Auckland
Regional Council
TE RAUHĪTANGA TAIAO

State of the Environment Monitoring

# Lake Water Quality Data Report 2006-2007

March 2008 Technical Publication 343

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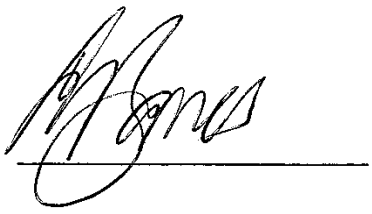

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# State of the Environment Monitoring: Lake Water Quality Data Report 2006-2007

Environmental Research
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# Contents



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# Acknowledgments

This report was prepared by the Monitoring and Research Group at the Auckland Regional Council. ARC staff, coordinated by Ross Winterburn and Marcus Cameron, collected samples. Watercare Laboratory Services Ltd. conducted the chemical analyses. Data management was undertaken by the Environmental Services team. Kylie Park assisted with data analysis and report preparation.

# 1 Background

There are over 30 lakes in the Auckland Region, which vary considerably in their physical, chemical and biological characteristics. Most are shallow and less than 10 hectares in size. The seven lakes monitored by the ARC are the largest natural fresh waterbodies in the Auckland Region (excluding the ten water supply reservoirs in the Hunua and Waitakere Ranges).

The Region's lakes are inextricably linked to their catchments. Land use activities contribute quantities of nutrients, sediment and other contaminants to varying degrees. These inputs can alter water quality and affect the diversity of plants and animals contained within.

Contaminants enter lakes through either point sources (e.g. stormwater, treated effluent, or factory wastewater), or via diffuse sources (e.g. runoff from agriculture or groundwater inputs). Most of the Region's lakes exhibit accelerated eutrophication (nutrient enrichment) as a result of these inputs.

Lake water quality has been routinely monitored in the Auckland Region since 1988, although infrequent records exist for Lake Pupuke from 1966. Water quality is currently monitored at Lakes Kereta, Kuwakatai, Ototoa, Pupuke, Spectacle, Tomarata and Wainamu. The data collected is summarised and reported annually, and contributes to the determination of the relative state of freshwater resources in the Auckland Region and for informing water quality guidelines, standards and indicators. Analysis of trends is reported separately.

Lakes have been selected that best represent or integrate the influences of specific land uses on water quality and are representative of the Region as a whole. This is achieved by including:

- Seven of the largest natural lakes within the region.
- Lakes located within catchments of different development types; rural, native and urban.
- Lakes with water quality ranging from good to poor.
- Lakes that are representative of the different types within the Region (i.e. dune and volcanic).

# 2 Programme objectives

The primary purpose of the monitoring programme, which began in its present form in 1992, is to provide state of the environment information as required under section 35 of the Resource Management Act, 1991. The information collected is important as it contributes to our understanding of how aquatic systems operate and how adjacent land uses may compromise the long-term sustainability of our Region's lakes. Lakes can be particularly sensitive habitats due to the vast size of their catchment in comparison to their relatively small receiving environment.

The objectives of this programme are to:

- Determine the temporal and spatial variability of selected water quality parameters at sites with different land-use influences throughout the region
- Provide a baseline of water quality information from which the presence, direction and magnitude of trends can be determined.

Subsidiary to these broad aims the programme also contributes to the:

- Identification of the present and potential impacts of catchment development activities
- Collection of baseline data for calibration of short-term surveys of similar areas
- Evaluation of improvement in water quality in response to pollution abatement activities
- Assessment of the effectiveness of land use planning policies intended to protect water quality
- Ensuring that existing environmental controls are adequate to avoid unacceptable adverse environmental impacts

This water quality programme fits under the "Natural Environment and Heritage" component of the ARCs Long Term Community Consultation Plan 2006-16. A key issue for the region is to manage the effects of growth and development on our natural environment. This includes balancing the needs for environmental protection with the community's social, economic and cultural well being and aspirations for our freshwater resources and animal and plant life.

Specific objectives include managing and minimising the effects of present and future urban and rural development, growth, and intensification across the Region. The water quality parameters provide information on the condition of the Region's lakes, and feedback on management actions. This is necessary to confirm that ARC's management strategies are effective in sustaining lake functions and uses. By achieving this outcome we are working towards achieving the ARC mission:

- "Working in partnership with our regional community to achieve social, economic, cultural and environmental wellbeing".

