Year 2000 Summary Report

Baseline Water Quality
Stream, Lake, and Saline Waters

Year 2000 Summary Report

Baseline Water Quality
Stream, Lake, and Saline Waters

Robert J. Wilcock
Morag J. Stroud

National Institute of Water & Atmospheric Research Ltd
PO Box 11-115, Hamilton
New Zealand
NIWA Client Report: ARC00259/2

Prepared for

Auckland Regional Council

Technical Publication Number 132,
ISSN 1175 205x
September 2000

CONTENTS

Executive Summary

The Auckland Regional Council and its antecedent organisations have been monitoring water quality as part of the Long-Term Baseline (LTB) programme since the mid-1980s. LTB data are presented in this Year 2000 Summary Report for 16 streams (January 1992 to January 2000), 18 saline water sites in Manukau, Waitemata and Kaipara Harbours (October 1987 to January 2000) and 7 lakes (November 1992 to November 1999).

A detailed summary of the data for the most recent year (January-December 1999) is also presented for the freshwater stream and saline harbour sites. The complete data records for all sites have been examined for trends and for the effects of human activities. A more detailed summary of lake water quality to January 1999 is also available under separate cover (Gibbs et al., 1999).

Freshwater streams

The analysis shows that many streams in the Auckland region have poor water quality.

Streams are mostly turbid and, in some cases, have high concentrations of suspended solids. Many streams had low dissolved oxygen concentrations, with Otara Creek, Lucas Creek, Papakura Stream and Puhinui Stream having summer minimum values that would not support healthy ecosystems.

All streams with the exception of the native forest reference, Cascades Stream, had elevated levels of faecal coliform bacteria, with medians above 100 MPN/100 mL and occasional very high values.

Apart from high nitrate levels in the market garden stream (Ngakoroa) nutrient concentrations were mostly low-to-moderate.

Concentrations of total zinc in urban streams exceeded the Canadian criteria for the protection of aquatic life more than half the time at two sites (Oteha and Puhinui), and exceeded ANZECC "trigger values" most of the time for all four urban streams.

The data indicate that apart from getting warmer there has been little change in water quality within the region over the last eight years. All but one stream are increasing in temperature at an average rate of 0.25°C per year, or 2.5°C in 10 years. Maximum temperatures of 25°C, or more, were recorded for 4 sites with two others at 24.5°C. These are known to be unsuitable temperatures for many freshwater organisms.

Urban streams and the streams in mixed land use catchments with a major urban component have the poorest water quality, while the reference stream (Cascades) clearly has the best water quality in nearly all respects. As would be expected, the streams in agricultural catchments are intermediate between these extremes. There was little difference in water quality between the streams in low intensity mixed land use catchments and those where the predominant land uses were market gardening and exotic forestry. These comparisons are tempered by the lack of replication of sites for some of these land uses. It would be beneficial to have a soft-bottomed pristine lowland reference stream. Thus, the decreasing order of stream water quality by dominant land use was

Native forest > exotic forest ≈ market garden ≈ mixed rural > rural/urban ≈ urban

Saline waters

Saline water quality is variable. The Mangere Wastewater Treatment Plant adversely affects the eastern Manukau Harbour, and indications are that this is getting worse not better. Upgrade of the plant is underway and designed to address this problem. Water quality in Waitemata Harbour and Manukau sites remote from the Mangere plant discharge is generally better, but some locations are faecally polluted by other sources.

The sites in Manukau Harbour affected by the Mangere WTP (Mangere Bridge, Puketutu Point and Shag Point) had concentrations of total ammonia that exceeded criteria for the protection of aquatic organisms. Maximum concentrations of NH_4-N occasionally exceeded acute exposure criteria, and median water concentrations indicated that chronic exposure criteria were exceeded for more than half the time. Concentrations of NH_4-N have increased at Mangere Bridge and Puketutu Point at an average rate of 0.025 mg/l per year.

Mangere Bridge and Puketutu point had the highest median (70 and 110 MPN/100 mL, respectively) and interquartile range values of faecal coliform concentration. Some sites in Waitemata Harbour had occasional faecal coliform values of 1000 or more MPN/100 mL, indicative of urban runoff or sewage displacement into stormwater drains during heavy rain.

Shelly Beach, Kaipara Harbour, had high suspended solids concentrations and associated high turbidity and low Secchi disk values.

Goat Island is an effective reference site, having the best water quality and least variability of the 18 saline sites. Coastal waters had consistently better water quality than the harbours.

Saline water temperature increased at an average of about 0.24°C per year for 11 East Coast and Waitemata sites. The seven Manukau sites did not have significant trends in temperature.

Water quality in decreasing order for the saline regions is

East Coast > Waitemata ≈ Kaipara >western Manukau >> eastern Manukau

Lakes

Most of the lakes have groundwater as their major source, and evaporation or seepage as their discharge. Because of this they have varying lake levels.

Changes in water level affects the chemistry of lake waters and also affects marginal vegetation and associated aquatic biota.

The two deepest lakes, Otatoa and Pupuke, have declining concentrations of chloride that are consistent with recent climatic effects, notably weaker winds carrying sea spray and salt.

Both lakes have shown recent releases of nutrients in near-bottom waters as a result of stratification that occurs in the absence of mixing by strong winds during summer. The elevated nutrient concentrations have stimulated algal growth resulting in a decrease in water clarity for Lakes Ototoa and Pupuke. Water quality for these two lakes may be deteriorating.

There have been recent increases in faecal bacteria, plant growth nutrients and chlorophyll *a*, with corresponding decrease in clarity for Lake Tomatoa.

Lake Spectacle has the worst water quality of the seven lakes and is responding to the intensive agriculture (mainly dairy farming) in the catchment.

Lake Kuwakatai has poor water quality, partly because it is shallow enough for wind mixing to re-suspend bottom sediments and partly because of inputs from farming. The lake is highly turbid and nutrient enriched.

Lake Kereta is shallow and turbid with high concentrations of faecal bacteria that derive from farm animals grazing near the shoreline and from waterfowl.

Lake Wainamu has undergone a recent deterioration in water quality that is associated with the loss of the benthic macrophyte community and the consequent increase in phytoplankton, causing the lake to become more turbid and greener than previously in the monitoring programme.

The lakes covered in the survey range from good water quality (oligo-mesotrophic) for Ototoa and Pupuke, to poor water quality (turbid/eutrophic) for Kuwakatai and Spectacle, with the latter being influenced predominantly by intensive agricultural land uses in their catchments.

The relative ranking of water quality for the seven lakes from best to worst was as follows

Ototoa > Pupuke > Tomarata > Wainamu > Kereta > Kuwakatai > Spectacle

1. INTRODUCTION

This report summarises water quality data collected as part of Long Term Baseline (LTB) Monitoring Programme covering the overall period of 1987 to January 2000, carried out by the Environmental Management Division of the Auckland Regional Council. Aquatic resources surveyed include freshwater streams and lakes throughout the region and saline sites in the Kaipara, Manukau and Waitemata Harbours and the Hauraki Gulf. Sampling conducted by the ARC in the Tamaki, Mahurangi, and Upper Waitemata Harbour is not presented in this report. This report is the second comprehensive summary report on the quality of the regions waters, and updates information provided in Technical Publication No. 65 (ARC 1995). The principal aims of this report are (1) to document water quality data over the specified period, and (2) to assess temporal trends.

The reporting format has been established in various ARC Environment Technical Publications, hereafter referred to as TPs, for freshwater lakes, streams and saline waters.

The ARC undertakes monitoring of the aquatic resources of the Auckland Region as part of its statutory responsibilities under Sections 30 and 35 of the Resource Management Act (1991).

The principal aims of LTB monitoring programme are as follows:

1. Determine the temporal and spatial variability of selected water quality parameters at sites with different land-use influences through out the Region;

2. Provide a baseline of water quality information from which the presence, direction and magnitude of trends can be determined.

Subsidiary to these aims are:

1. Identification of the present and potential impacts of catchment development activities;

2. Collection of baseline data for calibration of short term surveys of similar areas;

3. Evaluation of improvement in water quality in response to pollution abatement activities;

4. Assessment of the effectiveness of land use planning policies intended to protect water quality;

5. Ensuring that existing environmental controls are adequate to avoid unacceptable adverse environmental impacts.

Because of doubts about the quality assurance of data for the freshwater sites prior to 1992, the report reviews stream water quality data for 1992-2000. The lakes and saline water quality data have been previously reviewed (Vant & Lee 1998, Gibbs et al. 1999) and data for these sites has been supplemented so that the periods reviewed are Spring 1992 to Summer 1999 for the lakes, and October 1987 to January 2000 for the saline sites. Not all saline sites cover this period (see Table 2.2 below).

2. SAMPLING SITES AND SURVEY DETAILS

A team of field officers with an appropriately equipped vehicle collects all freshwater stream samples.

All of the ARC's saline LTB monitoring is carried out predominantly by helicopter instead of the more conventional boat method. The exception is the site at Shelly Beach in the Kaipara Harbour, which is accessed via a wharf. There are several advantages to gathering samples, and data, by helicopter, viz.:

1. Samples can be collected at approximately the same stage of the tide and within a narrow time frame;

2. The time for travel from collection to the laboratory is greatly reduced;

3. Sampling can be undertaken under more adverse weather conditions than is generally possible by small boat;

4. Substantial cost savings are involved in terms of equipment and staff resources.

LTB lake sites, except for Lake Pupuke, are also accessed by helicopter although sampling is carried out from an inflatable boat once the helicopter has landed. Shore based sampling which took three to four days by a land-based team with a boat, can now be accomplished in six hours.

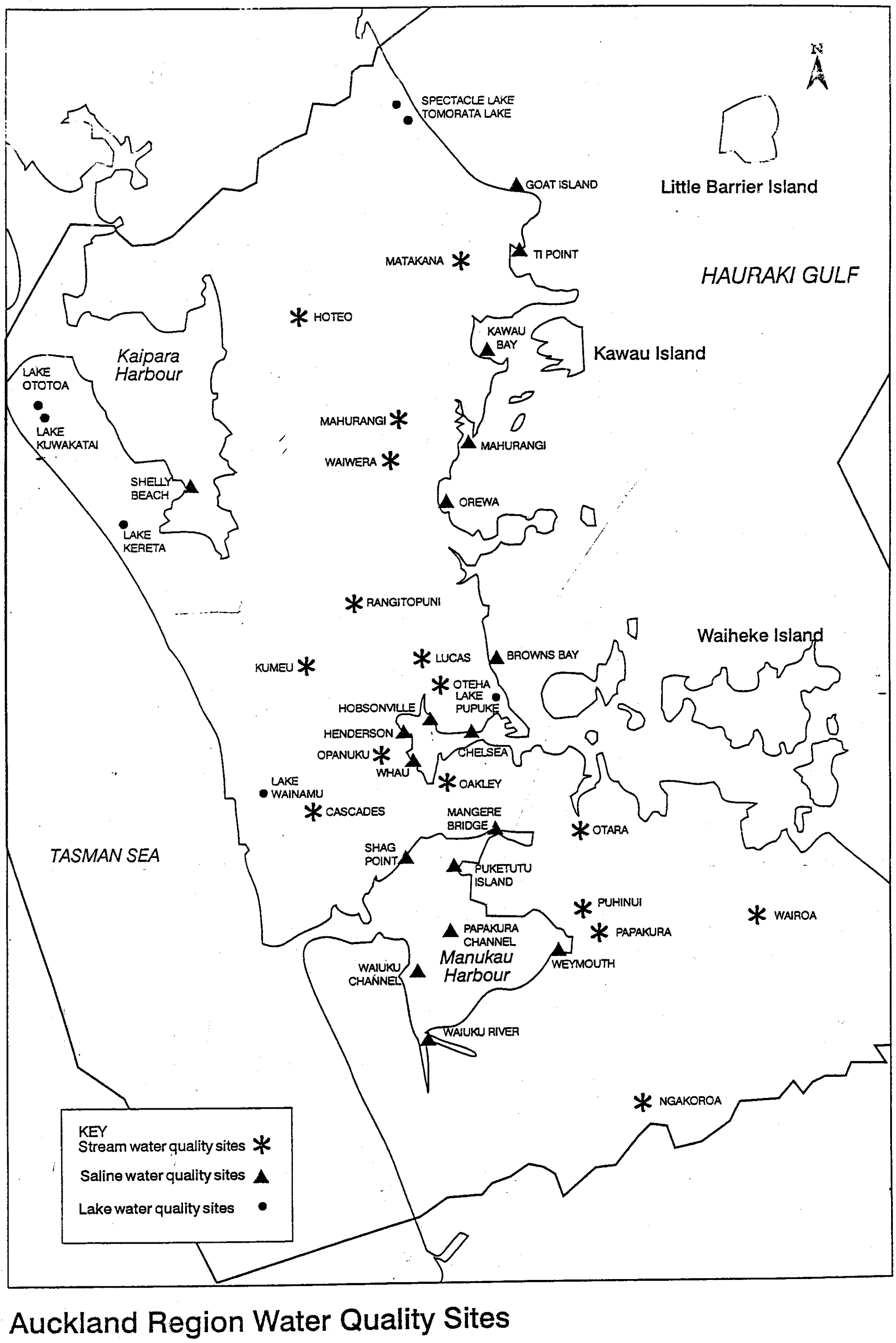


Fig. 2.1 Location of freshwater, saline and lake monitoring sites.

2.1 Freshwater Streams Surveys

A total of 16 freshwater sites representing notably different catchment development types, were sampled monthly for a range of water quality parameters.

The sites sampled are shown on a map of the region in Figure 2.1 and are listed in alphabetical order as follows:

1) Cascades Stream
2) Hoteo River
3) Kumeu River
4) Lucas Creek
5) Mahurangi River
6) Matakana River
7) Ngakoroa Stream
8) Oakley Creek
9) Opanuku Stream
10) Otara Creek
11) Oteha Stream
12) Papakura Stream
13) Puhinui Stream
14) Rangitopuni Stream
15) Wairoa River
16) Waiwera River

For ease of sampling the sites were split into two units based on logistical constraints, namely northern and southern. The two sampling units were sampled on sequential days with nine sites in the northern run and seven in the southern. Surface samples were taken at each site.

A detailed description of the sites that remained unchanged, including surrounding catchment uses and any known point sources influencing water quality, can be found in technical publications TP 28 (ARC 1993a) and TP 65 (ARC 1995), published by ARC. Sampling periods for LTB freshwater monitoring sites reviewed in this report, including those no longer sampled, is given in Table 2.1.

Table 2.1 LTB freshwater monthly monitoring sites.

