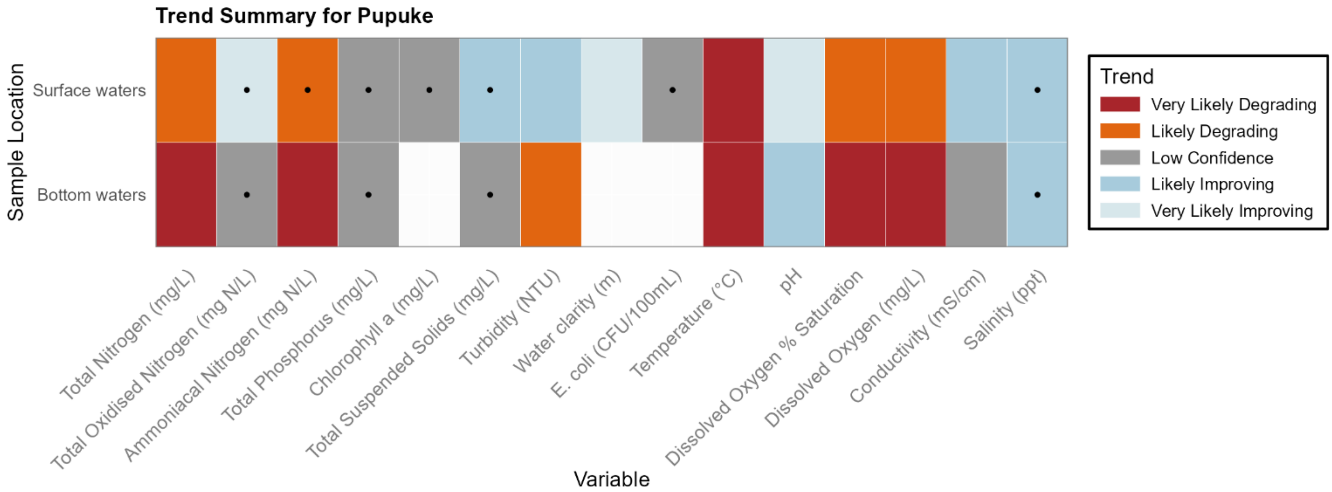


Figure 19. Ten-year trends for surface and bottom waters in Lake Pupuke. Sites with a Sen slope (I.e., rate of change) of zero are indicated with a black dot.

Both surface and bottom waters show degrading trends for both total nitrogen and ammoniacal nitrogen, with higher confidence degrading trends in the bottom waters (Figure 19). Section 5.3 identified these two parameters as degrading with the highest rate of change in Lake Pupuke bottom waters across the region, suggesting the lake water quality is vulnerable to decline. Figure 4 and Figure 5 show that the bottom waters of the lake had higher nitrogen concentrations than the surface waters. Along with degrading trends in these parameters, it suggests internal nutrient cycling is occurring from the lakebed sediments.

Trends in the surface and bottom waters for total phosphorus, as well as chlorophyll a, show low confidence (Figure 19), meaning it cannot be ascertained with confidence that these water quality parameters are improving or declining. Despite the low confidence trend in total phosphorus in the bottom waters, Figure 20 demonstrates that there were episodic increases in total phosphorus concentrations, which aligns with the possibility of internal nutrient cycling occurring from the lakebed sediments. Research into nutrient cycling in Lake Pupuke found that lake sediments had high phosphorus content, suggesting there is a very high potential for phosphorus release under certain conditions (Waters & Kelly, 2019). These releases could fuel algal bloom events over time. Research suggests that nutrient loading from the in-lake nutrient sources may largely be driving the primary productivity in Lake Pupuke (Waters & Kelly, 2019).

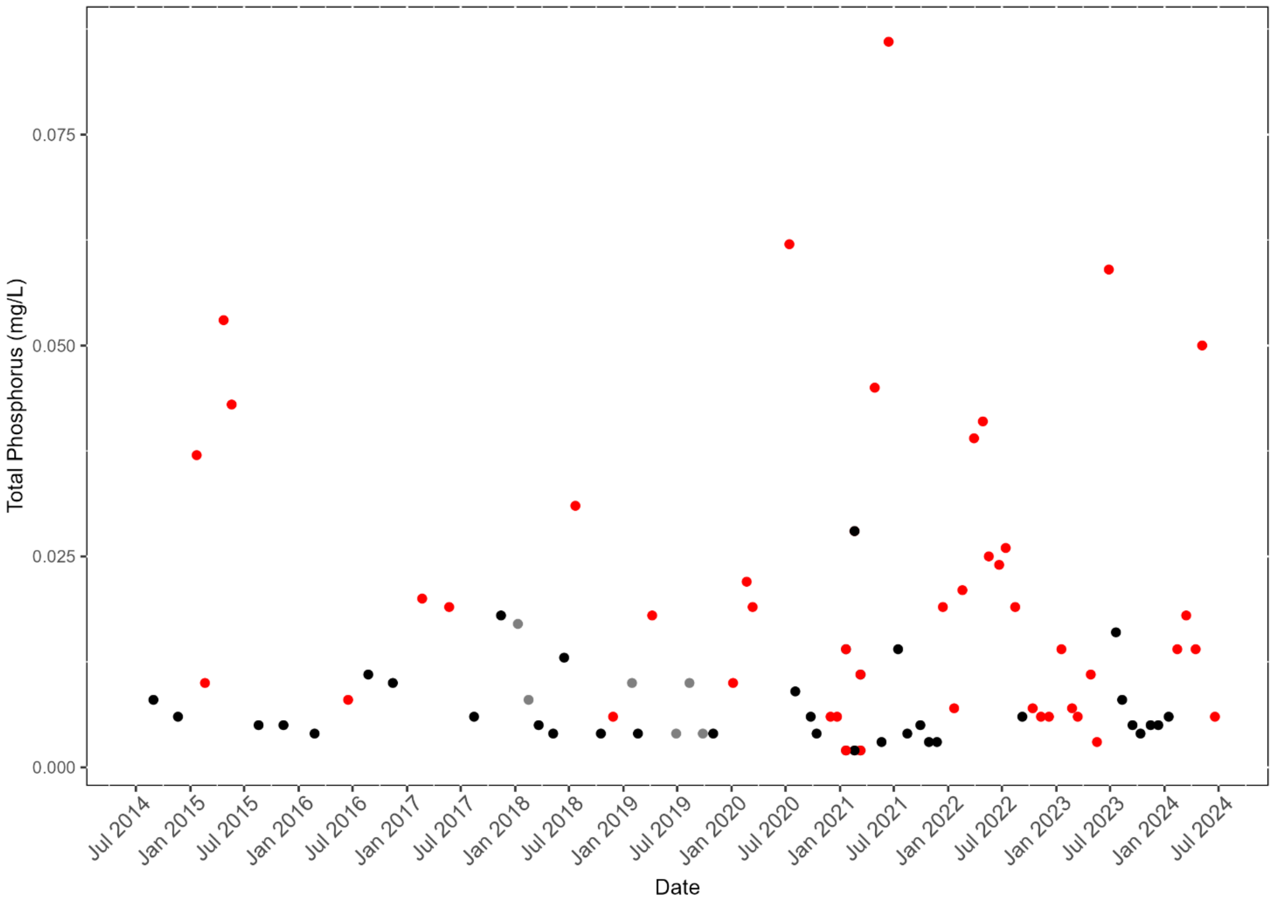


Figure 20. Time series for total phosphorus in the bottom waters of Lake Pupuke. Red dots indicate periods of anoxia, whilst grey dots indicate data that does not have corresponding dissolved oxygen information.

Degrading trends in nutrients could also be attributed to the existing presence of pest fish, which have a number of impacts on lake water quality through the addition of nutrients to the water through excrement (there are also contributions to nutrient load through waterfowl excrement), grazing on macrophytes and zooplankton (which disrupts the trophic cascade, reducing the grazing pressure on phytoplankton, and therefore the potential for increased algal blooms), and disturbing lakebed sediments through benthivorous feeding (Hussain, 2025).

In contrast to nitrogen parameters, total suspended solids, turbidity and water clarity were improving in surface waters (Figure 19), which may be a sign of less algae in the lake (however, low confidence trends in chlorophyll a cannot support this), or it could indicate increased dilution through increased rainfall for example. Previous reporting on data between the 1960s and 1990s showed an improvement in water clarity, however a decline in water clarity was noted from 2000 (Barnes & Burns, 2005) and subsequent trend analyses reported the same (Hamill & Lockie, 2015; Groom, 2021). Reduced water clarity in the lake has previously been attributed to the presence of coarse fish (Rowe et al., 2003 in Hamill & Lockie, 2015) as they are bottom feeders and disturb the lakebed sediments. This could be a factor in the observed degrading turbidity in the bottom waters (Figure 19), as feeding pits were commonly seen along the lakebed in recent surveys (Hussain, 2025).

Degrading trends in temperature (i.e., increasing temperatures) and dissolved oxygen (i.e., decreasing dissolved oxygen), suggest that the dynamics within the lake may be shifting. Increasing temperatures may cause stress on aquatic species, and also alter stratification patterns. Under a changing climate these trends could worsen, as stratification may extend (Woolway *et al.,* 2021) and intensify, as observed across New Zealand lakes in recent decades (Verberg *et al.,* 2010). As a result, the cool, bottom waters are likely to encounter more persistent periods of anoxia (low oxygen), aligning with the observed degrading dissolved oxygen trends. Low oxygen conditions increase the likelihood of nutrient release from the lakebed sediments and increase in-lake nutrient concentrations further, further fuelling the production of phytoplankton (Graham *et al.,* 2020).

Other physical parameters including conductivity, salinity and pH were improving (i.e., decreasing) throughout the water column (Figure 19). Lowering pH values is beneficial, as elevated pH has been found to increase the release rates of phosphorus from the lakebed sediments of Lake Pupuke (Waters & Kelly, 2019).

