



Lake Water Quality and Ecology monitoring programme

Annual Data Report, 2016/17

Alton Perrie
Environmental Science Department

For more information, contact the Greater Wellington Regional Council:

Wellington
PO Box 11646

Masterton
PO Box 41

T 06 826 1545
F 04 385 6960
www.gw.govt.nz

T 06 826 1545
F 06 378 2146
www.gw.govt.nz

GW/ESCI-T-17/96

November 2017

www.gw.govt.nz
info@gw.govt.nz

Report prepared by:	A Perrie	Environmental Scientist	
Report reviewed by:	MW Heath	Senior Environmental Scientist	
Report reviewed by:	MD Oliver	Team Leader	
Report approved for release by:	L Butcher	Manager, Environmental Science	 Date: November 2017

DISCLAIMER

This report has been prepared by Environmental Science staff of Greater Wellington Regional Council (GWRC) and as such does not constitute Council policy.

In preparing this report, the authors have used the best currently available data and have exercised all reasonable skill and care in presenting and interpreting these data. Nevertheless, GWRC does not accept any liability, whether direct, indirect, or consequential, arising out of the provision of the data and associated information within this report. Furthermore, as GWRC endeavours to continuously improve data quality, amendments to data included in, or used in the preparation of, this report may occur without notice at any time.

GWRC requests that if excerpts or inferences are drawn from this report for further use, due care should be taken to ensure the appropriate context is preserved and is accurately reflected and referenced in subsequent written or verbal communications. Any use of the data and information enclosed in this report, for example, by inclusion in a subsequent report or media release, should be accompanied by an acknowledgement of the source.

The report may be cited as:

Perrie A. 2017. *Lake Water Quality and Ecology monitoring programme: Annual data report, 2016/17*. Greater Wellington Regional Council, Publication No. GW/ESCI-T-17/96

Contents

1.	Introduction	1
2.	Overview of monitoring programme	2
2.1	Monitoring objectives	2
2.2	Monitoring sites, variables and protocol	3
2.2.1	Monitoring in 2016/17	3
2.3	Data analysis and reporting	4
2.3.1	Water quality	4
2.3.2	Submerged aquatic plant community assessments	7
3.	Lake Wairarapa	9
4.	Lake Onoke	13
	Acknowledgements	16
	References	17
	Appendix 1: Monitoring sites	18
	Appendix 2: Monitoring variables and methods	19
	Appendix 3: Water quality data from sites located upstream of Lake Onoke	21

1. Introduction

This report summarises the key results of the Lakes Water Quality and Ecology (LWQE) monitoring in the Wellington Region for the period 1 July 2016 to 30 June 2017 inclusive. The LWQE programme typically involves monthly monitoring of water quality and/or periodic assessments of submerged macrophyte (plant) community structure and composition in selected lakes.

Information on lake water levels during 2016/17 is presented in Harkness (2017).

2. Overview of monitoring programme

Greater Wellington Regional Council (GWRC) routinely monitors water quality in two lakes in the Wellington Region, Lake Wairarapa and Lake Onoke. Monitoring in Lake Wairarapa commenced in 1994 and the programme remained largely unchanged until 2012/13 when changes in monitoring frequency and some site locations and variables were implemented (see Cockeram & Perrie 2013 and Cockeram & Perrie 2014). In August 2009, water quality monitoring programmes were established for two additional lakes, Onoke and Waitawa (Figure 2.1). Monitoring of Lake Onoke is ongoing while monitoring of Lake Waitawa is restricted to 12-month periods every five years (initially in 2009/10 and then again in 2014/15).

In 2011 assessments of ecological condition, based on submerged macrophyte community structure and composition, were introduced for Lakes Kohangapiripiri, Kohangatera and Pounui (Figure 2.1). Assessments of macrophytes in all three of these lakes, as well as an inaugural assessment in Lake Waitawa, last occurred in early 2016.

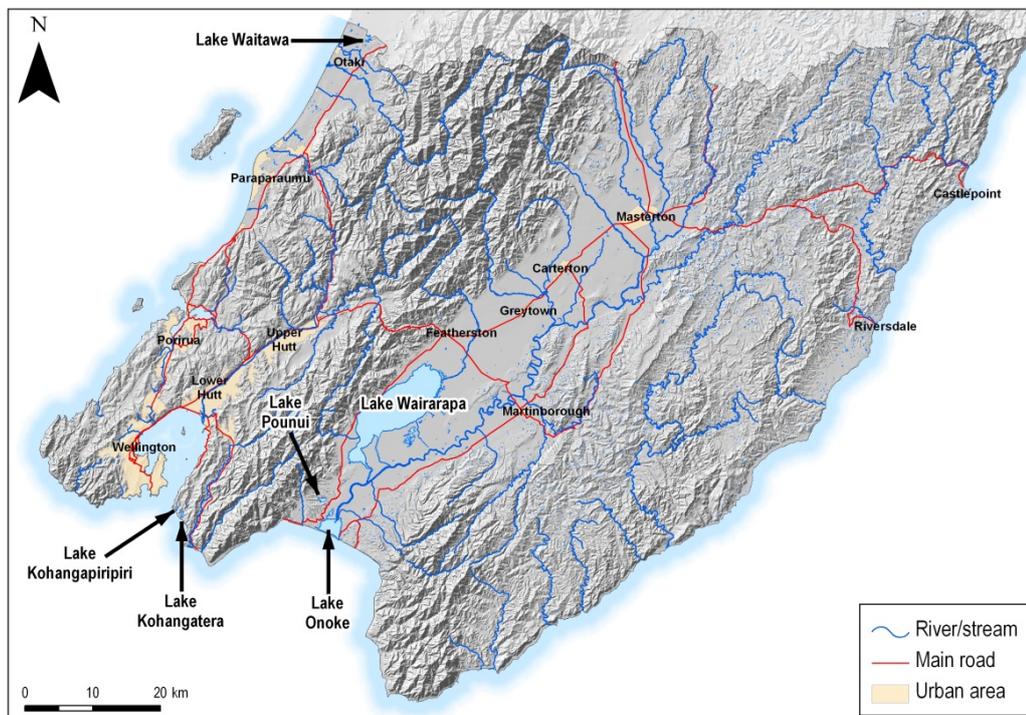


Figure 2.1: Locations of lakes routinely monitored in the Wellington Region

2.1 Monitoring objectives

The aims of GWRC's LWQE monitoring programme are to:

