



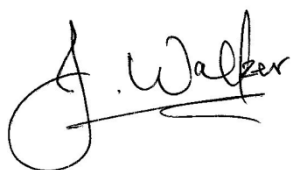
State of the Environment Monitoring River Water Quality Annual Report 2009

July 2010 Technical Report 2010/030

Auckland Regional Council
Technical Report No.030, July 2010
ISSN 1179-0504 (Print)
ISSN 1179-0512 (Online)
ISBN 978-1-877540-86-8

Reviewed by:

Approved for ARC Publication by:



Name: Dr Jarrod Walker

Name: Grant Barnes

Position: Project Leader - Marine

Position: Group Manager – Monitoring and Research

Organisation: Auckland Regional Council

Organisation: Auckland Regional Council

Date: 20th July 2010

Date: 23rd July 2010

Recommended Citation:

Neale, M. W. (2010). State of the Environment Monitoring: River Water Quality Annual Report 2009. Auckland Regional Council Technical Report 2010/030.

© 2010 Auckland Regional Council

This publication is provided strictly subject to Auckland Regional Council's (ARC) copyright and other intellectual property rights (if any) in the publication. Users of the publication may only access, reproduce and use the publication, in a secure digital medium or hard copy, for responsible genuine non-commercial purposes relating to personal, public service or educational purposes, provided that the publication is only ever accurately reproduced and proper attribution of its source, publication date and authorship is attached to any use or reproduction. This publication must not be used in any way for any commercial purpose without the prior written consent of ARC. ARC does not give any warranty whatsoever, including without limitation, as to the availability, accuracy, completeness, currency or reliability of the information or data (including third party data) made available via the publication and expressly disclaim (to the maximum extent permitted in law) all liability for any damage or loss resulting from your use of, or reliance on the publication or the information and data provided via the publication. The publication and information and data contained within it are provided on an "as is" basis.

State of the Environment Monitoring: River Water Quality Annual Report 2009

Martin W. Neale

Monitoring and Research Group,
Auckland Regional Council

Contents

1	Executive summary	1
2	Introduction	2
2.1	Auckland's rivers	2
2.2	Water quality	2
2.3	ARC monitoring programme	3
2.4	Programme objectives	4
2.5	Report scope	5
3	Methods	6
3.1	Sample sites	6
3.2	Monitoring network design	6
3.3	Programme changes	6
3.4	Sampling methodology	11
3.5	Data processing and analysis	13
4	Results	14
4.1	Box plots	15
4.2	Summary tables	26
4.3	Water quality indices and classes	47
5	Acknowledgements	50
6	Appendix 1	51
7	References	53

1 Executive summary

The Auckland Regional Council operates a long-term river water quality monitoring programme throughout the region. The objectives of this monitoring include State of the Environment reporting, identification of major environmental issues and the assessment of the efficacy of Council policy initiatives and strategies. This report documents any changes to the monitoring programme and provides a summary of the data collected during the 2009 calendar year.

Water quality is assessed monthly at 31 sites around the region using a combination of field based and laboratory tested parameters. The results are presented as box plots, which display the variation in the measured parameters at each of the sites, and in tables, which provide a statistical summary of each parameter at each of the sites.

The data was used to produce water quality indices, which allowed sites to be ranked and assigned a water quality class. This analysis allows the complex water quality data to be communicated in a simple form. The water quality indices indicated that during 2009 the best river water quality was in the Opanuku Stream in Waitakere, followed by the West Hoe Stream, Cascade Stream and Wairoa Tributary, all of which were classified as having excellent water quality. The worst water quality was observed in streams in and around the metropolitan urban area, of which the Puhinui Stream site was the lowest ranked in 2009.

2 Introduction

2.1 Auckland's rivers

The Auckland region has an estimated 16500 km of permanently flowing rivers, which increases to 28240 km when intermittent and ephemeral rivers are included (Storey & Wadhwa, 2009). As no mainland location in the region is greater than 20 km from the coast, the catchment areas of each river are relatively small. This means that most of the rivers reach the sea before they merge with others to form large rivers. Consequently, most rivers are first and second order (Table 1), meaning they are relatively small, with most less than a few metres wide.

The relatively low elevation of the Auckland region and the underlying geology also have a profound influence on the nature of the rivers, usually resulting in slow flowing, low gradient rivers with soft substrate beds. Fast flowing, high gradient rivers with hard stony substrates are mostly restricted to catchments that drain the Waitakere or Hunua Ranges.

Table 1

Permanent rivers of the Auckland region stratified by stream order (Storey & Wadhwa, 2009).

Stream order	Length (km)	% in order	Cumulative %
1	8753	52.7	52.7
2	4262	25.6	78.3
3	2121	12.7	91.0
4	1003	6.0	97.0
5	372	2.2	99.2
6	122	0.7	99.9
7	16	0.1	100

2.2 Water quality

The water quality (its physical and chemical characteristics) of a river partly determines how suitable it is for supporting animal and plant life and for use by humans.

At a given point in a river, water quality is a function of the temperature, amount of nutrients, oxygen, sediment and other pollutants in the water, and is dependent upon many factors of its catchment. In the absence of human influences, these factors include climate, topography, geology and soil type. Where there are human influences, the type of land cover and activities in the river's catchment can also strongly affect water quality.

The River Environment Classification (REC) (Snelder et al., 2004) classified each river in New Zealand by the land cover in its catchment as this is known to affect the quality and quantity of water, the types of ecological habitats and flow patterns in the river. The classification used is based on the following land cover types;

- Native forest (including natural alpine environments)
- Exotic forest
- Rural (includes all non-forested rural land)
- Urban

The majority (63%) of rivers within the Auckland region drain non-forested rural catchments (pastoral farming, horticulture and rural residential), followed by native forest catchments (21%), with exotic forest and urban catchments accounting for 8% each (Table 2).

The catchment land cover of rivers within the Auckland region is quite different from New Zealand as a whole (Table 2). These differences reflect the high population density in Auckland and the environmental pressures associated with this high population.

Table 2:

Catchment land cover for rivers in Auckland and New Zealand.

Land cover	% of rivers	
	Auckland	New Zealand
Rural	63	43
Native forest (inc. alpine)	21	51
Exotic forest	8	5
Urban	8	1

2.3 ARC monitoring programme

The overall aim of the ARC's freshwater State of the Environment monitoring programmes is to describe the quantity and quality of the region's freshwater resources, and to assess the effects of environmental stressors upon them. To meet this aim, the ARC's monitoring is carried out under two concurrent work streams. The **quantity** work stream measures the volume of the region's freshwater resources. The **quality** work stream measures the condition of the region's freshwater resource using a combination of physical, chemical and biological measures.

The ARC operates two river quality monitoring programmes, of which the Water Quality Programme is one. The Water Quality Programme monitors the physical,

chemical and microbiological properties of rivers at 31 sites. This monitoring provides information on the temperature, amounts of nutrients, oxygen, sediment and other pollutants in the sampled rivers. The results enable us to assess the life-supporting capacity of the river (how suitable it is for supporting plant and animal life) and its suitability for human use.

The River Water Quality Programme initially commenced with 8 sites in 1977-78 and ran until 1981; it was re-started with 17 sites in 1986 and has been running continuously ever since. The programme has evolved during its duration and the current 31 site network has been operating since January 2009. Each of the 31 sites is sampled monthly.

The monitoring programme is regionally representative. This means that it monitors all sizes and types of rivers, and also covers the range of different catchment land cover types found across the region. This allows us to extrapolate the results to infer the likely water quality of rivers that we do not sample.

2.4 Programme objectives

The information generated by the River Water Quality Programme, in conjunction with the ARC's other monitoring programmes, is used to meet the following objectives;

- Satisfy the ARC's obligations for state of the environment monitoring as required by section 35 of the Resource Management Act (1991).
- Contribute to community outcome monitoring required by the Local Government Act (2002).
- Help inform the efficiency and efficacy of ARC's policy initiatives and strategies.
- Assist with the identification of large scale or cumulative impacts of contaminants and disturbance associated with varying land uses.
- Provide baseline, regionally representative data from which impacts of individual activities can be measured through compliance monitoring.
- Provide baseline, regionally representative data to support preparation of environmental effects assessments required through the resource consent process.
- Address queries from the public and promote awareness of freshwater issues.

A key issue for the region is to manage the effects of development on our natural environment. This includes balancing the needs for sustainable environmental management with the community's social, economic and cultural well being.

Specific objectives include managing and minimising the adverse effects of present and future urban and rural development, growth and intensification across the region. Water quality provides information on the condition of the region's streams and feedback on management actions. Such information is necessary to confirm that ARC's management strategies are effective in sustaining stream functions and uses. By achieving this outcome we are working towards achieving the ARC mission of

“working in partnership with our regional community to achieve social, economic, cultural and environmental well being”.

2.5 Report scope

This report provides a tabular and graphical summary of the data collected from the 31 sites in the River Water Quality Programme during the 2009 calendar year.

Furthermore, the 2009 water quality data is used to produce an index for each site, which allows the complex water quality data to be communicated in a simple form.

This is the 20th annual report since the inception of the monitoring programme, and the fifth time since 2000 that the river water quality data has been reported separately from the marine and lake data. In addition, a comprehensive state and trends analysis of the water quality data was carried out in 2007 (see Scarsbrook, 2007).

All reports can be obtained from the publications area of the ARC website (www.arc.govt.nz).

3 Methods

3.1 Sample sites

The current ARC River Water Quality Programme operates with a network of 31 sites (Table 3). The number of sites sampled each year has varied due to logistical considerations and programme objectives, and the current network has been operating since January 2009. The location of the 31 sites is displayed on page 8 (Figure 1).

3.2 Monitoring network design

The sampling network began with 8 sites in 1977-78 with the objective of providing long-term data on water quality in the Auckland region (ARC, 1982). The current network was designed to provide broad geographical coverage and to cover the four major land cover classes (native forest, exotic forest, rural and urban) that exist in the Auckland region (ARC, 2008).

3.3 Programme changes

The programme was subject to an internal ARC review in late 2008. The aims of the review were twofold; the first was to remove redundancy and duplication from the programme, the second was to increase its regional representativeness. As a result several changes were made to the programme effective 1st January 2009. These included site and parameter changes, all of which are described below.

3.3.1 Site changes

There were multiple sites changes to the programme as a result of the review. Two sites were considered redundant and removed from the programme and ARC ceased sampling at other two sites that were previously sampled by both ARC and NIWA. The removal of these sites from the ARC programme, together with the variable changes described below, released sufficient resource for ARC to add six new sites to the programme allowing an increase in the regional representativeness of the programme. In addition, the Omaru Creek site was relocated upstream by one kilometre because the previous location was subject to saline influence.

