Greater Wellington
Te Pane Matua Taiao

A preliminary assessment of water quality in selected shallow lakes and lagoons in the Wellington Region

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Contents

1. Introduction

There are approximately 110 lakes over one hectare in size in the Wellington Region (and many more that are smaller). These lakes provide a range of biodiversity, cultural, water supply, recreational, aesthetic and food resource values, and include both natural and man-made lakes.

Greater Wellington Regional Council (GWRC) routinely monitors water quality in just two lakes, Lake Wairarapa and Lake Onoke (e.g., Hickson Rowden & Perrie 2019); although some water quality and ecological monitoring has also occurred in other lakes. For example, every five years or so, monthly monitoring of water quality has been carried out in Lake Waitawa and assessments of lake ecological condition, based on the submerged plant community condition (i.e., LakeSPI), have also been carried out in several lakes: Lake Pounui, Lake Waitawa, Lake Kohangapiripiri and Lake Kohangatera (de Winton 2011; Perrie & Milne 2012; Perrie et al. 2015; de Winton 2020).

Between December 2017 to April 2019, GWRC undertook a series of freshwater fish surveys[1] at 15 sites across 13 lakes and lagoons in the Wellington Region (Figure 2.1). As part of these surveys, water samples were collected for analysis of key water quality and phytoplankton variables. While sampling was typically limited to two occasions at each site, and hence cannot be considered a comprehensive assessment, these samples provide some insight into the current state of water quality in these lakes and lagoons; many of which previously had no, or very limited, water quality data available.

The purpose of this report is to summarise these data and provide recommendations for further monitoring in lakes and lagoons in the Wellington Region. Continuous water temperature and dissolved oxygen data collected during this period from one of these lakes – Lake Waiorongomai – is also presented, as are key observations made during sampling that relate to potential issues impacting on lake and lagoon ecological health.

[1] These fish surveys were undertaken to aid GWRC's understanding around the current state of fish communities in these lakes and lagoons and also as part of research undertaken via the University of Waikato into lake food-webs and trophic interactions. The findings from these fish surveys will be reported on separately.

2. Methods

2.1 Sites

The 15 sites surveyed across 13 lakes and lagoons as part of this assessment are presented in Figure 2.1. Coordinates of sampling sites and selected lake catchment characteristics are provided in Appendix 1. The location of sampling sites were primarily selected based on their representativeness of littoral habitat for the freshwater fish surveys.

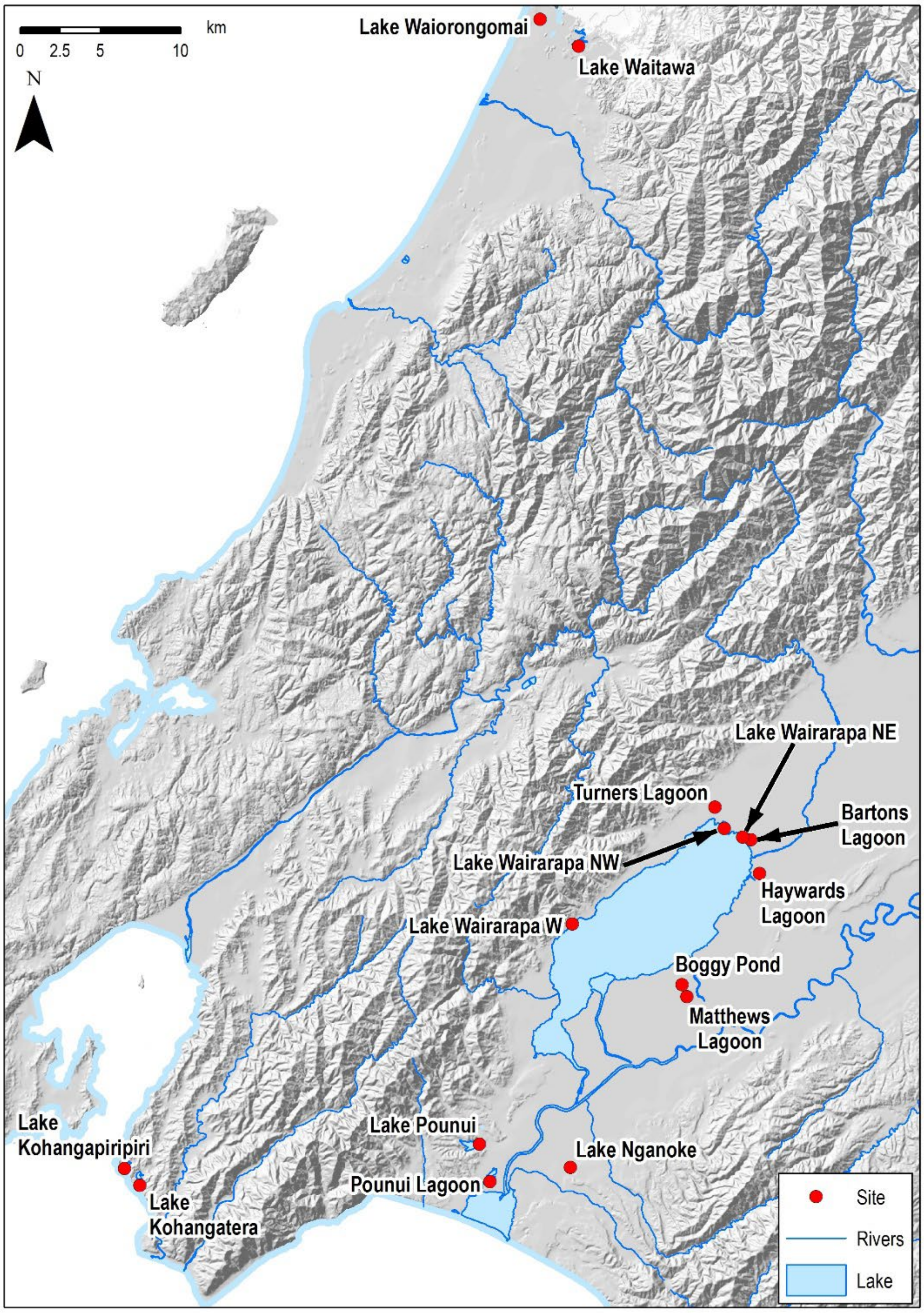

Figure 2.1: The 15 sites sampled across 13 lakes and lagoons for which water quality and phytoplankton data are summarised in this report

2.2 Water quality sampling

All sampling was undertaken between December to May of each year in 2017/18 and 2018/19. Two samples were collected from each site (except for Lake Pounui where only one sample was collected) with at least one month between sampling occasions and many sites were sampled once during each sampling year.

Water samples and field measurements were typically collected by wading from the lake edge to an area of open water free of macrophyte cover. Collection of samples from open water was considered to be more representative of the water body and less prone to being influenced by wave action and dense littoral vegetation that might impact on the quality of the samples collected. Samples were collected in accordance with the sub-surface grab method for sampling isothermal lakes described in Smith et al. (1989) and the total depth at the point of sampling was typically around 1-1.2 metres (but varied across systems and was dependant on the depths present). During all water quality sampling, care was taken to avoid the re-suspension of lake-bed sediments while wading.

Field measurements of dissolved oxygen and water temperature were recorded from ~0.2 metres below the surface using a hand-held YSI Pro ODO field meter which was calibrated on the day of sampling. Secchi disc measurements were collected, however, these data are not presented because on many occasions the Secchi disc was visible on the lake bottom and so did not accurately represent water clarity.