1. Assist in the detection of spatial and temporal changes in the condition of selected lakes;
2. Contribute to our understanding of freshwater biodiversity in the Wellington Region;
3. Determine the suitability of lakes for designated uses;

4. Provide information to assist in targeted investigations where remediation or mitigation of poor water quality or ecosystem health is desired; and
5. Provide information required to determine the effectiveness of regional plans and policies.

2.2 Monitoring sites, variables and protocol

Two types of lake monitoring are undertaken in the Wellington Region:

- Monthly analysis of water samples for a variety of physico-chemical variables (eg, dissolved oxygen, water temperature, pH, conductivity, visual clarity (Secchi depth), turbidity, suspended solids, chlorophyll *a* and dissolved and total nutrients) and monthly assessment of the phytoplankton community (taxa presence, relative abundance and, where potentially toxic cyanobacteria are present, cell counts and potentially cyanotoxin analysis); and
- Periodic assessments of macrophyte community structure and composition – as an indicator of ecological condition – in selected lakes (using the LakeSPI (Submerged Plant Index) methodology). These assessments are typically undertaken every five years and are next due in early 2021.

2.2.1 Monitoring in 2016/17

Routine monthly water quality sampling in Lakes Wairarapa and Onoke (and associated sites¹) carried out during 2016/17 and no LakeSPI surveys were undertaken.

Additional work undertaken in Lake Wairarapa during the 2016/17 period included:

- A survey of macrophyte communities (but not using LakeSPI methodology);
- An assessment of surface lakebed sediments to establish the potential for nutrients to be released from lakebed sediments and into the water column; and
- Lakebed cores to establish a paleolimnological history of the lake.

This work was contracted by GWRC to Cawthron and GNS and will be reported separately during the 2017/18 year.

Lake locations are shown in Figure 2.1, sampling sites on Lakes Onoke and Wairarapa are shown in Figure 2.2 and site coordinates can be found in Appendix 1. Note that as the monitoring site in Lake Onoke is located where the Ruamahanga River enters the lake, it is unlikely to be representative of water quality across the whole lake (see Perrie & Milne 2012).

¹ Two monitoring sites were added to the Lake Onoke sampling programme in July 2014. These sites are located upstream of Lake Onoke and were selected to provide further information on the relative effects of the discharges from Lake Wairarapa and the Ruamahanga River on the water quality in Lake Onoke

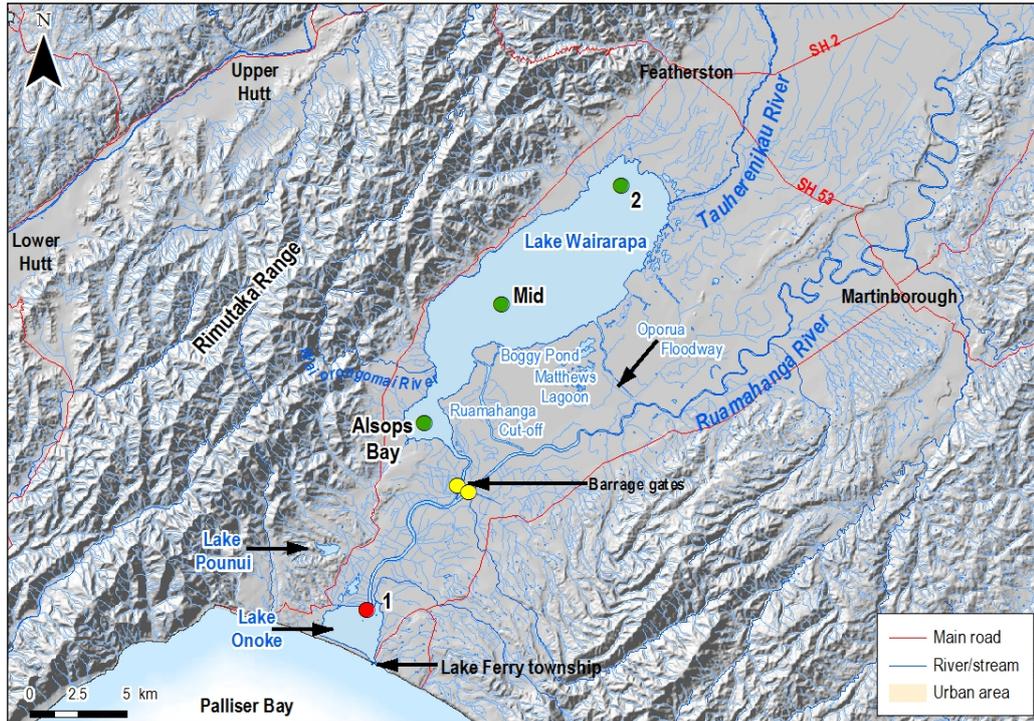


Figure 2.2: Lake Wairarapa and Lake Onoke sites monitored during 2016/17. Green circles = Lake Wairarapa sites, red circles = Lake Onoke main site and yellow circles = sites sampled to help inform the relative effects of the discharges from Lake Wairarapa and the Ruamahanga River on water quality in Lake Onoke

2.3 Data analysis and reporting

2.3.1 Water quality

Water quality data collected from Lakes Wairarapa and Onoke are summarised and assessed using the trophic level index (TLI), and where data is available, compared against relevant outcomes in GWRC’s Proposed Natural Resources Plan (PNRP) (GWRC 2015) and the National Objective Framework (NOF) of the National Policy Statement for Freshwater Management (NPS-FM, MfE 2014).