6.1.4 Summary

Overall, Lake Pupuke had elevated nutrient concentrations in the bottom waters and had a range of algae concentrations, indicating algal blooms occurring at times. Despite this, water clarity was one of the highest in the Auckland region. According to NPS-FM attributes, surface water conditions mostly were within A and B bands, except for phytoplankton (which signals algal blooms), dissolved oxygen (suggesting anoxic bottom waters), and submerged plants (reflecting a lack of native plants and dominance of invasive species). However, degrading trends in bottom water nutrients and turbidity, and temperatures and dissolved oxygen throughout the water column show that the lake is vulnerable to declining water quality. Key drivers of declining water quality in Lake Pupuke include the presence of pest fish, the high biomass of invasive macrophytes, nutrient loading from nutrient-rich sediments within the lake and anoxic conditions that could worsen with a changing climate, fuelling further nutrient loading.

6.2 Lake Rototoa

6.2.1 Lake characteristics, catchment land cover and biodiversity

Lake Rototoa is a 27-metre-deep dune lake on the South Head peninsula in northwest Auckland (Figure 21). The lake is the largest within the region and has previously been identified as having the best water quality (Hamill & Lockie, 2015; Groom, 2021). The lake stratifies seasonally and is predominantly fed by water through rainfall and groundwater, with an inflow stream in the north. There are no outflows, meaning inputs to the lake are not flushed out readily.

Figure 21. Lake Rototoa and surrounding catchment. Source: Hussain (2025).

The catchment surrounding Lake Rototoa is a mix of land covers, with predominantly rural land cover (Section 2.2.1). There is exotic forestry on one side, native forest to the north and west, and the rest of the catchment is rural. Native vegetation acts as a buffer of contaminants and stabilises the steep slopes, however, extensive land slips following Cyclone Gabrielle in February 2023 have impacted the riparian zone (Hussain, 2025). There is one public access location in the south (Figure 22).

Figure 22. Shoreline of Lake Rototoa where public access is located.

Lake Rototoa supports high biodiversity, providing habitat for the New Zealand dabchick, fernbird, grey duck and shag species (Hussain, 2025). Numerous native aquatic species are present in the lake including common bullies, banded kōkopu, dwarf īnanga and kākahi, although populations of kākahi have declined recently, leaving primarily mature individuals (Hussain, 2025). Prior to the introduction of perch in 1999, there were no exotic species of fish recorded in the lake (Ling *et al.,* 2019a).

Now several species of pest fish including perch, tench, rudd, koi carp and gambusia exist in the lake, which compete with native species and exert grazing pressure on submerged macrophytes (Hussain, 2025). A survey of fish communities in the lake found there had been increases in tench, perch and gambusia, reductions in goldfish and declines in native species such as common bully and dwarf īnanga. There were no reports of the presence of rudd in the lake. Increases in tench numbers and biomass are likely to contribute to a decline in water quality (Ling et al., 2019a). The population of kōura (freshwater crayfish) appears to have stabilised, however at a lower population density than before the introduction of perch (Ling *et al.,* 2019a).

The lake supports diverse native macrophyte communities, suggesting the lake is in high ecological condition. However, the extent of the native macrophytes has declined over time, with areas of bare lakebed, suggesting there is stress on the ecosystem (Hussain, 2025). However, there has also been a decline in the invasive species within the lake since 2017, largely due to Auckland Council's management of the invasive Hornwort within the lake (Hussain, 2025).

6.2.2 Threats to lake health

The threat of invasive submerged macrophyte species, as well as other aquatic species such as gold clam and grass carp, is ongoing due to the public access and recreational use of the lake, and therefore should be identified and managed early if they were to be found in the lake (Hussain, 2025). Auckland Council continues each year to raise awareness of the pathways of entry of these invasive species into the lake through the Check Clean Dry Campaign (MPI, 2020), to help reduce this risk (Studholme, B. (2025), pers. comm.). Surveillance for gold clam is undertaken multiple times a year in Lake Rototoa and began in 2023 (Studholme, B. (2025), pers. comm.).

Other threats to declining lake health include pest fish populations, catchment nutrient inputs (i.e., fertiliser use), degradation of the riparian yard due to pest species (e.g. deer), internal nutrient loading from lakebed sediments, and shifts in stratification patterns, including prolonged periods of anoxia. Whilst the presence of macrophytes within the lake provides some resilience, continuing eutrophication could lead to a tipping point being reached, and macrophyte collapse may occur, which would cause the lake to shift to an algal dominated state.

6.2.3 Water quality state and trends

Between July 2019 and June 2024, the state was mesotrophic with annual TLI scores below 3.5 (Figure 12). Section 4 shows the lake had low surface water nutrient concentrations in comparison to the other lakes, however, nutrient concentrations were higher in the bottom waters, with episodic high values in bottom waters for total phosphorus, and other nutrients (Figure 5). The lake had low algae concentrations, low turbidity and high water clarity (Figure 6).

Figure 23 presents the 10-year trends for surface water and bottom water between 2014 and 2024 in Lake Rototoa. Note that there are no trends presented for volatile suspended solids, *E. coli* and cyanobacteria due to not meeting the data requirements (see Section 2.5.2), and chlorophyll a and water clarity are only measured in the surface waters.

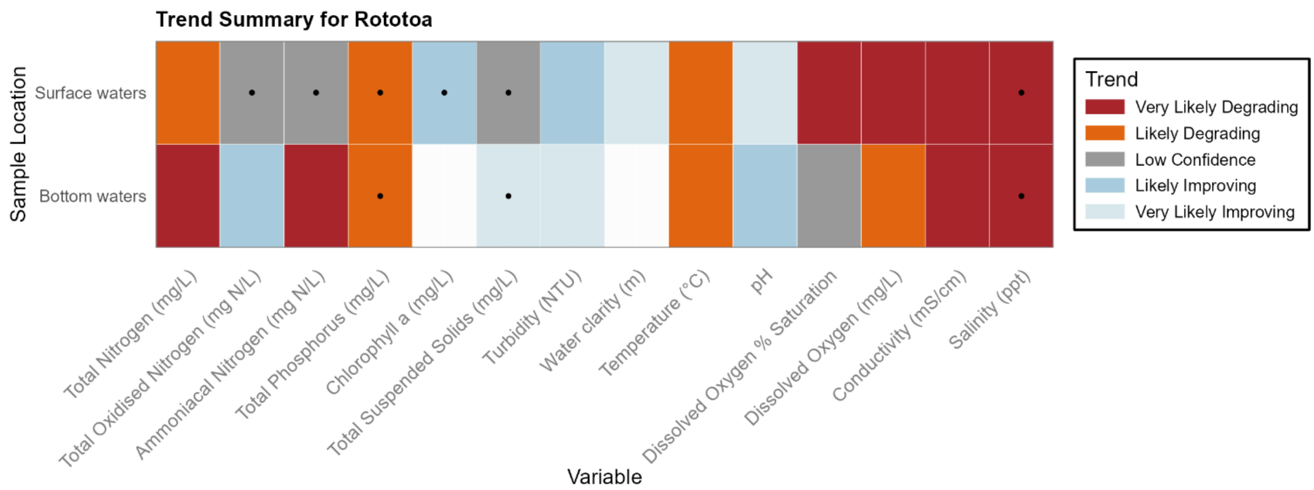


Figure 23. Ten-year trends for surface and bottom waters in Lake Rototoa. Sites with a Sen slope (I.e., rate of change) of zero are indicated with a black dot.

Most nutrient parameters in Lake Rototoa show degrading trends, with higher confidence in the degrading trends in the bottom waters (e.g., total nitrogen and ammoniacal nitrogen). As shown in Section 4, bottom water concentrations of nutrients were higher compared to the surface waters, and there were episodic high values throughout time. This could suggest that internal nutrient loading is occurring in the bottom waters of the lake under certain conditions (e.g., stratification and disturbance from pest fish). An example of the episodic high values of bottom water nutrients can be seen in Figure 24, which shows ammoniacal nitrogen concentrations in the bottom waters over time. Since 2020, when monthly sampling began, there have been values that were an order of magnitude higher than samples collected quarterly prior to 2020. This may suggest that the increase in sampling frequency to monthly may be picking up nutrient release events better than the quarterly sampling undertaken previously, which allows for a better understanding of processes within the lake, such as internal nutrient loading.