The Mahurangi River (Town Bridge) and Pakuranga Creek (Guy's Road) were the two sites removed from the programme. The Mahurangi River (Town Bridge) site was considered redundant because of the close proximity (less than 500 metres) of the Mahurangi (Water Supply) site and the similar water quality state and trends observed at the two sites (Scarsbrook, 2007). Therefore the Mahurangi River (Town Bridge) site was removed from the programme and the Mahurangi (Water Supply) site maintained.

Table 3

Sites sampled in 2009 in the River Water Quality Programme, together with their location details, catchment land cover and record start date.

Site name	NZTM X	NZTM Y	Land cover	Start date
Cascades Stream	1735628	5916378	Native forest	1978
Hoteo River (NIWA operated)	1735254	5972546	Rural	1986
Kaukapakapa River	1735833	5944978	Rural	2009
Kumeu River	1739252	5928781	Rural	1993
Lucas Creek	1751468	5934510	Urban	1993
Mahurangi River (Forestry HQ)	1747750	5965035	Exotic forest	1993
Mahurangi River (Water Supply)	1748864	5970457	Rural	1993
Makarau River	1736150	5953126	Rural	2009
Matakana River	1753500	5976481	Rural	1986
Ngakaroa Stream	1775164	5881624	Rural	1993
Oakley Creek	1751963	5917636	Urban	1994
Okura Creek	1751405	5938716	Rural	2003
Omaru Creek	1766268	5916749	Urban	1985
Opanuku Stream	1742086	5915581	Rural	1978
Otaki Creek	1764306	5907216	Urban	1985
Otara Creek (East Tamaki)	1767422	5907535	Urban	1986
Otara Creek (Kennell Hill)	1768335	5908376	Urban	1992
Oteha Stream	1751325	5933519	Urban	1986
Pakuranga Creek (Botany Rd)	1769973	5913013	Urban	1985
Pakuranga Creek (Greenmount Drive)	1769473	5910813	Urban	1985
Papakura Stream	1771240	5900290	Rural	1993
Puhinui Stream	1766440	5904295	Urban	1994
Rangitopuni River (NIWA operated)	1744450	5932301	Rural	1986
Riverhead Forest Stream	1737125	5933216	Exotic forest	2009
Vaughan Stream	1755414	5938729	Rural	2001
Wairoa River	1782682	5901720	Rural	1978
Wairoa Tributary	1784426	5898982	Native forest	2009
Waitangi River	1754343	5878534	Rural	2009
Waiwera River	1748628	5953665	Rural	1986
West Hoe Stream	1748314	5950610	Native forest	2002
Whangamaire Stream	1763578	5884625	Rural	2009

Figure 1

The distribution of the 31 sampling sites used in the ARC River Water Quality Programme.

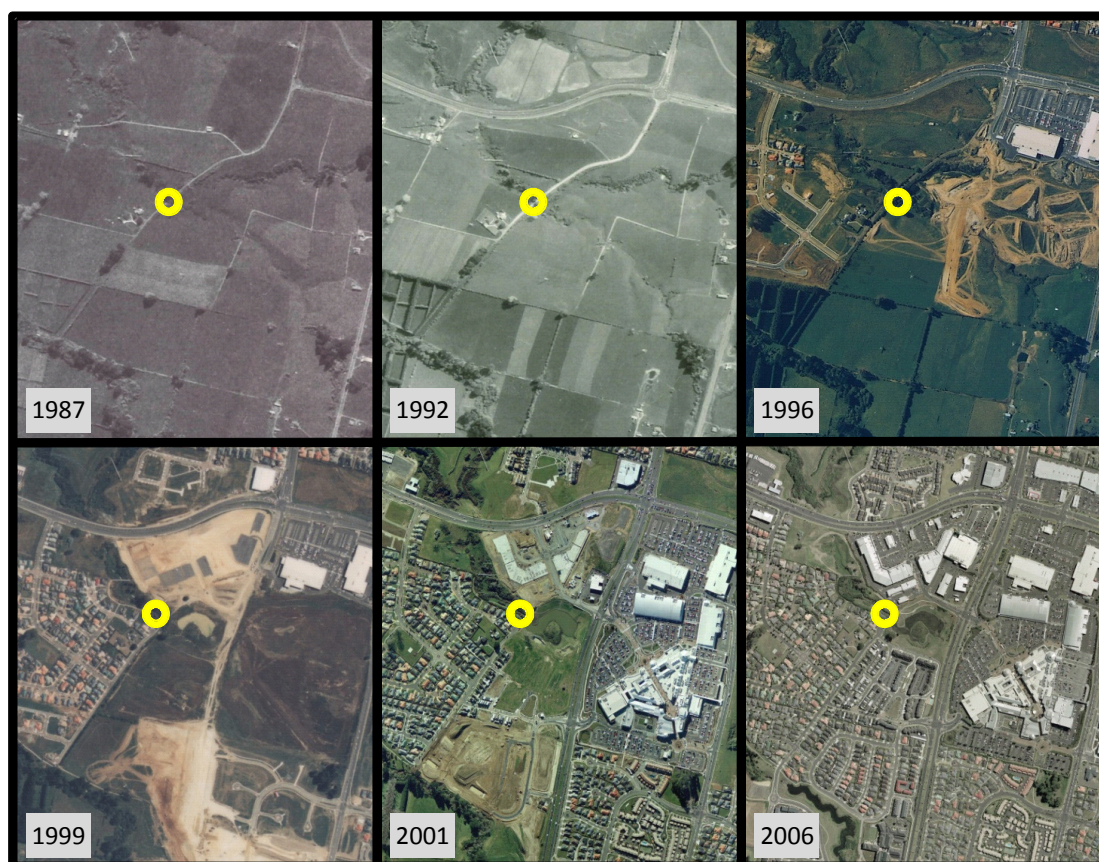


The three Pakuranga Creek sites were originally added to the water quality programme in 1985 to monitor the effects of urbanisation in the catchment (ARC, 1992). The urbanisation of the catchment is now extensive; indeed the catchment above the Guy's Road location is now entirely developed with no open stream channels remaining (Figure 2). The site is now located immediately downstream of a stormwater treatment pond and was removed from the programme because it no longer reflects the water quality of a riverine system.

Two sites have previously been sampled concurrently as part of the ARC River Water Quality Programme and the NIWA-operated National River Water Quality Network (NRWQN). This was considered a duplication of effort and therefore the ARC ceased sampling these sites in December 2008. For this and future reports, data from these two sites will be sourced under licence from the NIWA-maintained NRWQN database.

Figure 2

The urbanisation of the Pakuranga Creek catchment between 1987 and 2006. The ARC water quality site sampled between 1985 and 2008 is represented by the yellow circle.



A combination of the previously described site changes (four sites no longer sampled by ARC), and the parameter changes described below, allowed the addition of six new monitoring sites under the current resourcing of the programme. These six sites were selected primarily to increase the regional representativeness of the programme, but also to increase the monitoring on rivers of interest to the ARC.

The regional representativeness of the programme is important to the interpretation and wider application of the results. A network that is representative would have the proportion of monitoring sites in a river category (i.e. urban, rural, native forest and exotic forest) similar to the extent of the river resource in that river category (Snelder *et al.*, 2006). The ARC site network operating prior to 2009 was biased towards urban rivers; which accounted for 44% of the sampling effort, yet only 8% of the resource (Table 4). In contrast, the other three river types (native forest, exotic forest and rural) were under-represented.

The site changes in 2009 improved the regional representativeness of the network by moving the proportion of the sampling effort in each river category closer to that of the extent of the river resource in that category (Table 4). In general, this has involved an increase in the proportion of native forest, exotic forest and rural river sites in the ARC network, at the expense of urban sites. A perfectly balanced monitoring network is likely to be an unrealistic target, as regional representativeness is only one consideration in the network design. Other issues that have an influence on the network design include monitoring policy effectiveness, the effect of land use and consented activities and identifying emerging issues. However, it should be a broad target of the programme to aim for a sampling network that resembles the river resource as closely as practicable.

Table 4

The representativeness of the ARC River Water Quality Monitoring Programme network prior and post the 2009 site changes.

Land cover	% river resource	% ARC sampling effort	
		Prior 2009	Post 2009
Rural	63	44.4	48.4
Native forest (inc. alpine)	21	7.4	9.7
Exotic forest	8	3.7	6.5
Urban	8	44.4	35.5

In addition to the issue of regional representativeness, the rationale for selecting the six new sites included;

- an additional reference (native forest) site (Wairoa Tributary)
- an additional exotic forest site (Riverhead Forest Stream)

- the previously un-monitored larger freshwater tributaries of the Kaipara Harbour, an area of emerging interest for ARC (Kaukapakapa River and Makarau River)
- additional sites in Franklin that are affected by horticultural land use activities (Waitangi River and Whangamarie Stream).

3.3.2 Parameter changes

In addition to the site changes, a small number of changes were made to the parameters that are measured as part of the programme. These are detailed below;

- Faecal Coliforms were removed from the programme. Since the publication of the Microbiological Water Quality Guidelines in 2002, *Escherichia coli* has been the preferred microbiological indicator in freshwaters. The ARC has simultaneously monitored Faecal Coliforms and *E. coli* at some sites since 2005, and at all sites since 2006 to understand the relationship between the two indicators. Analysis indicated that the two indicators are highly correlated and hence the Faecal Coliforms indicator was removed from programme in December 2008.
- The method of determining Kjeldahl nitrogen was changed from a laboratory test to a calculation based on the measurements of total nitrogen and total oxidised nitrogen. Total nitrogen = Kjeldahl nitrogen + total oxidised nitrogen; therefore, only two of the parameters need to be measured to allow the third to be calculated. As total nitrogen and total oxidised nitrogen are considered more important than Kjeldahl nitrogen, it was decided that the latter would be determined by calculation.
- New field meters were employed from January 2009, which allowed pH to be determined in the field rather than by laboratory test. The new meters were primarily deployed to allow the determination of salinity at levels below 0.1ppt; an issue identified in previous data reports. The new meter (YSI 556) is able to measure pH whereas the previous meter (YSI 85) was not. Hence this parameter was measured in the field and no longer tested for at the laboratory.

3.4 Sampling methodology

For the 29 sites monitored by ARC, all sample collection is carried out by ARC staff. Up to 21 water quality parameters are routinely monitored in the programme (Table 5). Six parameters are determined in the field; the remainder are determined by laboratory tests.

Quality control measures are undertaken in accordance with Auckland Regional Council's internal standards which meet ISO 9001:2000. This covers procedures for the collection, transport and storage of samples, methods for data verification and quality assurance to ensure consistency across the monitoring programmes.

Laboratory samples are analysed under contract to the ARC by Watercare Laboratory Services Ltd, an IANZ accredited laboratory. Analytical methods follow the “Standard Methods for the Examination of Water and Wastewater” 21st Edition (APHA, 2005).