Site (Code)	Dominant land use	Catchment area (km^2)	Monitoring period
Cascades Stream (N9)	Native forest	4	26/06/86 – 7/01/00
Hoteo River (N5)	Mixed	268	24/06/86 – 7/01/00
Kumeu River @ Weza Lane (N8)	Mixed	48	26/06/86 – 7/01/00
Lucas Creek @ Gills Road bridge (N2)	Urban	6	3/08/93 – 7/01/00
Mahurangi @ Forest HQ (N3)	Exotic forest	5	24/06/86 – 7/01/00
Matakana (N4)	Mixed	15	16/12/86 – 7/01/00
Ngakoroa @ Mill Road (S5)	Market gardens	5	25/06/86 – 6/01/00
Oakley (S1)	Urban	13	8/08/94 – 6/01/00
Opanuku @ Candia Road (S2)	Mixed	20	26/06/86 – 6/01/00
Otara @ East Tamaki Road (S3)	Mixed	16	17/10/85 – 7/01/00
Oteha (N1)	Urban	13	24/06/86 – 7/01/00
Papakura @ Porchester Road (S4)	Mixed	46	25/06/86 – 6/1/00
Puhinui @ Ford (S7)	Urban	14	2/02/94 – 6/01/00
Rangitopuni (N7)	Mixed	92	24/06/86 – 7/01/00
Wairoa (S6)	Mixed	152	25/06/86 –6/01/00
Waiwera (N6)	Mixed	33	24/06/86 – 7/01/00

2.2 Saline Surveys

The sites referred to in this report (Fig. 2.1) are the same as those detailed in ARC Technical Report 65. The water quality of these sites for the period 1994-1997 has been reviewed previously (ARC 1993b, Vant & Lee 1998). The sites in sampling order were as follows:

Manukau Harbour

1) Weymouth
2) Waiuku River
3) Waiuku Channel
4) Puketutu Point
5) Mangere Bridge
6) Shag Point
7) Papakura Channel

East Coast and Waitemata Harbour

8) Goat Island
9) Ti Point
10) Kawau Bay
11) Mahurangi
12) Orewa
13) Browns Bay
14) Chelsea
15) Hobsonville
16) Henderson Creek
17) Whau Creek

Kaipara Harbour

18) Shelly Beach

Sites have been selected to best represent (integrate) the influences of specific land uses on water quality.

Due to logistical constraints the saline LTB data were collected on two separate days depending on the appropriate combination of tidal regime and time of day. The Manukau and Kaipara Harbours were collected concurrently while the middle Waitemata Harbour and Hauraki Gulf were collectively sampled as a separate sampling run.

Vertical salinity readings were taken at each site to ensure that waters were fully mixed. A difference in salinity between top and bottom of greater than 2 parts per thousand was used as an indication of incomplete mixing. If incomplete mixing was detected samples were taken at the top and bottom of the water column for analysis and comparison.

The survey protocols adopted allow samples to be collected approximately 1–2.5 hours after high tide for the Kaipara Harbour, middle Waitemata Harbour and Hauraki Gulf sites and 2.5–4 hours for the Manukau Harbour.

Surveys were conducted at monthly intervals (with a few exceptions) over the periods shown in Table 2.2, which also lists alternate names that have been used for some sites.

Table 2.2 LTB saline monthly monitoring sites.

Site	Monitoring period
Mangere Bridge	7/10/87 – 18/01/00
Puketutu Point	7/10/87 – 18/01/00
Shag Point (Titirangi)	7/10/87 – 18/01/00
Waiuku Channel (Grahams Beach)	7/10/87 – 18/01/00
Papakura Channel	7/10/87 – 10/06/99
Weymouth	5/10/87 – 18/01/00
Waiuku River (Clarks Beach)	5/10/87 – 18/01/00
Goat Island	20/08/93 – 24/01/00
Ti Point	19/03/91 – 24/01/00
Kawau Bay (Algies Beach)	19/03/91 – 17/06/99
Mahurangi	19/03/91 – 17/06/99
Orewa	19/03/91 – 24/01/00
Browns Bay	19/03/91 – 24/01/00
Chelsea	19/03/91 – 24/01/00
Hobsonville	19/03/91 – 17/06/99
Henderson Creek	19/03/91 – 24/01/00
Whau Creek	19/03/91 – 24/01/00
Shelly Beach (Kaipara Harbour)	6/11/91 – 18/01/00

The need for a reference site that has similar physical characteristics to the other sites without the compromising influence of surrounding catchment development has been previously established (ARC 1995). The Goat Island site was chosen as the reference because:

i) There is little development on nearby land that could adversely affect water quality
ii) Further development of land is unlikely in the future

iii) The site is adjacent to the marine reserve and unlikely to be influenced by recreational boat use during the summer months

iv) The site is on a relatively exposed area of eastern coastline and is likely to be well mixed due to current and tidal action

v) The depth of water, 10-30 metres is similar to other near-coastal sites in the programme

vi) The site presently has relatively pristine water quality

2.3 Lake Surveys

A total of 7 freshwater lakes in the region were sampled quarterly for a range of parameters.

The general locations of the lakes sampled are shown in Figure 2.1. Descriptions of all the lakes except Pupuke and maps showing greater detail of lake size, shape and surrounding land use have been presented in TP 89 (ARWB 1990). Information on Lake Pupuke has been presented in a number of ARC reports, the most recent being TP 93 (ARWB 1993).

The lakes were surveyed in the order of sampling given below. Data reviewed in this report covers the period 19 November 1992 – 29 November 1999, with the exception of Lake Pupuke. Lake Pupuke was sampled as a separate survey by laboratory staff of Watercare Services Ltd and data reviewed here are for the period 19 November 1992 – 2 December 1999.

1) Wainamu
2) Kereta
3) Kuwakatai
4) Ototoa
5) Spectacle
6) Tomarata
7) Pupuke

Previous findings have established that lake water quality can be adequately represented by depth profiles from a station located where the lake is deepest. In general, each profile comprised a surface sample and others taken at depth intervals of 5 or 10 m, with the exception of Lake Pupuke, for which samples were collected at 5, 25 and 50 m (ARC 1995, Gibbs et al. 1999).

Dissolved oxygen/temperature profiles were taken throughout the whole water column.

The water quality of the lakes has been reviewed in a recent report covering the period spring 1992 to autumn 1998 (Gibbs et al. 1999) and is updated here by including data up to December 1999.

3. METHODS AND DATA QUALITY ASSURANCE

The sampling protocols for the LTB surveys have changed little from those reported in various earlier ARC technical publications.

All samples collected in the surveys were analysed by the Watercare Services Ltd Laboratory at Mangere. Analytical methods utilised in these surveys are described in “Chemical Methods Manual” and “Microbiological and Biological Methods Manual” compiled by Laboratory Services, Watercare Services Ltd. These methods generally follow the "Standard Methods for the Examination of Water and Wastewater 18th Edition (APHA 1992).

A description of all the water quality variables in the LTB programmeme is given in Appendix 42.

4. STATISTICAL ANALYSIS

4.1 Freshwater and Saline sites

Water quality results are characteristically highly variable because of the wide variety of external factors influencing them. Results were pooled for each site and inspected for normality. Most of the parameters were found to be non-normal, significant at the 95% confidence level, therefore the median has been used predominantly in this report as the measure of central tendency (typical value) as 50% of the data are above and below this value. All outliers were included in calculation of summary statistics unless they were obvious typographical errors (e.g., a black disk value of 10.2 m for Oteha, which has a median of 0.28 m).

Variability in the data has been expressed as the interquartile range divided by the median (IQR/M). This value is the non-parametric equivalent of the coefficient of variance.

Non-parametric statistics have been employed in assessing significant differences between sites and within sites over time. Rank transformation procedures have been used which involves the application of standard parametric statistical analysis to the ranks of the data instead of the data themselves. Greater detail on the use of this technique can be found in Conover and Iman (1981).

Spatial differences between each variable were assessed by non-parametric analysis of variance (ANOVA) to test if the medians were equal. A Kruskal-Wallis test procedure was used to determine if there were any significant ($p<0.05$) differences between the sites. The merit of ANOVA analysis for this purpose is currently under review and because of this ANOVA has not been carried out for the saline sites at this time.

Comparisons between years for each site were carried out using the same non-parametric approach.

Statistical tests for seasonality and trends over time were performed using non-parametric techniques contained in a statistics program called WQSTAT PLUS (Intelligent Decision Technologies Ltd. 1998).

Data sets were first assessed for seasonality using the Kruskal-Wallis test. Where a seasonal component was found the data set was deseasonalised prior to trend analysis. Trend analysis consisted of the Kendall Tau procedure for data sets of less than five years and the Seasonal Kendall test for larger data sets. For large data sets a Seasonal Kendall slope estimate is calculated which is the equivalent of the Sen Slope Estimate (the non-parametric equivalent of regression analysis).

Summary statistics reported here are as follows: Median (M), IQR/M (%), Normality, Seasonality, Trend, and Slope. Median and IQR/M (%) values for the 1999 year and for the entire data set (1992 to January 2000) are given for each water quality variable and each of the 16 freshwater sites in Appendices 1-16 and the saline sites in Appendices 20-38.

4.2 Lakes

A description of how lake data was treated is given in the NIWA report, "ARC Lakes Monitoring Programme Review" (Gibbs et al. 1999). Data were analysed to yield means, maximum and minimum values for all variables during the review period (1992-1999), as well as mean summer and winter values for some variables. The NIWA report also includes a technical review of the ARC LTB monitoring programme for lakes, and an analysis of the data for each lake for the period 1992-1998. The present report provides a standard format for reporting LTB data, updated to December 1999.

5. WATER QUALITY VARIABLES

A standard list of physico-chemical parameters was monitored at each site on each sampling occasion. A core group of parameters was monitored irrespective of the resource under scrutiny with key indicator parameters added in as necessary.

A full list of the parameters used, what they measure, and likely sources and impacts on the environment, are summarised in Appendix 42.

6. RESULTS AND DISCUSSION

6.1 Freshwater Surveys

For each sampling run (northern or southern) the same sequence and approximate timing of sampling was followed on each occasion. In this way the temporal variability inherent in some parameters, such as dissolved oxygen, temperature and pH, was minimised for a particular site. To minimise the effects of variable weather the sampling runs for the nine northern sites and the seven southern sites were made on sequential days.

Detailed water quality results for the periods listed in Table 2.1, for each parameter and site combination, are presented in Appendices 1-16. All sites with data records from 1992 to January 2000 were assessed for normality, seasonality and for the presence of significant trends over time. Time-series plots of each variable at each site for January 1992-January 2000 are also presented in Appendices 1-16. The freshwater stream data for the period January 1992-January 2000 has recently been reviewed by NIWA (Wilcock & Stroud 2000).

Comparisons between values of water quality variables for each of the 16 sites are shown in box plots, with streams grouped according to the principal land use in each catchment (Appendix 17). Numbers of values reported as less (<) a detection limit, or greater than (>) some defined value are listed in Appendix 18. Results of ANOVA are presented in tables in Appendix 19.

6.1.1 Flow dependency of data

Stream water quality records were examined for the 26 high flow samplings to see if there were unusual or abnormal values for water quality variables. Variable values were compared with values for the same month in other years and with the whole data set for each site, using values of summary statistics for the 1992-2000 period (mean, median, SD, IQR) (Appendices 1-16). Values equalling or exceeding the annual mean or median, or "typical" values for that month, by 2SD were regarded as atypical.

There was only a rough correspondence between the numbers of instances where one or more water quality variables exceeded the defined criteria for typical base flow data at times when staff gauge height values similarly exceeded criteria for base flow. Thus, water quality results exceeded criteria for the three sites that had unusually high staff gauge heights during September 1996 and July 1998. Conversely, five sites had "extreme" gauge heights but average water quality values during July 1996.

Most of the variations in water quality occurring at higher than usual stream flows comprised elevated turbidity and suspended solids values, and lower than average values for black disk visibility and (less commonly) conductivity. Small catchments with high average (and highly variable) concentrations of presumptive and faecal coliform generally masked any effects caused by high flows.

6.1.2 Black disk

A large proportion of the streams (14 out of 16) had median black disk values less than 1.6 m, which is the recommended guideline value for Recreational Use (MfE 1994). Most of the streams are turbid and show little variation in black disk clarity with time. None of the streams had "clear waters" (i.e., medians of 3 m or more), and only Cascades and Ngakoroa exceeded 2 m. Streams with better visual clarity, such as Cascades, tended to show more variability in terms of IQR/M.

6.1.3 BOD

The majority of BOD values (1000 out of 1400) were < 2 or > a nominal value and therefore, of limited value for indicating the presence and size of organic loads to these streams. Maximum values were occasionally but not commonly above 5 mg/L, indicating that oxygen demands from organic wastes were not a major issue.

6.1.4 Chloride and conductivity

More than half the sites exhibited a significant positive trend (increase in concentration) for chloride, possibly in relation to changing rainfall patterns and/or wind directions. Five sites had increasing conductivity (the other 11 had no significant trend) over the monitoring period.

6.1.5 Dissolved oxygen

Most (12 out of 16) streams show increases in DO % saturation, but only 7 out of 16 show an increase in DO as mg/L. The general increase in % saturation is also attributable to the increase in water temperature at most sites over 1992-2000.

Saturation DO decreases with increasing temperature and thus, % saturation (the % ratio of DO to saturation DO at that temperature) increases for a given DO as temperature increases. The slight increase in average DO for the 16 streams (none had a negative trend) may also indicate some reduction in organic loading not detected by the rather coarse BOD results.

6.1.6 Presumptive and faecal coliforms

Presumptive and faecal coliform concentrations were with the exception of the native forest site uniformly high with median values being about 2000/100 mL and 800/100 mL, respectively. The results for catchments with rural land uses are consistent with an earlier review of water quality in agriculturally developed catchments of New Zealand (Smith et al. 1993), and the urban catchment values are similar to other findings also (Williamson 1993).

6.1.7 N nutrients

Ammonia nitrogen concentrations were generally low at all sites and the maximum value recorded was 0.34 mg/L. At the range of pH and temperatures measured the toxic, un-ionised form NH_3-N, was well below levels likely to be harmful to aquatic organisms (Hickey & Vickers 1994, Richardson 1997, Hickey et al. 1999, Hickey 2000). Concentrations of NO_2-N were with one exception uniformly low and yielded little useful information. Levels of NO_3-N were useful in discriminating sites by catchment land use with ranges of 0-0.1 mg/L for native bush, up to 1-4 mg/L for market gardening.

6.1.8 P nutrients

Dissolved reactive phosphorus (DRP) concentrations were mostly very low with occasional values of 0.1 or more mg/L occurring in urban and mixed land use catchment streams. Medians were 0.01-0.03 mg/L at all sites. Total phosphorus levels were a little higher than the DRP values. Medians were 0.03-0.17 mg/L and maximum values did not exceed 0.34 mg/L. These values suggest that P was not a major pollutant in these streams, although the median DRP concentrations correspond with trigger values for the growth of periphyton and the MfE guideline for the protection of stream aesthetic values, viz. 0.015-0.03 mg/L (Smith et al. 1993).

6.1.9 pH and temperature

The water quality data show the 16 streams to be of neutral to slightly alkaline pH, in common with many other New Zealand streams and rivers that are principally buffered by bicarbonate and respond to photosynthetic changes in total inorganic carbon (Close & Davies-Colley 1990; Wilcock et al. 1999). All streams but one had a positive trend for temperature increasing at the rate of about 0.25°C per year, or 2.5°C in 10 years. Maximum temperatures of ≥ 25°C were recorded for 4 sites with two others at 24.5°C. These are known to be unsuitable temperatures for many freshwater organisms (Quinn & Hickey 1990, Quinn et al. 1994, Richardson et al. 1994).

6.1.10 Suspended solids (non-filterable residue) and turbidity

Most streams are turbid and have poor visual clarity. Median SS and turbidity values were 1-15 mg/L and 2-27 NTU, respectively.

6.1.11 Heavy metals

There was a large proportion of "non-detects" in this data. Copper (48 our of 68) and lead (316 out of 326) were worst and little could be made of the remaining data for these metals. It is strongly recommended that detection limits and methods be reviewed before continuing to analyse stream waters for these elements. The Zn data was better (26 non-detects out of 390) and was consistent with typical values for urban streams in dry weather conditions.