Water samples requiring laboratory analysis were stored on ice upon collection and couriered to RJ Hill Laboratories in Hamilton. The variables monitored and analytical methods are summarised in Appendix 2. All lake water samples collected for dissolved nutrient analysis were filtered in the laboratory.

2.3 Phytoplankton community sampling

Water samples for phytoplankton analysis were collected at the same time and using the same approach as outlined above in Section 2.2 for water sample collection. Water samples were preserved with Lugols iodine and couriered to the Cawthron Institute in Nelson. Phytoplankton results were generally enumerated as “relative abundance” using Cawthron’s in-house method. On occasions when high relative abundance scores of potentially toxic cyanobacteria were detected, and coincided with the presence of visible algal scums, cell counts for potentially toxic cyanobacteria were also undertaken.

2.4 Continuous water temperature and dissolved oxygen monitoring

Continuous water temperature and dissolved oxygen measurements were collected from one site in Lake Waiorongomai (Figure 2.1) using D-Opto loggers. One logger was deployed on the lake bottom using a metal frame designed to hold the logger above lake-bed sediments and a second logger was hung ~0.1 m below a buoy at the water surface. This logger setup was installed by wading from the lake edge to a depth of approximately 1.2 m and was located outside of obvious growths of macrophytes. Therefore, measurements recorded are expected to be fairly representative of the open water of the lake.

Loggers were swapped each month during the period of deployment (February to May 2019). Prior to deployment each logger was calibrated following the manufacturer's instructions and, after installation within the lake, spot measurements with a hand-held YSI Pro ODO DO meter were undertaken to compare against continuous measurements.

2.5 Reporting approach

Water quality and phytoplankton results were summarised and assessed in the following ways:

- The Trophic Level Index (TLI) was calculated for each sampling occasion at each site following Burns et al. (2000). The TLI is nationally recognised lake condition indicator that incorporates four key lake water quality variables: water clarity (Secchi depth), total nitrogen, total phosphorus and chlorophyll *a*. However, given that representative Secchi depth data was not available for every site and sampling occasion, a TLI3 score was calculated as per Verburg et al. (2010; e.g., Secchi depth was excluded from the TLI calculation). TLI3 scores were then compared against the TLI thresholds in Burns et al (2000; see Appendix 3).

- An assessment was undertaken against the reference (minimally-impacted) condition thresholds for total nitrogen, total phosphorus and chlorophyll *a* that were developed for New Zealand shallow lakes (Schallenberg 2019; see Appendix 3). Data from each sampling occasion at each site were compared against both the Tier 1 and Tier 2 thresholds presented (Schallenberg 2019). Tier 1 thresholds are considered to reflect a slightly higher ecological integrity standard than Tier 2 thresholds, although Tier 2 thresholds are still considered to signify only minor impacts on lake condition (Schallenberg 2019).

- Lake condition was assessed against the total nitrogen, total phosphorus and chlorophyll *a* lake water quality attributes from the National Objectives Framework (NOF) outlined in the National Policy Statement for Freshwater Management (NPS-FM; MfE 2020). Application of the NOF classifies lakes into ecological health categories (see Appendix 3) and this was undertaken for each sampling occasion at each site.

- Continuous water temperature and dissolved oxygen data collected from Lake Waiorongomai were plotted and visually examined.

- Phytoplankton community relative abundance data were examined for the presence of potentially toxic cyanobacteria and samples that recorded classifications of either common-abundant, abundant or dominant, on at least one sampling occasion, were noted. For the two sites where full cell counts were undertaken (Matthews Lagoon and Pounui Lagoon), biovolumes were calculated and compared against the alert level framework, as per the interim guidelines for cyanobacteria in fresh waters (MfE 2009).

Some care must be taken with the results presented within this report as several of the reporting approaches used (e.g., calculation and assessment of TLI status and categorisation of NOF grades) require summary statistics based on data collected monthly for a period of 12 or more months (Burns et al. 2000; MfE 2020). Nevertheless, the assessments undertaken still provide insight into the current condition of the lakes and lagoons sampled. Furthermore, the development of the reference condition thresholds for New Zealand shallow lakes (Schallenberg 2019) are based on one-off sampling during summer/autumn periods (i.e., based on a similar sampling regime to the data collected and reported here).

3. Results

All water quality data collected across the 15 sites samples is presented in Appendix 4.

3.1 Trophic Level Index (TLI3)

Trophic Level Index (TLI3) scores for each sampling occasion are presented in Figure 3.1. Calculated trophic scores ranged from 2.9 to 7.1 which correspond to a trophic status of oligotrophic and hypertrophic, respectively. Across all sites, TLI3 scores were >5 on 19 sampling occasions indicating a supertrophic (or higher) status, and three sites – Lake Nganoke, Lake Waiorongomai and Matthews Lagoon – recorded TLI3 scores >5 on both sampling occasions. The lowest TLI3 scores were recorded from Lake Wairarapa (NE and NW), Bartons Lagoon and Lake Kohangapiripiri (Figure 3.1).

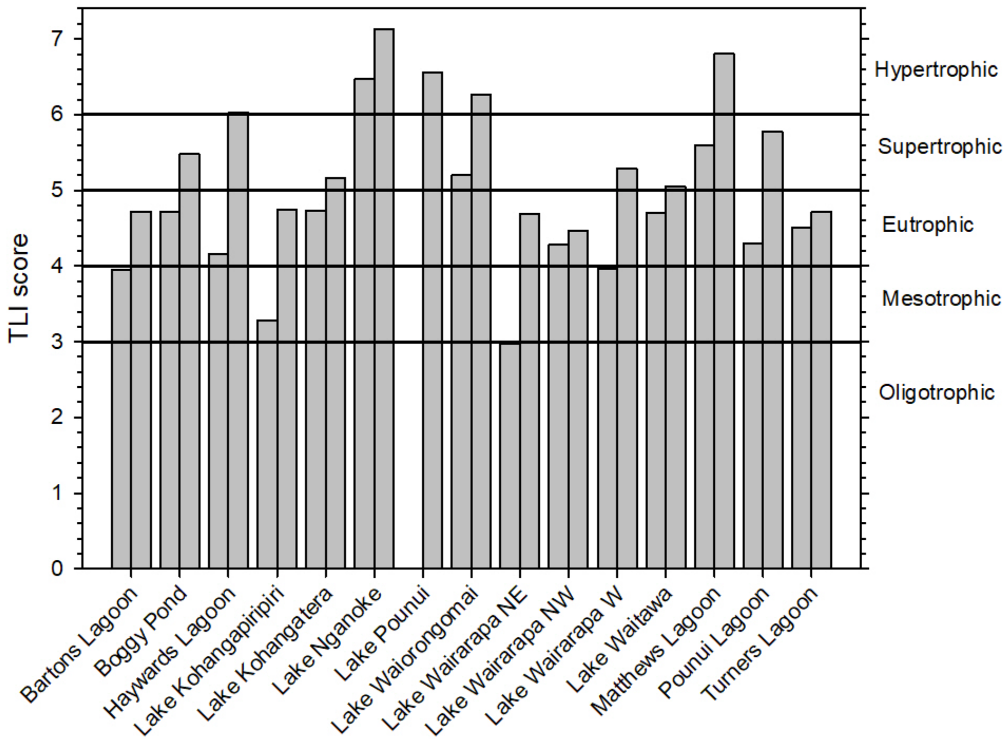

Figure 3.1: Trophic Level Index (TLI3) scores for each of the 15 sites sampled across 13 lakes, TLI3 scores are calculated for each sampling occasion. Horizontal lines indicate the different trophic status thresholds from Burns et al. (2000).