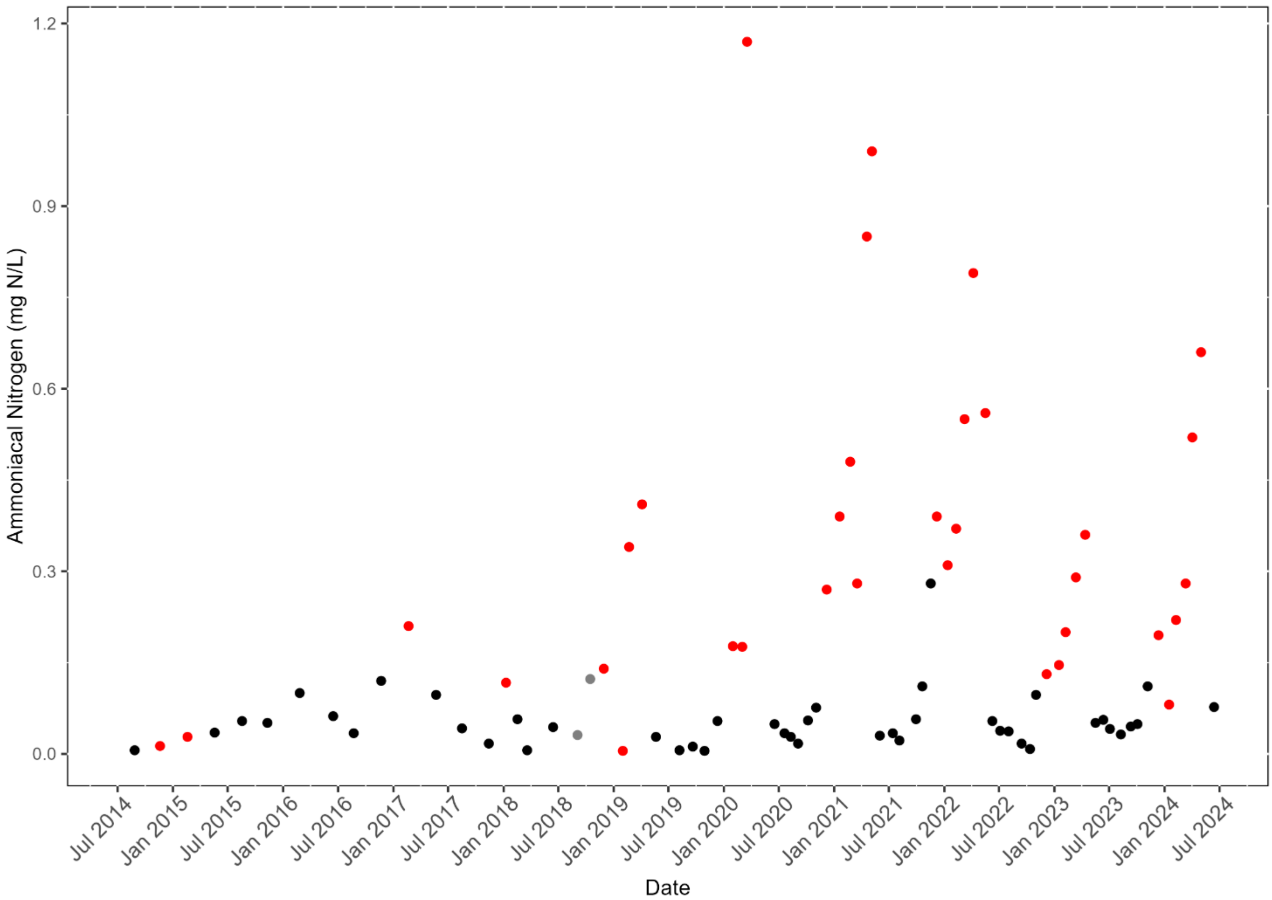


Figure 24. Time series for bottom water ammoniacal nitrogen in Lake Rototoa. Red dots indicate periods of anoxia, whilst grey dots indicate data that does not have corresponding dissolved oxygen information.

Both total nitrogen and ammoniacal nitrogen in the bottom waters were degrading at the highest rate of change across the four lakes with trend results (except for Lake Tomorata in total nitrogen). These trends should be considered carefully, as Lake Rototoa was the lake in the best state overall and is vulnerable to decline. Declining water quality in Lake Rototoa has been reported previously, with degradation evidenced between 1992 and 2005 and again between 2010 and 2019 (Barnes and Burns, 2005; Groom, 2021).

Due to the predominantly rural catchment land cover, there is potential for nutrients entering the lake through agricultural pathways, including livestock urine and waste, and the application of fertilisers (MfE, 2017b). Further, the pine forestry within the catchment can contribute nutrients and organic matter to the lake through various stages of forestry (i.e., planting, fertilising, and harvesting).

Forestry has also been considered to influence changes in submerged vegetation in Northland dune lakes (de Winton & Burton, 2017). Evidence of landslides within the riparian margin (Hussain, 2025) suggests that erosion of soils containing nutrients into the lake is another possible nutrient source.

In the past, researchers assumed that erosion and the presence of pest fish were the main stressors on Lake Rototoa. However, analysis of sediment cores from the lake provides evidence that the lake has undergone ecological changes over the past century, largely driven by nutrient enrichment from agriculture and forestry activities (Gregersen et al., 2022). The study found that long-term fertiliser use, which began around the 1940s, has introduced nitrogen and phosphorus into the lake, leading to increased algal growth, oxygen depletion, and shifts in diatom communities (Gregersen et al., 2022). The paper suggests that these impacts may be underestimated by water quality monitoring data alone and highlight the importance of understanding lake dynamics over longer timeframes (i.e., centuries) (Gregersen et al., 2022).

Figure 23 shows there were improving trends in chlorophyll a, total suspended solids, turbidity and water clarity. Effects of recent landslides may not have influenced these parameters due to the size of the lake, and instead the landslide effects may be seen on more localised scale, affecting the littoral zone of the lake and impacting the submerged macrophytes (Hussain, 2025). Lake Rototoa was one of the lakes with the highest water clarity, with a median of five metres. However, previously there has been evidence of reductions in water clarity, possibly due to the presence of pest fish including rudd, tench and perch (Hamill & Lockie, 2015; Groom, 2021).

In contrast, Figure 23 shows degrading trends in temperature (i.e., increasing temperatures) and dissolved oxygen (i.e., decreasing dissolved oxygen), indicating potential changes in lake dynamics. Increasing temperatures may cause stress on aquatic species, and also prolong stratification, whereby the surface waters remain warmer for longer, and these warmer, less dense waters do not mix with the cooler, denser bottom waters. As mentioned previously, these trends could worsen under a changing climate, as stratification may extend and intensity (Woolway *et al.,* 2021; Verberg *et al.,* 2010), resulting in persistent periods of anoxia (low oxygen) and an increased likelihood of nutrient release from the lakebed sediments. Observations from depth profiles of dissolved oxygen over the past five years[5] show anoxic conditions have shifted upwards in the water column, into shallower waters (< 10 metres) which aligns with decreased pH values in the hypolimnion (Hussain, 2025; Atoa, 2025). The upwards movement of acidic low dissolved oxygen conditions in the lake is thought to have contributed to the observed recession of submerged macrophytes over the past two years (Hussain, 2025).

6.2.4 Lake management

Recent work funded by the Auckland Council Natural Environment Targeted Rate (NETR) has focused on research to understand behavioural differences in perch to assess the feasibility of targeted control methods. This has included an acoustic survey to estimate population size and a fish tracking study of perch and tench to understand the seasonal movement patterns in the lake to

---

[5] See "Depth Profiles" tab in Lake water quality section of Water Quality and River Ecology Data Explorer.

identify opportunities for control efforts, although no seasonal differences were found (O'Driscoll *et al.,* 2021). An ongoing study into the timing of spawning of perch in the lake is being undertaken to help answer biological questions about perch breeding, as the behaviour of perch in Lake Rototoa is seemingly different from the research from European lakes where perch are native (Studholme, B., (2025), pers. comm.).

Further work to assist in this understanding included a spawning survey, which identified a wealth of spawning habitat for perch in the lake and a trial creating artificial spawning habitats, although this proved unsuccessful due to the widely available natural spawning habitat in the lake. These efforts are assisting staff to understand the best management practices to remove the perch from the lake, which is a high priority for management of Lake Rototoa, although effective control has not yet been achieved. In the meantime, management efforts are directed towards minimising the impacts of pest fish on lake ecology (Studholme, B., (2025), pers. comm.).

Kākahi are present in multiple areas of the lake, although live kākahi densities were only 1 – 5 mussels per m^2, or less (Hussain, 2025). There has been a decline in the kākahi population within the lake, which may be contributing to declining water quality through the release of stored nutrients in their biomass and reduction in the capacity for biofiltration (Ling *et al.,* 2019a). There are several historic kākahi beds, with a recent mortality event of approximately 80 per cent of the adult population and mass mortalities related to Cyclone Gabrielle in February 2023 (Ling *et al*., 2019a; Hussain, 2025).

Auckland Council is undertaking conservation initiatives to minimise the impact of pest fish on the kākahi life cycle, with promising results so far (Jones, M. (2025), pers. comm.) In late 2021, staff placed an enclosure in one location of the lake to exclude pest fish from this area and increase native host fish interaction with live kākahi, a necessary step for the kākahi life cycle. Over the past two years, there has been successful glochidia attachment onto the host fish within the enclosure, with no attachment naturally occurring outside of the enclosure, indicating intermediate success of the enclosures. Glochidia are understood to then drop off the host fish and live for multiple years within the sediment in the enclosure area. If kākahi emerge from the sediment within the enclosure over the coming years, this would demonstrate the success of the initiative and enable staff to consider applying this management effort to other locations within the lake, and other lakes (Jones, M. (2025), pers. comm.).

Lake Rototoa is currently in high ecological condition with diverse native submerged macrophytes, however, the cover and extent of these native macrophytes have declined over time, with areas of bare lakebed suggesting stress on the ecosystem (Hussain, 2025). Hornwort (invasive macrophyte) previously posed a threat of expansion in the lake, but that expansion has not occurred. Management efforts began in 2022, with the goal of sustained control, by applying an aquatic herbicide twice a year, with increased efforts to occur over the coming years. There is a hope for eradication, and the presence of Hornwort has reduced from five locations in the lake, to only three locations now (Clements, 2024.). Whilst it is harder to apply the herbicide in deeper locations, it appears that the management efforts have successfully contained this invasive species and reduced the biomass (de Winton 2019; Clements, 2024; Hussain, 2025).

6.2.5 Summary

Overall, Lake Rototoa had good water quality, with high water clarity and NPS-FM attributes in the A and B bands, except for dissolved oxygen and submerged plants. There was evidence of internal nutrient loading due to higher nutrient concentrations in the bottom waters of the lake. However, degrading trends in nutrient parameters suggest declining water quality may result in adverse changes to the high ecological values of the lake. Key drivers of declining water quality in Lake Rototoa include internal nutrient loading, anoxic conditions that could worsen with a changing climate, the presence of pest fish, and the threat of the expansion of invasive macrophytes. Auckland Council's ongoing work on raising awareness of invasive species entering the lake, the management of pest fish, invasive macrophyte control, and kākahi conservation are helping to maintain and improve the high ecological values of the lake.

6.3 Lake Tomorata

6.3.1 Lake characteristics, catchment land cover and biodiversity

Lake Tomorata is a 5-metre-deep dune lake in the Te Arai area, northeast of Auckland. Lake Tomorata is one of the three dune lakes in the Te Arai area, which make up the Ngāroto Lakes complex. All three lakes are within the Ngāti Manuhiri rohe, holding significant ecological, cultural, spiritual, and recreational values.