This is the 17th data report since the inception of the monitoring programme, although it is second time since 2000 that the data has been reported separately from the saline and stream water quality monitoring programmes. Previous reports described in the list of references can be obtained by contacting the Auckland Regional Council (09) 366 2000, in electronic format from the ARC's website: www.arc.govt.nz/publications or email: info@arc.govt.nz

## 2.1 Report content

This report provides 12-months of summary data from the 2007 lake year (September 2006 to August 2007) collected from 7 locations across the Auckland Region, and includes:

- 3-year rolling average of trophic level reported by lake.
- Summary statistics tabulated by parameter, grouped by lake.

## 2.2 Trophic Level Index

Trophic level classification was determined quantitatively based on four key variables; Chlorophyl *a*, visual clarity (Secchi depth (SD)), total phosphorus (TP) and total nitrogen (TN). Lakes were assigned the normal descriptive terms of oligo-, meso-, eutro-, super, or hypertrophic depending on their trophic level index (TLI). The TLI was determined from the sum of the following equations used to determine each individual trophic level (TL) value for Chla (TLc), SD (TLs), TP (TLp), and TN (TLn):

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

The equations normalise the annual average values of Chla, SD, TP and TN allowing comparison between variables (i.e. TN significantly lower than TP indicates the lakes is N-limited) and with other lakes following the lake classification system in Table 1 (Burns *et al.,* 2005).

Table 1: Values of key variables defining the boundaries of different lake types and trophic levels (Burns *et al.*, 2002).

| Lake Type | Trophic level | Chla (mg.m-3) | Secchi depth (m) | TP (mg.m-3) | TN (mg.m-3) |
|---|---|---|---|---|---|
| Microtrophic | < 2.0 | < 0.82 | > 15 | < 4.1 | < 73 |
| Oligotrophic | 2.0 to 3.0 | 0.82 – 2.0 | 15 – 7.0 | 4.1 – 9.0 | 73 – 157 |
| Mesotrophic | 3.0 to 4.0 | 2.0 – 5.0 | 7.0 – 2.8 | 9.0 - 20 | 157 – 337 |
| Eutrophic | 4.0 to 5.0 | 5.0 – 12 | 2.8 – 1.1 | 20 – 43 | 337 – 725 |
| Supertrophic | 5.0 to 6.0 | 12-31 | 1.1-0.4 | 43-96 | 725-1558 |
| Hypertrophic | 6.0 to 7.0 | >31 | >0.4 | >96 | >1558 |

## 2.3 Programme Design

Monitoring of lake water quality is consistent with the New Zealand Lakes Water Quality Monitoring Programme (Burns *et al.*, 2002). Water samples and site measurements are collected via helicopter (except Pupuke) 6-times per year (August, November, January, February, April, June) to coincide with periodic variation in thermal stratification as season changes.

Each lake is sampled from a single deep-water station where temperature and dissolved oxygen profiles are determined. Sampling is stratified by depth with two vertically distinct samples (epilimnion and hypolimnion) collected at all lakes except Pupuke (n=3) and Kereta (n=1).

Temporal variation is minimised by maintaining a consistent sampling time with each subsequent visit (± 1 hour). This avoids introducing diurnal variation to the dataset and improves the power of long term trend detection.

Environmental characteristics of the seven lakes are summarised in Table 2 and their locations are presented in Figure 1.

Table 2: Physical characteristics of the seven water quality monitoring sites.

| | Kereta | Kuwakatai | Ototoa | Pupuke | Spectacle | Tomarata | Wainamu |
|---|---|---|---|---|---|---|---|
| Lake area (ha) [a] | 32 | 29 | 110 | 110 | 50 | 16 | 14 |
| Max. depth (m) [a] | 1.5 | 19 | 29 | 57 | 7 | 5 | 15 |
| Catchment area (ha) [b] | 430 | 410 | 510 | 105 | 500 | 83 | 480 |
| Catchment land use | | | | | | | |
| Native forest/scrub [c] | 18% | 11% | 34% | 7% | 5% | 29% | 96% |
| Exotic forest [c] | 28% | 4% | 27% | 0% | 15% | 17% | 0% |
| Pasture [c] | 54% | 85% | 39% | 0% | 80% | 54% | 4% |
| Urban [c] | 0% | 0% | 0% | 93% | 0% | 0% | 0% |

a. Gibbs *et al.* (1999).

b. Calculated from the NIWA Rivers Environment Catchment layer (Snelder *et al.*, 2004).

c. Calculated from Landcover Database (LCDBII) (Leathwick *et al.*, 2003).