For the two NRWQN sites, sample collection is carried out by NIWA field teams. The NRWQN sites are monitored for the same parameters listed in Table 4, with the exception of salinity, suspended solids and the heavy metals. Temperature and dissolved oxygen are determined in the field, the remainder are determined by laboratory tests at NIWA’s water quality laboratory in Hamilton. Further information can be obtained from <https://secure.niwa.co.nz/wqis/index.do>.

Table 5

Parameters tested in 2009 in the River Water Quality Programme (laboratory test methods refer to those tests carried out by Watercare Services Ltd under contract from ARC).

Parameter	Code	Units	Method
Dissolved oxygen	DO (sat)	% sat	Portable YSI 556 meter
Dissolved oxygen	DO (ppm)	ppm	Portable YSI 556 meter
Temperature	Temp	°C	Portable YSI 556 meter
Conductivity	Cond	mS cm ⁻¹	Portable YSI 556 meter
Salinity	Salinity	ppt	Portable YSI 556 meter
pH	pH	pH units	Portable YSI 556 meter
Suspended solids	TSS	mg l ⁻¹	APHA (2005) 2540 D
Turbidity	Turb	NTU	APHA (2005) 2130 B
Ammoniacal nitrogen	Ammonia	mg N l ⁻¹	APHA (2005) 4500-NH ₃ G
Total oxidised nitrogen	TON	mg N l ⁻¹	APHA (2005) 4500-NO ₃ F
Kjedahl nitrogen	KN	mg N l ⁻¹	By calculation
Total nitrogen	TN	mg N l ⁻¹	APHA (2005) 4500-N C
Soluble reactive phosphorus	SRP	mg P l ⁻¹	APHA (2005) 4500-P F
Total phosphorus	TP	mg P l ⁻¹	APHA (2005) 4500-P B, F
Soluble copper	Cu sol	µg l ⁻¹	USEPA 200.8
Total copper	Cu tot	µg l ⁻¹	USEPA 200.8
Soluble zinc	Zn sol	µg l ⁻¹	USEPA 200.8
Total zinc	Zn tot	µg l ⁻¹	USEPA 200.8
Soluble lead	Pb sol	µg l ⁻¹	USEPA 200.8
Total Lead	Pb tot	µg l ⁻¹	USEPA 200.8
Eschericia coli	E. coli	cfu/100ml	APHA (2005) 9213 F

3.5 Data processing and analysis

All field and laboratory data generated by ARC are stored in the ARC's water quality archiving database (HYDSTRA). The data from the two sites operated by NIWA was extracted from the NIWA's web-based Water Quality Information System. The 2009 data was collated and used to produce;

- Box plots which display the variation in the measured parameters at each of the sites. These were produced in the software package Sigmaplot using the default percentile functions. The boxes represent the inter-quartile range (25th to 75th percentile) and the whiskers represent the 5th and 95th percentiles. The median is shown as a line in each box.
- Summary tables which provide a statistical summary of each parameter at each site. These were produced using the summary statistics function in Excel.
- Water Quality Indices which were produced using the data for seven water quality parameters to allow a water quality class to be assigned to each site. These were produced using a Excel workbook produced by the Canadian Council of Ministers of the Environment (2001). The application of this method to the ARC water quality data is described in Appendix 1.

For the purposes of this report, results that were reported as below the limit of detection were replaced by a value of half the limit of detection value (Chapman, 1996). For example, a value reported as less than a 1 mg l⁻¹ limit of detection would be included in the data analysis as 0.5 mg l⁻¹.

4 Results

The data from the 2009 calendar year are presented as;

- box plots which display the variation in the measured parameters at each of the sites (Section 3.1).
- tables which provide a statistical summary of each parameter at each site (Section 3.2)
- water quality indices produced using the data for seven water quality parameters allowing a water quality class to be assigned to each site (Section 3.3)

The results listed below should be used with discretion for the following reasons;

- Heavy metals
 - Heavy metals are monitored routinely at the 12 sites in the network that are affected by urban land use. In May and June 2009, all sites were tested for heavy metals to gauge the concentrations at all sites across the network. The results are presented in the summary tables (minimum and maximum) for the sites with only two samples, but have been omitted from the box plots because the calculation of meaningful percentiles is not possible with only two data points.
- Soluble lead
 - Soluble lead levels were typically very low in 2009 and hence the majority of tests returned results below the limit of detection. This resulted in many sites having a minimum, maximum, median and mean of $0.025 \mu\text{g l}^{-1}$ with a standard error of zero. This analysis is of limited value; the only real finding at these sites is that soluble lead is always below $0.05 \mu\text{g l}^{-1}$.

4.1 Box plots

Figure 3

Box plots showing the variation in dissolved oxygen % saturation (upper plot) and ppm (lower plot) at the 31 sites using data collected during the 2009 calendar year.

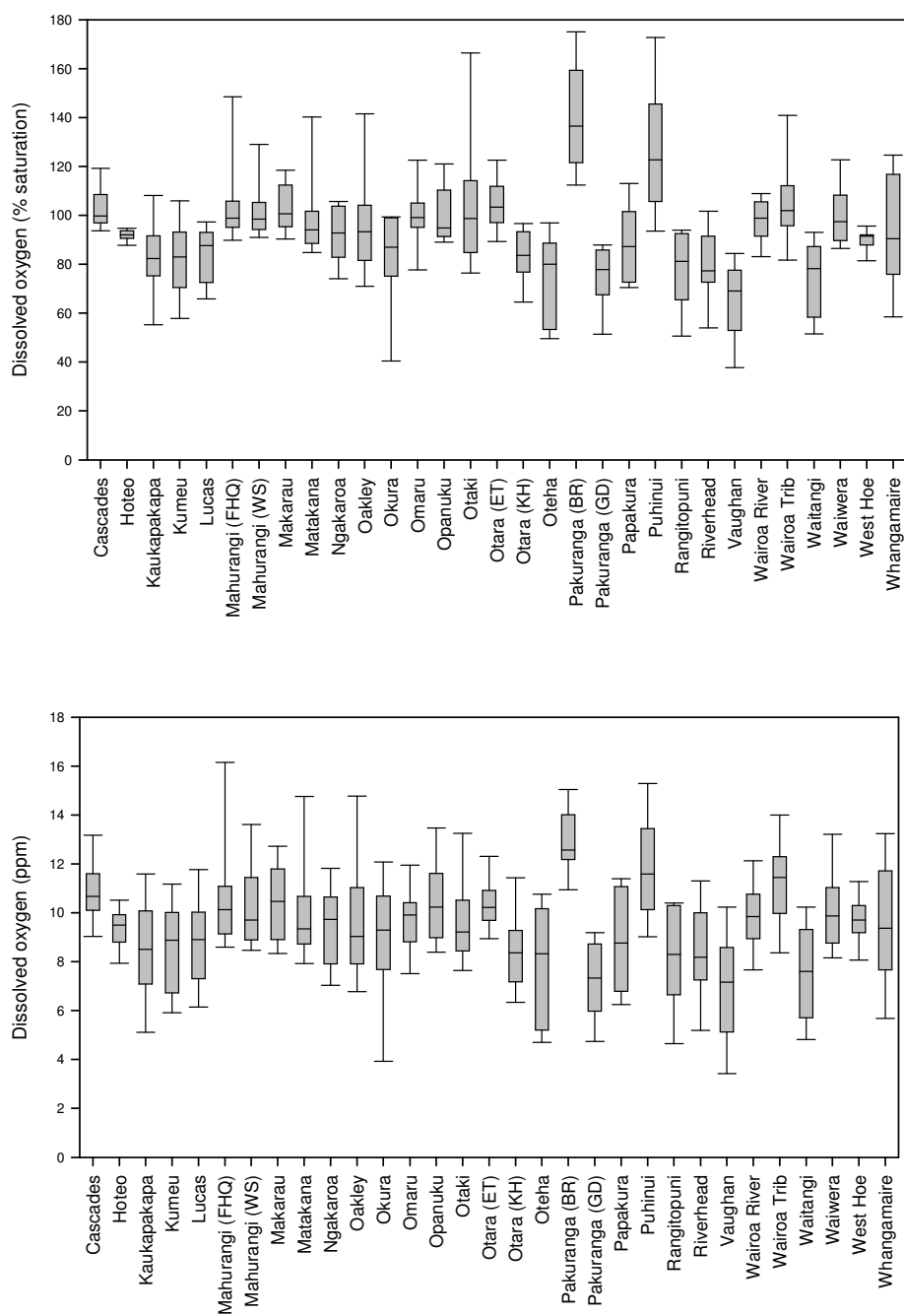


Figure 4

Box plots showing the variation in temperature (upper plot) and conductivity (lower plot) at the 31 sites using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis of the conductivity plot.