3.2 Comparison against reference condition

Assessments against the chlorophyll *a*, total nitrogen and total phosphorus reference condition thresholds for shallow lakes in New Zealand (Schallenberg 2019) are presented in Figures 3.2 to 3.4. All sites exceeded the Tier 1 chlorophyll *a* reference condition threshold (3.2 mg/m^3) on at least one sampling occasion. Most sites also exceeded the Tier 2 threshold (5.7 mg/m^3) on at least one sampling occasion, exceptions were Bartons Lagoon, Boggy Pond, Lake Kohangapiripiri and Turners Lagoon, which recorded concentrations below the Tier 2 threshold on both sampling occasions (Figure 3.2). Only one site, Lake Nganoke, exceeded the Tier 2 threshold on both sampling occasions.

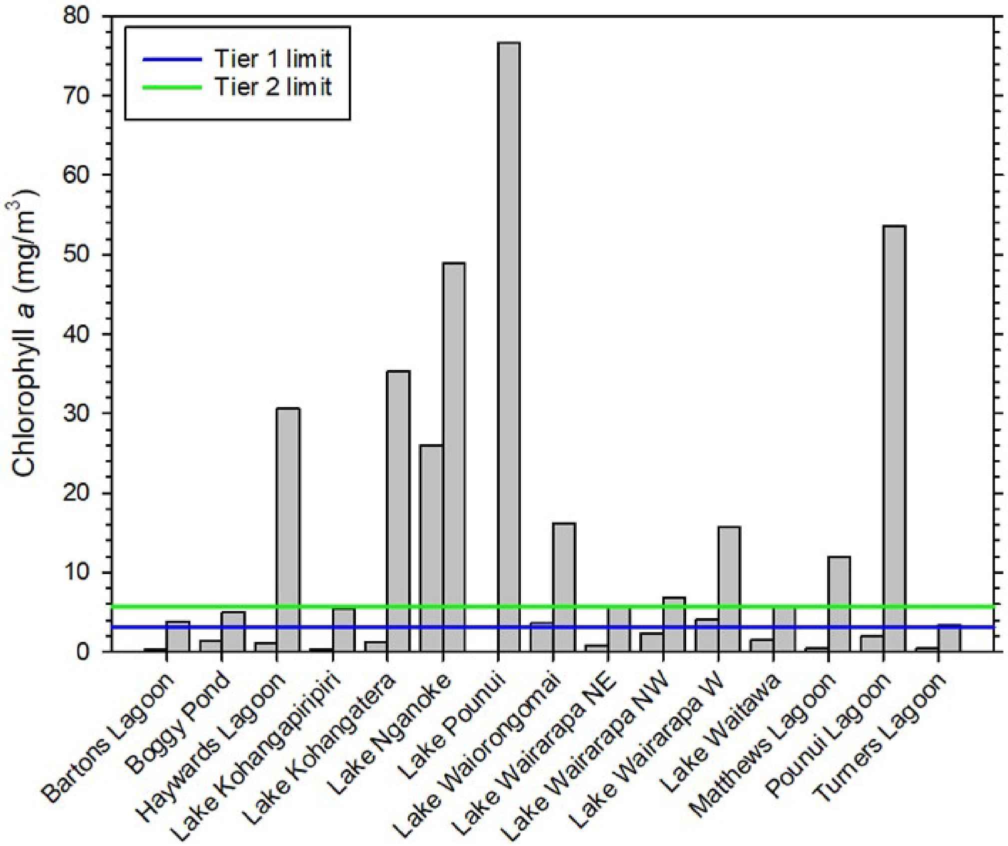

Figure 3.2: Chlorophyll a concentrations (mg/m^3) recorded at 15 sites across 13 lakes. Horizontal lines indicate the Tier 1 (blue) and Tier 2 (green) reference condition thresholds for shallow New Zealand lakes.

The Tier 1 reference threshold for total nitrogen (0.277 mg/L) was exceeded at all sites on all sampling occasions except for one sample collected from Lake Wairarapa NW. The majority of sites also exceeded the Tier 2 threshold (0.692 mg/L) on both sampling occasions; exceptions were Lake Kohangapiripiri, Lake Kohangatera Lake Pounui and Turners Lagoon which only exceeded on one sampling occasion and all three sites located on Lake Wairarapa, which were below the Tier 2 threshold on all sampling occasions. Seven sites exceeded the Tier 2 total nitrogen threshold on both sampling occasions (Figure 3.3).

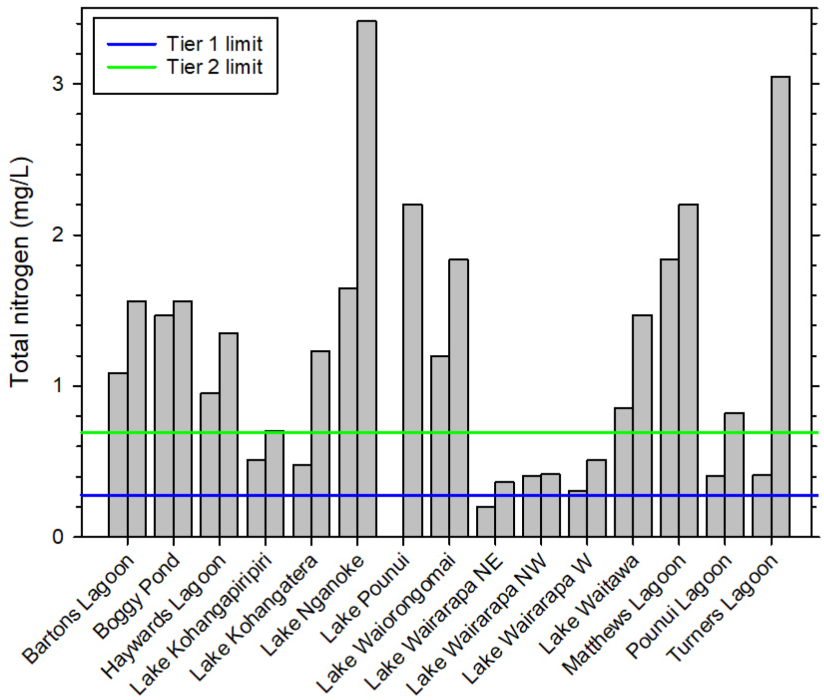

Figure 3.3: Total nitrogen concentrations (mg/m³) recorded at 15 sites across 13 lakes. Horizontal lines indicate the Tier 1 (blue) and Tier 2 (green) reference condition thresholds for shallow New Zealand lakes.

At all sites and on all sampling occasions the Tier 1 threshold for total phosphorus (0.0117 mg/L) was exceeded (Figure 3.4). Similarly, the Tier 2 threshold (0.023 mg/L) was exceeded on most sampling occasions at most sites, except in the case of one sampling occasion each from Lake Kohangapiripiri and Lake Wairarapa NE (Figure 3.4).