The TLI was developed by Burns et al. (2000) for assessing the water quality status of New Zealand lakes. The TLI is calculated using four key variables of lake water quality (chlorophyll *a*, Secchi depth, total phosphorus and total nitrogen) and is based on the following four regression equations:

1. $TL_c = 2.22 + 2.54 \log(\text{Chlorophyll } a)$
2. $TL_s = 5.10 + 2.27 \log\left(\frac{1}{\text{Secchidepth}} - \frac{1}{40}\right)$
3. $TL_p = 0.218 + 2.92 \log(\text{Total phosphorus})$
4. $TL_n = -3.61 + 3.01 \log(\text{Total nitrogen})$

TLI scores are calculated for each individual sampling occasion and then averaged (mean) over the reporting period, although note that this TLI calculation approach differs slightly to that outlined in Burns et al. (2000) and that used in some earlier reporting (eg, Cockeram & Perrie 2013)². Lake water quality is assigned an overall trophic level status according to this mean TLI score (Table 2.1). TLI scores (and hence trophic level status) are calculated and reported for an annual and, where data are available, a three-year (rolling mean) period. For lakes with multiple monitoring sites (Lake Wairarapa), TLI scores are calculated for each individual site and then averaged to provide an overall TLI score for the lake. To aid interpretation, Trophic Level scores and corresponding trophic values for each of the four key variables are also presented. These Trophic Level scores are calculated from the mean value of each variable over the reporting period.

Table 2.1: Classification of lake trophic status using the TLI (after Burns et al. 2000) and nutrient enrichment descriptions described in Burns et al. (1999)

Trophic status (nutrient enrichment)	TLI	Chlorophyll <i>a</i> (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

Data is available from both Lakes Onoke and Wairarapa to assess against the nutrient and phytoplankton (chlorophyll *a*) outcomes in the PNRP (Table 2.2). Following the guidance recommended in Greenfield et al. (2015), the assessment of the PNRP narrative outcomes was undertaken by comparing summary statistics calculated over a 3-year period of monthly monitoring, against the thresholds presented in Table 2.2. As stipulated in the PNRP, the assessment for Lake Onoke only included data that had been collected when the lake mouth was closed³.

² See Cockeram and Perrie (2014) for a summary of the changes to previous TLI reporting.

³ Lake Onoke is considered an ICOL (Intermittently Closed and Open Lagoon) and only when the lake mouth is closed does it “function” as a lake and the lake outcomes in the PNRP apply. When the lake mouth is open, Lake Onoke functions more like an estuary.

Table 2.2: Selected attributes and narratives from GWRC’s PNRP as well as suggested measures and thresholds for attributes taken from Greenfield et al. (2015)

Attribute	Narrative	Measure	Threshold
Nutrients	Total nitrogen and phosphorus concentrations do not cause an imbalance in aquatic plant, invertebrate or fish communities	Total nitrogen (mg/L)	Median <0.725
		Total phosphorus (mg/L)	Median <0.043
Phytoplankton	Phytoplankton communities are balanced and there is a low frequency of nuisance blooms	Chlorophyll a (mg/m ³)	Median <5 AND maximum ≤ 60

Four lake attributes – chlorophyll *a*, total phosphorus, total nitrogen and ammoniacal nitrogen – in the NOF of the NPS-FM (MFE 2014) were assessed using data collected from Lakes Onoke and Wairarapa. Attribute states were determined by comparing summary statistics based on one-year of monthly monitoring against the thresholds provided in the NOF (Table 2.3). As stipulated in the NPS-FM, Lake Onoke summary statistics were calculated separately for the occasions when the lake mouth was open and closed. In terms of the total nitrogen and ammoniacal nitrogen assessments lake sites were classified as the following: Lake Onoke and Alsops Bay in Lake Wairarapa were considered brackish and Site 2 and Middle site in Lake Wairarapa were considered polymictic (ie, too shallow to develop significant periods of thermal stratification).

Table 2.3: Attribute states and guideline values taken from the National Objectives Framework (MfE 2014)

Attribute State	Chlorophyll <i>a</i> (mg/m ³)	
	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
	Ammoniacal nitrogen (mg/L) ¹	
	Annual median	Annual maximum
A	≤ 0.03	≤0.05
B	>0.03 and ≤ 0.24	>0.05 and ≤ 0.40
C	>0.24 and ≤ 1.30	>0.40 and ≤ 2.20
D	>1.30	>2.20

¹ As required in the NPS-FM, prior to assessment, ammoniacal nitrogen concentrations were corrected for pH

During data processing, any water quality variables reported as less than or greater than detection limits were replaced by values one half of the detection limit or the detection limit respectively (eg, a value of <2 became 1, a value of >400 became 400). The exceptions are minimum and maximum values presented in the tabulated summaries in Sections 3–5 and Appendix 3 (eg, if a value was reported as <2 the minimum value presented is <2).

2.3.2 Submerged aquatic plant community assessments

Submerged aquatic plant communities are assessed using the nationally accepted LakeSPI (Submerged Plant Index) methodology developed by Clayton and Edwards (2006; refer Appendix 2). Application of the LakeSPI method results in three indices expressed as a percentage of expected pristine state:

- A native condition index (ie, the diversity and quality of the indigenous flora);

- An invasive condition index (ie, the degree of impact by invasive weed species); and
- An overall LakeSPI index that synthesises components of both the native condition and invasive condition indices to provide an overall indication of lake ecological condition.