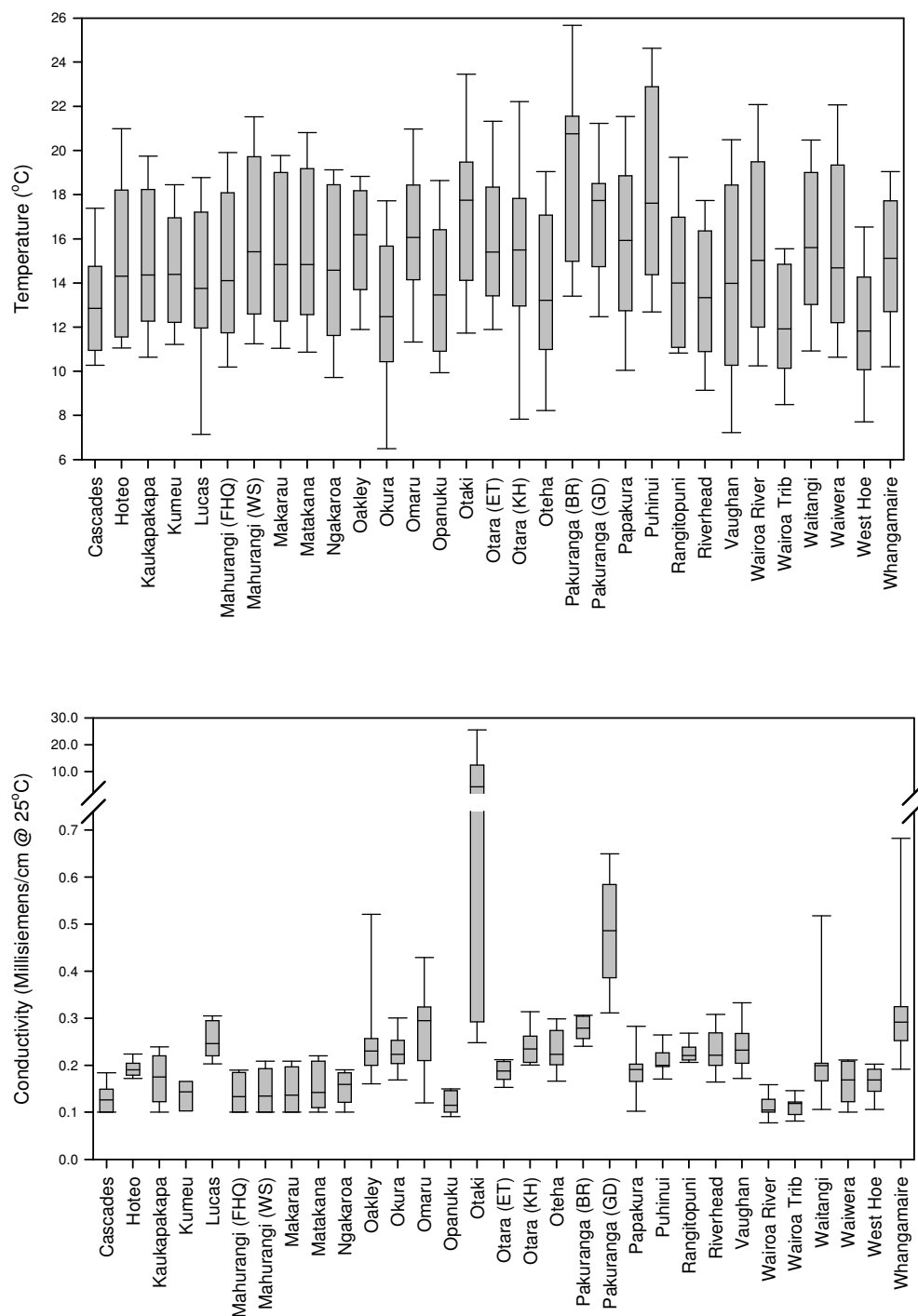


Figure 5

Box plots showing the variation in salinity (upper plot) and pH (lower plot) at the 31 sites using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis of the salinity plot.

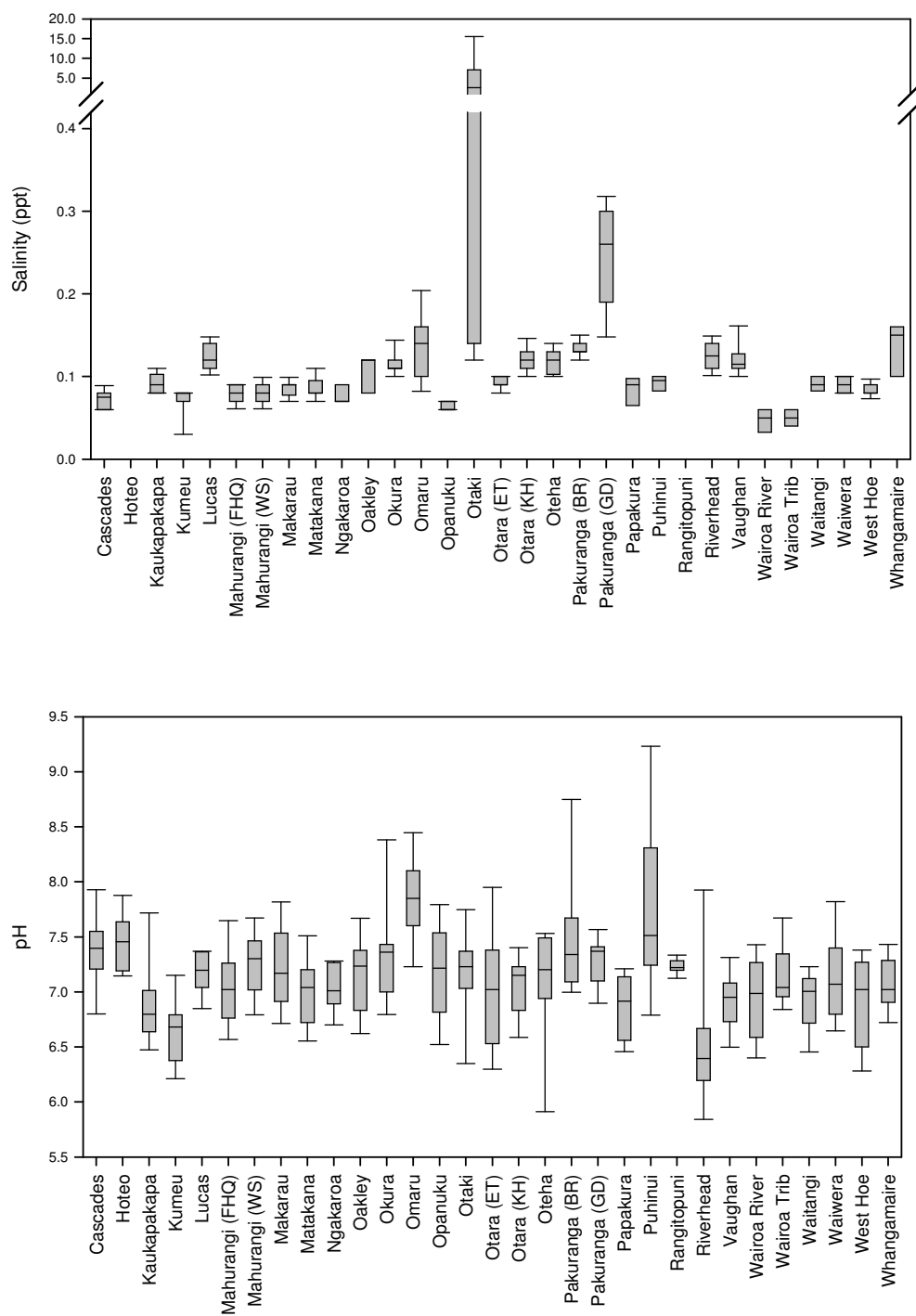


Figure 6

Box plots showing the variation in suspended sediment (upper plot) and turbidity (lower plot) at the 31 sites using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis of both plots.

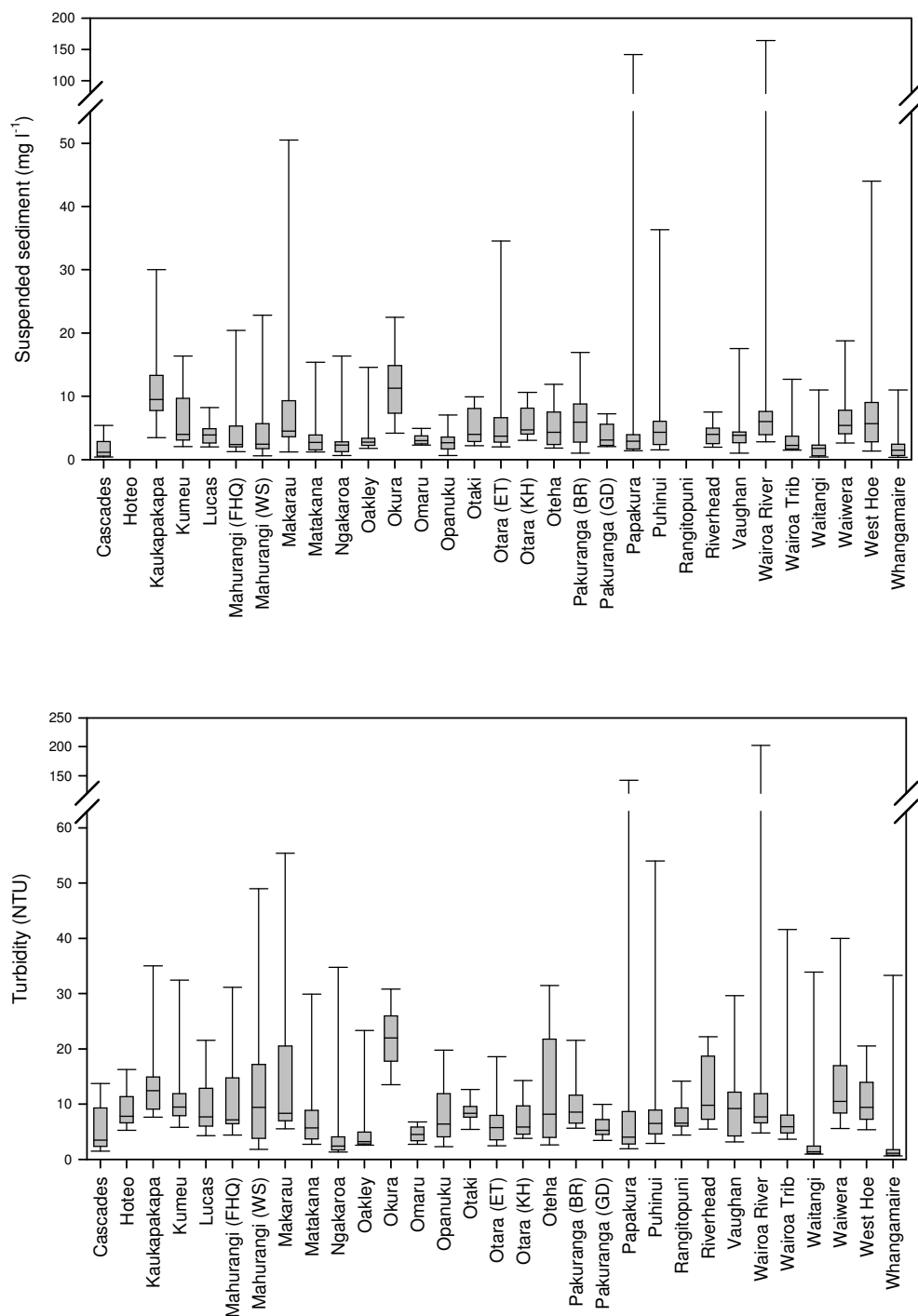


Figure 7

Box plots showing the variation in Ammoniacal nitrogen (upper plot) and total oxidised nitrogen (lower plot) at the 31 sites using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis of the total oxidised nitrogen plot.