Lake Tomorata is a polymictic lake, meaning the water column is generally well mixed. There are no natural inflow or outflows, although there is a wetland complex to the south of the lake (Figure 25) which is connected to the lake through sub-surface channels (Hussain, 2025).

Figure 25. Lake Tomorata and surrounding catchment, including wetland.

Exotic forestry and some mānuka/kānuka scrub occupy the eastern side, with rural pastureland in the rest of the catchment (Hussain, 2025). The wetland around the west and southern edges of the lake provides a buffered strip from the grassland, whilst on the north, there is limited riparian vegetation due to the public access, a boat ramp and sandy beach (Figure 26).

Figure 26. Northern side of the lake, with sandy beach and boat ramp for public access.

Lake Tomorata supports diverse biodiversity, including wetland birds such as the nationally threatened Australasian bittern, fairy tern, fernbird, and spotless crake. The lake also harbours regionally significant aquatic species, including kākahi and black mudfish. Native fish such as common bullies, longfin eels, and shortfin eels are abundant (Ling et al., 2019b). However, invasive fish species like rudd and tench are present in the lake which disrupts the ecosystem (Ling *et al.*, 2019b; Hussain, 2025). Both pest fish were illegally released into the lake in January 1971 (Ling & Studholme, 2024).

Over time, the lake has transitioned between vegetated and non-vegetated states. A recent survey identified limited macrophyte growth, with submerged vegetation covering less than 10% of the lake (Hussain, 2025), and according to LakeSPI scoring, the lake was classified as non-vegetated.

6.3.2 Threats to lake health

The presence of pest fish, lack of submerged vegetation and nutrient enrichment are the key threats to lake health in Lake Tomorata. The high volume of recreational activities on the lake may hinder efforts to restore submerged vegetation, increase the risk of the introduction of invasive species to the lake and cause sediment resuspension that may contribute to decreased water clarity and nutrient enrichment (Wells, 2016; Hussain, 2025). A previous recreational use survey conducted at both Lake Tomorata and Lake Rototoa (Gravitas, 2020) showed only 47 per cent of survey participants knew about the Check Clean Dry Campaign (MPI, 2020), suggesting further work can be done to improve the education around freshwater biosecurity in the region. Surveillance for gold clam began in 2023 and is completed multiple times a year in Lake Tomorata (Studholme, B. (2025), pers. comm.).

6.3.3 Water quality state and trends

Between July 2019 and June 2024, the lake was eutrophic with annual TLI scores between 4 and 4.8 (Figure 12). Section 4 shows the lake was nutrient enriched, with high algae concentrations, high sediment concentrations and poor water clarity.

Figure 27 presents the 10-year trends for surface waters between 2014 and 2024. Note that there are no trends for volatile suspended solids due to not meeting the data requirements (see Section 2.5.2).

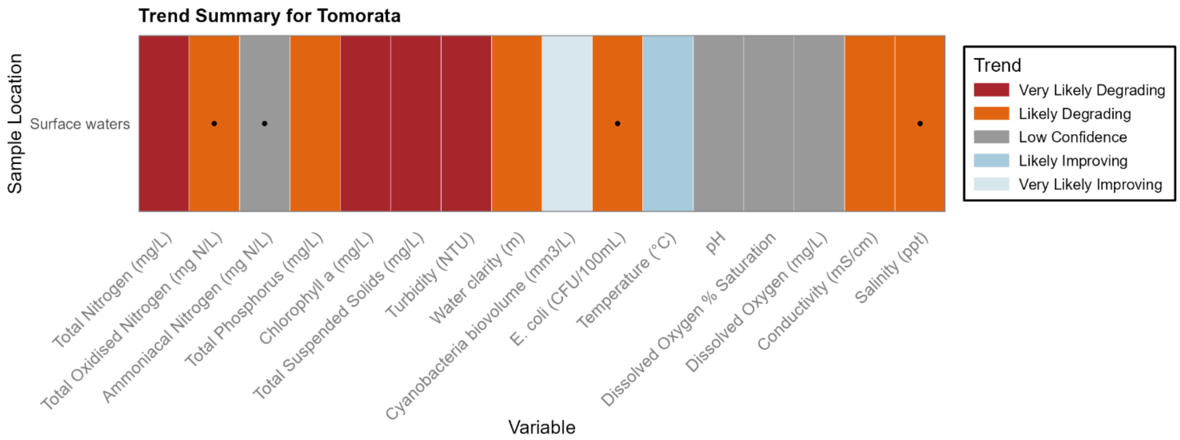


Figure 27. Ten-year trends for surface waters in Lake Tomorata. Sites with a Sen slope (I.e., rate of change) of zero are indicated with a black dot.

Most water quality variables in Lake Tomorata were degrading, except for cyanobacteria biovolume and temperature. The lake was already in a poor state (eutrophic) and had several degrading trends (including total nitrogen, chlorophyll a and total suspended solids) at the highest rate of change among the four lakes with trend results. These patterns suggest that the lake is at risk of further decline in the future. Trends between 1992 – 2005 reported improvements in water quality in the lake (Barnes and Burns, 2005), but subsequent trends between 2006 – 2012 and 2010 – 2019 revealed degrading water quality in Lake Tomorata, particularly linked to periods of reductions in vegetation extent (Hamill and Lockie, 2015; Groom, 2021).

For several of the NPS-FM attributes, Lake Tomorata was in the C band (i.e., total nitrogen and phytoplankton). Degrading trends in these parameters indicate this lake could become vulnerable to falling below the national bottom line over time. If total nitrogen continues degrading at the same rate (0.017 mg/L/year), the lake could shift to the D band (below the national bottom line) within 15 years.

It has been implied that lakes that are in a degraded state can be very difficult to restore, and the most pragmatic and effective way to manage these ecosystems is to maintain the lake resilience at the desired state (Özkundakci & Lehmann, 2019), and not let further degradation occur. However, with a changing climate, polymictic lakes become vulnerable to enhanced eutrophication due to increased internal loading, which can lead to a biological response of increased algae biomass, while changes in external loads will have a lesser relative impact (Me et al., 2018). This scenario may apply to Lake Tomorata, as there are limited direct external loads, as the lake has an extensive wetland margin which filters nutrients before they can enter the lake (Barnes & Burns, 2005; Hussain, 2025), although there are some drains through the wetland which enable unfiltered water to enter the lake. However, previous agricultural use of the surrounding catchment may have contributed to nutrient enrichment within the lake. Nutrients now stored in the lakebed sediments can be released through internal nutrient loading with sediment disturbance, either through wind dynamics or feeding patterns of pest fish.

Total suspended solids, turbidity and water clarity showed degrading trends, from one of the poorest states for these parameters across the region (Section 5.3). Natural fluctuations in water clarity and suspended sediment concentrations occur, driven by atmospheric conditions that are difficult to predict, especially in shallow, polymictic lakes where wind resuspends sediments. This natural resuspension can cause elevated TSS concentrations, as observed in de-vegetated lakes in the Waikato region (Özkundakci & Allan, 2019).

The lake has switched between vegetated and non-vegetated over time. Throughout the 1990s, the lake was non-vegetated, however, in 2008 native charophytes appeared in the lake, and water clarity improved (Hamill & Lockie, 2015). However, in 2012 the charophyte population reduced again (de Winton & Burton, 2017). The lake has been classed as non-vegetated between 2017 and 2024, although a survey in November 2020 recorded vegetation in the survey transects, and the lake was classed as being in moderate condition (de Winton *et al.,* 2022; Hussain, 2025). In multiple surveys, even though the overall LakeSPI score resulted in the classification of non-vegetated, there were observations of macrophyte regeneration and an increase in the distribution of macrophytes throughout the lake, with isolated germlings and young plants of charophytes (de Winton, 2019; Hussain, 2025). However, these showed low germination success, suggesting limited recruitment and/or germinating plants are being frequently removed or disturbed (de Winton, 2019). The abundant population of herbivorous adult rudd could have significantly contributed to macrophyte loss and prevented any subsequent re-establishment of the native plant community from a sediment seed bank (Ling *et al.*, 2019b).

6.3.4 Lake management

Management efforts in Lake Tomorata aim to get plants growing, or re-established, within the lake through several methods. As a trial, charophytes are being grown off-site, and these will be planted into the lake to see if they establish, and whether this method could be scaled up if there is successful growth of the plants (Studholme, B. (2025), pers. comm.).

In the meantime, there is ongoing pest fish management in Lake Tomorata with the goal of eradication of exotic fish from the lake. Intensive fish removal has been taking place twice a year in April and August, since August 2022 (Studholme, B. (2025) pers. comm.). Unpublished data indicate that there have been declines in catch per unit effort for all size classes since August 2022 for both rudd and tench. However, the decline has not been linear over time, with evidence of the catch per unit effort being higher in the autumn compared to winter (Studholme, B. (2025), pers. comm). It does appear that the fish removal efforts are continuing to maintain the pressure on these fish populations to reach potential eradication. This work is funded by Auckland Council's Natural Environment Targeted Rate (NETR), which has been in place since July 2018.

To assess the effectiveness of this pest fish management, yearly submerged macrophyte monitoring has been taking place. These surveys identified fewer feeding pits on the lakebed, suggesting pest fish numbers have reduced, which could allow submerged macrophytes to establish, as there are some germlings present in the lake (Hussain, 2024). However, since the 2023 floods, the lake has increased tannin staining, which is reducing light availability to allow the plants to grow (Hussain, 2024). Additionally, a juvenile kākahi has been found in the lake, and so monitoring of kākahi beds, macroinvertebrates, and zooplankton is being undertaken to assess changes in community assemblages as a result of the pest fish management (Studholme, B. (2025) pers. comm.).