6.1.12 Differences between sites

One way of comparing land use effects on water quality is to rank medians in terms of "best" to "worst" water quality. Variables were chosen using the following criteria. They had to have a good range of data values enabling useful discrimination between sites. Redundancies, whereby more than one measurement described the same property (e.g. black disk and turbidity), were avoided. Data had to relate directly to land use. The variables chosen were: black disk, DO % saturation, faecal coliform, NH_4-N, NO_3-N, TP and SS. Medians were ranked from "best" (1) to "worst" (16) in terms of water quality, and the summed ranks compared for land use differences (Table 6.1).

The reference native bush site (Cascades) clearly has the best water quality for most of the selected variables. There are a group of sites with comparable water quality that comprise exotic forestry, market gardening and mixed (including some dairy farming and residential development) as principal land uses in the catchments. The group with poorest water quality includes the four urban sites and some of the mixed land use sites that have large urban components (Otara, Papakura and Kumeu).

Table 6.1 Rank according to data in "Rank Sum" column. Sum of rankings for medians from "best" (1) to "worst" (16) water quality, for selected variables.

Site	Black disk	DO % saturation	Faecal coliform	NH_4-N	NO_3-N	TP	SS	Rank sum
Cascades	1	1	1	1	1	3	1	9
Matakana	3	11	5	5	2	3	4	33
Mahurangi	8	5	2	5	5	1	8	34
Ngakoroa	2	8	4	2	16	1	2	35
Wairoa	4	2	6	3	9	6	5	35
Opanuku	6	4	13	4	3	3	6	39
Waiwera	9	3	10	7	4	6	9	48
Hoteo	7	7	3	8	10	8	10	53
Oakley	5	10	10	9	15	10	3	62
Kumeu	11	9	10	10	11	10	11	72
Rangitopuni	13	12	7	11	7	10	13	73
Lucas	15	13	9	13	6	9	16	81
Papakura	10	14	15	12	13	15	7	86
Puhinui	14	6	14	15	14	10	14	87
Oteha	16	15	7	14	12	10	15	89
Otara	12	16	16	16	8	16	12	96

Streams can be ranked by dominant land use in decreasing order of water quality, thus

Native forest > exotic forest ≈ market garden ≈ mixed rural > rural/urban ≈ urban

6.1.13 Current water quality of Auckland streams

The monitoring data indicates that apart from getting warmer, there has been little change in water quality within the region over the last 8 years.

Streams tend to have poor visual clarity, be somewhat turbid and, in some cases, have high concentrations of suspended solids. This may in part be due to local soils having high clay content and therefore having a high potential to remain in suspension (Soil Bureau 1974). Inadequate riparian management, such as stock being allowed to graze too close to stream banks, or a lack of vegetation buffer zones to filter surface runoff during storm events, may also be contributing to the turbidity of these streams.

Median DO values were 58-98 % saturation, with Otara and Lucas being the worst sites and Otara also having elevated BOD values. Minimum DO values were 0-7.6 mg/L (0-74 %) and the mean ± SD of the minimum values was 3 ± 3mg/L, or 35 ± 23 % saturation. Several of the streams (notably, Lucas Creek, Otara Creek, Papakura

Stream and Puhinui Stream) exhibited low DO values that would not support healthy aquatic ecosystems at times. Low DO values nearly always occurred during summer-autumn (December-May) and were most likely associated with low flows.

Nitrogen and phosphorus levels were mostly low-to-moderate, with the exceptions of Otara Creek (high N and P) and Ngakaroa (high NO_3-N, probably due to fertiliser use in market gardening). Other streams (e.g., Oakley and Papakura) had intermittently elevated DRP levels. Streams in urban catchments or mixed land use catchments had much higher nutrient concentrations than others, as would be expected.

All streams apart from Cascades Stream (native bush) had median faecal coliform concentrations above 100 MPN/100 mL and several, including all catchments with some urban land use, were above 1000 MPN/100 mL. These data indicate that many of the streams are chronically contaminated with faecal matter. It should be born in mind, however, that very small streams are prone to occasional high concentrations of faecal bacteria because of their small dilution capacity and because there is often little opportunity for attenuation between the source and the monitoring point.

The urban streams had levels of Zn that are similar to values reported elsewhere for urban streams during base flow conditions. Soluble (filterable) Zn is the actively toxic component, but the proportion of total Zn in this form is dependent on pH and total hardness. For this reason criteria are usually given for total Zn, either as a function of total hardness or at some nominal hardness value, such as 50 or 100 mg/L as $CaCO_3$. Auckland water typically has a hardness of 30-50 mg/L as $CaCO_3$. The Canadian Water Quality Guideline for Zn is 0.030 mg/L based on a hardness of 100 mg/L as $CaCO_3$ (CCME 1992). The ANZECC guideline “trigger value” for protection of 95% of freshwater species is 0.008 mg/L (ANZECC & ARMCANZ 2000). Median (and maximum) concentrations of total Zn were 0.022 (0.19), 0.032 (0.46), 0.042 (0.87) and 0.061 (0.57) mg/L for Lucas, Oakley, Oteha and Puhinui, respectively. Thus, the Auckland urban streams exceeded the Canadian water quality criteria for the protection of aquatic life more than half the time in two sites, and exceeded ANZECC trigger values most of the time at all four urban sites.

6.2 Saline Surveys

Detailed water quality results, summary statistics, and time-series plots for each parameter and site combination up to January 2000 are presented in Appendices 20-38.

The saline LTB programme extends the original Manukau Harbour survey to the entire coastal zone of the Auckland region. An important goal of the original Manukau Harbour programme was to identify the water quality effects of a major point source –

the discharge of treated sewage wastewater from the Mangere Wastewater Treatment Plant in the northeast corner of the harbour. As a result, an important focus of the programme has been on contaminants in sewage wastewaters which are of potential concern, particularly microbiological indicators—faecal coliform and enterococci bacteria, biochemical oxygen demand, and forms of the plant nutrients nitrogen and phosphorus.[1] However, these parameters are also relevant to other coastal waters in the Auckland region. This is because they do provide a general indication of the effects of many human pressures on the coastal zone (from both point and non-point sources).

The survey also monitors parameters that are relevant to an assessment of the general ecological health of coastal waters. These include the dissolved oxygen level, pH, water temperature, and several measures of water clarity (Secchi disk depth, laboratory turbidity, and non-filterable residue or suspended solids). The survey can thus be described as addressing "general coastal water quality".

A cluster analysis[2] by Vant & Lee (1998) has shown the grouped the sites according to their water quality, as follows:

- I Mangere Bridge, Puketutu Island
- II Browns Bay, Goat Island, Kawau Bay, Mahurangi Harbour, Orewa Beach, Ti Point
- III Clarks Beach, Grahams Beach, Papakura Channel, Weymouth
- IV Chelsea, Henderson Creek, Hobsonville, Whau Creek

The Kaipara Harbour site (Shelly Beach) and that at Shag Point in Manukau Harbour were each assigned groups of their own.

The saline LTB survey has thus distinguished water bodies based on the extent of contamination by land-based activities, and identified at least four broad "coastal water zones" within the Auckland region.

6.2.1 Water temperature and pH

Temperatures across all sites were quite similar, with no clear geographical differences in median values (see box plots in Appendix 39). Shelly Beach exhibited the widest range of temperature (c. 18°C) of all sites. Time-series were similar for all sites, with the expected seasonal variations evident. Saline water temperatures

[1] Note that ammoniacal-nitrogen, which is often present in high concentrations in sewage wastewater, is also important because of its potential toxicity.
[2] Complete linkage clustering, using DataDesk (version 6.0).

increased at an average of about 0.24 °C per year for 11 East Coast and Waitemata sites. The seven Manukau sites did not indicate significant trends in temperature.

As expected there is little variation in pH at most sites. Seawater is strongly buffered by bicarbonate and most sites had median pH values of 8.1-8.2, consistent with this. The only exception to this was Mangere Bridge, which had a median pH of 7.9.

6.2.2 Chloride and salinity

The chloride and salinity data clearly show sites that are significantly affected by freshwater inputs (e.g. Henderson and Whau Creeks). The seven Manukau sites show a trend to decreasing salinity with time (average 0.13 ppt per year, or about a 4% decrease over 10 years). Three of the other 11 sites had trends of increasing salinity. These patterns were not shown in the chloride data.

6.2.3 Dissolved oxygen

Long-term median DO concentrations were close to saturation, with only three sites (Henderson, Creek, Mangere Bridge and Weymouth) being below 90%. As expected the reference site, Goat Island, had the least variance of all sites. Minimum values were generally lowest for the Manukau Harbour sites, three of the Waitemata sites (Chelsea, Henderson and Hobsonville) and for Browns Bay.

Five Waitemata sites and Shelly Beach (Kaipara Harbour) had trends of decreasing DO, averaging about 0.10 mg/L per year. Goat Island had a trend of increasing DO, whereas the seven Manukau sites indicate no change with time.

6.2.4 Biochemical oxygen demand

These data refer to the 5-day biochemical oxygen demand (BOD) test carried out with inhibition of nitrification. BOD levels were below the analytical limits of detection (“non-detects”) of 2 mg/L at most sites on most sampling occasions. Values of 1 mg/L have been substituted for < 2 mg/L in subsequent statistical analysis. Shelly Beach and the seven Manukau Harbour sites generally had higher BOD values than the East Coast and Waitemata Harbour sites. Shelly Beach and the Manukau sites had higher concentrations of phytoplankton (see section 6.2.9) and algae may have caused the elevated BOD values for these sites. The Manukau sites may be influenced by the Mangere Wastewater Treatment plant discharge, either directly or indirectly through stimulation of the growth of algae in the water column.

No further statistical analyses can be undertaken with this parameter due to the high number of non-detects.

6.2.5 Secchi disk depth

Long-term Secchi disk records are only available for the Manukau Harbour sites. These data show highly variable water clarity with the highest median (clearest water) occurring at the Papakura and Waiuku Channel sites, as was observed previously (ARC 1995). The sites having the poorest water clarity were Mangere Bridge, Henderson Creek and Shelly Beach.

Medians at the East Coast sites were approximately twice that recorded for the Waitemata and Manukau Harbour sites. Sites in the Waitemata Harbour had comparable Secchi depths to those in the Manukau Harbour, and the Kaipara Harbour site (Shelly Beach).

Only the Manukau sites had sufficient data for meaningful trend analysis. Of these, five out of seven indicated decreasing water clarity at an average rate of 0.03 m per year (or 0.3 m per decade).

6.2.6 Turbidity and suspended solids (non-filterable residue)

Median turbidity and suspended solids levels were considerably lower for East Coast sites than was found for the Kaipara, Manukau and Waitemata Harbours as might be expected.

Shelly Beach, Kaipara Harbour, had consistently the highest turbidity and suspended solids values, whereas the East Coast sites, Goat Island Kawau Bay and Ti Point, had the least turbid water. A similar result was found with Secchi disk depth.

Box plots of Secchi depth, SS and turbidity show consistently that the East Coast sites are much clearer (less turbid) than the Waitemata and Manukau Harbour sites. The Kaipara Harbour site, Shelly Beach, is markedly worse than the other sites with respect to water clarity.

Trend analysis indicates consistent patterns for the four principal locations. Turbidity and SS are declining (i.e. water clarity is improving) at nearly all Manukau and East Coast sites, but are not changing significantly at the Kaipara and Waitemata sites.

6.2.7 N nutrients

Concentrations of NH_4-N, NO_2-N and NO_3-N were, with the exception of the three Manukau sites affected by the Mangere Wastewater Treatment Plant, generally low. Medians for most sites were 0.006-0.034 mg/L, 0.001-0.009 mg/L and 0.005-0.097 mg/L for NH_4-N, NO_2-N and NO_3-N, respectively.

Water at the Mangere Bridge, Puketutu Point and Shag Point sites was clearly affected by Mangere Wastewater Treatment Plant discharge as evident by the high concentrations of NH_4-N and NO_2-N. Sewage effluent commonly has high concentrations of ammoniacal nitrogen, which are oxidised by microorganisms to nitrate via the short-lived intermediate form, nitrite (NO_2-N).

Mangere Bridge, Puketutu Island and Shag point had median NH_4-N values approximately one order of magnitude or more higher than any of the other sites. Ammonia toxicity is governed mostly by temperature, salinity and pH in saline waters. Given maximum summer temperatures of 25°C and typical pH and salinity values of 8.1 and 33 ppt, respectively, the water quality criteria for the protection of aquatic organisms are: 3-5 mg/L for the maximum total ammonia concentration, and 0.5-0.75 mg/L for continuous exposure (USEPA 1989). Maximum values at Puketutu Point have occasionally been close to the criterion but median values at this site and at the Mangere Bridge site often equal or exceed the chronic exposure value. On this basis waters in the eastern Manukau Harbour influenced by the Mangere Wastewater Treatment Plant have concentrations of ammonia nitrogen that present a chronic toxicity threat to aquatic organisms in those areas.

The elevated inorganic N concentrations in Manukau Harbour will undoubtedly stimulate phytoplankton growth, although this is known to be limited by the lack of available light in Manukau Harbour, with its highly turbid water (Vant & Safi 1996). Indeed, phytoplankton growth is greatest in summer, while inorganic N peaks in winter (Vant & Lee 1998).

Trend analysis yielded few conclusive results. Three of the Manukau sites show increasing NH_4-N values.

6.2.8 P nutrients

TP and DRP concentrations had a similar pattern to the inorganic nitrogen data, with values generally low at all sites other than those near to the Mangere Wastewater Treatment Plant. Most unpolluted sites had TP and DRP concentrations similar to the Goat Island control site with few trends being observed.

TP values up to 0.6 mg/L have been recorded from Mangere Bridge and Puketutu Point (0.5 mg/L for Shag Point), with long-term median values of 0.344 and 0.250 mg/L, respectively. DRP values are likewise significantly higher for these sites than for others in the monitoring programme.

Trend analysis indicates increasing concentrations of DRP at most Manukau sites with Mangere Bridge having a rate of increase of 0.01 mg/L per year (95% confidence value).

6.2.9 Chlorophyll *a*

Chlorophyll *a* has been monitored at three baseline sites, Mahurangi, Browns Bay and Papakura Channel since May 1993. Four more sites have been added since then but the comparative record only covers January 1998 - January 2000.

Shelly Beach had the highest chlorophyll *a* values, followed by the two Manukau sites, Waiuku Channel and Papakura Channel.

The data are insufficient for trend analysis.

6.2.10 Presumptive and faecal coliform

Presumptive coliforms derive from a wide range of sources but do not necessarily indicate faecal contamination. The data are a useful indicator of inputs from land and the relative abilities of different bodies of water to disperse pollutants. Dispersal and dilution of pollutants is more effective in open coastal waters than enclosed harbours. The relative order of decreasing input from land-based sources is Manukau > Waitemata > East Coast and Kaipara.

There were few consistent trends in the long-term data for presumptive coliform.

The faecal coliform data show that the two Manukau sites most influenced by the Mangere Wastewater Treatment Plant, Mangere Bridge and Puketutu Point, to have the highest median and interquartile range values. Most sites had very low median levels of faecal coliform concentrations and medians were 10 MPN/100 mL or less for 15 out of 18 sites. Some sites in Waitemata Harbour had occasional faecal coliform levels of 1000 or more MPN/100 mL, indicative of urban runoff inputs or sewage displacement into stormwater drains during heavy rain.

Trend analysis indicates decreases in the Manukau Harbour but increases at two Waitemata sites (Chelsea and Henderson).

6.2.11 Enterococci

Enterococci did not display the same patterns as the other bacterial indicators. Henderson and Whau Creeks had the highest concentrations, followed Mangere Bridge and Weymouth. Levels were generally less than 2 cfu/100 mL.