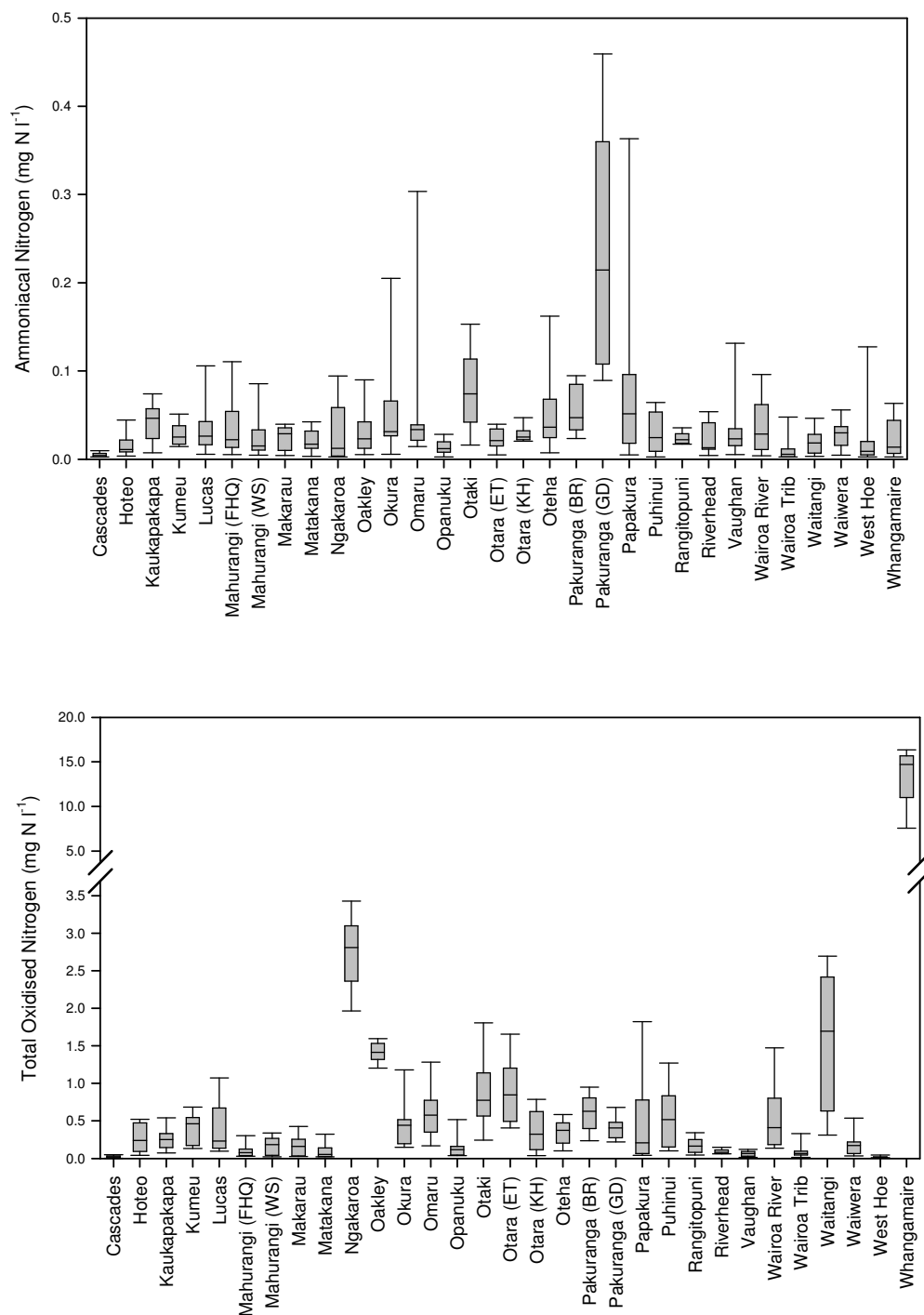


Figure 8

Box plots showing the variation in Kjeldhal nitrogen (upper plot) and total nitrogen (lower plot) at the 31 sites using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis on both plots.

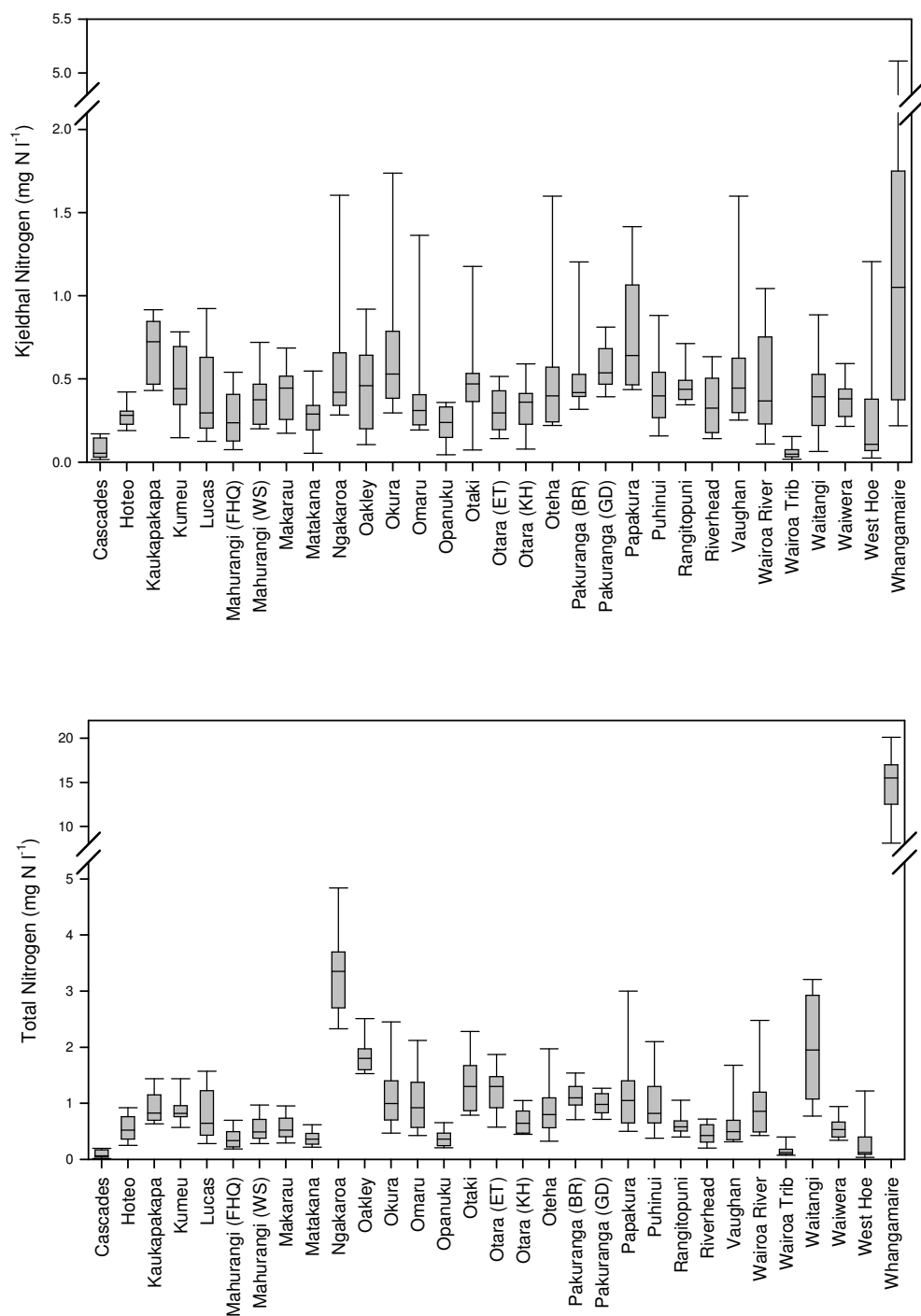


Figure 9

Box plots showing the variation in soluble reactive phosphorus (upper plot) and total phosphorus (lower plot) at the 31 sites using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis of the soluble reactive phosphorus plot.

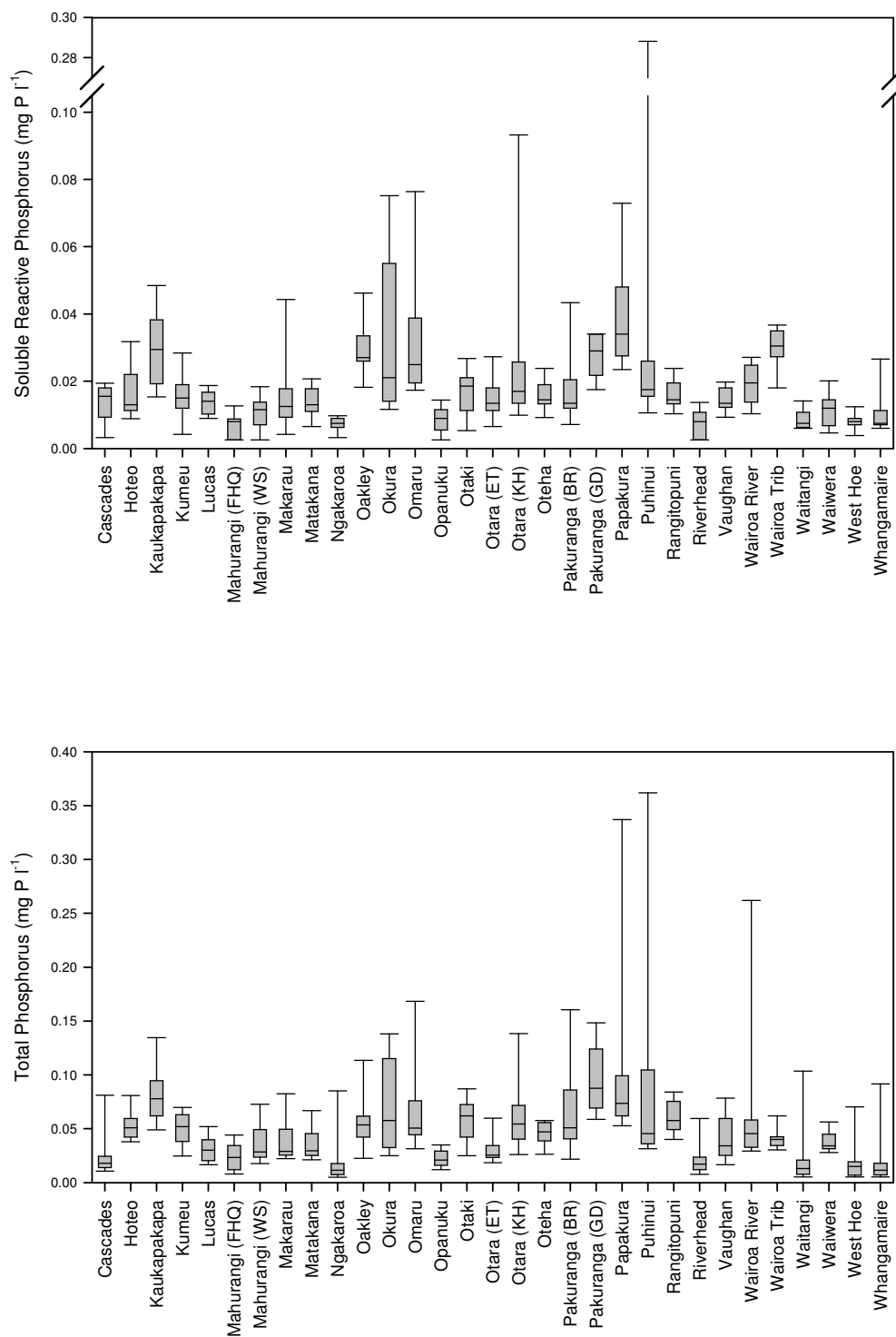


Figure 10

Box plots showing the variation in soluble copper (upper plot) and total copper (lower plot) at the 12 sites where it is monitored, using data collected during the 2009 calendar year.