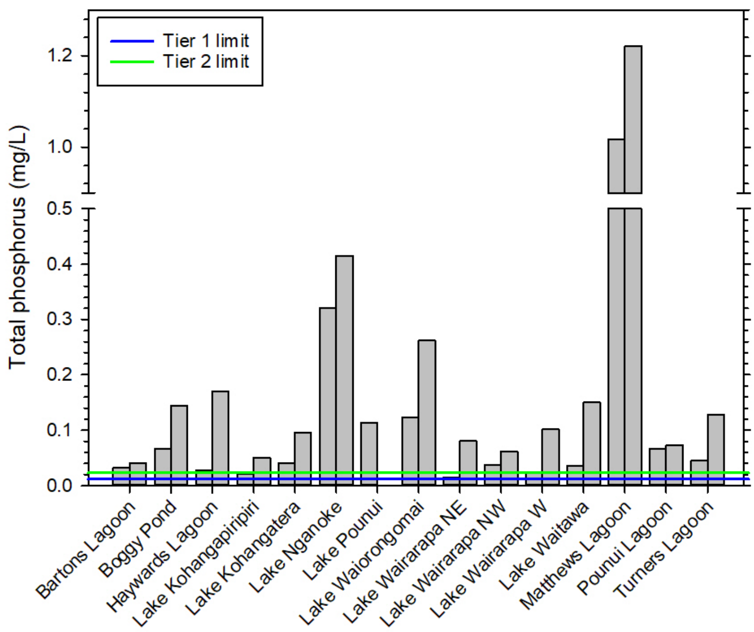

Figure 3.4: Total phosphorus concentrations (mg/m³) recorded at 15 sites across 13 lakes. Horizontal lines indicate the Tier 1 (blue) and Tier 2 (green) reference condition thresholds for shallow New Zealand lakes.

3.3 Assessment against the NOF

Classification of NOF grades for the chlorophyll *a*, total nitrogen and total phosphorus attributes, for each sampling occasion, are presented in Table 3.1. Sites were far more likely to be graded in the "D" band for the total nitrogen and total phosphorus attribute thresholds than for the chlorophyll *a* attribute, although it is important to again reiterate this assessment should be undertaken using an annual median or maximum generated from data collected monthly (MfE 2020).

Sites graded "D" on one sampling occasion for either the median or maximum (or both) chlorophyll *a* attributes were Haywards Lagoon, Lake Kohangatera, Lake Pounui, Lake Waiorongomai and Lake Wairarapa W. On both sampling occasions Lake Nganoke received "D" grades for both chlorophyll *a* attributes. All 15 sites sampled were graded "D" for either the TN or TP attribute on at least one sampling occasion. Several sites received "D" grades on both sampling occasions for the TN and TP attributes. These sites were Boggy Pond, Lake Nganoke, Lake Wairorongomai, and Matthews Lagoon (Table 3.1).

Table 3.1: NPS-FM NOF (MFE 2020) classification for each chlorophyll *a*, total nitrogen and total phosphorus sample

Site	Chlorophyll *a*		Total nitrogen	Total phosphorus
	Annual median	Annual maximum		
Bartons Lagoon	A/B	A/A	D/D	C/C
Boggy Pond	A/B	A/A	D/D	D/D
Haywards Lagoon	A/D	A/C	D/D	C/D
Lake Kohangapiripiri	A/B	A/A	C/C	C/D
Lake Kohangatera	A/D	A/C	B/D	C/D
Lake Nganoke	D/D	C/C	D/D	D/D
Lake Pounui	D	D	D	D
Lake Waiorongomai	B/D	A/D	D/D	D/D
Lake Wairarapa NE	A/C	A/A	A/B	B/D
Lake Wairarapa NW	A/C	A/A	B/B	C/D
Lake Wairarapa W	B/D	A/B	B/C	C/D
Lake Waitawa	A/C	A/A	D/D	C/D
Matthews Lagoon	A/C	A/B	D/D	D/D
Pounui Lagoon	A/D	A/D	B/D	D/D
Turners Lagoon	A/B	A/A	B/D	C/D

3.4 Lake Waiorongomai continuous water temperature and dissolved oxygen

A section of the continuous water temperature data collected from Lake Waiorongomai is presented in Figure 3.5. Despite the shallow nature of the lake (~1.5 m) and the depth at the location of the logger installation (~1.2 m), there were clear differences in water temperatures recorded at the lake surface and the lake bottom. Water temperatures recorded near the water surface showed significant diurnal variation and this was far less pronounced at the lake bottom. On occasion, water temperatures recorded at the lake surface exceeded 27°C and, at times, the difference between the lake surface and lake bottom temperatures were >5°C. During each diurnal cycle, there is a period where water temperatures near the lake surface and lake bottom were similar, indicating that during this period any thermal stratification (and mixing) in the lake follows a diurnal cycle. By April the difference between water temperatures recorded from near the surface and the lake bottom was greatly reduced compared with February (Figure 3.6).

Measurements of dissolved oxygen (% saturation; DO) recorded from the surface waters exhibited significant diurnal variation, with saturation regularly recorded above 250% and below 60% (Figure 3.7). On several occasions, DO saturation below 40% were recorded. Diurnal variation was less pronounced in March and April compared to February (Figure 3.8). Dissolved oxygen percent saturations recorded from the lake bottom were typically at 0%, or very close to it, for the period monitored (Figures 3.7 and 3.8). However, these results should be interpreted with care, as despite efforts to place the logger above the lakebed sediments, we cannot be certain that this was always achieved[2].

[2] For example, on one occasion the spot DO check measurements (with a handheld meter) taken from the lake bottom recorded % saturations significantly higher than 0% recorded by the logger whereas on other occasions, the DO check measurements were more aligned. This likely indicates the difficulties in getting accurate DO measurements from the lake bottom using the current set-up.

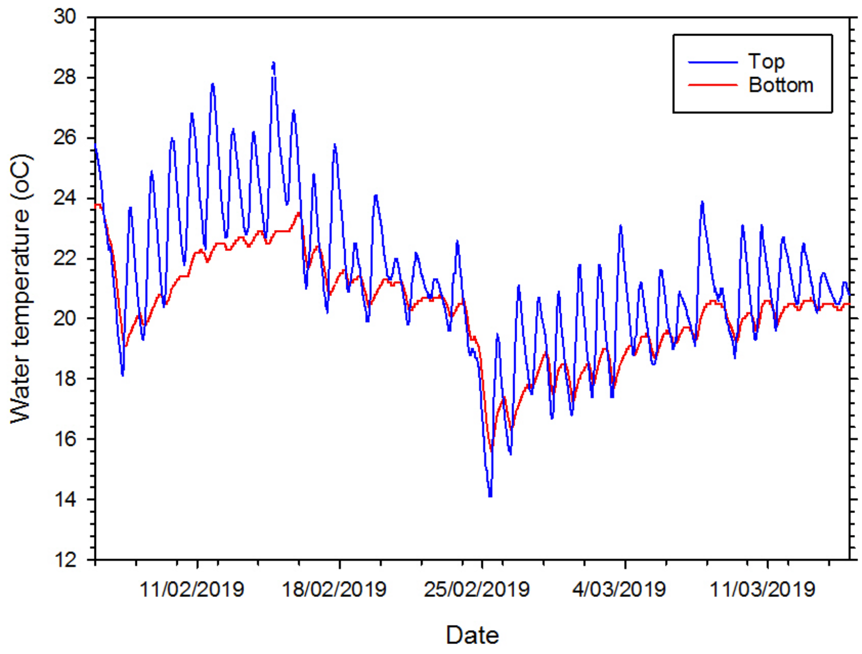

Figure 3.5: A section (6 to 14 February 2019) of the continuous water temperature data collected from near the water surface (Top) and from the lake bottom (Bottom) in Lake Waiorongomai