The data set was considered too small for meaningful trend analysis.

6.2.12 Differences between sites

Goat Island is an effective reference site, having the best water quality and least variability of the 18 sites.

Waters of the eastern Manukau Harbour are clearly influenced by the Mangere Wastewater Treatment Plant. Concentrations of NH_4-N, TP, DRP, and presumptive and faecal coliform were highest for the sites most directly affected by the sewage effluent discharge. Ammoniacal nitrogen at these sites often exceeds the USEPA chronic exposure criteria for protection of saline organisms, and trend analysis indicates a worsening situation.

Some Waitemata Harbour sites (notably Henderson, Hobsonville and Whau) also had poor water quality in terms of high faecal bacteria concentrations.

Water at the Kaipara Harbour site, Shelly Beach, had high SS concentrations and associated high turbidity and low Secchi disk values.

6.2.13 Current water quality of saline waters in the Auckland region

Saline water quality is variable. The Mangere Wastewater Treatment Plant adversely affects eastern regions of Manukau Harbour, and indications are that this is getting worse, not better. Current upgrades to the plant are designed to address this problem.

Water quality in Waitemata Harbour and Manukau sites remote from the Mangere Wastewater Treatment Plant is generally better, but some locations are faecally polluted.

Water quality of the East Coast sites is of a uniformly high standard.

The order of decreasing water quality for the saline regions is

East Coast > Waitemata ≈ Kaipara >western Manukau >> eastern Manukau

6.3 Lake Surveys

Detailed water quality results for the period 1992–1999 for each parameter and site combination are presented in Appendix 41. The lake monitoring programme has recently been reviewed by NIWA (Gibbs et al. 1999).

6.3.1 Morphology and land use

The general morphological data for the 7 lakes (Table 6.2) show that most of these lakes have ground water as their major water source and evaporation or seepage as their discharge. A consequence of this is that, water levels are likely to fluctuate significantly for some lakes (ARWB 1990). No water level data was provided with the monitoring data for assessment.

Changes in water level alter the volume of a lake and have the potential to effect the chemical concentrations within the lake water column, especially in shallow lakes. Large changes will also effect the marginal vegetation and aquatic biota where the lake bed is gently shelving from the shore. Desiccation of these sediments may increase lake turbidity due to resuspension of fine material when the lake level rises again.

Table 6.2: Comparison of the morphology of the seven lakes monitored. (Data extracted from Vant et al. 1990 and ARWB 1990).

Lake	Pupuke	Spectacle	Tomarata	Ototoa	Kuwakatai	Kereta	Wainamu
Area (ha)	110	50	16	110	29	32	14
Maximum depth (m)	57	7	5	29	19	1.5	15
Catchment area (ha)	800	700	300	625	610		520
Surface Inflows	N	Y	N	N	Y	N	Y
Surface outflows	N	Y	N	N	N	N	Y
Land use in catchment*	Urban	H, A, F	P, F	P, Sc, F	P, D, Sc	P, F	Rp, Sc
Lake use**	Rec	Ws, Rec	Rec	Rec, Ws	Ws	A	Rec

*A agriculture; H horticulture; D dairying; F pine forestry; P pasture; Rp regenerated pasture; Sc scrub / bush
**A aesthetics; Rec recreational water sports-boating-fishing-swimming; Ws water supply

Because of the major contribution of groundwater to each lake, it is also likely that the water quality of each lake will reflect the land use in its catchment.

6.3.2 Physical properties

The lakes all experience seasonal cycles of temperature, and the deeper lakes also experience thermal stratification in summer. Oxygen concentration changes in the bottom waters indicate some degree of bottom water oxygen depletion in all lakes in summer. Oxygen depletion proceeds to anoxia in the bottom waters of the deeper lakes during stratification. Table 6.3 presents a comparative summary of all temperature and oxygen data as well as water clarity (Secchi depth) data for the 7 lakes. Table 6.4 presents a summary of the mean summer and winter values of these data to assess differences between lakes at these times.

Surface temperatures (means, maximum, and minimum) were generally similar (Table 6.3) and were highest in summer but lowest in winter (Table 6.4). Summer and winter surface temperatures of all lakes were essentially the same except for Lake Kuwakatai, which was slightly warmer than the other lakes in summer.

Near bottom minimum temperatures were also similar between lakes (Table 6.3) and essentially the same in winter (Table 6.4). However, maximum near bottom temperatures (Table 6.3) and mean summer near bottom temperatures (Table 6.4) were quite different between lakes, with deeper lakes having much cooler bottom waters during summer. These data indicate a degree of thermal structure and possible stratification even in the shallowest lakes in summer.

Table 6.3: Temperature (°C), oxygen (mg/L), and water clarity (m), all data collected.

Lake		Pupuke	Spectacle	Tomarata	Ototoa	Kuwakatai	Kereta	Wainamu
Temperature	(mean)	16.8	17.5	17.6	17.6	17.9	19.2	17.4
(surface)	(max)	25.5	26	26.5	25.5	26.5	24.6	25
	(min)	12.2	12	11.7	11.5	11.5	12	11.8
Temperature	(mean)	12.5	17.1	16.9	15.6	16.0		14.9
(near bottom)	(max)	16.4	25.2	23.6	22.1	22.2		20.3
	(min)	11.4	11.6	11.5	11.3	11.2		10.9
Oxygen	mean)	8.7	9.3	8.8	9.2	9.9	*	8.9
(surface)	(max)	10.8	11.8	10.6	11.6	12.6		11.2
	(min)	7.1	6.5	6.4	7.4	6.5		7.1
Oxygen	(mean)	2.2	3.8	6.7	5.8	5.9		7.2
(near bottom)	(max)	9.9	8.1	9.8	10	10.7		10.2
	(min)	0	0	0.5	0.1	0.1		0.3
Water clarity	(mean)	4.6	0.44	1.4	5.1	1.2		1.0
(Secchi depth)	(max)	6.5	0.7	2.6	8.4	2	*	2.2
	(min)	1.4	0.2	0.8	2.8	0.5		0.45

* = insufficient data

Table 6.4 Temperature (°C), oxygen (mg/L), and water clarity (m) summer and winter only.

Lake		Pupuke	Spectacle	Tomarata	Ototoa	Kuwakatai	Kereta	Wainamu
Temperature (surface)								
Summer	(mean)	23.7	23.3	23.5	23.4	24.3	23.1	23.9
Winter	(mean)	12.5	12.8	12.7	12.5	12.8	*	12.6
Temperature (bottom)								
Summer	(mean)	12.2	22.6	21.8	18.5	21.5		18.6
Winter	(mean)	12.3	12.2	12.3	12.1	11.9		11.6
Oxygen (surface)								
Summer	(mean)	7.9	8.1	8.4	8.5	9.0	*	8.2
Winter	(mean)	8.9	10.1	9.1	9.6	10.8	*	9.3
Oxygen (bottom)								
Summer	(mean)	0.6	3.1	4.2	1.6	1.8		0.8
Winter	(mean)	7.7	5.0	7.3	9.2	8.3		9.0
Water clarity	(mean)							
(Secchi depth)	Summer	2.3	0.5	1.3	5.4	1.4		1.4
	Winter	5.2	0.3	1.5	5.3	1.1	*	0.8

* = insufficient data

Similar observations can be made for oxygen. The oxygen data (Table 6.3) indicate that although the surface waters remain relatively well oxygenated throughout the year, the near bottom waters can become anaerobic at some time during the stratified period. The summer-winter comparisons (Table 6.4) show that all the lakes monitored experienced oxygen depletion in summer and there was a small amount of near bottom oxygen depletion in winter in Lakes Spectacle and Kuwakatai. These data indicate that nutrient releases from the sediments might be expected in summer in most, if not all, of the seven lakes monitored.

Water clarity (Secchi depth) was generally greater in the larger, deeper lakes (Pupuke and Ototoa) with Lake Ototoa being the clearest. Although there were two other lakes with depths greater than 10 m, their water clarity was not much greater than the shallower lakes monitored. The summer winter comparison indicates that water clarity was greater in summer than winter except for Lakes Pupuke and Tomarata (Table 6.4).

Comparing the data presented in Tables 6.3 and 6.4, it is clear that the general interpretations are the same with the range and variability being emphasised in Table 6.3 and the similarity between lakes being demonstrated in Table 6.4. The differences between these two tables — i.e. the maximum / minimum values in Table 6.3 vs. the summer / winter values in Table 6.4 are probably caused by inter-annual variability. Maximum temperatures and minimum oxygen concentrations both can have potentially adverse effects on the lake biota. However, mean temperatures (Table 6.3) mask the seasonal change between summer and winter (Table 6.4), and hence it may be more useful to assess temperature data using seasonally weighted means or just summer and winter mean data.

6.3.3 Chemical and bacteriological quality

Important changes or events in the water chemistry of each lake can determine the on-going water quality in subsequent seasons and even years. Consequently the mean annual data may be more meaningful for rapid inter-lake comparisons and overall water quality assessments.

Because visual clarity is usually associated with good water quality, it is reasonable to assume that the water quality of Lakes Pupuke and Ototoa will be greater than the other lakes monitored, and this is generally so (Table 6.5). Other key water quality indicators — primary production (as chlorophyll *a*), turbidity, and faecal coliform levels — are all low and consistent with high quality water. However, estimates of total plant growth nutrient concentrations, dissolved inorganic N and P, are relatively high (Table 6.5) suggesting that these two lakes are capable of having a much higher productivity than they appear to exhibit in the annual mean data. Periods of high productivity do occur in these lakes (Gibbs et al. 1999).

Table 6.5 Comparative summary of the annual mean chemical and bacteriological quality of the seven lakes monitored — surface and (bottom) concentrations.

		Lakes						
Variable	**Units**	**Pupuke**	**Spectacle**	**Tomarata**	**Ototoa**	**Kuwakatai**	**Kereta**	**Wainamu**
pH	pH	8.5	7.6	7.3	7.8	8.2	8.5	7.6
		(7.4)	(7.5)	(7.2)	(7.3)	(7.7)		(7.3)
Conductivity	mS/m	27.6	28.2	17.1	20.6	23.9	26.0	21.6
		(28.3)	(28.8)	(17.9)	(21.3)	(24.2)		(21.2)
Chloride	mg/L	37.4	37.1	36.1	38.6	40.6	42.2	41.4
		(37.3)	(37.6)	(37.9)	(39.2)	(40.9)		(40.7)
BOD	mg/L	2.0	3.7	1.9	0.4	3.7	2.7	2.8
		(1.8)	(4.4)	(2.4)	(-)	(3.6)		(0.4)
Turbidity	NTU	0.6	11.4	2.3	0.8	2.8	6.4	9.8
		(2.6)	(14.1)	(2.7)	(2.6)	(2.1)		(12.1)
SS	mg/L	2.2	15.7	3.2	1.1	6.1	10.2	4.0
		(4.4)	(20.3)	(4.3)	(6.6)	(6.1)		(4.6)
Chlorophyll *a*	µg/L	10.6	98.1	11.6	4.2	57.8	17.0	12.6
		(8.9)	(103.2)	(12.1)	(6.4)	(47.7)		(9.4)
Faecal	/100mL	12.3	182	59	3	52	619	28
coliform (MPN)		(8.2)	(61)	(25)	(4)	(19)		(13)
Presumptive	/100mL	20.7	299	84	16	71	967	96
coli (MPN)		(14.1)	(281)	(51)	(9)	(36)		(30)
P (m/f)	µg/L	9.4	12.7	9.5	7.1	9.4	11.0	11.5
		(18.8)	(13.8)	(9.2)	(8.2)	(12.4)		(13.6)
P (total)	µg/L	22.3	98.4	25.3	16.1	71.8	50.9	38.2
		(52.1)	(105.0)	(22.5)	(31.0)	(45.4)		(64.2)
NH_4/NH_3	µg/L	10.8	34.5	12.1	8.7	30	21.8	10.2
		(232.7)	(30.7)	(17.5)	(64.4)	(76.6)		(16.9)
NO_2	µg/L	3.4	6.2	1.9	1.5	3.8	2.2	2.9
		(5.5)	(5.5)	(2.1)	(2.3)	(4.1)		(4.0)
NO_3/NO_2	µg/L	11.8	49.2	14.2	20.7	31.7	5.8	25.4
		(31.8)	(42.2)	(9.7)	(8.2)	(33.9)		(29.5)
TKN	mg/L	0.4	1.0	0.5	0.3	0.9	0.9	0.4
		(0.5)	(1.2)	(0.6)	(0.5)	(0.8)		(0.4)

Of the other five lakes, Lake Kereta has the poorest water quality with very high faecal coliform concentrations that are well above the former guideline of 200 MPN for bathing waters (DoH 1992). However, based on suspended solids (SS), BOD, and mean chlorophyll production, it has a higher water quality than Lakes Spectacle and Kuwakatai.

Lake Spectacle and Lake Kuwakatai both have very poor water quality, with high SS and faecal coliform counts, and mean chlorophyll production very much greater than any of the other lakes. The poor water quality of Lake Spectacle is also reflected in the very low water clarity — maximum Secchi depth 0.7 m (Table 6.3). These three lakes have relatively high BOD loads indicating land drainage may be an important factor in their nutrient and carbon budgets.

Lake Wainamu and Lake Tomarata fall into a middle range of water quality having similar BOD loads to the other lakes but relatively low mean chlorophyll production. They also have a middle range of faecal coliform counts and the highest maximum water clarity after Lakes Pupuke and Ototoa (Table 6.3).

From these mean data (Tables 6.3 and 6.5), the seven lakes can be ranked in order of decreasing water quality:

Ototoa > Pupuke > Tomarata > Wainamu > Kereta > Kuwakatai > Spectacle

6.3.4 Chloride as an indicator of climate change

There is a clear and significant difference in the mean chloride concentrations between east and west coast locations and this may have some bearing on interpretation of the data from individual lakes. Specifically, lakes on the west coast have a higher mean chloride concentration than lakes on the eastern coast (Table 6.5).

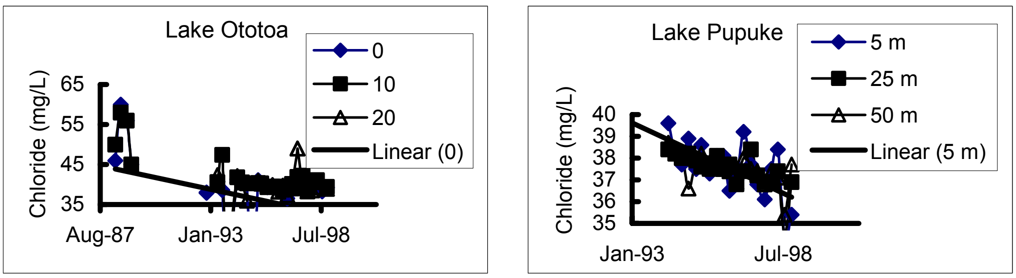
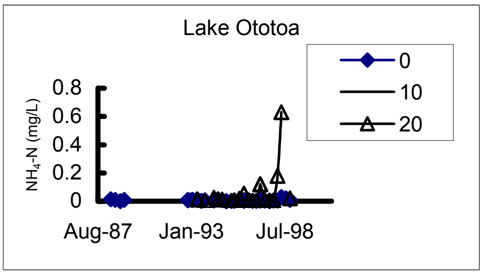


Fig. 6.1: Time series data showing a gradual reduction in chloride concentration in Lakes Ototoa and Pupuke.