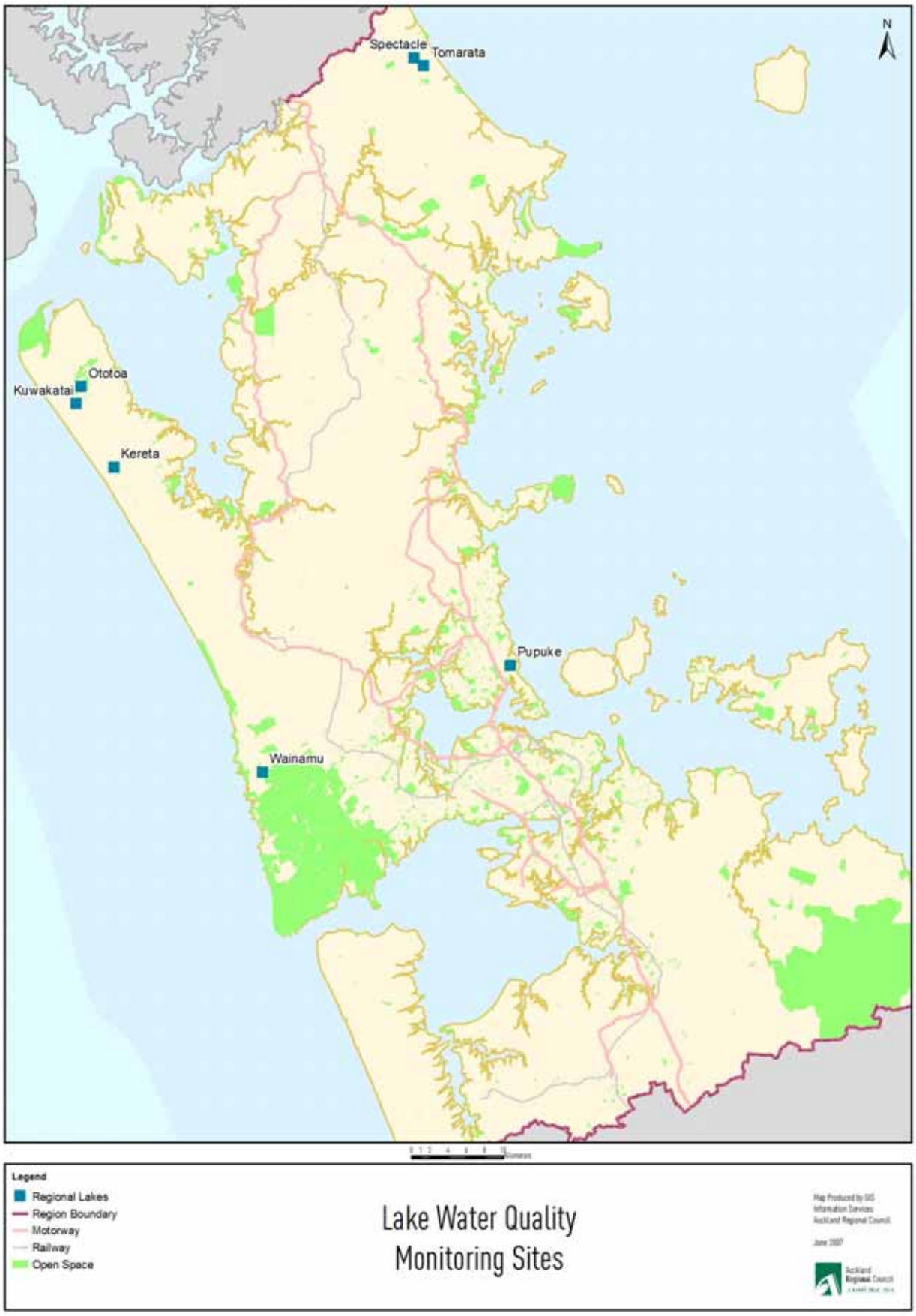


Figure 1: The location of the seven monitored lakes

## 2.4 Water Quality Parameters

The water quality of the Region's lakes is determined by routinely measuring 12 parameters. Some are determined in the field but most are analysed in the laboratory. The number and type of parameters has varied since the programmes inception as new technology became more affordable, instrument sensitivity improved and the programme objectives were modified. Details of the laboratory analytes and field measurements are given in Appendix 1.

## 2.5 Quality Control, Data Storage and Analysis

Quality control measures are undertaken in accordance with Auckland Regional Council's internal standards, including procedures for the collection, transport and storage of samples, and methods for data verification and quality assurance to ensure consistency across the monitoring programme. Samples are analysed under contract to the ARC by Watercare Laboratory Services Ltd, an IANZ accredited laboratory. Analytical methods follow the "Standard Methods for the Examination of Water and Wastewater" 18th Edition (APHA, 1992). All field and laboratory data are stored in the ARCs water quality archiving database (HYDSTRA).