The LakeSPI index is used to place the lake vegetation into one of five categories of lake condition (Table 2.4).

Table 2.4: Classification of lake ecological condition using the LakeSPI index (from Verburg et al. 2010)

Lake ecological condition	LakeSPI index (% of expected pristine state)
Non-vegetated	0
Poor	>0–20
Moderate	>20–50
High	>50–75
Excellent	>75

3. Lake Wairarapa

Water samples were collected from Lake Wairarapa on 11 occasions during 2016/17; adverse weather conditions in November 2016 inhibited safe access to the sampling sites. Due to intermittent access to the Alsops Bay site, this site was only sampled on eight occasions⁴. A summary of water quality for each site is presented in Table 3.1.

Trophic level classes based on mean values for each variable, overall TLI scores at each site for the 2016/17 year and a three-year period (July 2014 to June 2017) are presented in Table 3.2. Annual mean TLI scores for each site ranged from 4.8 (eutrophic) to 5.3 (supertrophic) and mean TLI scores for the three-year period were 4.8 (eutrophic) at Alsops Bay and 5.1 (supertrophic) at both Site 2 and at Middle site (Table 3.2). Overall, based on the average (mean) of the three sites assessed over the three-year period, the lake can be classed as supertrophic with a TLI score of 5.0.

Table 3.3 summarises the comparison of Lake Wairarapa data against the lake PNRP outcomes for chlorophyll *a*, total phosphorus and total nitrogen. Site 2 and Middle site did not comply with the chlorophyll *a* (maximum) and total phosphorus outcomes but did comply for total nitrogen for the July 2014 to June 2017 period assessed. The Alsops Bay site fully complied with all outcomes over this period.

An assessment of Lake Wairarapa data against NPS-FM attribute thresholds is summarised in Table 3.4. Over the one-year period (July 2016 to June 2017) assessed, NPS-FM bottom lines (ie, “D” state) were exceeded for total nitrogen at Site 2 and total phosphorus at Middle site. Chlorophyll *a* and ammonia states ranged from A to C across the three sites during this period (Table 3.4).

⁴The Alsops Bay site cannot be accessed when lake levels are low. This site was not sampled in December 2016, January and February 2017.

Table 3.1: Summary of water quality in Lake Wairarapa at each site, based on 11 sampling occasions (except at Alsops Bay, $n=8$) between July 2016 and June 2017 (D.L. = detection limit)

Variable	Site 2 ($n=11$)					Middle ($n=11$)					Alsops Bay ($n=8$)				
	Mean	Med	Min	Max	% $n < D.L.$	Mean	Med	Min	Max	% $n < D.L.$	Mean	Med	Min	Max	% $n < D.L.$
Water temperature (°C)	14.0	13.6	9.3	18.8	-	13.7	13.7	9.3	18.4	-	12.0	10.9	8.7	17.2	-
Dissolved oxygen (% saturation)	101.0	100.4	94.5	108.0	-	100.4	101.5	94.9	104.6	-	102.7	101.4	96.5	116.1	-
Dissolved oxygen (mg/L)	10.4	10.3	9.1	11.5	-	10.5	10.5	9.2	11.9	-	10.9	11.0	10.0	11.7	-
pH	7.5	7.4	7.1	8.1	-	7.5	7.6	7.0	7.8	-	7.5	7.4	7.0	8.0	-
Conductivity (µS/cm)	544	429	162	1,550	-	569	447	176	1,702	-	1,083	755	301	2,416	-
Secchi depth (m)	0.22	0.19	0.08	0.46	-	0.22	0.17	0.07	0.51	-	0.39	0.23	0.13	1.40	-
Turbidity (NTU)	94.0	52.0	15.2	290.0	0	104.6	93.0	13.6	250.0	0	44.4	42.0	2.3	123.0	0
Total suspended solids (mg/L)	74.5	43.0	11.0	250.0	0	94.0	82.0	12.0	250.0	0	37.0	31.0	4.0	108.0	0
Volatile suspended solids (mg/L) ¹	5.3	3.0	<2.0	16.0	45	5.7	6.0	<2.0	14.0	27	3.3	2.5	<2.0	8.0	25
Total nitrogen (mg/L)	0.770	0.820	0.210	1.060	0	0.714	0.750	0.210	1.000	0	0.621	0.650	0.180	1.000	0
Total Kjeldahl nitrogen (mg/L)	0.475	0.360	0.210	0.830	0	0.474	0.380	0.210	1.000	0	0.309	0.280	0.180	0.420	0
Nitrite-nitrate nitrogen (mg/L)	0.294	0.320	<0.002	0.720	18	0.240	0.220	<0.002	0.490	18	0.313	0.345	<0.002	0.720	25
Ammoniacal nitrogen (mg/L)	0.007	0.005	<0.010	0.019	82	0.017	0.005	<0.010	0.081	55	0.011	0.005	<0.010	0.036	63
Total phosphorus (mg/L)	0.070	0.048	0.014	0.178	0	0.086	0.074	0.010	0.250	0	0.042	0.040	0.006	0.084	0
Dissolved reactive phosphorus (mg/L)	0.010	0.010	<0.004	0.018	9	0.010	0.011	<0.004	0.016	18	0.007	0.007	<0.004	0.014	38
Chlorophyll <i>a</i> (mg/m ³) ¹	7.1	6.0	<3.0	14.0	18	6.5	6.0	<3.0	19.0	45	5.7	3.0	<3.0	17.0	63
Pheophytin <i>a</i> (mg/m ³) ¹	3.2	1.5	<3.0	9.5	100	3.3	2	<3.0	9	100	2.8	2	<3.0	6	75
Absorbance at 340 nm (AU/cm)	0.075	0.071	0.025	0.149	0	0.083	0.077	0.023	0.154	0	0.055	0.055	0.012	0.104	0
Absorbance at 440 nm (AU/cm)	0.029	0.030	0.006	0.069	0	0.033	0.031	0.005	0.071	0	0.020	0.017	<0.002	0.047	13
Absorbance at 780 nm (AU/cm)	0.007	0.007	<0.002	0.016	9	0.007	0.006	<0.002	0.018	9	0.005	0.003	<0.002	0.011	38