As all seven lakes are within a similar distance from the sea on each coast, the higher chloride in the west coast lakes would be consistent with stronger prevailing westerly winds carrying more sea spray into those lakes than the easterly winds carry into lakes on the east coast. The significance of this only becomes apparent when considering individual lakes — e.g. the two deepest lakes, Lake Ototoa on the west coast, and Lake Pupuke on the east coast.



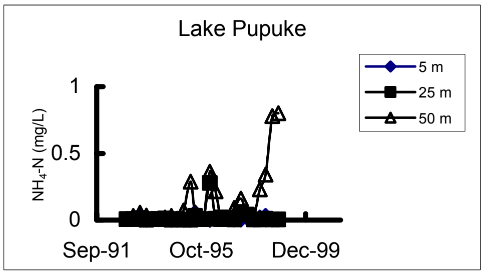


Fig. 6.2: Time series data showing a recent increase in bottom water ammonium (NH_4-N) concentrations, most likely derived from sediment release.

The time-series plots of the chloride data from these two lakes show a decline over the monitoring period (Fig. 6.1). This either means a higher rainfall to increase the flushing rate or weaker winds carrying less sea spray, suggesting a milder climate. In support of this change in climate is the observation that in both lakes the incidence of nutrient release from the sediments has increased over the same period (Fig. 6.2). These nutrient releases are most likely to occur when the lakes are allowed to stratify without strong wind mixing in summer.

Similar chloride declines and sediment nutrient release increases are also apparent in the data from Lakes Tomarata, Kuwakatai, and Wainamu. Lake Kereta and Lake Spectacle do not show this pattern but other factors such as water depth (L. Kereta = 1.5 m) or water abstraction (Lake Spectacle) could mask these effects by preventing the lakes having short stratification events.

The increase in nutrient recycling from the sediments indicates that the overall water quality of the 5 lakes affected is deteriorating. Furthermore, the rate of that deterioration may be increasing. Higher nutrient concentrations can promote higher chlorophyll production and biomass in the water column, and hence a decrease in water clarity. This in turn may reduce light penetration and thus the depth limit of benthic macrophyte communities in the lakes. In the very long term, this process has the potential to destabilise the sediments and allow sediment resuspension thus lowering the water clarity even further — a positive feed back mechanism known as eutrophication.

The data supplied show that near-bottom water turbidity in these lakes has also been increasing in recent years (Fig. 6.3), consistent with the above scenario.

Although eutrophication is a natural process of lake degradation, it can be accelerated by changes in the catchment leading to increased nutrient loads entering the lake. In the 7 lakes monitored, there is little or no flushing and hence nutrients entering these lakes will remain there to be recycled each year. Consequently these lakes are very likely to have a relatively high rate of deterioration without careful management of land use in their catchments.

The monitoring data (Figs. 6.2 and 6.3) indicate that the water quality may be deteriorating in both Lake Ototoa and Lake Pupuke and several of the other lakes. While this conclusion is only tentative, these data do provide a clear indication that there have been changes in some of the water quality parameters measured between 1992 and 1998.

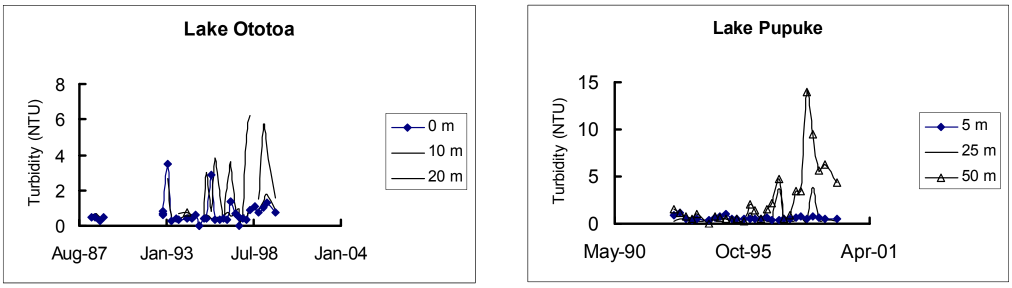


Fig. 6.3: Time series data showing a recent increase in near bottom water turbidity.

6.3.5 Individual assessments of each lake

Lake Pupuke

Lake Pupuke is the only coastal lake monitored that has an urban catchment. In the catchment are several parks and reserves and a golf course. The lake has no major surface inflows but does have a subsurface outflow.

The 1992-99 data on Lake Pupuke is not sufficiently definitive to state with certainty whether the lake's water quality is deteriorating or not. Trophic indicators such as water clarity suggest the water quality is improving. However, mean annual chlorophyll and in-lake nutrient concentrations are increasing suggesting the water quality is deteriorating.

The large number of missing values and imprecise records in the Lake Pupuke data set causes much of this uncertainty.

Lake Tomarata

Lake Tomarata, a small dune lake on the east coast south of Mangawhai, is bordered on the seaward side by exotic pine plantations and on the western side by pasture that is currently used for dairy farming. The lake margins on the east have sparse scrub and a few acacias. The absence of in-water vegetation along that shoreline leaves sandy beaches and that side of the lake is reserved for swimming. The north, west and southern shores have a considerable expanse of wetland that probably acts as a buffer zone between the lake and the farmland.

Lake Tomarata is the third best water quality lake within the monitoring programme. However, there have been recent increases in faecal coliform counts, plant growth nutrients, and chlorophyll *a*, plus a decrease in water clarity that point to the water quality slowly deteriorating. Sudden changes in faecal coliform counts, water clarity, and nitrate nitrogen concentrations indicate that an event — possibly a flood or change in catchment land use — occurred in spring 1995. The change in light levels at that time may have triggered the loss of the benthic mat of aquatic algae previously reported in this lake but it is more likely that the cause was the introduction of the coarse fish, Rudd.

Plants in the marginal wetland fringe are typically associated with low nutrients.

Lake Spectacle

Lake Spectacle, just north of Lake Tomarata is completely surrounded by pasture presently used for dairy farming. The earlier report (ARWB 1990) indicated that the land between the two lobes of the lake was used for horticulture. On-site inspection shows that this is no longer the case although shelterbelt hedges are still present. Local areas of housing have increased in the catchment with 5 recently built houses overlooking the northern lobe of the lake.

Lake Spectacle has the worst water quality of the lakes monitored. The land surrounding the lake is used for dairy farming and it is unlikely that the narrow marginal wetland fringe is capable of blocking nutrients, bacteria, and suspended solids from reaching the lake, especially where run-off is channeled in drains. Consequently the lake is highly turbid with suspended solids and has high annual mean chlorophyll. BOD levels are high but faecal coliform counts have recently been decreasing. There is evidence of periodic bottom water anoxia and subsequent nutrient release from the sediments.

Alligator weed may be a recent introduction to this lake.

Lake Ototoa

Lake Ototoa is a large deep lake (Table 6.2) behind the dunes on the South Kaipara Heads on the west coast. It has the best water quality of the lakes monitored. The catchment has a relatively steep slope at the lakeshore and this effectively prevents stock entry to the water. The lake catchment has farmland on the eastern side, and exotic pine forest on the western side behind a crown reserve on the western shores.

Lake Ototoa has a high water quality due in part to its depth (max =29m) and the steep slope of the land along its shore preventing stock access to the lake. The monitoring data indicates that a milder climate and possibly land use (forestry practices) are causing the lake water quality to deteriorate. Specifically, these are reducing hypolimnetic oxygen concentrations in summer allowing sediment nutrient release. A consequence is decreasing water clarity although this may be augmented from silt erosion from land use.

Lake Kuwakatai

Lake Kuwakatai lies a short distance due south of Lake Ototoa and, although the catchment size (Table 6.2) and type are essentially the same, the lake has very poor water quality and is ranked as second worst after Lake Spectacle. The major differences between Lake Kuwakatai and Lake Ototoa are a shallower water depth, axial orientation of the long narrow lake to the prevailing westerly wind, land management practices that allow stock direct access to the lake, and the presence of coarse fish in the lake. The catchment also supports 3 dairy farms.

Being close to Lake Ototoa with the highest water quality, factors contributing to that water quality difference can be identified. Specifically, lake morphology and land management practices combine to produce a highly turbid and nutrient enriched lake. Stock access to the lake and coarse fish both contribute to the destabilisation of sediments near the shore, and hence the turbidity.

Notwithstanding this, the monitoring data was sufficient to be able to distinguish effects attributable to climate change, all of which are causing a further deterioration of the lakes water quality.

Lake Kereta

Lake Kereta lies about 8 km south of Lakes Ototoa and Kuwakatai. It is the largest of a number of classical shallow dune lakes formed by trapping water in the hollow behind the coastal dunes on the west coast of the south Kaipara heads. The main source of water to the lake is groundwater from beneath the pastured farmland on its eastern shores. Stock have unrestricted access to the lake and the lake has a large population of swans. With a maximum depth of about 1.5 m and a heavy infestation of submerged and emergent aquatic macrophytes dominated by *Ceratophyllum demersum* (Hornwort), this lake is a natural waterfowl habitat.

Lake Kereta is a shallow turbid dune lake ranking slightly better water quality than Lakes Spectacle and Kuwakatai. The high faecal coliform counts reflect the direct access of stock to the water and large populations of resident waterfowl — including swans. The lake has large expanses of Hornwort and these may stabilize the water column enough to allow SS to settle. Consequently the water quality appears to be improving, although large algal blooms are still occurring given the right conditions.

Note: Drifting banks of Hornwort in the very shallow water may reduce lateral mixing and consequently sampling from a single point may reflect only the local sampling position rather than the whole lake.

Lake Wainamu

Lake Wainamu is a drowned valley blocked by a large dune of black iron sand at its western end. The catchment is steep and covered with bush and scrub. Some areas near the lake have free ranging stock grazing to the lake edge.

Lake Wainamu has the 4th best water quality of the lakes monitored. On-site observations indicate that the benthic macrophyte community has recently been lost. A number of parameters point to that loss occurring in the mid 1990s as the data show a sudden and progressive deterioration in lake water quality from that time on.

7. SUMMARY AND CONCLUSIONS

The long-term baseline water quality surveys fulfil a vital role in the management of the water resources of the Auckland Region. They also fulfil a statutory responsibility of the ARC Environment under Sections 30 and 35 of the Resource Management Act (1991).

7.1 Freshwater Stream Surveys

Monthly monitoring results for sixteen freshwater stream sites with notably different land uses, between 1992 and January 2000, are presented. The aims of the survey, detailed in the introduction have been achieved as follows:

1. There have been very few long-term changes (trends) in water quality since 1992, with temperature being the main exception.

2. The Otara Stream had consistently poorer water quality than most other sites for most parameters.

3. As expected the Cascades Stream, our reference site, had the highest water quality overall.

4. All streams but one had a positive trend for temperature increasing at the rate of about 0.25°C per year, or 2.5°C in a decade. This could have a major adverse effect on stream ecosystems if it continues.

5. Visual clarity was generally poor with 14 out of the 16 streams having median black disk values less than the guideline value (1.6 m) for recreational use. Cascades Stream (native bush) and Ngakoroa Stream (market garden) were notably clearer (less turbid) than the other streams.

6. All streams apart from the reference had elevated concentrations of faecal bacteria.

7. Nutrient concentrations were with the exception of nitrate low-to-moderate. Nitrate levels in Ngakoroa stream were high, possibly as a result of nitrogenous fertiliser use in market gardening.

8. Cascades (a native bush catchment) and Mahurangi (exotic forest) had the lowest organic loadings and best oxygenated waters of the streams. Otara was worst in these respects.

9. Urban streams generally had the poorest water quality of the land use, although some of the "mixed" land use catchments were also poor in this regard. These mixed land use catchments had a substantial urban component.

10. The urban streams had Zn concentrations that often exceeded criteria for the protection of aquatic life.

11. As an overall summary, streams other than the native bush reference had poor visual clarity, high suspended solids concentrations and elevated levels of faecal bacteria. Some had occasional very low levels of dissolved oxygen that would not sustain healthy aquatic ecosystems. Several catchments display degraded water quality, which can be related to catchment land use activities, particularly the urbanisation process.

7.2 Saline Surveys

Monthly monitoring results from 1987 to January 2000 are presented for eighteen saline sites. The sites were located in the Kaipara Harbour (1), Manukau Harbour (7) East Coast (6) and Middle Waitemata Harbour (4). Sites were selected to provide integration of the influence of many of the significant catchments in the region on water quality. The aims of the survey, detailed in the introduction have been achieved as follows:

1. Two sites in the Manukau Harbour, Puketutu Island and Mangere Bridge that are influenced by the discharge from Mangere Wastewater Treatment Plant had significantly higher levels of bacteria, nutrients and oxygen demanding substances than other saline sites.

2. Trend analysis show that water quality is getting worse for these two sites.

3. The East Coast sites had the highest water quality.

4. The Waitemata, Kaipara and Manukau Harbour sites had considerably higher levels of suspended materials and were more turbid than the East Coast sites.

5. Eastern Manukau Harbour sites near the Mangere Wastewater Treatment Plant have concentrations of total ammonia that present a chronic toxicity threat to aquatic organisms in those areas.

6. Significant trends were identified for the following variables: water temperature (increasing), dissolved oxygen (decreasing for Waitemata and Kaipara sites), water clarity (decreasing for the Manukau sites), ammonia (increasing for three Manukau sites), total phosphorus and dissolved reactive phosphorus (increasing at most Manukau sites).

In general, waters of the East Coast and outer Manukau Harbour are of good to excellent quality. Water in the Waitemata Harbour sites is variable and is affected by urban sources. The inner Manukau Harbour sites influenced by the discharge from Mangere Treatment Plant have the poorest water quality, having high concentrations of nutrients and faecal bacteria.

Water clarity was excellent for the coastal sites but often poor for the harbour sites. Notably, Shelly Beach had high suspended solids concentrations and turbidities and low Secchi disk depths.

7.3 Lake Surveys

Quarterly monitoring results are presented for seven freshwater lakes in the Auckland region. Data spanning the period 19 November 1992 – 29 November 1999 are summarised for Lakes Kereta, Kuwakatai, Ototoa, Spectacle, Tomarata and Wainamu. Data for 19 November 1992 – 2 December 1999 are summarised for Lake Pupuke.

The aims of the survey, detailed in the introduction have been achieved as follows:

1. Data collected has been used to describe the water quality at each lake,

2. The seven lakes were ranked in order of decreasing water quality using this data, thus
Ototoa > Pupuke > Tomarata > Wainamu > Kereta > Kuwakatai > Spectacle

3. Time-series for the two deepest lakes, Otatoa and Pupuke, show declining concentrations of chloride that are consistent with recent climatic effects, notably weaker winds carrying sea spray and salt.

4. Both lakes have shown recent releases of nutrients in near-bottom waters as a result of stratification that occurs in the absence of mixing by strong winds during summer. The elevated nutrient concentrations have stimulated algal growth resulting in a decrease in water clarity for Lakes Ototoa and Pupuke. Water quality for these two lakes may be deteriorating.

5. There have been recent increases in faecal bacteria, plant growth nutrients and chlorophyll *a*, with corresponding decrease in clarity for Lake Tomatoa.

6. Lake Spectacle has the worst water quality of the seven lakes and is responding to the intensive agriculture (mainly dairy farming) in the catchment.

7. Lake Kuwakatai has poor water quality, partly because it is shallow enough for wind mixing to re-suspend bottom sediments and partly because of inputs from farming. The lake is highly turbid and nutrient enriched.