6.3.5 Summary

Overall, monitoring data show that Lake Tomorata was in a poor eutrophic state with nutrient enrichment, algal blooms and poor water clarity. There were mostly degrading trends in nutrient parameters, algae and sediment parameters, suggesting lake health may worsen if there are no interventions in the lake. However, the intensive pest fish removal within the lake is showing promising signs towards eradicating rudd and tench from Lake Tomorata, which will reduce substrate disturbance and alter the trophic cascade. In the future, fish numbers decline, zooplankton populations may increase, which consume phytoplankton, and therefore there may be reductions in algal concentrations within the lake. Whilst macrophyte regeneration within the lake has been observed (Hussain, 2025), the poor substrate condition and high concentrations of tannins may limit the potential for native macrophyte regeneration across the lake. Additionally, the high recreational use poses a further threat to macrophyte regeneration and potential nutrient enrichment through sediment disturbance (Hussain, 2025).

6.4 Lake Wainamu

6.4.1 Lake characteristics, catchment land cover and biodiversity

Lake Wainamu is a 15-metre-deep, seasonally stratified dune lake that is surrounded by a catchment dominated by native forest (Figure 28). There is a permanent inflow and an intermittent outflow stream from the lake that drains into the Te Henga wetland. The lake is in the Waitākere Ranges Regional Park and attracts recreational users, particularly during summer months.

Figure 28. Lake Wainamu surrounded by predominantly native forest.

The lake has remained classified as non-vegetated since 2010 due to the addition of grass carp into the lake in 2009 to control the invasive weed Egeria, which has not been observed in the lake since 2012 (de Winton *et al.,* 2022). Additional fish species, either identified in recent lake surveys, or detected through eDNA, include perch, catfish, tench, goldfish, bully species and banded kōkopu (de Winton *et al.,* 2022; Chaffe, 2023).

6.4.2 Threats to lake health

The presence of pest fish can contribute to nutrient enrichment, disturb lakebed sediments through their feeding patterns, reduce water clarity and suppress any potential submerged vegetation regrowth. Without submerged macrophytes, the lake lacks in-lake competition for dissolved nutrients and has no lakebed stabilisation, which results in a turbid, algal dominant state (Hussain, 2025). Catchment erosion and landslides contribute large sources of nutrients, organic matter and sediment into the lake, which provides a long-term internal source of these contaminants, fuelling further nutrient enrichment and decreases in water clarity.

Due to the recreational use of the lake, there is also a risk of the introduction of additional invasive species such as Hornwort and gold clam.

6.4.3 Water quality state and trends

Between July 2019 and June 2024, the lake fluctuated between mesotrophic and eutrophic with annual TLI scores between 3.7 and 4.6 (Figure 12). The highest annual TLI score (indicating the lowest ecological health) was for the year July 2022 – June 2023, which covered the time when the lake experienced impacts from extreme weather events. Section 4 presents evidence of elevated phosphorus concentrations, with potential nutrient loading occurring due to higher nutrient concentrations in the bottom waters, high turbidity and total suspended solids, and poor water clarity (Figure 4, Figure 5 and Figure 6). Overall, the NPS-FM attributes were good, with most attributes in bands A - C (except for dissolved oxygen attributes and no grades for submerged vegetation (See Section 4.7)).

Figure 29 presents a summary of 10-year trends for surface water and bottom water for Lake Wainamu. Note that there are no trends for volatile suspended solids and *E. coli* due to not meeting the data requirements (see Section 2.5.2), and chlorophyll a, water clarity and cyanobacteria are only measured in the surface waters.

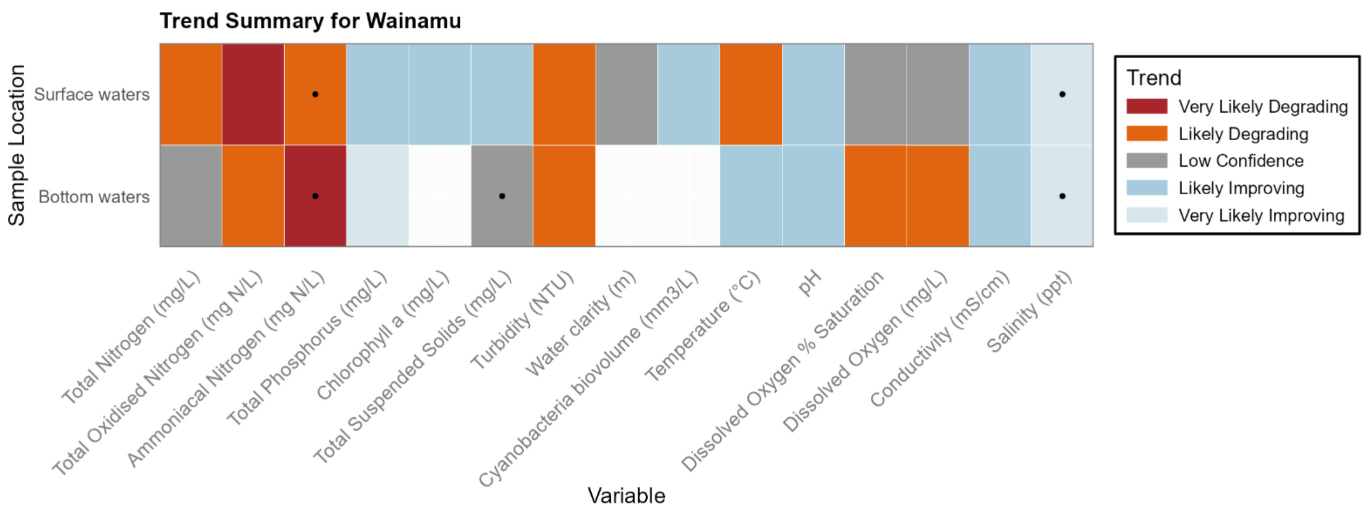


Figure 29. Ten-year trends for surface and bottom waters in Lake Wainamu. Sites with a Sen slope (I.e., rate of change) of zero are indicated with a black dot.

Both the surface and bottom waters showed degrading trends in nitrogen parameters (except for bottom waters total nitrogen which showed a low confidence trend), suggesting increasing nutrient enrichment in the lake. The very likely degrading trend in ammoniacal nitrogen in the bottom waters may indicate increasing concentrations due to internal nutrient loading from lakebed sediments. Conversely, there are improving trends in the surface and bottom waters for total phosphorus. Lake

Wainamu had some of the highest concentrations of phosphorus in the region and is currently in the B band for the NPS-FM attribute for total phosphorus (Figure 14), after previous reporting placed the lake in the C band for this attribute (Groom, 2021). Therefore, the improvements in total phosphorus are a promising indication of declining phosphorus concentrations within the lake. Despite evidence of nutrient enrichment and elevated algal growth (C band for phytoplankton attribute in Figure 14), there were improving trends for chlorophyll a at the magnitude (Sen slope) of -0.00023 mg/L/yr. This could indicate that if improving trends continue in this lake, the NPS-FM band for the phytoplankton attribute could improve within the decade.

Total suspended solids were improving in the surface waters, however, there were low confidence trends in the bottom waters. Turbidity was degrading in both the surface and bottom waters, at the highest magnitudes across the region, from the poorest state for this parameter. The lake has previously been reported to have low water clarity (Barnes & Burns, 2005), thought to be due to a high suspended sediment concentration, partially influenced by the natural source of sand located on the lake edge, as well as sediment disturbance from the presence of pest fish.

Pest fish management between 2004 and 2015, which removed nearly 25,000 pest fish (88% of which were perch), aimed to improve water clarity within the lake (Rowe & Verberg, 2015). Observations suggested this was successful in improving water clarity, however, the stocking of grass carp in 2009 to remove the invasive submerged macrophytes is thought to have caused a reduction in the water clarity and increased the suspended sediments over the subsequent years (Hamill & Lockie, 2015). Figure 29 shows a low confidence trend in water clarity, although the trend direction suggests that water clarity was decreasing (i.e., getting worse).

Extreme weather events may have influenced water quality trends in Lake Wainamu. Figure 30 shows time series for total phosphorus in the surface and bottom waters, turbidity in the bottom waters and water clarity in the lake. There was evidence of peaks in these parameters (or inverse peak in water clarity) around March 2023. It is unclear on the influence of these peaks on the overall trend across the 10 years, however, events such as the Auckland Anniversary floods in January 2023 and Cyclone Gabrielle in February 2023 have impacted the lake. Figure 31 shows a photograph of the discolouration of the lake after the event, which appears orange from the sediment entering the lake. The sub-image demonstrates the scale of the landslides that were observed in the upper lake catchment. This helps contextualise the near-zero readings of water clarity on the lake, and the peaks in the other parameters. Storm events likely mobilised phosphorus from soils and sediment, which entered the lakes and caused peaks in total phosphorus and other parameters. The lake took a while to recover from this event, with values in all parameters dropping (or increasing for water clarity) a year later in 2024.