¹ The detection limits for chlorophyll *a*, pheophytin *a* and volatile suspended solids (see Appendix 2) could not always be achieved by the laboratory.

Table 3.2: Trophic level values for each of the four TLI variables as well as an overall mean TLI score for Lake Wairarapa, based on both July 2016 to June 2017 and the three-year period July 2014 to June 2017 (note variable *n* between sites). Trophic level classes are provided in brackets

Site 2		
	Annual mean (<i>n</i> =11)	Three-year mean (<i>n</i> =35)
Chlorophyll <i>a</i>	4.2 (eutrophic)	4.1 (eutrophic)
Secchi depth	6.7 (hypertrophic)	6.6 (hypertrophic)
Total phosphorus	5.3 (supertrophic)	5.3 (supertrophic)
Total nitrogen	5.0 (supertrophic)	4.7 (eutrophic)
Overall TLI score	5.3 (supertrophic)	5.1 (supertrophic)
Middle site		
	Annual mean (<i>n</i> =11)	Three-year mean (<i>n</i> =35)
Chlorophyll <i>a</i>	4.0 (eutrophic)	4.1 (eutrophic)
Secchi depth	6.7 (hypertrophic)	6.5 (hypertrophic)
Total phosphorus	5.5 (supertrophic)	5.3 (supertrophic)
Total nitrogen	4.9 (eutrophic)	4.5 (eutrophic)
Overall TLI score	5.3 (supertrophic)	5.1 (supertrophic)
Alsops Bay		
	Annual mean (<i>n</i> =8)	Three-year mean (<i>n</i> =24)
Chlorophyll <i>a</i>	3.7 (mesotrophic)	3.8 (mesotrophic)
Secchi depth	6.3 (hypertrophic)	6.2 (hypertrophic)
Total phosphorus	4.7 (eutrophic)	4.7 (eutrophic)
Total nitrogen	4.6 (eutrophic)	4.4 (eutrophic)
Overall TLI score	4.8 (eutrophic)	4.8 (eutrophic)

Table 3.3: Comparison of Lake Wairarapa data against PNRP outcomes for the three-year period July 2014 to June 2017

Variable	PNRP outcome threshold	Outcome met? (value)		
		Site 2 (<i>n</i> =35)	Middle site (<i>n</i> =35)	Alsops Bay (<i>n</i> =24)
Chlorophyll <i>a</i> medium (mg/m ³)	Median <12	Yes (5.5)	Yes (5.0)	Yes (3.3)
Chlorophyll <i>a</i> (mg/m ³)	Maximum <60	No (79.0)	No (111.0)	Yes (40.0)
Total Phosphorus median (mg/L)	Median <0.043	No (0.057)	No (0.061)	Yes (0.035)
Total nitrogen median (mg/L)	Median <0.725	Yes (0.570)	Yes (0.540)	Yes (0.460)

Table 3.4: Comparison of Lake Wairarapa data against NPS-FM attribute states¹ for the one-year period July 2016 to June 2017 (median or maximum values are provided in brackets)

NPS-FM state			
	Site 2 (<i>n</i> =11)	Middle site (<i>n</i> =11)	Alsops Bay (<i>n</i> =11)
Total phosphorus median	C (0.048 mg/L)	D (0.074 mg/L)	C (0.040 mg/L)
Total nitrogen median	D (0.820 mg/L)	C (0.750 mg/L)	C (0.650 mg/L)
Chlorophyll a median	C (6.0 mg/m ³)	C (6.0 mg/m ³)	B (3.0 mg/m ³)
Chlorophyll a maximum	B (14.0 mg/L)	B (19.0 mg/L)	B (17.0 mg/L)
Ammonia median	A (0.003 mg/L)	A (0.003 mg/L)	A (0.004 mg/L)
Ammonia maximum	A (0.012 mg/L)	B (0.056 mg/L)	A (0.019 mg/L)

¹For this assessment, Site 2 and Middle site were considered "polymictic" and Alsops Bay "brackish".

4. Lake Onoke

Water samples were collected from one site on Lake Onoke on 12 occasions during 2016/17 and the results are summarised in Table 4.1. Trophic level classes based on mean values generated for the three-year period July 2014 to June 2017 ranged from mesotrophic (chlorophyll *a*) to supertrophic (Secchi depth). Overall, based on the three-year assessment, the lake can be classed as eutrophic with a TLI score of 4.4 (Table 4.2). Water quality summaries for the two sites sampled upstream of Lake Onoke are provided in Appendix 3.