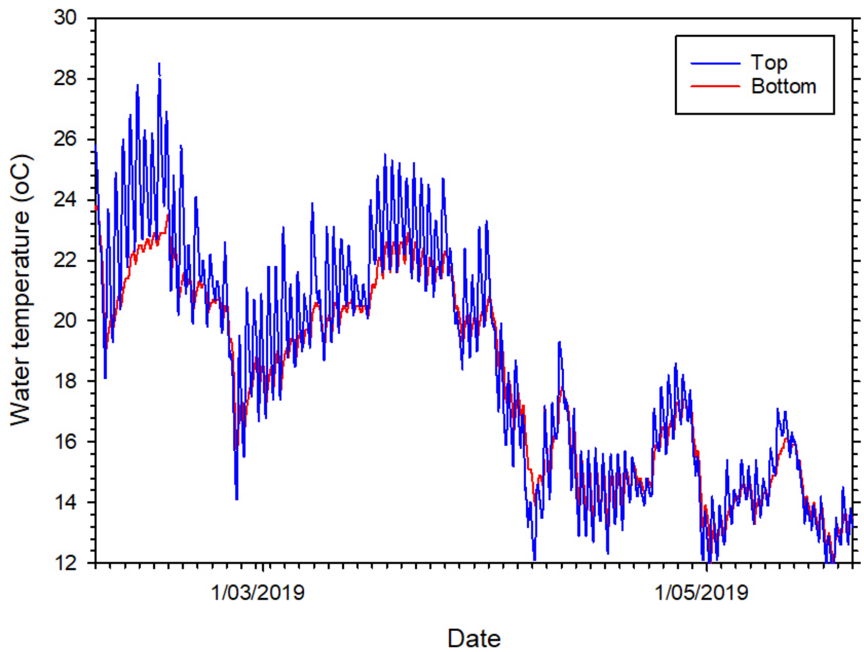

Figure 3.6: Full record (6 Feb to 21 May 2019) of the continuous water temperature data collected from near the water surface (Top) and from the lake bottom (Bottom) in Lake Waiorongomai

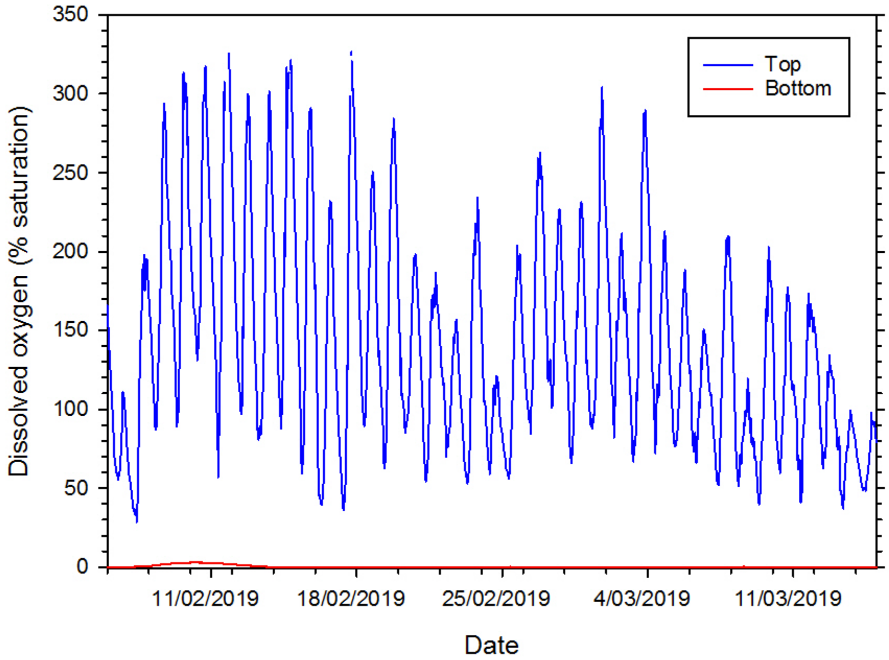

Figure 3.7: A section (6 to 14 February 2019) of the continuous dissolved oxygen data (% saturation) collected from near the water surface (Top) and from the lake bottom (Bottom) in Lake Waiorongomai

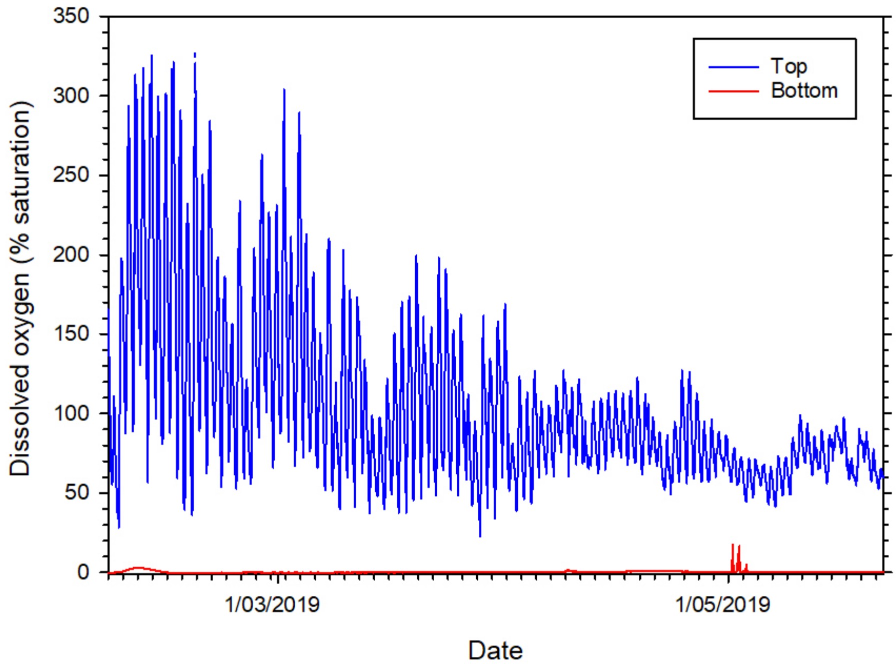

Figure 3.8: Full record (6 Feb to 21 May 2019) of the continuous dissolved oxygen data (% saturation) collected from near the water surface (Top) and from the lake bottom (Bottom) in Lake Waiorongomai

3.5 Presence of potentially toxic cyanobacteria

Potentially toxic cyanobacteria were regularly recorded at the sites sampled although they did not typically make up a dominant component of the phytoplankton community (e.g., relative abundance scores ≤4). However, the following sites recorded potentially toxic cyanobacteria with relative abundances classified as either common-abundant, abundant or dominant (e.g., relative abundance scores >4), on at least one sampling occasion:

- Lake Pounui
- Pounui Lagoon
- Lake Wairarapa W, NW and NE
- Lake Waitawa
- Lake Nganoke (both sampling occasions)
- Haywards Lagoon
- Matthews Lagoon

Potentially toxic cyanobacteria cell counts, and subsequent calculation of cell biovolumes, were undertaken on a single occasion from samples collected at two sites: Pounui Lagoon and Matthews Lagoon. These samples returned biovolumes of 0.5 and 30 mm^3/L for these sites, respectively, which correspond to the “alert” and “action” levels of the interim cyanobacterial guidelines (MfE 2009).

4. Discussion

Based on the analyses undertaken in this report, water quality – in terms of concentrations of chlorophyll *a*, total phosphorus and total nitrogen – appears to be degraded in the majority of lakes and lagoons sampled. Calculation of the TLI3 typically placed sites in the eutrophic to hypertrophic classes (e.g., high to extremely high nutrient enrichment (Burns et al. 1999)), and many sites are unlikely to meet the bottom line for at least one of the key lake water quality attributes in the NOF (MfE 2020). An assessment against reference condition thresholds (i.e., indicative of minimal impacts) for shallow New Zealand lakes indicates that water quality has deteriorated significantly in most of the lakes and lagoons sampled. Potentially toxic cyanobacteria were also common to abundant in water samples collected from a number of lakes and lagoons and calculation of cell biovolumes, albeit from only two waterbodies, indicate that at times there may be a high risk to recreational users[3].