Initial data analysis is performed in HYDSTRA using specially designed scripts that interpret, collate and output pre-determined summary statistics. For the purposes of data analysis, non-detect results (results below instrument sensitivity and reported with 'less than' values) were assumed to be half the corresponding value, and results greater than the value reported were taken as equal to the value reported. Computation of trophic level indices is undertaken using Lakewatch software (Lakes Consulting, 2000). The software incorporates the Burns trophic level assessment method (Burns *et al.*, 2002), and provides an efficient means of elucidating key water quality indicators to determine trophic level.

Only values obtained from the epilimnion where included in the analysis in situations where the lake was stratified. During isothermal conditons all values were included (Table 3).

Table 3: Synopsis of data included in the analysis of results presented in section 3. Samples are reported either singularly (surface only (SU)) or aggregated with bottom (BT). Not sampled = "-".

| Lake | Oct-06 | Nov-06 | Jan-07 | Feb-07 | Apr-07 | May-07 | Aug-07 | Total |
|---|---|---|---|---|---|---|---|---|
| Wainamu | - | SU, BT | SU | SU | SU | SU, BT | SU, BT | 9 |
| Tomarata | - | SU, BT | SU, BT | SU, BT | SU, BT | SU, BT | SU, BT | 12 |
| Kereta# | - | SU | SU | SU | SU | SU | SU | 6 |
| Kuwakatai | - | SU | SU | SU | SU | SU, BT | SU, BT | 8 |
| Ototoa | - | SU | SU | SU | SU | SU, BT | SU, BT | 8 |
| Pupuke | SU | SU | SU | SU | SU | SU | - | 6 |
| Spectacle | - | SU, BT | SU, BT | SU, BT | SU, BT | SU, BT | SU, BT | 12 |

# Kereta is sampled with a single surface grab.

## 2.6 Programme changes

An external peer review Lakes WQ Monitoring Programme was completed in 1999 (Gibbs *et al.*, 1999). The review assessed the quality of data collected, determined the trophic state of the lakes monitored, and concluded whether the monitoring programme was effective and recommended improvements where necessary (Table 4).

A full description of changes adopted following the Gibbs *et al.* (1999) report are described in 2005-06 lakes water quality data report (ARC, 2006) There have been no further changes to the sampling programme to report.

## 2.7 Reports

Comprehensive trend analysis is conducted approximately every 5 years, with the last report published in 2005 (Barnes and Burns, 2005). Auckland Regional Council's 2004 State of the Environment Report briefly summaries water quality issues, including an assessment of the ecological health of the Region's freshwater resources and land use pressures (ARC, 2004).

The data contained in this report will also be used to populate relevant environmental indicators anticipated as a web-based reporting initiative currently in the early planning stages. When live this information can be accessed at the ARCs website www.arc.govt.nz.

Water quality data can be obtained from the ARC website at http://maps.arc.govt.nz/website/maps/map_hydrotel.htm

# 3 Results

The results are presented in two sections. Section 3.1 summarises the trophic level index for each lake over a 3-year rolling average and compares it to the long-term average (Table 5). Section 3.2 lists a statistical summary of routine water quality variables obtained from each of the 7 monitoring sites for the 2007 lake year (Table 6).

## 3.1 Trophic Level

Table 5: Three year rolling average trophic level values for the seven monitored lakes in the Auckland Region comparing 2007 and 2006 with 1995.

| Lake | 2006/07 Trophic state | TLI 3-yr rolling avg to 2007 | TLI 3-yr rolling avg to 2006 | TLI 3-yr rolling avg to 1995 |
|---|---|---|---|---|
| Ototoa | Mesotrophic | 3.9 | 3.9 | 3.6 |
| Pupuke | Eutrophic | 4.3 | 4.2 | 4.3 |
| Kuwakatai | Supertrophic | 5.2 | 5.3 | 5.6 |
| Kereta | Supertrophic | 5.3 | 4.8 | 5.4 |
| Wainamu | Eutrophic | 4.6 | 4.7 | 4.7 |
| Tomarata | Eurtrophic | 4.5 | 4.4 | 4.7 |
| Spectacle | Hypertrophic | 6.3 | 6.3 | 6.2 |

## 3.2 Water Quality Variables

Table 6 Lake based summary statistics for 12 water quality variables obtained during the 2007 lake year (01 September 2006 to 31 August 2007).