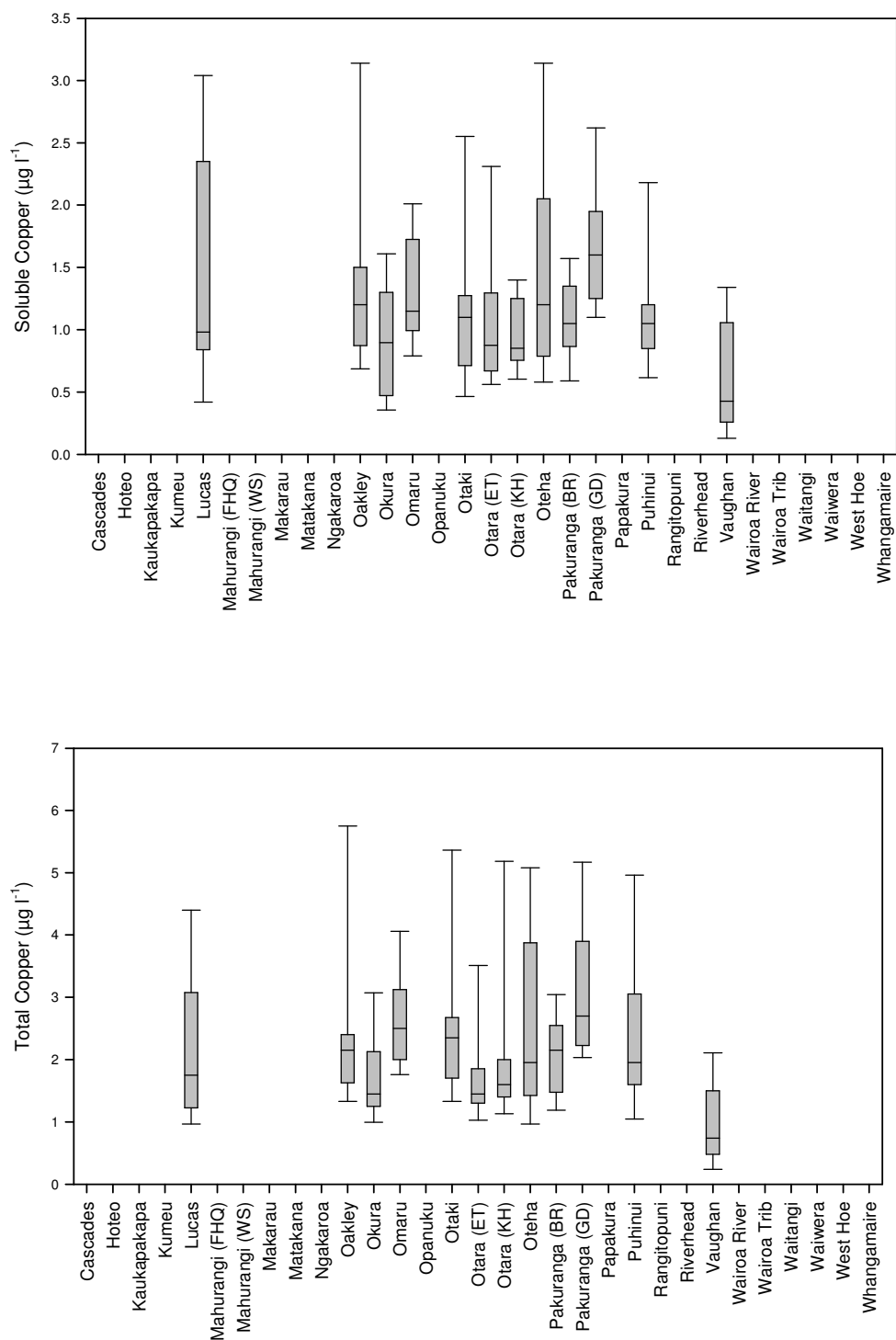


Figure 11

Box plots showing the variation in soluble zinc (upper plot) and total zinc (lower plot) at the 12 sites where it is monitored, using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis of the soluble zinc plot.

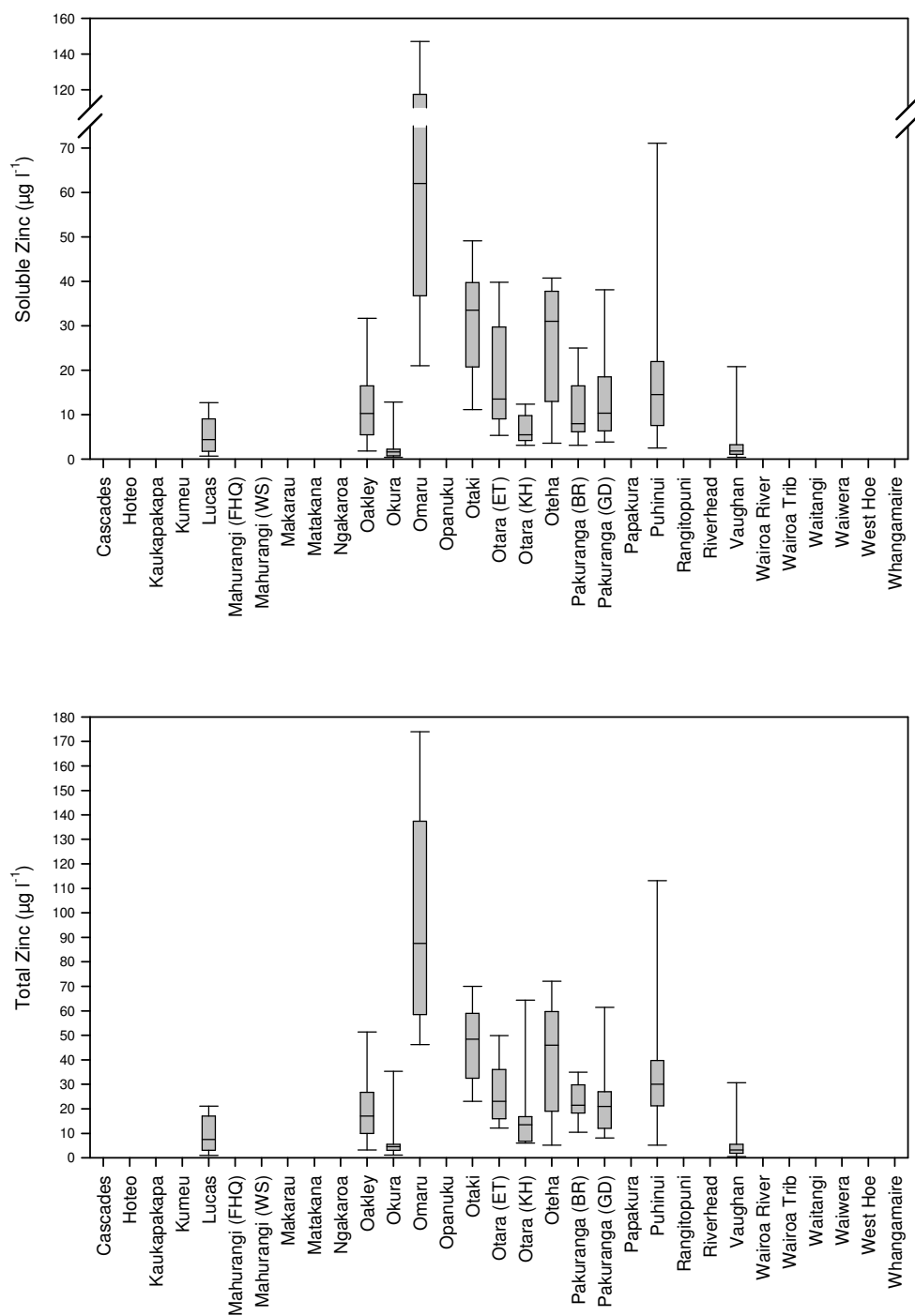


Figure 12

Box plots showing the variation in soluble lead (upper plot) and total lead (lower plot) at the 12 sites where it is monitored, using data collected during the 2009 calendar year. Note the axis break and scale change on the y-axis of the soluble lead plot.