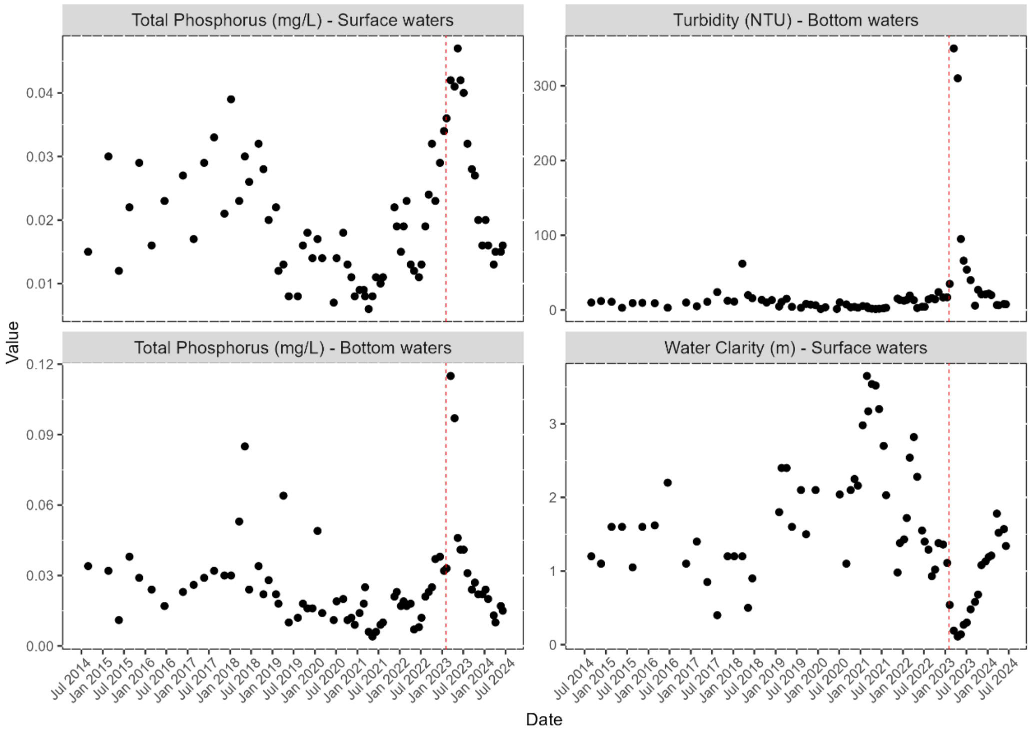


Figure 30. Time series for multiple parameters in Lake Wainamu, with the red dashed line showing the timing of Cyclone Gabrielle in February 2023.

Figure 31. Photograph of Lake Wainamu post-flooding events in February 2023. Sub-image shows extent of landslides in the upstream catchment area.

Physical parameters included improving pH throughout the water column (i.e., values decreasing towards neutral), which aligns with previous reporting (Groom, 2021; Hamill & Lockie, 2015). Surface water temperatures were degrading (i.e., increasing) and bottom waters were improving (i.e., decreasing), which could affect stratification patterns within the lake. Furthermore, bottom water dissolved oxygen was degrading (i.e., getting lower), suggesting there were more anoxic periods, which increases the likelihood of biogeochmeical conditions for nutrient release from the lakebed sediments, which can exacerbate nutrient loading and increase in-lake nutrient concentrations further, which can fuel the production of phytoplankton (Graham *et al.,* 2020).

6.4.4 Summary

Overall, Lake Wainamu had elevated nutrient and algae concentrations, high turbidity and poor water clarity. Several pest fish species were present, and no submerged vegetation, resulting in a turbid, algal dominant state. Despite the surrounding native forest catchment, the lake had poor water quality and is vulnerable to further declines in water quality, as demonstrated by the degrading trends in nitrogen parameters, evidence of nutrient loading, and degrading trends in temperature and dissolved oxygen. Pressures from pest fish, nutrient enrichment, recreational use of the lake and catchment erosion contribute towards declining water quality in the lake.

7 Summary

This report has provided an overview of the current state of lake water quality and identified trends in water quality over the most recent 10-year period (2014-2024).

Several pressures affect the current lake health of lakes across the region, including, but not limited to, catchment land cover, coarse fish, encroachment by invasive species, historic internal nutrient loading and a changing climate.

The state of the thirteen currently monitored lakes was assessed using multiple water quality parameters, the lake Trophic Level Index (TLI), lake ecology and NPS-FM 2020 attributes. Using the Trophic Level Index (TLI), most lakes in Auckland were in poor health (12 out of 13 lakes), and were also classified as poor ecological condition based on the amount of native submerged macrophytes. Lake Rototoa had the best water quality in the region and was classified as being in high ecological condition. Lake Keretā had the worst water quality in the region and was in a non-vegetated, algal dominated state. There were only two lakes classified as being in high ecological condition (Lake Rototoa and Lake Pokorua) according to assessments of submerged macrophytes (LakeSPI), whilst most of the lakes were classified as being in poor condition or non-vegetated.

Lake mixing type influences lake health. Shallow, polymictic lakes were in worse health than the deeper, seasonally stratified lakes, with higher nutrient, algae and suspended matter concentrations, with low water clarity. In seasonally stratified lakes, there was evidence of higher nutrient concentrations in the bottom waters, coupled with persistent anoxia, suggesting internal nutrient loading (nutrient release from lakebed sediments) contributes towards nutrient enrichment in these lakes.

Across the region, *E. coli* levels were generally low, but episodic high results were observed in lakes with high numbers of waterfowl. Cyanobacteria biovolume was low in publicly accessible lakes, but higher in other lakes, with cyanobacteria blooms throughout the year.

There were some lakes below the national bottom line across all attributes in the NPS-FM 2020, with all lakes below the national bottom line for the two dissolved oxygen attributes, and most lakes were below the national bottom line for the native submerged plants attribute. Lake Rototoa and Lake Pupuke had the fewest attributes below the national bottom line, suggesting they were in the best state for water quality. The shallow, polymictic lakes had the most attributes below the national bottom line, highlighting their degraded condition.

Trend analysis was conducted on four lakes that have data available for the 10-year trend period July 2014 – June 2024. These lakes were Lake Pupuke, Lake Rototoa, Lake Tomorata and Lake Wainamu, which are publicly accessible lakes in the region. Across the four lakes, there were mainly degrading trends in total nitrogen, ammoniacal nitrogen, dissolved oxygen and *E. coli*. Trends varied across the lakes and sampling locations (surface and bottom waters), therefore, trends were further explored on an individual lake level.

Several degrading trends in Lake Tomorata had the highest magnitude of the reported trends (i.e., the rate of change). This lake was already in the worst state of the four lakes and is at risk of declining to an even worse state in the future. Lake Rototoa and Lake Pupuke bottom waters had the highest rate of degradation in ammoniacal nitrogen and total nitrogen, which should be considered carefully, as these are the lakes in the best state overall and are vulnerable to decline with further nutrient enrichment.

Lake Pupuke is the deepest lake in the Auckland region, surrounded by an urban catchment. The lake is used recreationally and supports diverse biodiversity both around the lake and within the lake. The lake fluctuated between a mesotrophic and eutrophic state, with some of the best water clarity in the region. The lake was classed as being in poor ecological condition due to the domination of invasive submerged macrophytes, although native charophytes have increased in recent years. The 10-year trends showed improvements in some parameters (e.g., total suspended solids and turbidity), but degradation in other parameters (e.g., total nitrogen and ammoniacal nitrogen in the bottom waters). This is likely due to the process of internal nutrient cycling occurring from the lakebed sediments, which is thought to be driving primary productivity in Lake Pupuke and could intensify with changes in stratification patterns with a changing climate. Overall, Lake Pupuke was in a good state but is vulnerable to decline due to multiple pressures on lake health.

Lake Rototoa, the second largest lake in the Auckland region, had the best water quality (mesotrophic) and was classed as being in high ecological condition. The lake supports high biodiversity, with numerous native aquatic species (fish and vegetation), including kākahi, although populations have recently declined. Ten-year trends showed mainly degrading trends in nutrient parameters, particularly in the bottom waters. The rate of change in total nitrogen and ammoniacal nitrogen in the bottom waters was the highest across the lakes, which should be considered carefully, as Lake Rototoa was in the best state overall and is vulnerable to decline. These observations align with previous reporting of declining water quality in Lake Rototoa. There are several pressures on lake health, including pest fish. Management efforts to preserve the high ecological values of the lake include eradicating the invasive species Hornwort, researching perch behaviour to assist in pest fish management, and undertaking kākahi conservation initiatives.

Lake Tomorata is a shallow, non-vegetated, polymictic lake with high recreational use, which was in poor condition (eutrophic). The lake supports several species of threatened wetland birds, as well as regionally significant aquatic species, including kākahi and black mudfish. However, the lake contains invasive fish species such as rudd and tench, which have disrupted the lake ecosystem and limited macrophyte growth in the algal dominated lake. Ten-year trends show most water quality parameters were degrading in Lake Tomorata, some of which are happening at the highest rate of change across the four lakes assessed for trends. The lake is vulnerable to further decline, from an already poor state, and could fall below the national bottom line for multiple attributes in the NPS-FM 2020 without active intervention. Pest fish eradication of rudd and tench from the lake is underway, with ongoing monitoring of macrophytes and zooplankton to assess ecosystem response to the pest fish removal.

Lake Wainamu is a recreationally used dune lake located in the Waitākere Ranges Regional Park, surrounded by native forest. The lake has fluctuated between a mesotrophic and eutrophic state, with decreased water quality evident around the time of Auckland Anniversary floods and Cyclone Gabrielle (January – February 2023), where the lake was impacted by large landslides in the surrounding catchment. The lake is non-vegetated following the use of grass carp to eradicate invasive macrophytes (Egeria), which used to dominate the lake. Ten-year trends are mixed, with degrading trends in nitrogen parameters, turbidity and bottom waters dissolved oxygen, and improving trends in total phosphorus and chlorophyll a. Overall, Lake Wainamu is vulnerable to further decline, with evidence of internal nutrient loading and increasingly frequent anoxic periods, which may increase nutrient loading. Without submerged macrophytes, there is limited in-lake competition for dissolved nutrients and no lakebed stabilisation, which results in the turbid, algal dominant state.

Management efforts are underway in a few lakes across the region, largely funded by the Natural Environment Targeted Rate (NETR). Work includes feasibility assessments into targeted pest fish control, conservation initiatives to minimise pest fish impacts on kākahi life cycles, eradication of invasive macrophyte species, intensive pest fish removal, charophyte growth trials and transplantation, increasing community awareness of pathways for the introduction of invasive species through the Check Clean Dry Campaign and gold clam surveillance. Additionally, lake management plans are being developed in partnership with mana whenua for some other lakes across the region (e.g., Lake Whatihua), with the intention to include more lakes in the future.