Table 4.1: Summary of water quality in Lake Onoke, based on 12 sampling occasions between July 2016 and June 2017 (D.L. = detection limit)

Variable	Mean	Median	Minimum	Maximum	% <i>n</i> < D.L.
Water temperature (°C)	14.3	15.0	7.4	21.8	-
Dissolved oxygen (% saturation)	101.7	101.1	91.7	117.8	-
Dissolved oxygen (mg/L)	10.4	10.1	8.0	14.2	-
pH	7.4	7.3	7.2	7.9	-
Conductivity (µS/cm)	2,133	707	170	8,120	-
Secchi depth (m) ¹	0.43	0.37	0.18	0.70	-
Turbidity (NTU)	27.8	25.0	2.3	80.0	0
Total suspended solids (mg/L)	32.6	21.5	<2.0	105.0	8
Volatile suspended solids(mg/L)	2.6	1.0	<2.0	8.0	58
Total nitrogen (mg/L)	0.654	0.645	0.220	0.940	0
Total Kjeldahl nitrogen (mg/L)	0.280	0.265	0.130	0.440	0
Nitrite-nitrate nitrogen (mg/L)	0.372	0.385	0.088	0.740	0
Ammoniacal nitrogen (mg/L)	0.015	0.010	<0.01	0.035	42
Total phosphorus (mg/L)	0.039	0.034	0.016	0.111	0
Dissolved reactive phosphorus (mg/L)	0.011	0.010	0.007	0.018	0
Chlorophyll <i>a</i> (mg/m ³)	2.9	1.5	<3.0	6.0	58
Absorbance at 340 nm (AU/cm)	0.036	0.033	0.012	0.081	0
Absorbance at 440 nm (AU/cm)	0.010	0.009	0.002	0.029	0
Absorbance at 780 nm (AU/cm)	0.002	0.001	<0.002	0.005	75

¹ Summary statistics based on ten observations and on two sampling occasions the Secchi disc was visible on the lake bottom (>0.75 m and >0.6 m).

Table 4.2: Trophic level values for each of the four TLI variables as well as an overall TLI score for Lake Onoke based on both July 2016 to June 2017 ($n=12$) and the three-year period July 2014 to June 2017 ($n=35$). Trophic level classes are provided in brackets

Variable	TLI score	
	Annual mean (July 2016 to June 2017, $n=12$)	Three-year mean (July 2014 to June 2017, $n=35$)
Chlorophyll <i>a</i>	3.2 (mesotrophic)	3.1 (mesotrophic)
Secchi depth	6.0 (hypertrophic)	5.7 (supertrophic)
Total phosphorus	4.7 (eutrophic)	4.5 (eutrophic)
Total nitrogen	4.8 (eutrophic)	4.4 (eutrophic)
Overall TLI score	4.6 (eutrophic)	4.4 (eutrophic)

Over the three-year period (July 2014 – June 2017) assessed against the PNRP lake outcomes, Lake Onoke was blocked on seven occasions. A summary of the relevant data from these seven occasions is provided in Table 4.3. The PNRP outcome was met across all three variables – chlorophyll *a*, total phosphorus and total nitrogen (Table 4.3) – although note that seven data points from this three-year period is a relatively small sample size for this assessment.

Table 4.3: Comparison of Lake Onoke data against PNRP outcomes for the seven occasions that the Lake Onoke mouth was closed during the three-year period July 2014 to June 2017 (total $n=35$)

Variable	Median	Minimum	Maximum	PNRP outcome threshold	Outcome met?
Chlorophyll <i>a</i> (mg/m ³)	1.5	<3.0	45	Median <12 and Maximum <60	Yes
Total phosphorus (mg/L)	0.016	0.008	0.032	Median <0.043	Yes
Total nitrogen (mg/L)	0.300	<0.300	0.94	Median <0.725	Yes

Summary statistics for data collected during the July 2016 – June 2017 for when the mouth of Lake Onoke was open ($n=9$) and closed ($n=3$) are presented in Table 4.4. The assessment against NOF for periods when the lake mouth was open places the lake in the “A” state for chlorophyll *a* and ammoniacal nitrogen and the “C” state for total phosphorus and total nitrogen. The three data points available for when the lake mouth was closed were considered insufficient to undertake an assessment against NOF.

Table 4.4: Comparison of Lake Onoke data against NPS-FM attribute states for periods when the lake mouth is open ($n=9$) and closed ($n=3$) during the one-year period July 2016 to June 2017 (total $n=12$)

Variable	Median	Minimum	Maximum	NPS-FM state (lake type = brackish)
Lake Onoke mouth open ($n=9$)				
Chlorophyll <i>a</i> (mg/m ³)	1.5	<3.0	5.0	A
Total phosphorus (mg/L)	0.037	0.019	0.111	C
Total nitrogen (mg/L)	0.610	0.220	0.900	C
Ammoniacal nitrogen (mg/L)	0.005	<0.010	0.016	Med = A; Max = A
Lake Onoke mouth closed ($n=3$)				
Chlorophyll <i>a</i> (mg/m ³)	1.5	1.5	6.0	Insufficient data
Total phosphorus (mg/L)	0.026	0.016	0.032	Insufficient data
Total nitrogen (mg/L)	0.800	0.600	0.940	Insufficient data
Ammoniacal nitrogen (mg/L)	0.015	<0.010	0.019	Insufficient data

Acknowledgements

Grant Nalder, John Tattersall and James Allen (GWRC Harbours Department) provided safe boating on Lake Wairarapa; Joanna McVeagh and Katie Brasell collected many of the water samples.

Shyam Morar prepared the GIS maps, Mark Heath and Megan Oliver reviewed a draft version of this report.