| | Lake Wainamu | | | | | | | Lake Tomarata | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Count | Mean | Median | Minimum | Maximum | IQR | Skewness | Count | Mean | Median | Minimum | Maximum | IQR | Skewness |
| Dissolved oxygen (% saturation) | 9 | 92.3 | 88.6 | 78.7 | 112.4 | 12.66 | 0.69 | 12 | 87.0 | 90.8 | 50.5 | 103.0 | 6.93 | -2.36 |
| Temperature (°C) | 9 | 17.9 | 17.1 | 12.7 | 23.7 | 3.40 | 0.28 | 12 | 19.1 | 19.7 | 12.9 | 23.1 | 5.53 | -0.68 |
| Water clarity [1] (m) | 6 | 1.9 | 2.2 | 0.6 | 2.6 | 0.95 | -0.96 | 6 | 2.6 | 2.7 | 2.0 | 3.0 | 0.50 | -0.76 |
| Chlorophyll a [1] ($g\ m^{-3}$) | 6 | 0.011 | 0.008 | 0.006 | 0.022 | 0.0051 | 1.6534 | 6 | 0.009 | 0.010 | 0.004 | 0.013 | 0.0062 | -0.4055 |
| Total phosphorus ($g\ m^{-3}$) | 9 | 0.055 | 0.041 | 0.030 | 0.178 | 0.0140 | 2.7712 | 12 | 0.035 | 0.032 | 0.025 | 0.051 | 0.0118 | 0.8429 |
| Total nitrogen ($g\ m^{-3}$) | 9 | 0.294 | 0.335 | 0.058 | 0.449 | 0.1090 | -1.0561 | 12 | 0.450 | 0.508 | 0.058 | 0.879 | 0.3840 | -0.2669 |
| Total oxidised nitrogen ($g\ m^{-3}$) | 9 | 0.014 | 0.009 | 0.001 | 0.041 | 0.0090 | 1.3655 | 12 | 0.011 | 0.009 | 0.003 | 0.028 | 0.0033 | 1.5249 |
| Total ammoniacal nitrogen ($g\ m^{-3}$) | 9 | 0.005 | 0.003 | 0.003 | 0.018 | 0.0035 | 2.2754 | 12 | 0.008 | 0.007 | 0.003 | 0.019 | 0.0100 | 0.6368 |
| Dissolved reactive phosphorus ($g\ m^{-3}$) | 9 | 0.013 | 0.014 | 0.008 | 0.018 | 0.0070 | -0.4275 | 12 | 0.010 | 0.010 | 0.008 | 0.012 | 0.0010 | 0.7642 |
| pH | 9 | 7.6 | 7.6 | 7.4 | 8.0 | 0.22 | 0.65 | 12 | 7.6 | 7.6 | 7.3 | 7.9 | 0.37 | 0.09 |
| Chloride ($g\ m^{-3}$) | 9 | 48.7 | 45.1 | 43.1 | 61.8 | 3.50 | 1.48 | 12 | 40.2 | 38.5 | 34.9 | 52.6 | 6.38 | 1.39 |
| Conductivity (mS/m@25°C) | 9 | 22.6 | 22.4 | 21.3 | 24.5 | 1.50 | 0.59 | 12 | 18.8 | 18.3 | 17.5 | 25.6 | 0.70 | 3.14 |
| Total suspended solids ($g\ m^{-3}$) | 9 | 3.3 | 3.0 | 0.8 | 6.0 | 2.50 | 0.08 | 12 | 10.0 | 2.7 | 1.0 | 86.8 | 1.75 | 3.43 |
| E.coli (cfu/100ml) [1] | 6 | 17 | 4 | 2 | 78 | 4.5 | 2.4 | 6 | 27 | 22 | 6 | 58 | 28.3 | 0.7 |

1= measured at surface only.