In conclusion, the expansion of the lake water quality programme has provided a more representative and comprehensive assessment of lake health across the Tāmaki Makaurau / Auckland region. The increased sampling frequency revealed greater variability in the data, which provides enhanced insights into lake dynamics that may have been overlooked previously due to the limited sampling frequency. This report has shown that most lakes across Auckland were in poor health, with several pressures including invasive species and nutrient enrichment. While some lakes were in a good state, degrading trends highlight their vulnerability to future decline. Ongoing monitoring and management efforts are essential to maintain and enhance the ecological values of Auckland’s lakes.

8 References

Auckland Council. (2025). Provisional 2023/24 Land Cover Database (LCDB) update for the Auckland Region [Data set]. Prepared by Auckland Council for State of the environment reporting. Unpublished.

Atoa, J., Buckthought, L., Dikareva, N., Kamke, J., Ingley, R. and Surrey, G. (2025) Water Quality and River Ecology Dashboard Methodology. Supplementary Report. Auckland Council.

Atoa, J. (2025) Lake water quality in Tāmaki Makaurau: Annual Data Summary 2024. Auckland Council.

Barnes, G. and Burns, N. (2005) Water Quality of Selected Lakes in the Auckland Region (1992-2005). Auckland Regional Council technical report, TP268.

Burns, N., Bryers, G. and Bowman, E. (2000) Protocol for monitoring trophic levels of New Zealand lakes and reservoirs. Report prepared for Ministry for the Environment (99/2).

Burns, N., McIntosh, J., Scholes, P. (2005) Strategies for manging the lakes of the Rotorua District, New Zealand. Lake Reserve. Management 25:284-286.

Cawthron Institute (2024) Land Air Water Aotearoa (LAWA) factsheet: Calculating water quality trends in rivers and lakes. Available at: https://www.lawa.org.nz/learn/factsheets/calculating-water-quality-trends (Accessed March 2024).

Chaffe, A. (2023) Freshwater fish eDNA in Auckland lakes: Results from 2022 surveys. Internal Auckland Council report.

Clements, D. (2024) Lake Rototoa Hornwort control works 2022 – 2024. Report prepared by NIWA for Auckland Council.

de Winton, M. and Burton, T. (2017) LakeSPI Assessment of 33 Auckland Lakes: 2017 Update. Auckland Council technical report, TR2017/028.

de Winton, M. (2019) Ecological baselines and monitoring for Lakes Rototoa and Tomarata. Unpublished report prepared for Auckland Council: Project ARC19208 (Stage one).

de Winton, M., Elcock, S. and Taumoepeau, A. (2022) LakeSPI assessment of 15 Auckland lakes: 2021/2022. Auckland Council technical report, TR2022/21.

Fraser, C. and Snelder, T. (2025) LWP-Trends library Version 2502 March 2025. LWP Ltd Report. Accessed by https://landwaterpeople.co.nz/pdf-reports/.

Fraser, C. (2023) Auckland Council river, groundwater and lake water quality state and trend analysis: For observations up to June 2022. Report prepared for Auckland Council.

Graham, E., Woodward, B., Dudley, B., Stevens, L., Verberg, P., Zeldis, J., Hofstra, D., Matheson, F. and Elliott, S. (2020) Consequences of inaction: Potential ramifications of delaying proposed nutrient source reductions for New Zealand rivers, lakes and estuaries. Report prepared for Ministry for the Environment. NIWA Client Report No: 2020046HN.

Gravitas (2020) Auckland Council Lake Users Survey – Research Report August 2020. Unpublished report prepared for Auckland Council.

Gregersen, R., Howarth, J. Wood, S., Vandergoes, M., Puddick, J., Moy, C., Li, X., Pearman, J., Moody, A., and Simon, K. (2022) Resolving 500 years of anthropogenic impacts in a mesotrophic lake: nutrients outweigh other drivers of lake change. *Environmental Science and Technology* 56: 16940 – 16951.

Groom, J. (2021) Lake water quality state and trends in Tāmaki Makaurau / Auckland 2010 – 2019. State of the Environment Report. Auckland Council technical report 2021/04.

Hamill, K. and Lockie, S. (2015) State of the environment monitoring. Auckland lake water quality: state and trends. Auckland Council technical report, TR2015/007.

Helsel, D. R. (2012) Statistics for censored environmental data using MINITAB and R, second edition. Wiley.

Hussain, E. (2024) Lake Tomorata baseline macrophyte assessment – November 2024. Report prepared for Auckland Council.

Hussain, E. (2025) Auckland Lake Assessments 2024. Report prepared for Auckland Council.

Larned, S., Snelder, T., Whitehead, A. and Fraser, C. (2018) Water quality state and trends in New Zealand lakes: Analyses of national data ending in 2017. Report prepared for Ministry for the Environment.

LAWA (2024) Factsheet: Lake Trophic Level Index. Published September 2024; Accessed April 2025.

Ling, N., Tempero, G., Pyper, N., Powrie, W. and Prentice, M. (2019a) Status of the fish community of Lake Rototoa in 2019. Unpublished report prepared by University of Waikato for Auckland Council.

Ling, N., Pyper, N., Prentice, M. and Powrie, W. (2019b) Status of the fish community of Lake Tomarata in 2019. Unpublished report prepared by University of Waikato for Auckland Council.

Ling, N. and Studholme, B. (2024) Targeted removal of exotic fish at Lake Tomarata. Presentation given at New Zealand Freshwater Sciences Society Conference in November 2024.

McBride, G. (2016). National Objectives Framework – Statistical considerations for design and assessment. Prepared for the Ministry for the Environment by National Institute of Water and Atmospheric Research Limited, September 2016 (NIWA client report no: HAM16022, NIWA project number MFE16203).

Me, W., Hamilton, D., McBride, C., Abell, J. and Hicks, B. (2019) Modelling hydrology and water quality in a mixed land use catchment and eutrophic lake: Effects of nutrient load reductions and climate change. Environmental Modelling and Software 109: 114-133.

Ministry for the Environment (2017a) National Policy Statement for Freshwater Management 2014 (Amended 2017). http://www.mfe.govt.nz/publications/fresh-water/nationalpolicy-statement-freshwater-management-2014-amended-2017

Ministry for the Environment (MfE) (2017b) New Zealand's Environmental Reporting Series: Our fresh water 2017. Available at: https://www.mfe.govt.nz/sites/default/files/media/Environmental%20reporting/our-fresh-water-2017_1.pdf

Ministry for the Environment (MfE) (2024) National Policy Statement for Freshwater Management 2020. Available at: https://environment.govt.nz/assets/publications/Freshwater/NPSFM-amended-october-2024.pdf

Ministry for the Environment and Health New Zealand (2024) Aotearoa New Zealand Guidelines for Cyanobacteria in Recreational Freshwaters. Wood SA, Puddick J, Hamilton DP, Paul WJ, Safi KA, Williamson WM, Thomson-Laing G, Hawes I, McBride G, Kelly LT, Holloway M, Cridge B, Cressey P, Fairbrother P (Eds). Wellington: Ministry for the Environment.

Ministry for Primary Industries (MPI) (2020) Check, Clean, Dry Campaign – Biosecurity New Zealand. [Online] https://www.biosecurity.govt.nz/travel-recreation/outdoor-activities/check-clean-dry

National Environmental Monitoring Standards (NEMS). (2020) Sampling, measuring, processing and archiving of discrete lake water quality data. Version 1.0.0.

O'Driscoll, R., Escobar-Flores, P., Baker, C., and Graham, E. (2021) Acoustic assessment of perch in Lake Rototoa. Report prepared by NIWA for Auckland Council.

Özkundakci, D. and Allan, M. (2019) Patterns and drivers of spatio-temporal variability of suspended sediment in the Waikato lakes, New Zealand. New Zealand Journal of Marine and Freshwater Research 53(4): 536-554.

Özkundakci, D. and Lehmann, M. (2019) Lake resilience: concept, observation and management. New Zealand Journal of Marine and Freshwater Research 53(4): 481-488.

R Core Team (2023) R: A language and environment for statistical computing. R Foundation for Statistical Computing. Version R-4.0.2. Vienna, Austria. URL: https://www.R-project.org

Rowe, D. and Verberg, P. (2015) Long-term effects of the pest fish reduction programme in Lake Wainamu on water clarity. Unpublished report prepared by NIWA, for Auckland Council.

Schallenberg L, Thomson-Laing G, Steiner K, Shchapov K, Hampton H, Brasell K, Pearman J, Wood S. (2024) Review of 'lakes' in the Freshwater Ecosystems of New Zealand database. Nelson: Cawthron Institute. Cawthron Report 4039. Prepared for Ministry for the Environment.

Verburg, P., Hamill, K., Unwin, M., and Abell, J. (2010) Lake water quality in New Zealand 2010: Status and trends. NIWA Client report for the Ministry for the Environment. NIWA Client report number: HAM2010-107.

Waters, S. and Kelly, D. (2019) Lake Pupuke: Nutrient recycling and management of legacy nutrients. Report prepared for Auckland Council. Cawthron Report No. 3349. P 49.

Wells, R. (2016) The impacts of recreational activities on Lake Tomarata's ecology and water quality. Report prepared for Auckland Council. TR2016/003

Whitehead, A., Fraser, C., Snelder, T. and White., R. (2021) Water quality state and trends in New Zealand lakes: Analyses of national lakes data ending in 2020. Report prepared for Ministry for the Environment.

Winslow, L., Read, J., Woolway, R., Brentrup, J., Leach, T., Zwart, J., Albers, S., and Collinge, D. (2022) Package 'rLakeAnalyzer': Lake Physics Tools. Version 1.11.4.1.

Woolway, R. et al. (2021) Phenological shifts in lake stratification under climate change. Nature Communications 12:2318.

9 Acknowledgements

Auckland Council's lake water quality monitoring programme has benefited from the efforts of numerous people since its inception. We acknowledge the efforts from members of the environmental teams within Auckland Council for their help with undertaking the sampling, with special thanks to Natalie Gilligan and Chris Drake.

Thanks to Kylie Robertson and Jade McMurtry for data management and quality assurance processes.