In addition to elevated concentrations of chlorophyll *a* and nutrients, spot measurements of water temperatures were often high (>23°C; see Appendix 4) and may be impacting on sensitive aquatic fauna (Olsen et al. 2012). Spot measurements of dissolved oxygen were often indicative of significant in-lake respiration and/or photosynthetic activity (see Appendix 4); with both low and extremely high concentrations recorded at several sites and this may also be impacting on sensitive aquatic fauna (Wetzel 1983). The continuous water temperature and dissolved oxygen data collected from Lake Waiorongomai indicate that these conditions may persist for several weeks in these shallow systems. Further, monitoring in Lake Waiorongomai indicates that, despite their shallow nature, these lakes may develop anoxic conditions in the lake bottom waters. The development of anoxia has further implications for aquatic fauna, in particular, benthic species (e.g., kakahi), and may also enhance within-lake nutrient cycling (Vant 1987).

Invasive aquatic plant species, such as hornwort, were observed in several lakes and lagoons (Boggy Pond, Lake Waiorongomai, Lake Waitawa and Matthews Lagoon) and these, along with phytoplankton photosynthetic activity may be driving the extremes observed in dissolved oxygen concentrations (and in some cases pH; see Appendix 4). At several sites (Bartons, Haywards and Turners Lagoon), significant lakebed cover (>50%) of benthic cyanobacteria or filamentous algae (green and brown) were observed on at least one sampling occasion (e.g., Figure 4.1). Proliferation of benthic algae often appeared to be smothering both indigenous and exotic macrophytes, and may be causing a reduction in the cover of both. Further work is required to be understand how invasive macrophytes and proliferation of benthic algae might be impacting on indigenous macrophyte communities as well as the wider ecosystem health of these lakes and lagoons.

3 Although recreational use of many of these water bodies may not be high, it can be common in some.

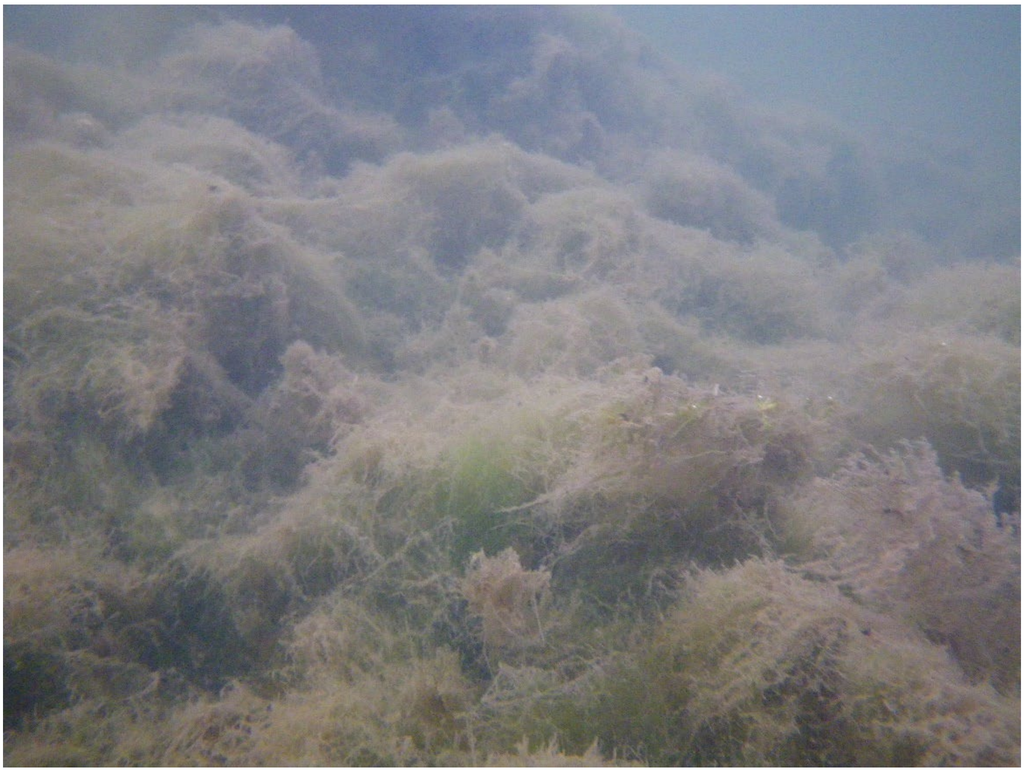

Figure 4.1: Filamentous algae covering the bed of Bartons Lagoon in February 2019

While it was outside of the scope of this report to analyse the drivers of lake water quality, many of the shallow lakes and lagoons sampled are located in catchments dominated by non-native vegetation (e.g., contain large proportions of pastoral land cover; see Appendix 1); hence the widespread poor water quality that was observed is not surprising (Drake et al. 2010). However, the association of poor water quality with increasing non-native vegetation cover in a lakes' upstream catchment is not evident for every lake and lagoon sampled (Figure 4.2). For example, Lake Pounui which has a minimally impacted catchment (e.g., low proportion of non-native vegetation) but has very poor water quality, whereas Bartons Lagoon has moderate water quality (mesotrophic to eutrophic) despite 75% of its catchment being in non-native vegetation.

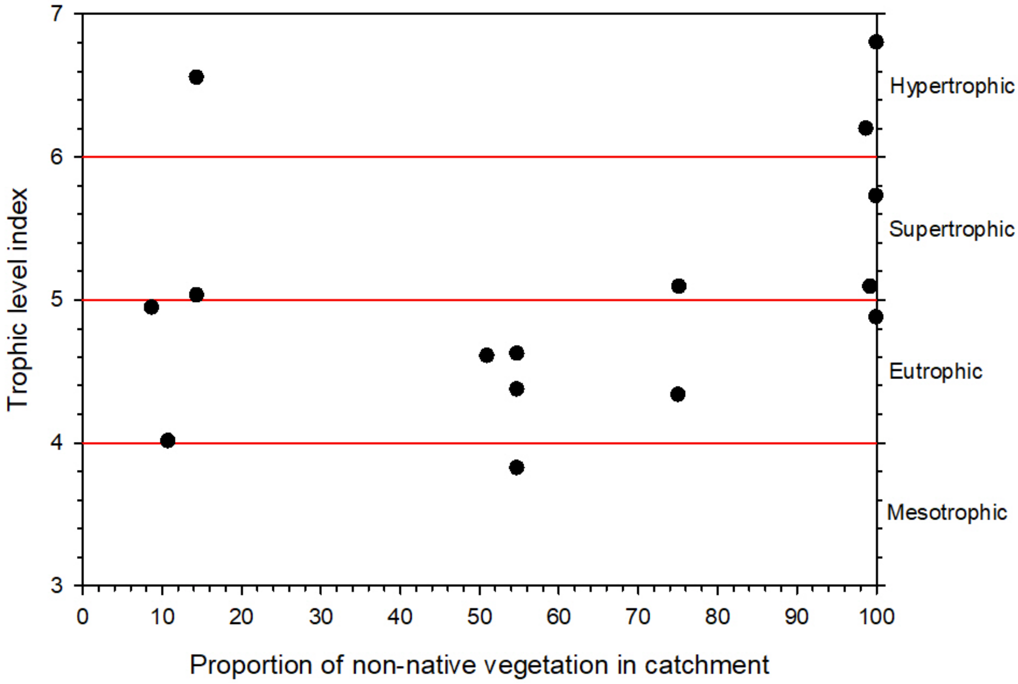

Figure 4.2: Mean Trophic Level Index (TLI3) scores by the proportion (%) of non-native vegetation in each lakes' upstream catchment. Horizontal red lines indicate different trophic status (as per Burns et al. 2000).