| | Lake Kereta[1] | | | | | | Lake Kuwakatai | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Count | Mean | Median | Minimum | Maximum | IQR | Skewness | Count | Mean | Median | Minimum | Maximum | IQR | Skewness |
| Dissolved oxygen (% saturation) | 6 | 77.9 | 92.1 | 5.3 | 150.2 | 82.18 | -0.37 | 8 | 87.8 | 87.5 | 58.8 | 120.6 | 35.05 | 0.20 |
| Temperature (°C) | 6 | 21.1 | 21.4 | 14.5 | 26.5 | 4.90 | -0.40 | 8 | 17.8 | 17.7 | 12.5 | 23.3 | 4.60 | -0.07 |
| Water clarity [1] (m) | Na | Na | Na | Na | Na | Na | Na | 6 | 1.8 | 1.5 | 1.2 | 3.0 | 0.54 | 1.65 |
| Chlorophyll a [1] ($g\ m^{-3}$) | 6 | 0.055 | 0.019 | 0.002 | 0.216 | 0.0488 | 2.0532 | 6 | 0.028 | 0.033 | 0.005 | 0.050 | 0.0263 | -0.3921 |
| Total phosphorus ($g\ m^{-3}$) | 6 | 0.102 | 0.051 | 0.031 | 0.357 | 0.0355 | 2.3419 | 8 | 0.051 | 0.046 | 0.040 | 0.071 | 0.0133 | 1.0583 |
| Total nitrogen ($g\ m^{-3}$) | 6 | 1.409 | 0.991 | 0.741 | 2.878 | 1.0168 | 1.2401 | 8 | 0.779 | 0.743 | 0.058 | 1.433 | 0.2388 | -0.2019 |
| Total oxidised nitrogen ($g\ m^{-3}$) | 6 | 0.005 | 0.005 | 0.001 | 0.010 | 0.0043 | 0.1992 | 8 | 0.036 | 0.011 | 0.003 | 0.126 | 0.0330 | 1.4590 |
| Total ammoniacal nitrogen ($g\ m^{-3}$) | 6 | 0.013 | 0.013 | 0.003 | 0.030 | 0.0105 | 0.8433 | 8 | 0.053 | 0.010 | 0.003 | 0.320 | 0.0193 | 2.7466 |
| Dissolved reactive phosphorus ($g\ m^{-3}$) | 6 | 0.010 | 0.009 | 0.007 | 0.016 | 0.0040 | 1.1284 | 8 | 0.011 | 0.012 | 0.005 | 0.017 | 0.0045 | -0.0075 |
| pH | 6 | 9.3 | 9.6 | 8.0 | 10.1 | 1.44 | -0.80 | 8 | 8.3 | 8.0 | 7.8 | 9.3 | 0.46 | 1.39 |
| Chloride ($g\ m^{-3}$) | 6 | 52.8 | 49.8 | 44.6 | 72.4 | 9.00 | 1.64 | 8 | 44.4 | 42.2 | 34.3 | 58.2 | 7.18 | 0.90 |
| Conductivity (mS/m@25°C) | 6 | 28.8 | 28.1 | 25.4 | 32.6 | 4.40 | 0.45 | 8 | 24.3 | 24.3 | 23.9 | 25.3 | 0.35 | 1.86 |
| Total suspended solids ($g\ m^{-3}$) | 6 | 25.3 | 13.1 | 2.0 | 93.5 | 23.05 | 1.97 | 8 | 5.5 | 3.4 | 2.0 | 11.0 | 6.28 | 0.78 |
| E.coli (cfu/100ml) [1] | 6 | 510 | 20 | 1 | 2600 | 288.3 | 2.3 | 6 | 10 | 6 | 1 | 34 | 3.5 | 2.2 |

1= measured at surface only.