Thanks to both RJ Hill Laboratories and Watercare Services Ltd for their services in laboratory analysis of these samples.

Thank you to Jenni Gadd, Sietse Bouma, Maddison Jones (Auckland Council) and James Dare (Bay of Plenty Regional Council) for providing comments that improved this report.

10 Appendix 1: Monitored water quality parameters

Summary of reported lake water quality parameters (adapted from Atoa *et al.,* (2025)).

Parameter		Description
Nutrients and algae	Chlorophyll a	Chlorophyll a is a photosynthetic pigment in plants and algae and is used as a measure of algal (phytoplankton) biomass in the water column. The concentration of chlorophyll a is affected by nutrients (which encourage algal growth), daylight, wind direction, shading, temperature and low flow in lakes.
	Nitrogen Species Ammoniacal Nitrogen (NH_3, NH_4^+) Total Oxidised Nitrogen (TOxN, NO_2, NO_3-) Total Nitrogen (TN)	Nitrogen (N) in the environment can be grouped into two main forms: organic nitrogen and inorganic nitrogen. Inorganic forms are bioavailable and can be taken up by plants. Organic N is not bioavailable and can only be converted to inorganic N via microbial processes (or production of inorganic fertilisers). High concentrations of bioavailable N can cause algal blooms, nuisance plant growth and eutrophication, and some forms can be toxic to aquatic organisms. Ammoniacal-N is a combination of un-ionised ammonia (NH_3) and the ammonium ion (NH_4^+). Un-ionised ammonia is the more toxic form to aquatic life and is highly dependent on water temperature, salinity and pH. Total Oxidised N (TOxN) is the sum of nitrite and nitrate. Nitrite (NO_2^-) is an intermediary product formed during the oxidation of ammonium via a microbial process called nitrification. The nitrification process rapidly converts nitrite to nitrate, so it is short lived in the environment. The presence of nitrite typically indicates an active discharge of ammonium-containing N in the immediate vicinity of the sampling site. Nitrate is the end product of the nitrification process. Nitrate (NO_3^-) is very stable and highly water soluble. It can be toxic to aquatic life in high concentrations. Total Nitrogen includes all forms of organic, inorganic, dissolved and particulate nitrogen.
	Dissolved Reactive Phosphorus (DRP) Total Phosphorus (TP)	Phosphorus is found in water as dissolved and particulate forms. Dissolved Reactive Phosphorus is an immediately bioavailable form that can be taken up by plants, adding to nuisance plant growth, eutrophication and algal blooms. Particulate phosphorus consists of organic material, as well as phosphorus in minerals and adsorbed onto mineral surfaces. Total Phosphorus is a measure of both dissolved and particulate forms in a water sample. The adsorption and desorption of phosphate from mineral surfaces creates a buffer that regulates dissolved phosphate concentrations in rivers and estuaries.
Suspended sediment and water clarity	Turbidity	Turbidity is a measure of light scattered in water by particles including inorganic substances such as sediment and organic material such as algae. High turbidity reduces water clarity by scattering and absorbing the light in the water.
	Total Suspended Solids	Total suspended solids are a measure of the concentration of suspended material in the water column such as plankton, non-living organic material, silica, clay and silt. Turbidity and total suspended solids are usually closely correlated but can vary where tannins or other coloured compounds can increase turbidity but are not associated with solid particles.

Parameter		Description
	Volatile Suspended Solids	Volatile suspended solids represent the organic matter content of the suspended solids in a water sample.
	Water clarity	Water clarity refers to the ability of light to travel through water, which is needed for aquatic plants to grow. Water clarity may be reduced when there is an increase in suspended sediment or how much algae is in the water. In lakes water clarity is measured by Secchi depth.
Physical Parameters	Temperature	Surface water temperature is primarily driven by seasonal and diurnal changes in solar radiation and climatic conditions. Temperature affects biological processes and moderates the toxicity of contaminants. Sites are monitored in the same order for consistency within site but differences between sites can be related to the time of day typically sampled.
	pH	pH is a measure of the concentration of hydrogen ions in water. Low pH (<7) indicates that the water is more acidic, while high pH (>7) indicates it is more alkaline. Freshwaters are typically between pH 6.5 to 8. pH fluctuates with diurnal cycles of photosynthesis and respiration and affects biological processes and toxicity of some contaminants such as ammonia and metals.
	Dissolved Oxygen (DO) mg/L Dissolved Oxygen % Saturation	Dissolved Oxygen (mg/L) is the concentration of dissolved oxygen present in the water, while DO (% saturation) expresses the amount of oxygen as a percentage of the maximum capacity of oxygen the water can hold depending on the temperature, atmospheric pressure and salinity conditions at the time. Cold water can hold more DO so the same concentration (mg/L) will have a lower saturation in cold water compared to warm water. Dissolved oxygen levels vary diurnally and seasonally as a result of plant photosynthesis and respiration of living organisms. Reduced DO levels can affect the growth and reproduction of aquatic organisms and in extreme cases cause stress and/or death.
	Salinity	Salinity is the concentration of dissolved salts (such as chloride, nitrate, nitrite, phosphate, sodium, magnesium, calcium) in water. It can indicate the intrusion of salt waters into lakes or indicate possible pollution. Salinity levels affect the toxicity of some contaminants.
	Conductivity	Electrical conductivity reflects the total ionic content of the water, which is affected by the presence of dissolved salts. In freshwaters, conductivity is a general indicator of water quality. Deionised (nearly pure) water has a conductivity of approximately 0.05 mS/cm while seawater is approximately 50 mS/cm.
Human health	*E. coli*	*Escherichia coli* bacteria are found in the gut of warm-blooded animals (including humans, cows, ducks etc.). When found in rivers and lakes, *E. coli* indicate possible faecal pollution. While most *E. coli* themselves are harmless they serve as an easily detectable indicator for other potentially harmful bacteria, protozoa or viruses in the water, which can pose an increased risk to human health.
	Cyanobacteria biovolume	Cyanobacteria are a group of naturally occurring bacteria that can photosynthesise like true algae. In lakes, planktonic cyanobacteria are suspended in the water column and multiply to form ‘blooms’ in high concentrations. Blooms can reduce light in the water column, impact visual clarity and reduce the dissolved oxygen in the water. Some species can produce toxins that are harmful to animals and humans.

11 Appendix 2: Changes in analytical methods of laboratory parameters

Group	Parameter	Units	Watercare Lab Methods 2009-June 2017*	WCS Detection Limit	Hill Lab Methods July 2017-current*	Hills Detection Limit July 2017 – current*
Clarity	Total suspended solids	mg/L	APHA (2005/2012) 2540 D	0.2	APHA (2017) 2540 D 23rd ed (modified)	3 (2017-Oct 2020) 1 (October 2020-Current)
Clarity	Turbidity	NTU	APHA (2005/2012) 2130 B (modified)	0.1 (2010-August 2015) 0.05 (from August 2015)	APHA (2017) 2130 B 23rd ed (modified)	0.05
Clarity	Volatile suspended solids (Lakes programme only)	mg/L	NA	NA	APHA (2017) 2540 E (modified)	3 (June 2019 to October 2020), 1 (October 2020 to current)
Nutrients	Ammoniacal nitrogen	mg N/L	APHA (2005/2012) 4500-NH3 G (Modified) APHA (online edition) 4500-NH3 H (modified) (from July 2016)	0.005	APHA (2017) 4500-NH3 H 23rd ed	0.005
Nutrients	Total oxidised nitrogen	mg N/L	APHA (2005/2012) 4500-NO3 F (modified) APHA (online edition) 4500-NO3 I (from July 2016)	0.002	APHA (2017) 4500-$NO3^-$ I Flow injection	0.001
Nutrients	Total Kjedahl nitrogen	mg N/L	Calculation	0.02	Calculation (TN – (NO3N+NO2N))	0.01
Nutrients	Total nitrogen	mg N/L	APHA (2005/2012) 4500-P J, 4500-NO3 F (modified) APHA (online edition) 4500-P J (modified), 4500-NO3 I (from July 2016)	0.02 0.01 (from September 2014)	APHA (2017) 4500-N C & 4500-$NO3^-$ I 23rd ed (modified)	0.01
Nutrients	Dissolved reactive phosphorus	mg P/L	APHA (2005/2012) 4500-P B, F (modified) APHA (online edition) 4500-P F (from October 2015)	0.005 0.002 (from September 2014)	APHA (2017) 4500-P G 23rd ed (modified) Flow injection	0.004 0.001 (from May 2019)

Nutrients	Total phosphorus	mg P/L	APHA (2005/2012) 4500-P B, J (modified)	0.005 0.004 (from August 2014)	APHA (2017) 4500-P B, E (modified) APHA (2017) 4500-P H (modified) (from December 2020)	0.004 0.002 (from December 2020)
Algae	Chlorophyll a	mg/L	APHA (2005/2012) 10200 H (Modified)	0.0006	APHA (2017) 10200 H (modified) 23rd ed. APHA 10150 C (modified) 23rd ed (from May 2024)	0.003 (Aug 2017 to May 2019)0.0002 (from June 2019 to June 2020) 0.00002 (from July 2020)
Bacteria	*Escherichia coli*	cfu/100mL	USEPA (2002) Method 1603	2	APHA (2017) 9222 G APHA (2017) 9222 I 23rd ed (From March 2020)	1
Modifiers	Dissolved non-purgeable organic carbon	mg/L	NA	NA	APHA (2012/2017) 5310 C (modified) 23rd ed.	0.3
Algae	Cyanobacteria biovolume (Lakes programme only)	mm^3L^{-1}	NA	NA	Microscopic analysis of settled sample following the Utermöhl/Nauwerck method	NA
Physical	pH		APHA 4500-H B	0.1	NA	NA

*unless otherwise specified.

Find out more:
environmentaldata@aucklandcouncil.govt.nz
or visit knowledgeauckland.org.nz and
aucklandcouncil.govt.nz

Auckland Council
Te Kaunihera o Tāmaki Makaurau