8. Lake Kereta is shallow and turbid with high concentrations of faecal bacteria that derive from farm animals grazing near the shoreline and from waterfowl.

9. Lake Wainamu has undergone a recent deterioration in water quality that is associated with the loss of the benthic macrophyte community and the consequent increase in phytoplankton, causing the lake to become more turbid and greener than previously in the monitoring programme.

10. At present there is little data on the phytoplankton, zooplankton, macrophyte and macroinvertebrate communities in and around the lakes monitored. Some of these are publicly visible indicators of trophic condition and hence frequently the first indication that "something has gone wrong" with a lake. Assessment of these aspects will enhance the water quality data presently being collected.

11. The lakes covered in the survey range from good water quality (oligo-mesotrophic) for Ototoa and Pupuke, to poor water quality (turbid/eutrophic) for Kuwakatai and Spectacle, with the latter being influenced predominantly by intensive agricultural land uses in their catchments.

8. REFERENCES

ANZECC & ARMCANZ (2000). National water quality management strategy: Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australia.

APHA (1992). Standard methods for the examination of water and wastewater 18th edition. American Public Health Association, American Waterworks Association, Water Environment Federation. 949P.

ARC (1993a). Auckland Stream Water Quality Data - Review of baseline information collected in a five year period from June 1986 - June 1991. Technical Publication 28, Auckland Regional Council Environment.

ARC (1993b). Saline baseline water quality survey of the Waitemata Harbour and Hauraki Gulf - First Annual Report. Technical Publication 30, Auckland Regional Council Environment.

ARC (1995). Baseline water quality survey of the Auckland region. Annual report April 1993-March 1994. Technical Publication 65, Auckland Regional Council Environment.

ARWB (1987). Proceedings of the groundwater chemistry workshop. Technical Publication 41. Auckland Regional Water Board.

ARWB (1990). Freshwater lakes water quality survey - first annual report. Technical Publication 89. Auckland Regional Water Board.

ARWB (1993). Changes in the water quality of Lake Pupuke 1966-1990. Technical Publication 93, Auckland Regional Water Board.

CCME (1992). Canadian water quality guidelines prepared by the Task Force on water Quality Guidelines of the Canadian Council of Ministers of the Environment, Ottawa, Canada.

Close, M.E.; Davies-Colley, R.J. (1990). Baseflow water chemistry in New Zealand rivers. *New Zealand journal of marine and freshwater research 24*: 319-341.

Conover, W.J.; Iman, R.L. (1981). Rank transformations as a bridge between parametric and non-parametric Statistics. *The American Statistician*, *35(3):* 124-129.

DoH (1992). Provisional microbiological water quality guidelines for recreational and shellfish-gathering waters in New Zealand. January 1992, Public Health Services, Department of Health, Wellington.

Gibbs, M.; Boothroyd, I.; Champion, P.; Green, J.; Duggan, I. (1999). ARC lakes monitoring programme review. Client Report ARC00256, prepared for ARC.

Hickey, C.W. (2000). Ecotoxicology: laboratory and field approaches. In: New Zealand stream invertebrates: Ecology and implications for management. K.C. Collier; M. Winterbourn, ed. Caxton Press, Christchurch, New Zealand. pp. 313-343.

Hickey, C.W.; Quinn, J.M.; Davies-Colley, R.J. (1989). Effluent characteristics of dairy shed oxidation ponds and their potential impacts on rivers. *New Zealand journal of marine and freshwater research 23*: 569-584.

Hickey, C.W.; Vickers, M. L. (1994). Toxicity of ammonia to nine native New Zealand freshwater invertebrate species. *Archives of environmental contamination and toxicology 26*: 292-298.

Hickey, C.W.; Golding, L.G.; Martin, M.L.; Croker, G.F.(1999). Chronic toxicity of ammonia to New Zealand freshwater invertebrates: a mesocosm study. *Archives of environmental contamination and toxicology 37*: 338-351.

Intelligent Decision Technologies Ltd. (1998). WQSTAT PLUS User's guide. Intelligent Decision Technologies Ltd., Longmont CO 80501, USA.

MfE (1994). Water quality guidelines No. 2. Guidelines for the management of water colour and clarity. Ministry for the Environment, Wellington, 16 p.

MWD (1987). Lake managers handbook. Miscellaneous Publication Number 103, Water and Soil Conservation Authority, Ministry of Works and Development, Wellington.

Quinn, J.M.; Hickey, C.W. (1990). Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *New Zealand journal of marine and freshwater research 24*: 387-409.

Quinn, J.M.; Steele, G.L.; Hickey, C.W.; Vickers, M.L. (1994). Upper thermal tolerances of twelve New Zealand stream invertebrate species. *New Zealand journal of marine and freshwater research 28*: 391-397.

Richardson, J. (1997). Acute ammonia toxicity for eight New Zealand indigenous freshwater species. *New Zealand journal of marine and freshwater research 31*: 185-190.

Richardson, J.; Boubée, J.A.T.; West, D.W. (1994). Thermal tolerance and preference of some native New Zealand freshwater fish. *New Zealand journal of marine and freshwater research 28*: 399-407.

Smith, C.M.; Wilcock, R.J.; Vant, W.N.; Smith, D.G.; Cooper, A.B. (1993). Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture. MAF Policy Technical Paper 93/10, September 1993. MAF Policy and Ministry for the Environment, Wellington, New Zealand, 208 pp.

Soil Bureau (1974). Single factor map showing dominant clay constituents (less than 2 microns) in topsoils of the North Island, New Zealand. Soil Bureau, DSIR, Wellington.

USEPA(1985). Ambient water quality criteria for ammonia (1984) Criteria and Standards Divisions, Environmental Protection Agency, Washington DC, EPA - 440/5-84-026.

USEPA(1989). Ambient water quality criteria for ammonia (saltwater) - 1989 Criteria and Standards Divisions, Environmental Protection Agency, Washington DC, EPA -440/5-88-004.

Vant, W.N.; Pridmore, R.D.; Challis, D.A. (1990). Changes in the water quality of Lake Pupuke 1966-1990. Auckland Regional Water Board technical publication No. 93, November 1990.

Vant, W.N.; Safi, K.A. (1996). Size-fractionated phytoplankton biomass and photosynthesis in Manukau Harbour, New Zealand. *New Zealand journal of marine and freshwater research 30*: 115-125.

Vant, W.N.; Lee, D.E. (1998). Review of Auckland Regional Council's saline long term baseline programme. NIWA Client Report No. ARC80239, prepared for ARC.

Wilcock, R.J.; Nagels, J.W.; Rodda, H.J.E.; O'Connor, M.B.; Thorrold, B.S.; Barnett, J.W. (1999). Water quality of a lowland stream in a New Zealand dairy farming catchment. *New Zealand journal of marine and freshwater research 33*: 683-696.

Wilcock, R.J.; Stroud, M.J. (2000). Review of the long-term baseline water quality programme for freshwater streams 1992-2000. NIWA Client Report No. ARC00259, prepared for ARC.

Williamson, R.B. (1993). Urban runoff data book, 2nd ed. Water Quality Centre Publication No. 20, NIWAR, Hamilton.

APPENDICES

APPENDIX 1: WATER TEMPERATURE – FRESHWATER

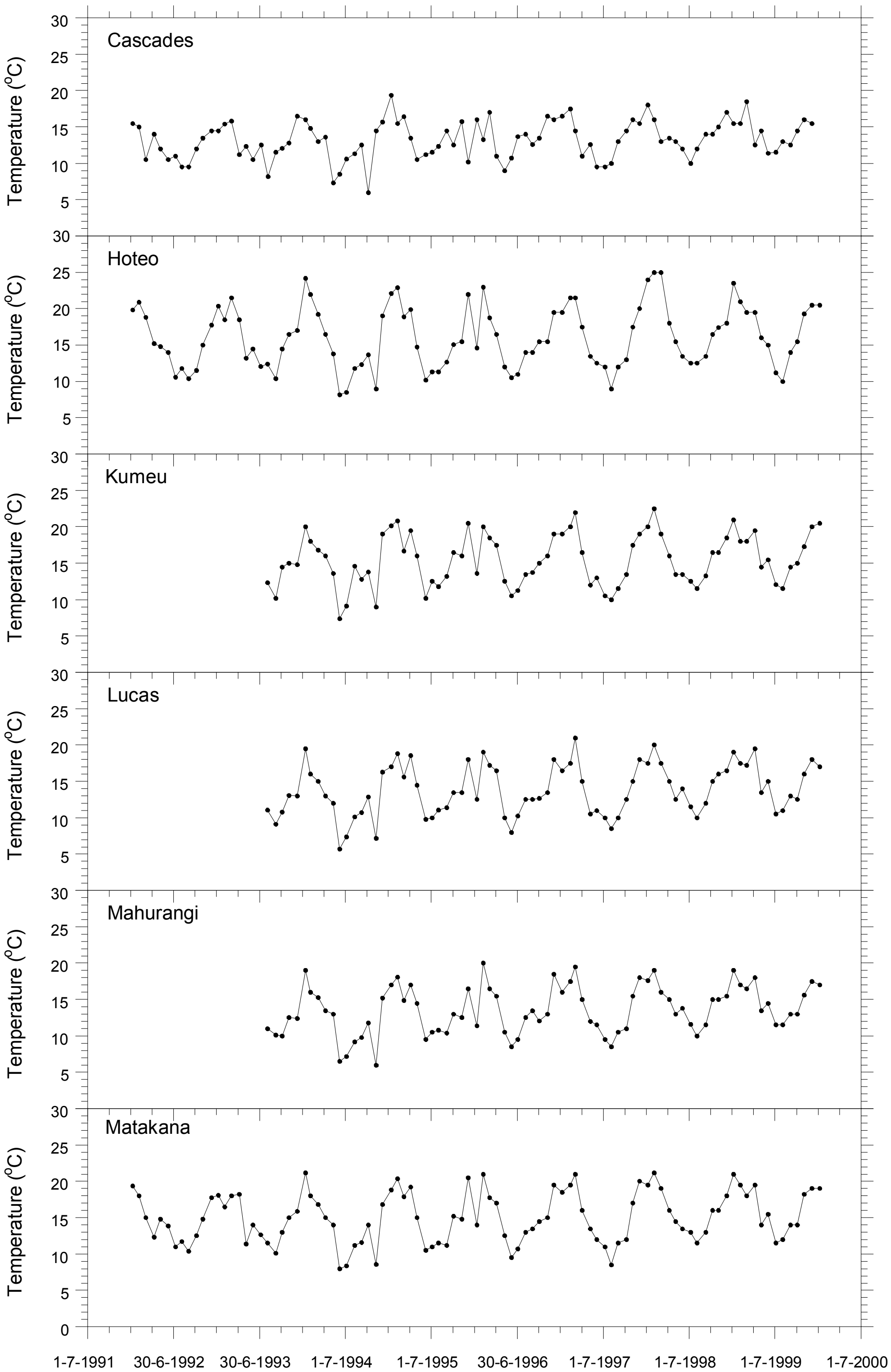
a) Temperature (deg C) during January 1999 - December 1999

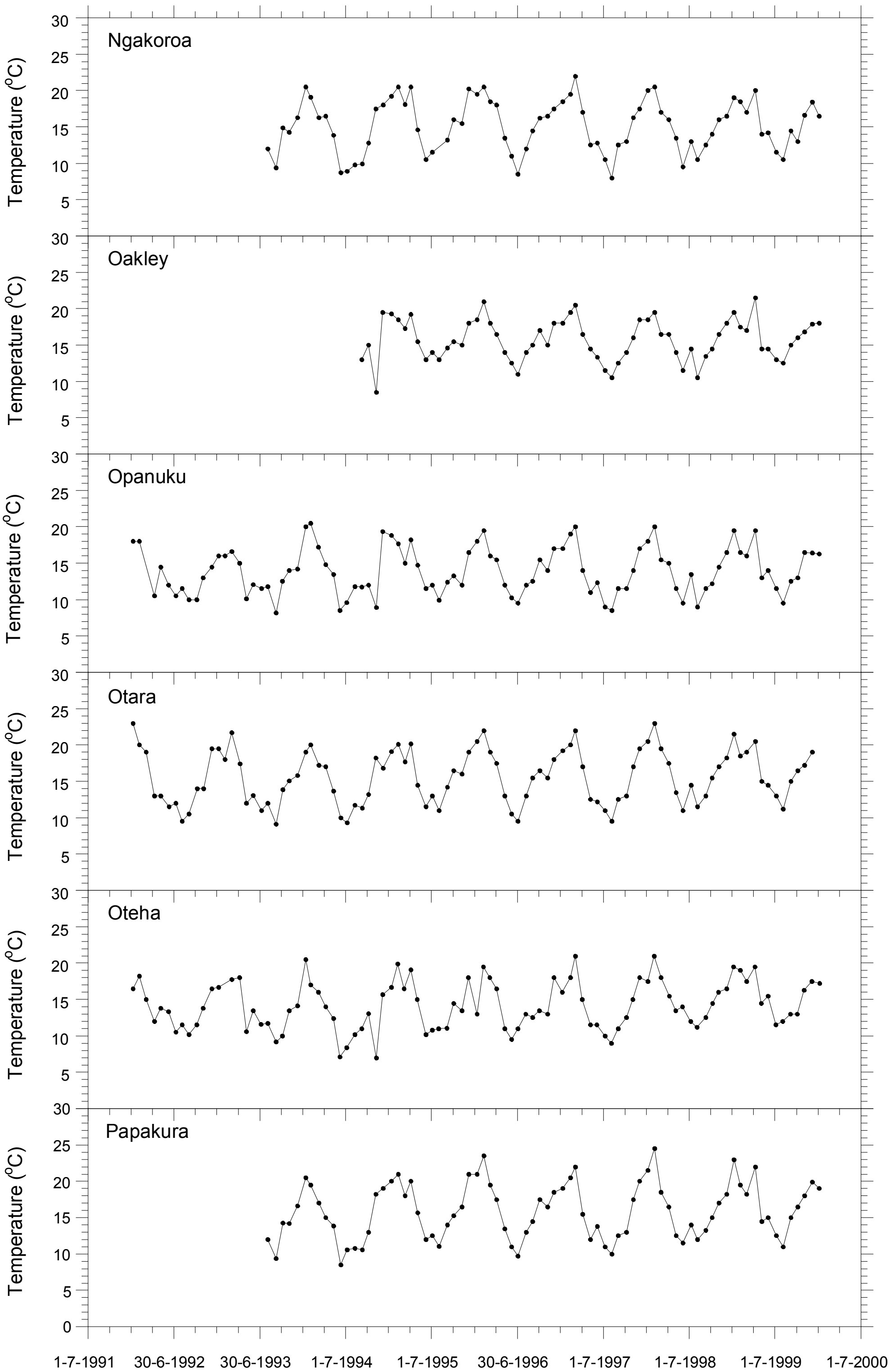
Date	Cascades	Hoteo	Kumeu	Lucas	Mahurangi	Matakana	Ngakoroa	Oakley	Opanuku	Otara	Oteha	Papakura	Puhinui	Rangitopuni	Wairoa	Waiwera
Jan-99	15.5	23.5	21.0	19.0	19.0	21.0	19.0	19.5	19.5	21.5	19.5	23.0	24.5	23.0	24.0	23.5
Feb-99	15.5	21.0	18.0	17.5	17.0	19.5	18.5	17.5	16.5	18.5	19.0	19.5	22.0	20.5	21.0	20.5
Mar-99	18.5	19.5	18.0	17.3	16.5	18.0	17.0	17.0	16.0	19.0	17.5	18.3	20.5	19.5	19.5	19.5
Apr-99	12.5	19.5	19.5	19.5	18.0	19.5	20.0	21.5	19.5	20.5	19.5	22.0	21.5	19.5	20.5	19.5
May-99	14.5	16.0	14.5	13.5	13.5	14.0	14.0	14.5	13.0	15.0	14.5	14.5	14.5	15.0	15.0	14.5
Jun-99	11.4	15.0	15.5	15.0	14.5	15.5	14.2	14.5	14.0	14.5	15.5	15.0	15.5	15.5	10.0	15.0
Jul-99	11.5	11.2	12.1	10.5	11.5	11.5	11.5	13.0	11.5	13.0	11.5	12.5	13.5	11.0	11.5	11.0
Aug-99	13.0	10.0	11.5	11.0	11.5	12.0	10.5	12.5	9.5	11.2	12.0	11.0	13.0	11.0	12.0	11.0
Sep-99	12.5	14.0	14.5	13.0	13.0	14.0	14.5	15.0	12.5	15.0	13.0	15.0	16.0	14.0	14.5	14.5
Oct-99	14.5	15.5	15.0	12.5	13.0	14.0	13.0	16.0	13.0	16.5	13.0	16.5	18.5	15.0	17.0	15.0
Nov-99	16.0	19.3	17.3	16.0	15.6	18.2	16.6	16.8	16.5	17.2	16.3	18.0	16.4	17.7	16.5	18.0
Dec-99	15.5	20.5	20.0	18.0	17.5	19.0	18.4	17.9	16.4	19.0	17.5	19.9	20.5	20.0	20.3	21.5
median	14.5	17.7	16.4	15.5	15.1	16.8	15.6	16.4	15.0	16.9	15.9	17.3	17.5	16.6	16.8	16.5
IQR/median (%)	20.7	31.2	25.9	32.3	28.2	31.3	31.8	19.5	25.0	25.2	33.0	28.7	34.4	31.6	42.7	33.3