| | Lake Ototoa | | | | | | Lake Pupuke | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Count | Mean | Median | Minimum | Maximum | IQR | Skewness | Count | Mean | Median | Minimum | Maximum | IQR | Skewness |
| Dissolved oxygen (% saturation) | 8 | 95.1 | 95.5 | 87.5 | 104.8 | 6.66 | 0.47 | 6 | 98.2 | 99.3 | 85.9 | 107.9 | 9.80 | -0.49 |
| Temperature (°C) | 8 | 18.0 | 18.1 | 12.8 | 23.1 | 4.40 | -0.33 | 6 | 19.4 | 19.1 | 16.1 | 22.8 | 3.93 | 0.18 |
| Water clarity [1] (m) | 6 | 5.9 | 6.1 | 4.5 | 6.3 | 0.28 | -2.24 | 5 | 4.4 | 4.2 | 3.3 | 6.3 | 0.90 | 1.38 |
| Chlorophyll a [1] ($g\ m^{-3}$) | 6 | 0.014 | 0.005 | 0.001 | 0.061 | 0.0059 | 2.3534 | 6 | 0.007 | 0.008 | 0.002 | 0.014 | 0.0079 | -0.0233 |
| Total phosphorus ($g\ m^{-3}$) | 8 | 0.026 | 0.025 | 0.016 | 0.043 | 0.0085 | 1.2795 | 6 | 0.030 | 0.029 | 0.020 | 0.040 | 0.0050 | 0.2175 |
| Total nitrogen ($g\ m^{-3}$) | 8 | 0.256 | 0.259 | 0.057 | 0.446 | 0.1945 | 0.1227 | 6 | 0.276 | 0.248 | 0.055 | 0.611 | 0.2690 | 0.6109 |
| Total oxidised nitrogen ($g\ m^{-3}$) | 8 | 0.006 | 0.007 | 0.001 | 0.010 | 0.0038 | -0.6738 | 6 | 0.011 | 0.011 | 0.005 | 0.021 | 0.0075 | 0.5814 |
| Total ammoniacal nitrogen ($g\ m^{-3}$) | 8 | 0.006 | 0.004 | 0.003 | 0.016 | 0.0048 | 1.6545 | 6 | 0.005 | 0.003 | 0.003 | 0.009 | 0.0041 | 1.0129 |
| Dissolved reactive phosphorus ($g\ m^{-3}$) | 8 | 0.008 | 0.008 | 0.005 | 0.010 | 0.0013 | -0.4769 | 6 | 0.011 | 0.010 | 0.006 | 0.020 | 0.0033 | 1.5895 |
| pH | 8 | 7.7 | 7.7 | 7.5 | 7.9 | 0.12 | -0.99 | 6 | 8.7 | 8.8 | 8.0 | 9.2 | 0.66 | -0.59 |
| Chloride ($g\ m^{-3}$) | 8 | 44.3 | 42.8 | 36.1 | 56.0 | 6.40 | 0.91 | 6 | 36.9 | 34.6 | 34.1 | 47.6 | 1.78 | 2.31 |
| Conductivity (mS/m@25°C) | 8 | 21.9 | 22.3 | 19.2 | 22.6 | 0.83 | -2.15 | 6 | 31.1 | 28.5 | 25.2 | 45.3 | 3.85 | 1.97 |
| Total suspended solids ($g\ m^{-3}$) | 8 | 1.5 | 1.7 | 0.3 | 2.4 | 0.85 | -0.78 | 6 | 3.6 | 2.9 | 1.3 | 9.0 | 0.65 | 2.10 |
| E.coli (cfu/100ml) [1] | 6 | 3 | 2 | 1 | 10 | 0.8 | 2.3 | 6 | 1 | 1 | 1 | 2 | 0.8 | 1.0 |

1= measured at surface only.

| | Lake Spectacle | | | | | | |
|---|---|---|---|---|---|---|---|
| | Count | Mean | Median | Minimum | Maximum | IQR | Skewness |
| Dissolved oxygen (% saturation) | 12 | 75.3 | 76.5 | 7.5 | 101.1 | 22.39 | -1.89 |
| Temperature (°C) | 12 | 18.9 | 19.6 | 12.9 | 23.1 | 5.63 | -0.67 |
| Water clarity [1] (m) | 6 | 0.4 | 0.4 | 0.3 | 0.6 | 0.11 | 0.99 |
| Chlorophyll a [1] ($g\ m^{-3}$) | 6 | 0.060 | 0.065 | 0.005 | 0.112 | 0.0303 | -0.1651 |
| Total phosphorus ($g\ m^{-3}$) | 12 | 0.130 | 0.116 | 0.081 | 0.219 | 0.0683 | 0.7526 |
| Total nitrogen ($g\ m^{-3}$) | 12 | 1.224 | 1.284 | 0.059 | 2.129 | 0.8223 | -0.5709 |
| Total oxidised nitrogen ($g\ m^{-3}$) | 12 | 0.094 | 0.011 | 0.001 | 0.409 | 0.1185 | 1.6907 |
| Total ammoniacal nitrogen ($g\ m^{-3}$) | 12 | 0.047 | 0.027 | 0.003 | 0.131 | 0.0678 | 0.8921 |
| Dissolved reactive phosphorus ($g\ m^{-3}$) | 12 | 0.015 | 0.014 | 0.009 | 0.023 | 0.0025 | 1.0163 |
| pH | 12 | 7.7 | 7.7 | 7.1 | 9.2 | 0.77 | 1.54 |
| Chloride ($g\ m^{-3}$) | 12 | 40.2 | 39.2 | 34.1 | 52.5 | 7.38 | 1.13 |
| Conductivity (mS/m@25°C) | 12 | 30.0 | 26.6 | 25.2 | 68.9 | 1.10 | 3.45 |
| Total suspended solids ($g\ m^{-3}$) | 12 | 28.8 | 22.7 | 20.0 | 65.0 | 11.18 | 2.28 |
| E.coli (cfu/100ml) [1] | 6 | 50 | 14 | 1 | 168 | 77.3 | 1.3 |

1= measured at surface only.