The lack of a clear relationship between water quality and catchment land cover for each site may reflect 1) the limited amount of sampling undertaken here (i.e., samples aren't representative) or 2) that an individual lakes' characteristics, such as lake size, hydraulic residence time, legacy inputs, and the aquatic communities present, etc., may be interacting with existing land cover impacts to potentially worsen or mitigate them to result in the water quality observed. However, significantly more water quality data (e.g., regular monthly monitoring), coupled with the collection of relevant ecological information (e.g., data on planktonic and aquatic vegetation, benthic invertebrates, zooplankton and fish communities) and knowledge of potential drivers (e.g., detailed land use information, within-lake nutrient cycling, etc.) is required to better understand both the current state of these lakes and lagoons, and to further identify key drivers and determine, where desirable, appropriate management actions.

Given the limited number of water samples collected for the analyses presented here, some care must be taken when interpreting the results. However, the results summarised are not too dissimilar to those reported for the couple of lakes which have longer-term datasets available (e.g., see Perrie et al. 2012; 2015) and nationally, one-off collection of water samples from shallow lakes have been shown to correlate reasonable well with longer-term datasets (Drake et al. 2010). Hence, while not a comprehensive assessment of water quality, these results provide a valuable insight into the potential state of water quality and ecological condition of a number shallow lakes and lagoons in the Wellington Region that have previously received little monitoring attention.

5. Conclusions and recommendations

Based on the analyses undertaken in this report, water quality appears to be degraded in the majority of lakes and lagoons sampled, with many lakes exhibiting high to extremely high nutrient enrichment, elevated phytoplankton biomass and the potential for the proliferation of potentially toxic cyanobacteria blooms. Nutrient enrichment as well as high water temperatures and extreme (low and high) concentrations of dissolved oxygen, the presence of invasive aquatic plants and proliferation of benthic algae, may all be impacting on the ecological health of most shallow lakes and lagoons in the Wellington Region.

While some care must be taken when interpreting the results presented here due to the limited data available, it appears that many of these lakes and lagoons are severely degraded when compared to their potential reference condition and, as a consequence, many are unlikely to meet the bottom line for at least one of the key lake water quality attributes in the NOF (MfE 2020).

Far more regular water quality monitoring (e.g., monthly spot sampling as well as continuous monitoring of selected variables) is required to better represent the current state of the majority of the lakes and lagoons sampled here. Furthermore, this water quality monitoring needs to be collected in conjunction with developing a better understanding of key 1) ecological (e.g., phytoplankton, zooplankton, fish and aquatic plant communities); 2) lake characteristic (e.g., residence time); and 3) lake catchment information/data. Only with such information will GWRC be able fulfil its monitoring and reporting requirements under the Proposed Natural Resources Plan (GWRC 2019) and the NPS-FM (MfE 2020). This information will be also be vital to identify key drivers of lake ecological health and determine, where desirable, appropriate management actions.

Acknowledgements

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Appendix 1: Lake sampling site details

Lake/lagoon site	FENZ ID	Sampling coordinates		% non-native vegetation in catchment
Bartons Lagoon	301	1794254	5439853	75.0
Boggy Pond	515	1789951	5430826	99.2
Haywards Lagoon	2078	1794782	5437744	75.1
L. Kohangapiripiri	3	1755197	5419353	10.7
L. Kohangatera	4	1756143	5418317	8.6
L. Nganoke	195	1783003	5419436	100.0
L. Pounui	229	1777321	5420874	14.3
L. Waiorongomai	841	1781109	5491010	99.9
L. Wairarapa NE	1708	1793746	5440007	54.7
L. Wairarapa NW	1708	1792584	5440565	54.7
L. Wairarapa W	1708	1783122	5434595	54.7
L. Waitawa	831	1783505	5489319	99.9
Matthews Lagoon	511	1790258	5430067	98.7
Pounui Lagoon	119	1777971	5418542	14.3
Turners Lagoon	Not in FENZ	1792015	5441888	50.9

Appendix 2: Laboratory analytical methodologies

Table A2.1: Laboratory analytical methods for lake water samples

Variable	Method	Detection limit
pH	pH meter. APHA 4500-H+ B 22nd ed. 2012	0.1 pH units
Turbidity	Analysis using a Hach 2100N, Turbidity meter. APHA 2130 B 22nd Ed. 2012	0.05 NTU
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N	0.001 mg/L
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3 - I (modified) 22nd Ed. 2012	0.001 mg/L
Nitrate-N + Nitrite-N (NNN)	Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO_3 - I (modified) 22nd Ed. 2012	0.001 mg/L
Ammoniacal nitrogen	Phenol/hypochlorite colorimetry. Flow injection analyers. (NH_4-N = NH_4+-N + NH_3-N) APHA 4500-NH_3 F 22nd Ed. 2012	0.005 mg/L
Total Kjeldahl nitrogen	Kjeldahl digestion, phenol/hyperclorite colorimetry (Discrete Analysis). APHA 4500-N Org C. (modified) 4500- F (modified) 22nd Ed. 2012	0.1 mg/L
Total nitrogen	Calculation: TKN + Nitrate-N +Nitrite-N	0.05 mg/L
Dissolved reactive phosphorus	Filtered sample. Molybdenum blue colorimetry. Flow injection analyser. APHA 4500-P G 22nd Ed. 2012	0.001 mg/L
Total phosphorus	Total Phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd Ed. 2012	0.004 mg/L
Chlorophyll *a* (mg/m^3)	Acetone extraction. Spectroscopy. APHA 10200 H (modified) 22nd Ed. 2012	0.003 mg/L

Appendix 3: TLI, NPS-FM NOF and Reference condition thresholds

Table A3.1: Classification of lake trophic status using the TLI (Burns et al. 2000) and nutrient enrichment descriptions described in Burns et al. (1999)

Trophic status (nutrient enrichment)	**TLI**	**Chlorophyll *a* (mg/m^3)**	**Secchi depth (m)**	**Total phosphorus (mg/L)**	**Total nitrogen (mg/L)**
Ultra-microtrophic (practically pure)	0.0–1.0	0.13–0.33	33–25	0.00084–0.0018	0.016–0.034
Microtrophic (very low)	1.0–2.0	0.33–0.82	25–15	0.0018–0.0041	0.034–0.073
Oligotrophic (low)	2.0–3.0	0.82–2.0	15–7.0	0.0041–0.009	0.073–0.157
Mesotrophic (medium)	3.0–4.0	2.0–5.0	7.0–2.8	0.0090–0.0200	0.157–0.337
Eutrophic (high)	4.0–5.0	5.0–12	2.8–1.1	0.0200–0.0430	0.337–0.725
Supertrophic (very high)	5.0–6.0	12–31	1.1–0.4	0.0430–0.0960	0.725–1.558
Hypertrophic (extremely high)	>6.0	>31	<0.4	>0.0960	>1.558

Table A3.2: Tier 1 and 2 reference condition limits for shallow lakes for total nitrogen, total phosphorus and chlorophyll *a* (Schallenberg 2019)