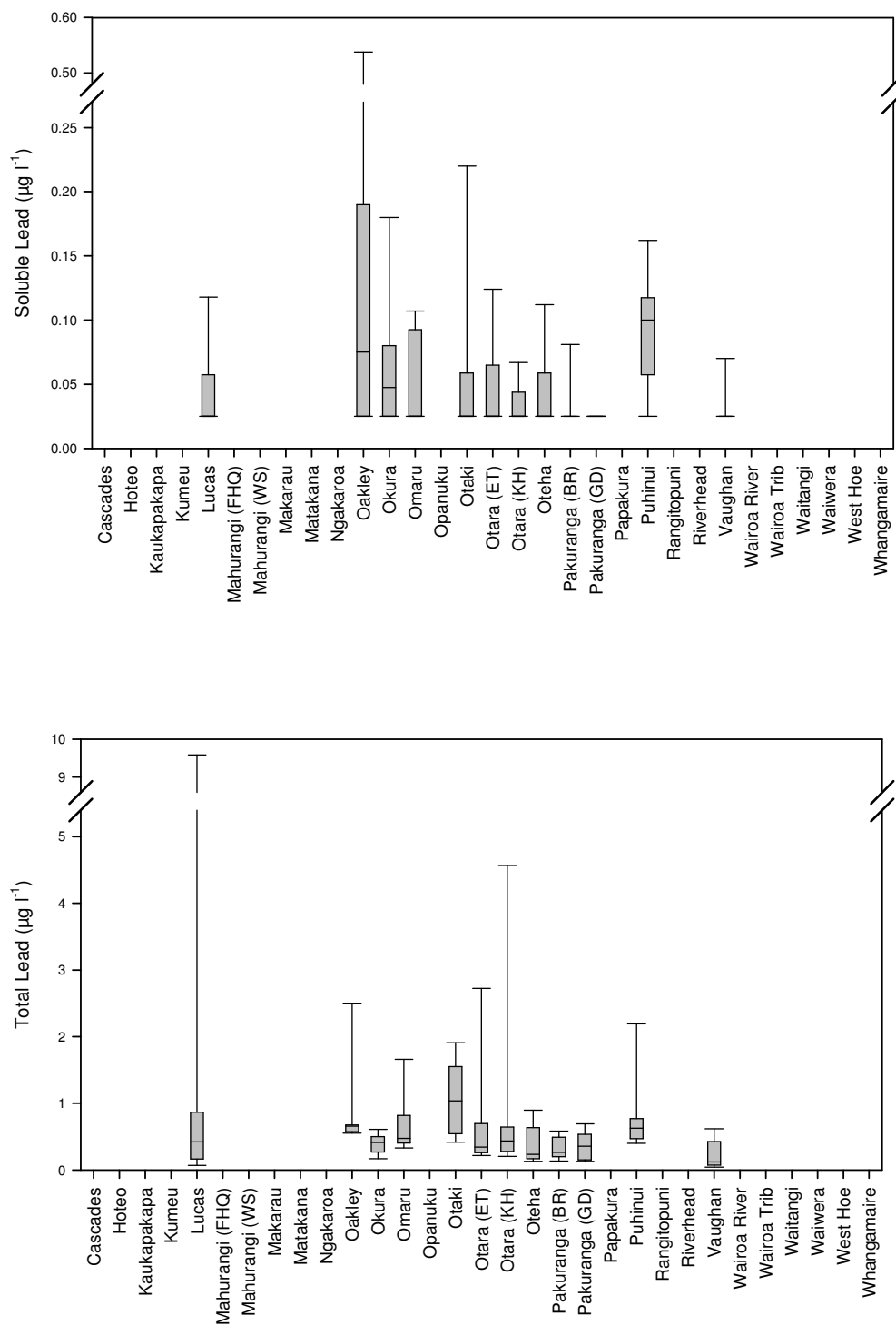
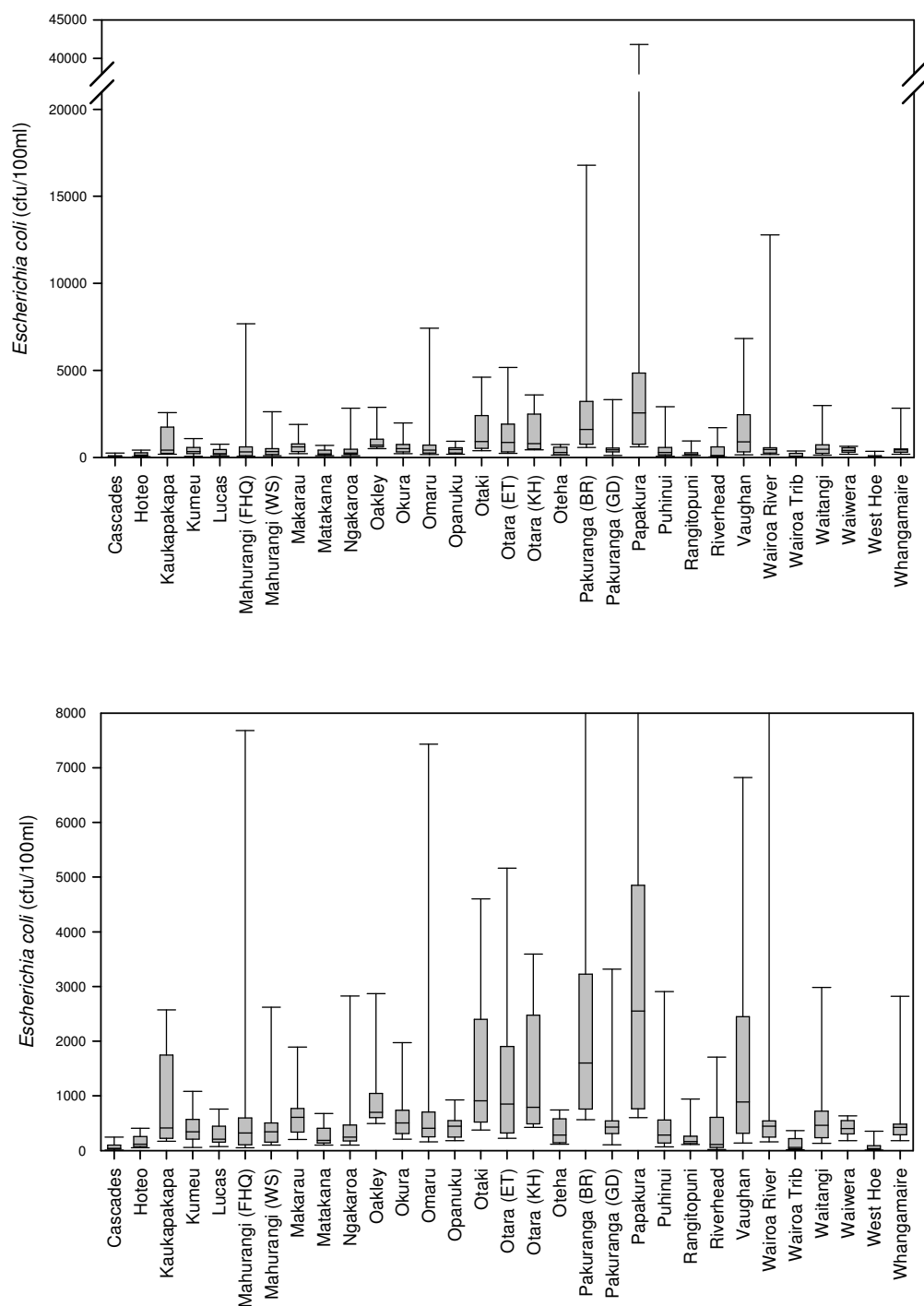


Figure 13

Box plots showing the variation in *Escherichia coli* at the 31 sites using data collected during the 2009 calendar year. The upper plot has y-axis which covers the full range of the data; the lower plot y-axis is limited to 8000 to provide greater resolution for sites with lower *Escherichia coli* levels. Note the axis break and scale change on the y-axis of the upper plot.



4.2 Summary tables

Table 6

Dissolved oxygen (% saturation)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	10	93.7	120.9	99.8	102.6	2.7
Hoteo River (NIWA operated)	12	87.6	95.2	92.1	91.9	0.7
Kaukapakapa River	10	53.3	109.0	82.3	83.1	4.8
Kumeu River	9	57.8	106.0	83.0	81.9	5.0
Lucas Creek	11	64.5	98.0	87.6	84.0	3.4
Mahurangi River (Forestry HQ)	10	89.6	153.0	98.9	104.0	5.7
Mahurangi River (Water Supply)	10	90.7	130.7	98.5	101.9	3.8
Makarau River	10	90.1	118.9	100.7	102.7	3.0
Matakana River	10	84.8	144.3	94.1	98.5	5.5
Ngakaroa Stream	9	74.1	105.6	92.8	92.2	3.7
Oakley Creek	10	70.0	145.5	93.4	95.5	6.6
Okura Creek	12	27.0	99.3	87.0	83.0	5.8
Omaru Creek	11	77.3	123.9	99.1	99.0	4.1
Opanuku Stream	10	89.0	122.2	94.8	99.8	3.5
Otaki Creek	11	74.7	173.2	98.7	105.3	8.5
Otara Creek (East Tamaki)	11	87.6	123.5	103.3	105.0	3.3
Otara Creek (Kennell Hill)	11	62.0	96.7	83.6	83.8	3.1
Oteha Stream	12	49.4	97.3	80.0	75.0	5.1
Pakuranga Creek (Botany Rd)	11	111.1	177.9	136.5	140.1	6.2
Pakuranga Creek (Greenmount Drive)	11	48.8	88.3	77.8	75.6	3.6
Papakura Stream	10	70.5	114.0	87.2	87.3	4.9
Puhinui Stream	10	93.0	175.6	122.7	126.7	8.2
Rangitopuni River (NIWA operated)	12	48.8	94.0	81.2	78.0	4.6
Riverhead Forest Stream	10	52.0	102.3	77.4	80.1	4.5
Vaughan Stream	12	35.3	85.9	69.0	65.3	4.6
Wairoa River	10	82.5	109.0	98.9	98.0	2.7
Wairoa Tributary	9	81.7	140.0	102.0	105.2	5.5
Waitangi River	10	51.2	93.0	78.1	74.2	5.0
Waiwera River	10	86.4	124.2	97.4	100.1	3.7
West Hoe Stream	12	78.8	95.9	91.5	90.1	1.3
Whangamaire Stream	10	56.8	125.4	90.4	93.3	7.1

Table 7

Dissolved oxygen (ppm)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	10	9.0	13.2	10.7	10.9	0.4
Hoteo River (NIWA operated)	12	7.9	10.7	9.5	9.3	0.2
Kaukapakapa River	10	4.9	11.6	8.5	8.5	0.6
Kumeu River	9	5.9	11.2	8.9	8.5	0.6
Lucas Creek	11	6.0	12.0	8.9	8.8	0.5
Mahurangi River (Forestry HQ)	10	8.5	16.6	10.1	10.7	0.7
Mahurangi River (Water Supply)	10	8.4	13.7	9.7	10.2	0.5
Makarau River	10	8.3	12.8	10.5	10.4	0.5
Matakana River	10	7.9	15.2	9.3	9.9	0.7
Ngakaroa Stream	9	7.0	11.8	9.7	9.3	0.5
Oakley Creek	10	6.7	15.1	9.0	9.6	0.8
Okura Creek	12	2.6	12.3	9.3	9.0	0.7
Omaru Creek	11	7.4	12.2	9.9	9.7	0.4
Opanuku Stream	10	8.3	13.6	10.2	10.5	0.5
Otaki Creek	11	7.6	13.3	9.2	9.7	0.6
Otara Creek (East Tamaki)	11	8.9	12.5	10.2	10.4	0.3
Otara Creek (Kennell Hill)	11	6.3	11.7	8.4	8.5	0.5
Oteha Stream	12	4.7	10.9	8.3	7.9	0.7
Pakuranga Creek (Botany Rd)	11	10.7	15.2	12.6	12.9	0.4
Pakuranga Creek (Greenmount Drive)	11	4.4	9.2	7.3	7.4	0.4
Papakura Stream	10	6.2	11.4	8.8	8.8	0.6
Puhinui Stream	10	9.0	15.3	11.6	11.9	0.7
Rangitopuni River (NIWA operated)	12	4.5	10.4	8.3	8.1	0.6
Riverhead Forest Stream	10	5.0	11.3	8.2	8.5	0.6
Vaughan Stream	12	3.1	10.5	7.2	6.9	0.7
Wairoa River	10	7.6	12.3	9.8	9.9	0.4
Wairoa Tributary	9	8.4	14.0	11.4	11.2	0.6
Waitangi River	10	4.8	10.3	7.6	7.5	0.6
Waiwera River	10	8.1	13.3	9.9	10.1	0.5
West Hoe Stream	12	7.7	11.5	9.7	9.7	0.3
Whangamaire Stream	10	5.5	13.3	9.4	9.5	0.8