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# Appendix I: Water Quality Monitoring Parameters

List of variables routinely monitored in the ARC Lakes Water Quality Monitoring Programme. A full description is produced in Wilcock & Martin (2003).

| WQ Parameter | Relevance to programme |
|---|---|
| Dissolved oxygen | A measure of the life supporting capacity of a waterbody, influenced by atmospheric transfer, respiration, photosynthesis and temperature. DO concentrations can also regulate the release of bioavailable nutrients from sediments. |
| Temperature | Organisms can only tolerate a particular range of temperatures. Outside of this range metabolic rates can be affected. Temperature profiles are a useful measure of the annual pattern of stratification many lakes exhibit. Separate layers of water can develop in warm calm conditions that exhibit different physical and chemical characteristics. All these factors can impact the life supporting capacity of water. |
| Conductivity | A measure of the total soluble salt content of water. Salt content is an important influence on the biota that can inhabit an ecosystem. The lakes monitored are all close to the sea and may be influenced to varying degrees by wind blown salt spray. |
| pH | Indicates the acid/alkaline state of water. Natural freshwaters normally have a pH approaching neutrality (7), although the accepted range for most biota is 6 – 9. High pH mobilises toxic compounds, which may potentially affect aquatic organisms. |
| Nutrients (N and P) | Nitrogen and phosphorus are essential elements for plant growth. When found in high quantities of their bio-available form excessive growths of algae may result, degrading water quality. |
| Chlorophyll a | An indirect measure of photosynthetic algae abundance. |
| Turbidity & Suspended solids | Provides a measure of the level of material suspended in the water column potentially available to scatter light and reduce water clarity. High turbidity and suspended solids can reduce the productivity of a waterbody and interfere with the respiration organs of some aquatic biota. |
| Faecal indicators | Indicates the level of faecal contamination. Major sources of microbial pollution in the environment are derived from agricultural and urban land uses. |

Table 5: Analytical methods of analysis

| Identifier (+ unit) | Parameter | Method |
|---|---|---|
| DO (ppm) | Dissolved oxygen | Handheld meter (YSI-58, YSI-85) |
| DO (% sat) | Dissolved oxygen saturation | Calculation based on DO (ppm) and Temp (°C) |
| Temp (°C) | Temperature | Handheld meter (YSI-58, YSI-85) |
| Cond @ 25 ° (mS/m) | Conductivity | APHA (1998) 2510 B |
| Cl ($g.m^{-3}$) | Chloride | APHA (1998) 4500-Cl D |
| pH | pH | APHA (1998) 4500-H B |
| SS ($g.m^{-3}$) | Suspended solids | APHA (1998) 2540 D |
| Turb (NTU) | Turbidity | APHA (1998) 2130 B |
| SD (m) | Secchi disk | Secchi disk |
| NH4-N ($gN.m^{-3}$) | Ammoniacal nitrogen | APHA (1998) 4500-NH3 G |
| NO3-N+NO2-N (aka NNN) ($gN.m^{-3}$) | Nitrate/Nitrite nitrogen | APHA (1998) 4500-NO3 F |
| TKN ($g.N.m^{-3}$) | Total Kjeldahl nitrogen | APHA (1998) 4500 C |
| TN ($g.m^{-3}$) | Total nitrogen | Calculation NNN ($gN.m^{-3}$) + TKN ($g.N.m^{-3}$) |
| DRP ($g.m^{-3}$) | Dissolved reactive phosphorus | APHA (1998) 4500-P F |
| TP ($g.m^{-3}$) | Total phosphorus | APHA (1998) 4500-P B, F |
| Chl a | Chlorophyll a | APHA (1998) PART 10200 |
| FaeC (MPN/100ml) | Faecal colifoms | APHA (1998) 9221 E |
| Pres (MPN/100ml) | Presumptive coliforms | APHA (1998) 9221 B |
| E. coli (cfu/100ml) | Escherichia coli | APHA (1998) 9213 F |

# Appendix 2

Photograph 1: Southerly aerial view of Lake Kereta.

Photograph 2: Aerial view of Lake Spectacle to the southeast.

Photograph 3: Aerial view of Lake Tomarata to the northwest.

Photograph 4: Easterly aerial view of Lake Wainamu.

Photograph 5: South-westerly aerial view of Lake Ototoa.

Photograph 6: Aerial view of Lake Pupuke looking south towards Takapuna City.