Variable	**Tier 1**	**Tier 2**
Total nitrogen (mg/L)	0.277	0.692
Total phosphorus (mg/L)	0.0117	0.023
Chlorophyll a (mg/m^3)	3.2	5.7

Table A3.3: Attribute states and guideline values taken from the National Objectives Framework (MfE 2020)

Attribute State	Chlorophyll *a* (mg/m³)	
	Annual median	**Annual maximum**
A	≤ 2	≤ 10
B	>2 and ≤ 5	>10 and ≤ 25
C	>5 and ≤ 12	>25 and ≤ 60
D	>12	>60
	Total phosphorus (mg/L)	
	Annual median	
A	≤ 0.010	
B	>0.010 and ≤ 0.020	
C	>0.020 and ≤ 0.050	
D	>0.050	
	Total nitrogen (mg/L)	
	Annual median: Seasonally stratified & brackish lakes	**Annual median: Polymictic lakes**
A	≤0.160	≤ 0.300
B	>0.160 and ≤ 0.350	>0.300 and ≤ 0.500
C	>0.350 and ≤ 0.750	>0.500 and ≤ 0.800
D	>0.750	>0.800

Appendix 4: Physico-chemical water quality summary tables

Table A4.1: Physico-chemical data available for the 15 sites sampled across 13 lakes during the summer/autumn periods during 2017/18 and 2018/19. Two samples/measurements were collected from each site except for Lake Pounui (one sample). Raw laboratory data is presented

Lake/lagoon site	Water temperature (°C)	Electrical conductivity (µS/cm)	Dissolved oxygen (% saturation)	Dissolved oxygen (mg/L)	pH	Turbidity (NTU)
Bartons Lagoon	14.2 – 20.4	135 –143	89.8 – 94.2	8.12 – 9.67	7.1 – 7.3	1.9 – 9.3
Boggy Pond	15.9 – 22.5	483 – 665	67.2 – 111	6.61 – 9.62	7.9 – 8.2	2.7 – 4.1
Haywards Lagoon	16.5 – 17.5	141 – 174	95.3 – 110.1	9.31 – 10.54	7.4 – 7.8	1.4 – 11.1
L. Kohangapiripiri	14.5 – 20.1	567 – 631	99.3 – 106.4	9.65 – 10.12	7.4 – 7.6	0.9 – 5.3
Lake Kohangatera	14.6 – 15.2	269 – 2,430	73.3 – 120.7	7.37 – 12.25	7.0 – 8.3	4.3 – 14.8
L. Nganoke	18.1 – 26.3	343 – 347	130.1 – 330	12.3 – 25.6	7.8 – 9.9	10.3 – 18.7
L. Pounui	23.3	192	132.6	11.3	9.0	25.7
L. Waiorongomai	17.5 - 25.7	423 - 463	104.8 – 163.7	10.03 – 13.4	7.9 – 10.2	2.9 – 4.2
L. Wairarapa NE	13.4 – 15.7	123.6 – 1,676	86.6 – 94.0	8.6 – 9.82	7.3 – 7.7	2.6 – 24.5
L. Wairarapa NW	24.1 – 28.9	760 – 1,043	104.0 – 119.0	8.74 – 9.11	8.1 – 8.6	8.8 – 12.0
L. Wairarapa W	17.5 – 20.8	657 – 1,560	110.1 – 106.2	9.49 – 10.54	7.9 – 7.9	8.5 – 69.0
L. Waitawa	15.8 – 26.2	226 – 234	58.7 – 122.1	5.81 – 9.88	7.4 – 8.6	0.8 – 1.6
Matthews Lagoon	16.3 – 27.6	580 – 918	42.7 – 162.9	4.19 – 12.84	7.8 – 9.5	4.5 – 6.7
Pounui Lagoon	24.7 – 25.3	221 – 1,846	119.8 – 128.7	9.95 – 10.56	7.8 – 8.9	14.1 – 55.3
Turners Lagoon	13.1 – 23.7	196 – 209	88.4 – 126.6	9.29 – 10.71	7.4 – 8.9	2.2 – 2.7

Table A4.1: Cont. Physico-chemical data available for the 15 sites sampled across 13 lakes during the summer/autumn periods during 2017/18 and 2018/19. Two samples/measurements were collected from each site except for Lake Pounui (one sample). Raw laboratory data is presented (hence some negative values for ammoniacal nitrogen and nitrate-nitrite nitrogen are presented)

Lake/lagoon site	Dissolved reactive phosphorus (mg/L)	Total phosphorus (mg/L)	Ammonical nitrogen (mg/L)	Nitrate-nitrite nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Total nitrogen (mg/L)	Chlorophyll *a* (mg/m³)
Bartons Lagoon	0.005 – 0.020	0.033 – 0.041	0.013 – 0.023	0.746 – 1.237	0.325 – 0.341	1.086 – 1.562	0.4 – 3.8
Boggy Pond	0.024 – 0.062	0.067 – 1.44	0.002 – 0.004	0.001 – 0.001	1.465 – 1.562	1.465 – 1.562	1.4 – 5.0
Haywards Lagoon	0.009 – 0.037	0.028 – 0.170	0.007 – 0.087	0.004 – 0.888	0.464 – 0.946	0.950 – 1.352	1.0 – 30.6
L. Kohangapiripiri	0.001 – 0.005	0.021 – 0.051	-0.004 – 0.001	-0.002 – 0.015	0.508 – 0.690	0.508 – 0.705	0.4 – 5.5
L. Kohangatera	0.003 – 0.032	0.040 – 0.096	0.010 – 0.025	0.000 – 0.499	0.476 – 0.729	0.476 – 1.227	1.3 – 35.4
L. Nganoke	0.030 – 0.042	0.321 – 0.416	0.006 – 0.038	0.001 – 0.003	1.648 – 3.411	1.649 – 3.414	26.0 – 49.0
L. Pounui	0.001	0.114	0.013	0.000	2.203	2.203	76.7
L. Waiorongomai	0.045 – 0.045	0.123 – 0.262	0.005 – 0.067	0.001 – 0.002	1.192 – 1.835	1.194 –1.836	3.6 – 16.1
L. Wairarapa NE	0.003 – 0.013	0.014 – 0.081	0.001 – 0.003	0.007 – 0.068	0.134 – 0.359	0.202 – 0.365	0.8 – 5.8
L. Wairarapa NW	0.000 – 0.015	0.038 – 0.062	-0.004 – 0.002	0.000 – 0.011	0.391 – 0.415	0.403 – 0.415	2.3 – 6.8
L. Wairarapa W	0.001 – 0.004	0.024 – 0.102	0.003 – 0.005	0.000 – 0.000	0.308 – 0.510	0.308 – 0.511	4.1 – 15.8
L. Waitawa	0.002 – 0.124	0.036 – 0.151	0.009 – 0.195	0.003 – 0.631	0.839 – 0.850	0.853 – 1.470	1.5 – 5.7
Matthews Lagoon	0.775 – 1.075	1.018 – 1.221	0.0020 – 0.233	0.003 – 0.008	1.835 – 2.195	1.839 – 2.203	0.5 – 12.0
Pounui Lagoon	0.004 – 0.007	0.067 – 0.074	0.006 – 0.016	0.001 – 0.001	0.403 – 0.823	0.404 – 0.824	2.0 – 53.6
Turners Lagoon	0.035 – 0.099	0.045 – 0.129	-0.001 – 0.022	0.039 – 2.586	0.371 – 0.460	0.410 – 3.046	0.6 – 3.3