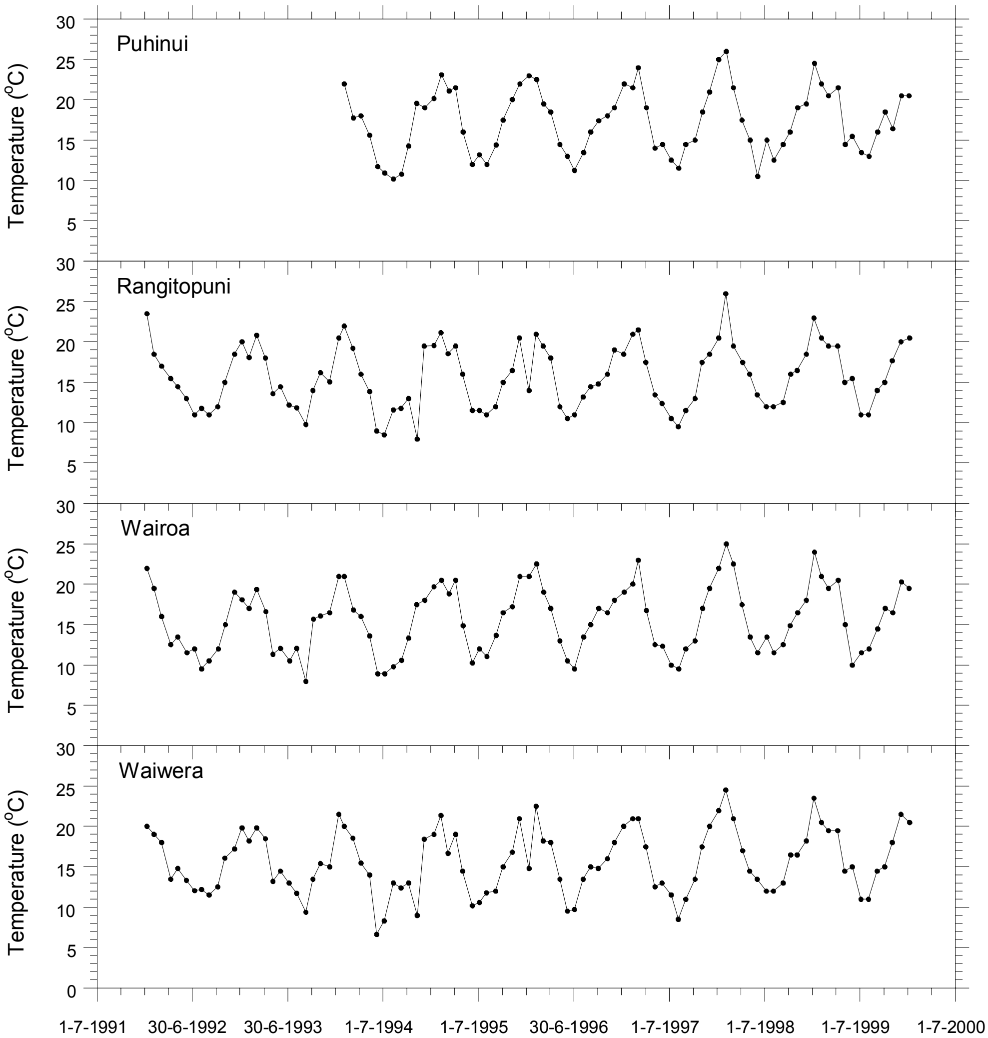
b) Statistical Summary for 1992-2000: Temperature (degrees C)

	Cascades	Hoteo	Kumeu	Lucas	Mahurangi	Matakana	Ngakoroa	Oakley	Opanuku	Otara	Oteha	Papakura	Puhinui	Rangitopuni	Wairoa	Waiwera
N	96	97	78	78	78	97	77	65	96	96	96	78	72	97	97	97
Median	13.2	15.5	15.3	13.5	13.3	14.8	16.0	15.5	13.8	15.5	13.8	15.6	17.5	15.5	16.0	15.0
Normality	Y	Y	Y	Y	Y	N	Y	Y	Y	N	N	Y	Y	N	Y	Y
Seasonality	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Trend	95%	95%	95%	95%	95%	95%	NS	NS	NS	95%	95%	95%	90%	95%	95%	95%
Slope	0.25	0.3	0.31	0.39	0.5	0.25	NS	NS	NS	0.24	0.28	0.33	0.29	0.18	0.25	0.26

c) The graphs on the following page show temperature measurements from January1992 to January 2000 (where data are available)


Cascades
Hoteo
Kumeu
Lucas
Mahurangi
Matakana
Temperature (°C)
0
5
10
15
20
25
30
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000


Ngakoroa
Oakley
Opanuku
Otara
Oteha
Papakura
Temperature (°C)
0
5
10
15
20
25
30
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000


Puhinui
Rangitopuni
Wairoa
Waiwera
Temperature (°C)
Temperature (°C)
Temperature (°C)
Temperature (°C)
30
25
20
15
10
5
0
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000

APPENDIX 2: DISSOLVED OXYGEN SATURATION– FRESHWATER

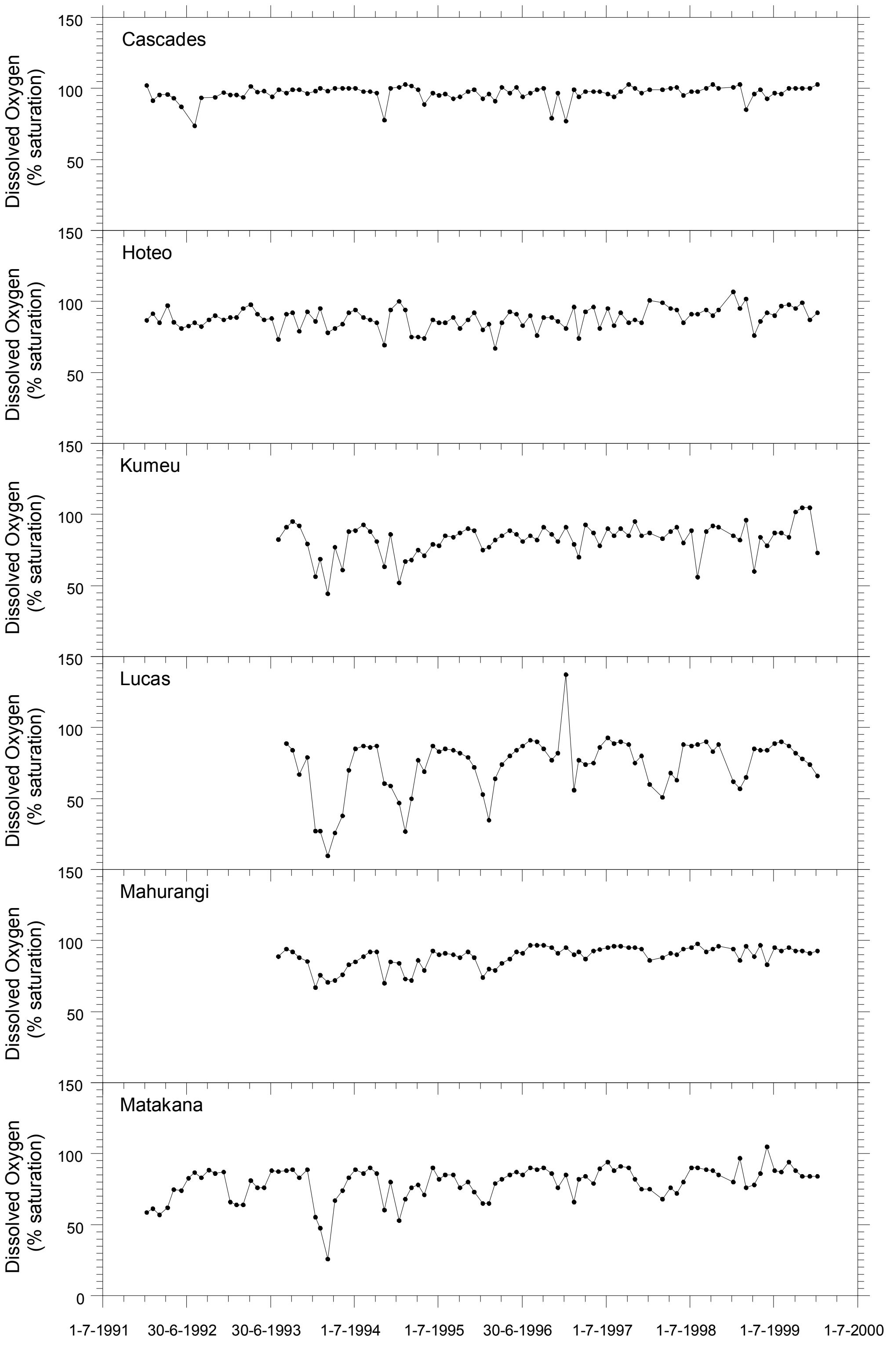
a) Dissolved oxygen (% saturation) during January 1999 - December 1999

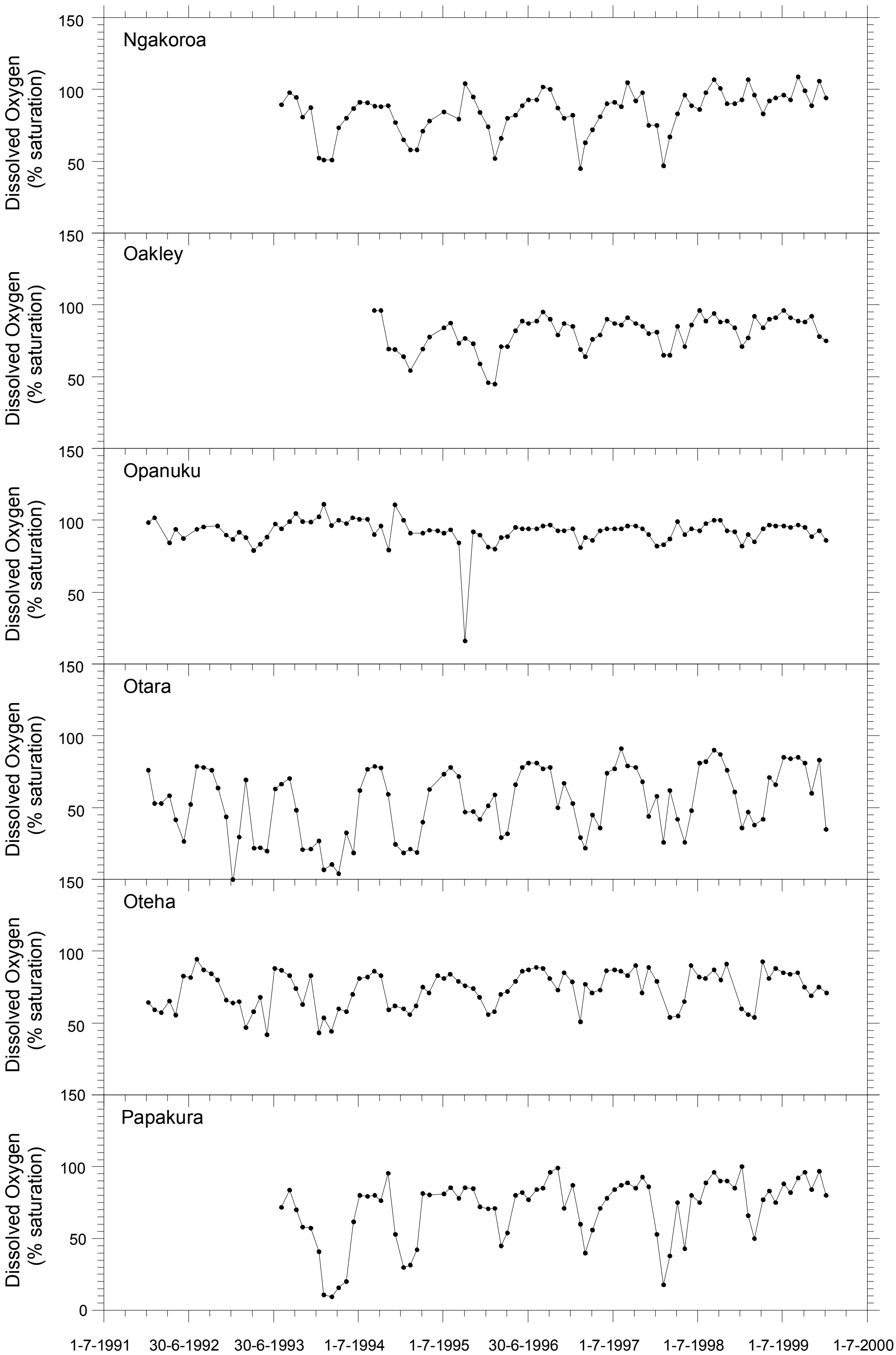
Date	Cascades	Hoteo	Kumeu	Lucas	Mahurangi	Matakana	Ngakoroa	Oakley	Opanuku	Otara	Oteha	Papakura	Puhinui	Rangitopuni	Wairoa	Waiwera
Jan-99	101	107	85	62	94	80	93	71	82	36	60	100	66	81	142	95
Feb-99	103	95	82	57	86	97	107	77	90	47	56	66	88	51	104	89
Mar-99	85	102	96	65	96	76	96	92	85	38	54	50	75	93	108	44
Apr-99	96	76	60	85	89	78	83	84	94	42	93	77	88	78	96	85
May-99	99	86	84	84	97	86	92	90	97	71	81	83	91	82	106	94
Jun-99	93	92	78	84	83	105	94	91	96	66	88	75	91	81	89	93
Jul-99	97	90	87	89	95	88	96	96	96	85	85	88	98	89	97	99
Aug-99	96	97	87	90	93	87	93	91	95	84	84	82	101	90	100	96
Sep-99	100	98	84	87	95	94	109	89	97	85	85	92	112	102	103	109
Oct-99	100	95	102	82	93	88	99	88	95	81	75	96	109	89	110	107
Nov-99	100	99	105	78	93	84	89	92	89	60	69	84	87	74	94	104
Dec-99	100	87	105	74	91	84	106	78	93	83	75	97	125	83	104	129
median	99.5	95.0	86.0	83.0	93.0	86.5	95.0	89.5	94.5	68.5	78.0	83.5	91.0	82.5	103.5	95.5
IQR/median (%)	4.0	10.5	18.6	19.9	5.4	10.4	10.5	11.7	6.9	56.9	26.3	21.6	19.2	12.1	10.1	15.2