References

- Burns N, Bryers G and Bowman E. 2000. *Protocols for monitoring trophic levels of New Zealand lakes and reservoirs*. Report prepared for the Ministry for the Environment by Lakes Consulting, Pauanui.
- Burns NM, Rutherford JC and Clayton JS. 1999. A monitoring and classification system for New Zealand lakes and reservoirs. *Journal of Lake and Reservoir Management*, 15(4): 255-271.
- Clayton T and Edwards T. 2006. *LakeSPI – A method for monitoring ecological condition in New Zealand lakes*. Technical report (version 2). Ministry for the Environment, Wellington.
- Cockeram B and Perrie A. 2013. *Lakes State of the Environment monitoring programme: Annual data report, 2012/13*. Greater Wellington Regional Council, Publication No. GW/ESCI-T-13/115, Wellington.
- Cockeram B and Perrie A. 2014. *Lakes State of the Environment monitoring programme: Annual data report, 2013/14*. Greater Wellington Regional Council, Publication No. GW/ESCI-T-14/119, Wellington.
- Greenfield S, Milne J, Perrie A, Oliver M, Tidswell S and Crisp P. 2015. *Technical guidance document: Aquatic ecosystem health and contact recreation outcomes in the Proposed Natural Resources Plan*. Greater Wellington Regional Council, Publication No. GW/ESCI-T-15/45, Wellington.
- GWRC. 2015. *Proposed Natural Resources Plan for the Wellington Region – Te Tikanga Taiao o Te Upoko o Te Ika a Maui*. Greater Wellington Regional Council, Publication No. GW/EP-G-15/44, Wellington.
- Harkness M. 2017. *Hydrology State of the Environment monitoring programme: Annual data report, 2016/17*. Greater Wellington Regional Council, Publication No. GW/ESCI-T-17/94, Wellington.
- Ministry for the Environment. 2014. *National Policy Statement for Freshwater Management 2014*. Publication No. ME1155, Ministry for the Environment, Wellington.
- Perrie A and Milne J. 2012. *Lake water quality and ecology in the Wellington region: State and trends*. Greater Wellington Regional Council, Publication No. GW/EMI-T-12/139, Wellington.
- Smith D, McBride G, Bryers G, Davis-Colley R, Quinn J and Vant W. 1989. *A national water quality network for New Zealand*. Department of Scientific and Industrial Research, Hamilton.
- Verburg P, Hamill K, Unwin M and Abell J. 2010. *Lake water quality in New Zealand 2010: Status and trends*. Report No. HAM2010-107 prepared for the Ministry for the Environment by NIWA, Hamilton.

Appendix 1: Monitoring sites

Table A1.1 provides site information for Lake Wairarapa and Lake Onoke routine sampling sites.

Table A1.1: Monitoring site information for routine water quality sampling sites

Lake	Site no./name	Monitoring variables ¹	NZTM site coordinates		Lake characteristics
			Easting	Easting	
Wairarapa	2 (stump)	Monthly sampling: typical water quality suite plus phytoplankton (relative abundance)	1791644	5439152	Max depth: ~2.5 m; Lake area: 7,850 ha; Catchment area: 57,245 ha; Landcover: indigenous forest and scrub 43.9%, pasture 54%, urban 0.4% and other 1.7%.
	Middle	Monthly sampling: typical water quality suite	1785607	5433715	
	Alsops Bay	Monthly sampling: typical water quality suite plus occasional phytoplankton	1781568	5427654	
Onoke	1	Monthly sampling: typical water quality suite plus phytoplankton (relative abundance)	1778829	5417842	Max depth: ~5.5 m; Lake area: 622 ha; Catchment area: 341,744 ha; Landcover: indigenous forest and scrub 27.5%, pasture 64%, horticulture 1%, exotic forest 3.7%, urban 0.7% and other 3.1%
	Ruamahanga River at Boat Ramp ²	Monthly sampling: typical water quality suite	1783984	5423866	
	Lake Wairarapa downstream of Barrage Gates ²	Monthly sampling: typical water quality suite	1783638	5423977	

¹ The 'typical' water quality suite varies slightly between sites/lakes but for all sites that are sampled regularly (monthly), water samples are, at minimum, analysed for core lake water quality variables (eg, dissolved and total nutrients, chlorophyll *a* and water clarity (Secchi depth).

² These sites are located upstream of Lake Onoke and were selected to provide information on the relative effects of the discharges from Lake Wairarapa and the Ruamahanga River on water quality in Lake Onoke.

Appendix 2: Monitoring variables and methods

Physico-chemical water quality (monthly spot measurements)

Lake Wairarapa monitoring sites are accessed by boat and the Lake Onoke monitoring sites (including the two upstream monitoring sites) are accessed by wading from the lake or river edge. Water samples are collected in accordance with the sub-surface grab method for sampling isothermal lakes described in Smith et al. (1989) and in the case of Lake Onoke, a 'grab pole' is used to collect water samples in an effort to minimise the potential effects of re-suspension of lakebed sediments (caused by wading) on the samples. Note that the sub-surface grab method differs from protocols outlined in Burns et al. (2000) for the sampling of isothermal lakes.

Field measurements (conductivity, dissolved oxygen and temperature) are generally taken using YSI professional plus and YSI ProODO field meters which are calibrated on the day of sampling. Secchi disc measurement methodology is consistent with the procedure outlined in Burns et al. (2000) except that an underwater viewer is not used. Note that all field measurements collected from Lake Onoke (and upstream sites) are made from a 'wading position', although care is taken to minimise any disturbance of lakebed sediments.

Water samples requiring laboratory analysis are stored on ice upon collection and couriered overnight to RJ Hill Laboratories in Hamilton. The variables monitored and current analytical methods are summarised in Table A2.1. All lake water samples collected for dissolved nutrient analysis are filtered in the laboratory.

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
Total suspended solids	Filtration using Whatman 934 AH, Advantec GC-50 or 1-2 equivalent filters (nominal pore size 1.2 - 1.5µm), gravimetric determination. APHA 2540 D 22nd Ed. 2012	2 mg/L
Volatile suspended solids ¹	Filtration (GF/C, 1.2 µm). Ashing 550°C, 30 min. Gravimetric. APHA 2540 E 22nd Ed. 2012	2 mg/L
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N	0.002 mg/L
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO ₃ - I (modified) 22nd Ed. 2012	0.002 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	0.002 mg/L
Ammoniacal nitrogen	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH ₄ -N = NH ₄ ⁺ -N + NH ₃ -N) APHA 4500-NH ₃ F (modified from manual analysis) 22nd Ed. 2012	0.01 mg/L
Total Kjeldahl nitrogen	Kjeldahl digestion, phenol/hyperchlorite 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	0.1 mg/L
Dissolved reactive phosphorus	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd Ed. 2012	0.004 mg/L
Total phosphorus	Total Phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd Ed. 2012	0.004 mg/L
Chlorophyll <i>a</i> (mg/m ³) ¹	Acetone extraction. Spectroscopy. APHA 10200 H (modified) 22nd Ed. 2012	0.003 mg/L
Pheophytin <i>a</i> (mg/m ³) ¹	Acetone extraction. Spectroscopy. APHA 10200 H (modified) 22nd Ed. 2012	0.003 mg/L
Absorbance at 340 nm	Filtered sample. Spectrophotometry, 1cm cell. APHA 5910 B 22nd Ed. 2012	0.002 AU/cm
Absorbance at 440 nm	Filtered sample. Spectrophotometry, 1cm cell. APHA 5910 B 22nd Ed. 2012	0.002 AU/cm
Absorbance at 780 nm	Filtered sample. Spectrophotometry, 1cm cell. APHA 5910 B 22nd Ed. 2012	0.002 AU/cm

¹ Note the detection limit for these variables is not always achieved (ie, is often higher than indicated here).

Submerged aquatic plants

Surveys of submerged aquatic plants follow the nationally accepted LakeSPI (Submerged Plant Index) methodology developed by Clayton and Edwards (2006). This involves scuba divers assessing 11 metrics over a 2 m wide transect from the shore to the deepest vegetation limit at several sites which are representative of the lake. Metrics include measures of diversity, the presence of key plant communities, the depth of vegetation growth, and the extent that invasive weeds are represented.

Appendix 3: Water quality data from sites located upstream of Lake Onoke

Tables A3.1 and A3.2 summarise monthly water quality data collected from two sites located upstream of Lake Onoke during 2016/17. These sites, Lake Wairarapa downstream of Barrage Gates and Ruamahanga River at Boat Ramp, were selected to provide information on the relative effects of the discharges from Lake Wairarapa and the Ruamahanga River (respectively) on water quality in Lake Onoke.

Table A3.1: Summary of water quality for Lake Wairarapa downstream of Barrage Gates, based on 12 sampling occasions between July 2016 and June 2017 (D.L. = detection limit)

Variable	Mean	Median	Minimum	Maximum	% <i>n</i> <D.L.
Water temperature (°C)	13.9	15.0	7.0	20.0	-
Dissolved oxygen (% saturation)	100.0	98.4	93.5	117.5	-
Dissolved oxygen (mg/L)	10.4	10.1	8.6	14.3	-
pH	7.4	7.4	7.0	7.8	-
Conductivity (µS/cm)	789	249	97	5,645	-
Turbidity (NTU)	61.4	43.0	1.4	200.0	0
Total suspended solids (mg/L)	70.0	43.0	3.0	250.0	0
Volatile suspended solids (mg/L) ¹	4.4	4.0	<2.0	15.0	33
Total nitrogen (mg/L)	0.704	0.765	0.350	0.960	0
Total Kjeldahl nitrogen (mg/L)	0.416	0.400	0.160	0.770	0
Nitrite-nitrate nitrogen (mg/L)	0.289	0.235	<0.002	0.760	8
Ammoniacal nitrogen (mg/L)	0.010	0.005	<0.010	0.026	67
Total phosphorus (mg/L)	0.080	0.046	0.018	0.290	0
Dissolved reactive phosphorus (mg/L)	0.008	0.009	<0.004	0.012	17
Chlorophyll <i>a</i> (mg/m ³)	6.6	6.0	<3.0	20.0	50

¹ The typical detection limit for volatile suspended solids could not be achieved by the laboratory on one sampling occasion.

Table A3.2: Summary of water quality for Ruamahanga River at Boat Ramp, based on 12 sampling occasions between July 2016 and June 2017 (D.L. = detection limit)

Variable	Mean	Median	Minimum	Maximum	% <i>n</i> <D.L.
Water temperature (°C)	14.3	15.2	7.7	21.3	-
Dissolved oxygen (% saturation)	102.1	100.9	92.9	118.6	-
Dissolved oxygen (mg/L)	10.6	9.9	9.3	14.2	-
pH	7.4	7.4	6.7	7.8	-
Conductivity (µS/cm)	204	156	81	740	-
Turbidity (NTU)	12.0	6.5	1.5	69.0	-
Total suspended solids (mg/L)	17.3	7.5	<2.0	119.0	8
Volatile suspended solids (mg/L)	1.8	1.0	<2.0	7.0	83
Total nitrogen (mg/L)	0.723	0.685	0.200	1.420	0
Total Kjeldahl nitrogen (mg/L)	0.213	0.185	<0.1	0.530	8
Nitrite-nitrate nitrogen (mg/L)	0.506	0.505	0.109	0.890	0
Ammoniacal nitrogen (mg/L)	0.020	0.015	<0.010	0.048	8
Total phosphorus (mg/L)	0.031	0.025	0.013	0.110	0
Dissolved reactive phosphorus (mg/L)	0.015	0.012	0.009	0.034	0
Chlorophyll <i>a</i> (mg/m ³) ²	1.5	1.5	<3.0	1.5	100