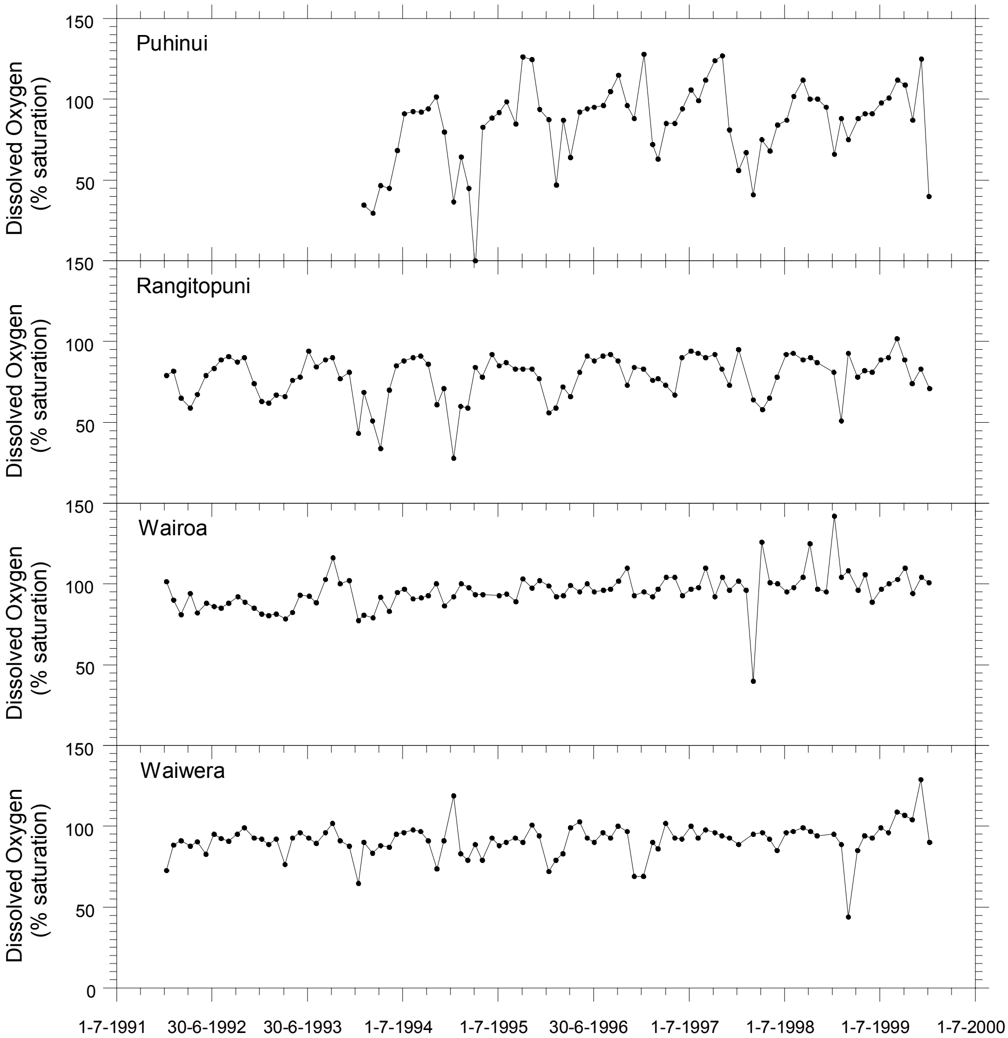
b) Statistical Summary for 1992-2000: Dissolved oxygen (% saturation)

	Cascades	Hoteo	Kumeu	Lucas	Mahurangi	Matakana	Ngakoroa	Oakley	Opanuku	Otara	Oteha	Papakura	Puhinui	Rangitopuni	Wairoa	Waiwera
N	93	95	76	75	76	95	76	63	93	96	95	77	72	95	96	95
Median	98.0	89.0	85.0	80.0	91.0	83.0	88.3	84.0	93.7	58.2	75.0	79.6	89.7	81.6	95.0	93.0
Normality	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Seasonality	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Trend	99%	99%	90%	95%	95%	95%	95%	95%	NS	95%	90%	95%	90%	90%	99%	95%
Slope	0.40	0.80	1.07	1.28	1.56	1.09	2.11	2.09	NS	2.16	0.76	2.56	1.80	0.59	2.14	0.69

c) The graphs on the following page show dissolved oxygen (% saturation) measurements from January1992 to January 2000 (where data are available)


Cascades
Hoteo
Kumeu
Lucas
Mahurangi
Matakana
Dissolved Oxygen (% saturation)
150
100
50
0
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000


Ngakoroa
Oakley
Opanuku
Otara
Oteha
Papakura
Dissolved Oxygen (% saturation)
150
100
50
0
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000


Puhinui
Rangitopuni
Wairoa
Waiwera
Dissolved Oxygen (% saturation)
150
100
50
0
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000

APPENDIX 3: BIOCHEMICAL OXYGEN DEMAND– FRESHWATER

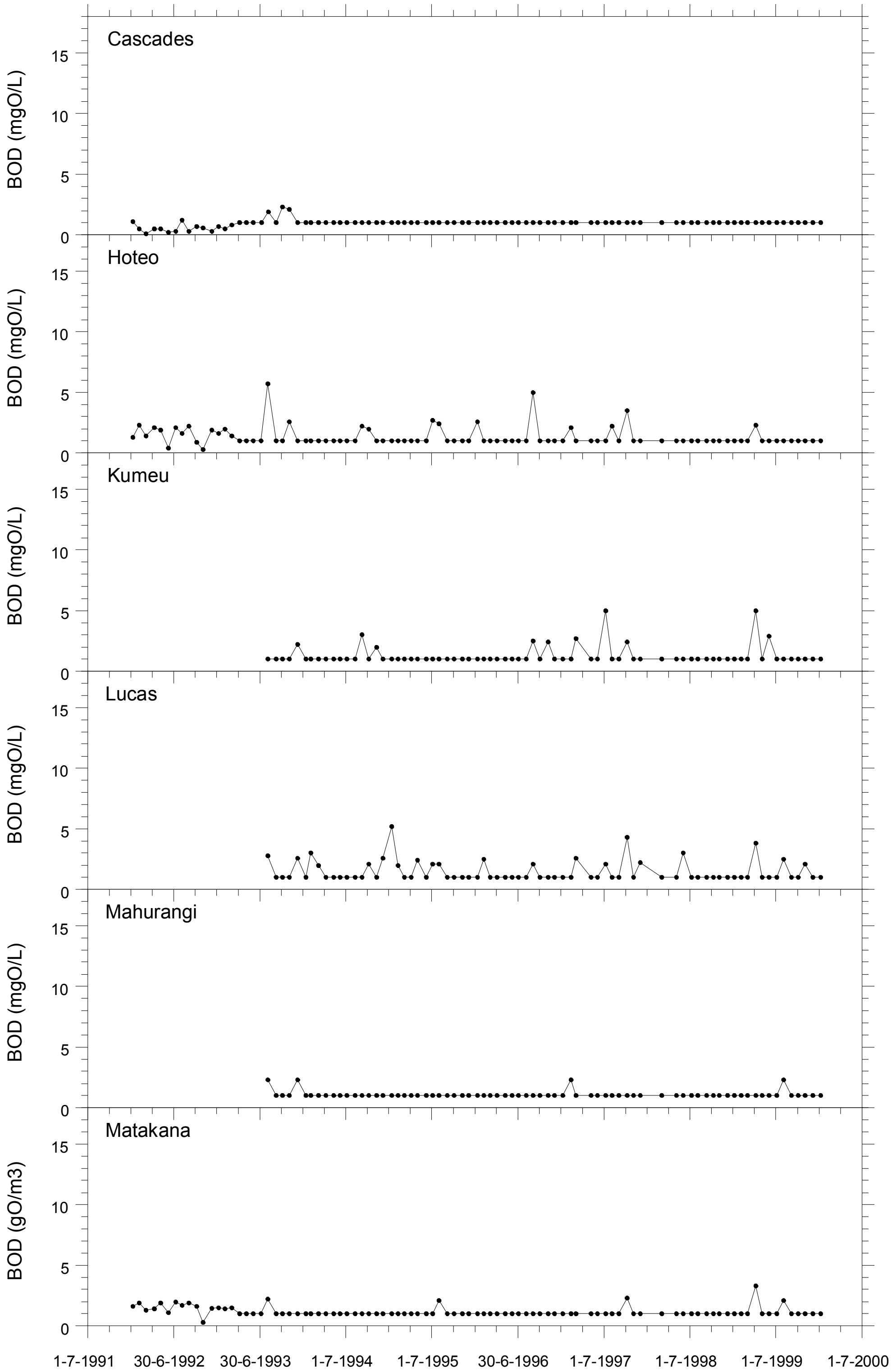
a) Biochemical oxygen demand (g/m3) during January 1999 - December 1999

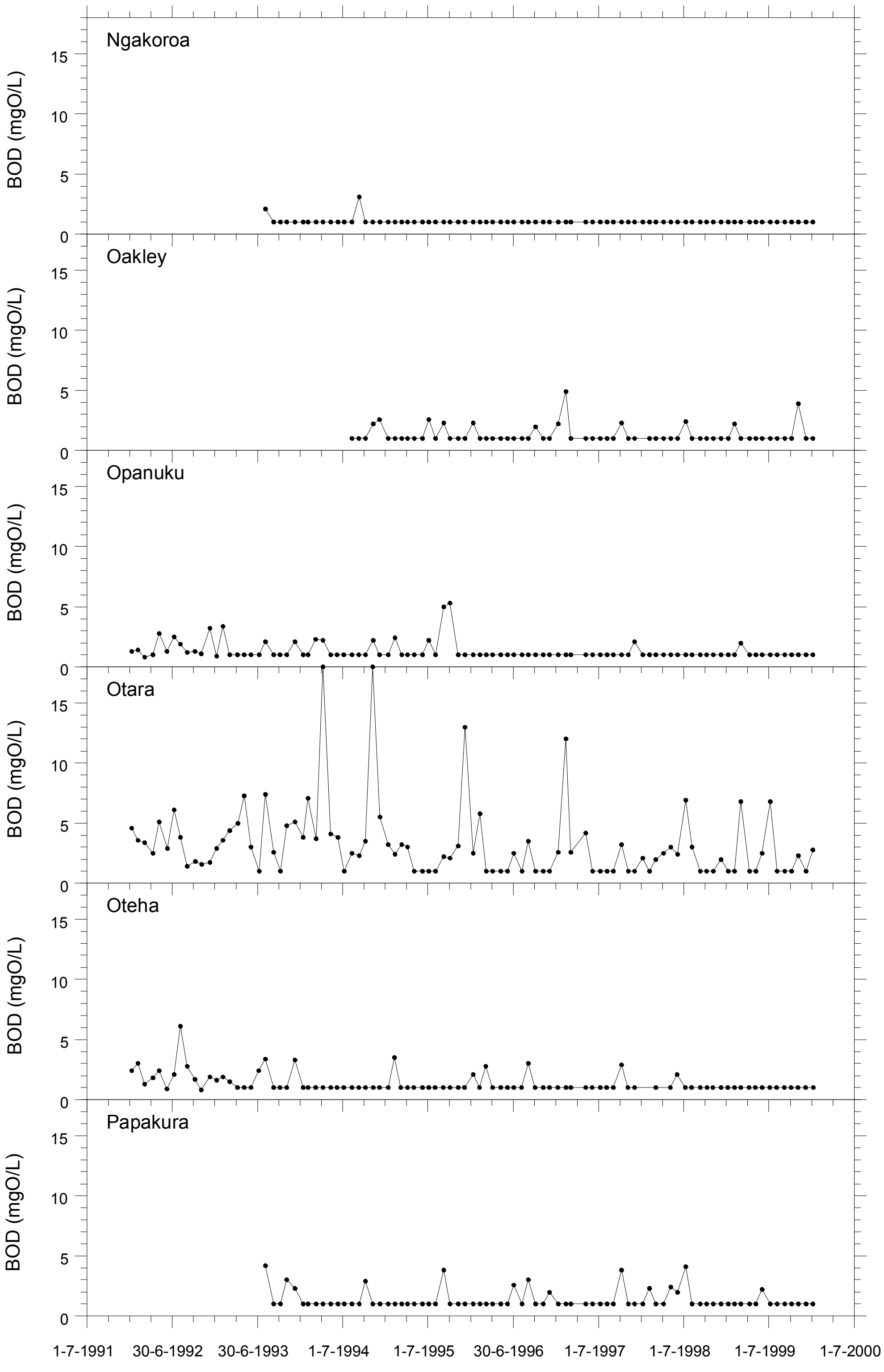
Date	Cascades	Hoteo	Kumeu	Lucas	Mahurangi	Matakana	Ngakoroa	Oakley	Opanuku	Otara	Oteha	Papakura	Puhinui	Rangitopuni	Wairoa	Waiwera
Jan-99	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	2.4	<2	<2	<2
Feb-99	<2	<2	<2	<2	<2	<2	<2	2.2	<2	<2	<2	<2	<2	3.1	<2	<2
Mar-99	<2	<2	<2	<2	<2	<2	<2	<2	2.0	6.8	<2	<2	<2	2.9	<2	<2
Apr-99	<2	2.3	5.0	3.8	<2	3.3	<2	<2	<2	<2	<2	<2	2.8	4.4	<2	2.3
May-99	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Jun-99	<2	<2	2.9	<2	<2	<2	<2	<2	<2	2.5	<2	2.2	2.6	<2	2.3	<2
Jul-99	<2	<2	<2	<2	<2	<2	<2	<2	<2	6.8	<2	<2	<2	<2	<2	<2
Aug-99	<2	<2	<2	2.5	2.3	2.1	<2	<2	<2	<2	<2	<2	<2	2.6	<2	<2
Sep-99	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	2.0	<2	<2	<2
Oct-99	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	2.6	<2	<2	<2
Nov-99	<2	<2	<2	2.1	<2	<2	<2	3.9	<2	2.3	<2	<2	3.6	<2	<2	<2
Dec-99	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
median	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
IQR/median (%)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

* = insufficient data

b) **Statistical Summary for 1992-2000: Insufficient data above detection limits**

c) Insufficient data is available above the detection limits for graph production


Cascades
Hoteo
Kumeu
Lucas
Mahurangi
Matakana
BOD (mgO/L)
BOD (gO/m3)
0
5
10
15
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000


Ngakoroa
Oakley
Opanuku
Otara
Oteha
Papakura
BOD (mgO/L)
0
5
10
15
1-7-1991
30-6-1992
30-6-1993
1-7-1994
1-7-1995
30-6-1996
1-7-1997
1-7-1998
1-7-1999
1-7-2000