Table 8

Temperature (°C)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	10	10.3	17.6	12.8	13.0	0.75
Hoteo River (NIWA operated)	12	11.0	21.2	14.3	15.3	1.06
Kaukapakapa River	10	10.5	19.9	14.4	15.1	1.06
Kumeu River	9	11.2	18.5	14.4	14.5	0.84
Lucas Creek	11	6.5	18.8	13.8	14.0	1.14
Mahurangi River (Forestry HQ)	10	10.0	20.1	14.1	14.7	1.09
Mahurangi River (Water Supply)	10	11.2	21.7	15.4	16.1	1.20
Makarau River	10	11.0	19.8	14.8	15.4	1.10
Matakana River	10	10.8	21.0	14.8	15.6	1.13
Ngakaroa Stream	9	9.7	19.1	14.6	14.8	1.19
Oakley Creek	10	11.8	18.8	16.2	15.9	0.78
Okura Creek	12	5.4	17.7	12.5	12.7	1.05
Omaru Creek	11	11.0	21.3	16.1	16.4	0.91
Opanuku Stream	10	9.8	18.9	13.5	13.7	0.97
Otaki Creek	11	11.4	24.1	17.8	17.5	1.10
Otara Creek (East Tamaki)	11	11.7	21.6	15.4	16.2	0.93
Otara Creek (Kennell Hill)	11	7.0	22.8	15.5	15.6	1.29
Oteha Stream	12	7.2	19.1	13.2	13.9	1.05
Pakuranga Creek (Botany Rd)	11	13.3	26.2	20.8	19.2	1.24
Pakuranga Creek (Greenmount Drive)	11	12.2	21.4	17.7	17.1	0.83
Papakura Stream	10	9.8	21.8	15.9	15.8	1.20
Puhinui Stream	10	12.7	24.7	17.6	18.2	1.38
Rangitopuni River (NIWA operated)	12	10.8	19.9	14.0	14.3	0.95
Riverhead Forest Stream	10	9.0	17.8	13.3	13.5	0.94
Vaughan Stream	12	6.6	21.1	14.0	14.2	1.31
Wairoa River	10	10.1	22.3	15.0	15.6	1.29
Wairoa Tributary	9	8.5	15.6	11.9	12.2	0.85
Waitangi River	10	10.9	20.6	15.6	15.8	1.06
Waiwera River	10	10.5	22.3	14.7	15.6	1.28
West Hoe Stream	12	7.1	16.9	11.8	12.2	0.83
Whangamaire Stream	10	10.1	19.1	15.1	15.0	0.95

Table 9

Conductivity (Millisiemens/cm @ 25°C)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	10	0.10	0.19	0.13	0.13	0.01
Hoteo River (NIWA operated)	12	0.17	0.23	0.19	0.19	0.00
Kaukapakapa River	10	0.10	0.24	0.18	0.17	0.02
Kumeu River	8	0.10	0.17	0.14	0.14	0.01
Lucas Creek	11	0.20	0.31	0.25	0.25	0.01
Mahurangi River (Forestry HQ)	10	0.10	0.19	0.13	0.14	0.01
Mahurangi River (Water Supply)	10	0.10	0.21	0.13	0.14	0.01
Makarau River	10	0.10	0.21	0.14	0.15	0.01
Matakana River	9	0.10	0.22	0.14	0.16	0.02
Ngakaroa Stream	9	0.10	0.19	0.16	0.15	0.01
Oakley Creek	10	0.16	0.55	0.23	0.25	0.03
Okura Creek	12	0.16	0.32	0.22	0.23	0.01
Omaru Creek	11	0.10	0.44	0.30	0.28	0.03
Opanuku Stream	10	0.09	0.15	0.12	0.12	0.01
Otaki Creek	11	0.25	26.42	4.37	7.48	2.77
Otara Creek (East Tamaki)	11	0.15	0.21	0.19	0.19	0.01
Otara Creek (Kennell Hill)	11	0.20	0.33	0.24	0.24	0.01
Oteha Stream	12	0.16	0.30	0.22	0.23	0.01
Pakuranga Creek (Botany Rd)	11	0.24	0.31	0.28	0.28	0.01
Pakuranga Creek (Greenmount Drive)	11	0.29	0.66	0.49	0.48	0.03
Papakura Stream	10	0.10	0.29	0.19	0.19	0.02
Puhinui Stream	10	0.17	0.27	0.20	0.21	0.01
Rangitopuni River (NIWA operated)	12	0.21	0.27	0.22	0.23	0.01
Riverhead Forest Stream	10	0.16	0.31	0.22	0.23	0.01
Vaughan Stream	12	0.16	0.35	0.23	0.24	0.01
Wairoa River	10	0.08	0.16	0.10	0.11	0.01
Wairoa Tributary	9	0.08	0.15	0.12	0.11	0.01
Waitangi River	10	0.10	0.55	0.20	0.22	0.04
Waiwera River	10	0.10	0.21	0.17	0.17	0.01
West Hoe Stream	12	0.10	0.21	0.17	0.16	0.01
Whangamaire Stream	10	0.19	0.72	0.29	0.32	0.05

Table 10
Salinity (ppt)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	10	0.06	0.09	0.08	0.07	0.003
Hoteo River (NIWA operated)	Not measured at this site					
Kaukapakapa River	10	0.08	0.11	0.09	0.09	0.004
Kumeu River	9	0.03	0.08	0.08	0.07	0.005
Lucas Creek	11	0.10	0.15	0.12	0.12	0.005
Mahurangi River (Forestry HQ)	10	0.06	0.09	0.08	0.08	0.003
Mahurangi River (Water Supply)	10	0.06	0.10	0.08	0.08	0.004
Makarau River	10	0.07	0.10	0.09	0.09	0.003
Matakana River	9	0.07	0.11	0.08	0.08	0.004
Ngakaroa Stream	7	0.01	0.09	0.07	0.07	0.011
Oakley Creek	8	0.02	0.12	0.12	0.10	0.013
Okura Creek	12	0.10	0.15	0.11	0.12	0.004
Omaru Creek	11	0.08	0.21	0.14	0.14	0.012
Opanuku Stream	10	0.06	0.07	0.06	0.06	0.002
Otaki Creek	11	0.12	16.17	2.56	4.46	1.682
Otara Creek (East Tamaki)	11	0.08	0.10	0.09	0.09	0.002
Otara Creek (Kennell Hill)	11	0.10	0.15	0.12	0.12	0.005
Oteha Stream	12	0.10	0.14	0.12	0.12	0.004
Pakuranga Creek (Botany Rd)	11	0.12	0.15	0.13	0.13	0.003
Pakuranga Creek (Greenmount Drive)	11	0.14	0.32	0.26	0.24	0.018
Papakura Stream	8	0.01	0.10	0.09	0.08	0.011
Puhinui Stream	8	0.01	0.13	0.10	0.09	0.012
Rangitopuni River (NIWA operated)	Not measured at this site					
Riverhead Forest Stream	10	0.10	0.15	0.13	0.12	0.005
Vaughan Stream	12	0.10	0.17	0.12	0.12	0.006
Wairoa River	8	0.01	0.06	0.05	0.05	0.006
Wairoa Tributary	7	0.01	0.06	0.05	0.05	0.006
Waitangi River	8	0.02	0.10	0.09	0.08	0.009
Waiwera River	10	0.08	0.10	0.09	0.09	0.003
West Hoe Stream	12	0.07	0.10	0.08	0.08	0.002
Whangamaire Stream	8	0.03	0.16	0.15	0.13	0.016

Table 11
pH (pH units)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	10	6.8	8.0	7.4	7.4	0.10
Hoteo River (NIWA operated)	12	7.1	8.0	7.5	7.5	0.07
Kaukapakapa River	10	6.5	7.8	6.8	6.9	0.12
Kumeu River	9	6.2	7.2	6.7	6.6	0.10
Lucas Creek	10	6.8	7.4	7.2	7.2	0.06
Mahurangi River (Forestry HQ)	10	6.6	7.7	7.0	7.0	0.11
Mahurangi River (Water Supply)	10	6.8	7.7	7.3	7.2	0.09
Makarau River	10	6.7	7.8	7.2	7.2	0.12
Matakana River	10	6.6	7.5	7.0	7.0	0.10
Ngakaroa Stream	9	6.7	7.3	7.0	7.0	0.07
Oakley Creek	10	6.6	7.7	7.2	7.2	0.10
Okura Creek	11	6.8	8.6	7.4	7.3	0.15
Omaru Creek	11	7.2	8.5	7.9	7.8	0.11
Opanuku Stream	10	6.5	7.8	7.2	7.2	0.14
Otaki Creek	11	6.2	7.8	7.2	7.2	0.12
Otara Creek (East Tamaki)	11	6.3	8.1	7.0	7.0	0.16
Otara Creek (Kennell Hill)	11	6.6	7.4	7.2	7.0	0.08
Oteha Stream	11	5.7	7.5	7.2	7.1	0.16
Pakuranga Creek (Botany Rd)	11	7.0	8.9	7.3	7.5	0.18
Pakuranga Creek (Greenmount Drive)	11	6.9	7.6	7.4	7.3	0.06
Papakura Stream	10	6.5	7.2	6.9	6.9	0.09
Puhinui Stream	10	6.7	9.3	7.5	7.7	0.24
Rangitopuni River (NIWA operated)	12	7.1	7.4	7.2	7.2	0.02
Riverhead Forest Stream	10	5.8	8.0	6.4	6.5	0.19
Vaughan Stream	11	6.5	7.4	7.0	6.9	0.08
Wairoa River	10	6.4	7.4	7.0	7.0	0.11
Wairoa Tributary	9	6.8	7.7	7.0	7.2	0.09
Waitangi River	10	6.5	7.2	7.0	6.9	0.08
Waiwera River	10	6.6	7.8	7.1	7.1	0.13
West Hoe Stream	11	6.3	7.4	7.0	6.9	0.13
Whangamaire Stream	9	6.7	7.4	7.0	7.1	0.08

Table 12Suspended sediment (mg l⁻¹)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	0.4	6.0	1.2	1.8	0.5
Hoteo River (NIWA operated)	not measured at this site					
Kaukapakapa River	12	2.2	36.0	9.5	11.7	2.4
Kumeu River	11	2	18.0	4.0	6.5	1.5
Lucas Creek	12	2	8.8	3.9	4.3	0.6
Mahurangi River (Forestry HQ)	12	1	24.0	2.4	5.2	1.9
Mahurangi River (Water Supply)	12	0.4	27.0	2.5	5.4	2.2
Makarau River	12	1	67.0	4.5	10.5	5.2
Matakana River	12	1.2	20.0	2.7	4.1	1.5
Ngakaroa Stream	12	0.4	22.0	2.3	3.7	1.7
Oakley Creek	12	1.6	19.0	2.8	4.1	1.4
Okura Creek	12	3.2	22.7	11.3	11.9	1.8
Omaru Creek	12	2.2	5.4	3.0	3.2	0.3
Opanuku Stream	12	0.4	8.4	2.7	2.9	0.6
Otaki Creek	12	2	10.2	4.0	5.1	0.8
Otara Creek (East Tamaki)	12	2	46.0	3.7	7.5	3.5
Otara Creek (Kennell Hill)	12	2.8	11.0	4.7	5.8	0.8
Oteha Stream	12	1.8	12.3	4.3	5.2	1.0
Pakuranga Creek (Botany Rd)	12	0.4	19.0	5.9	6.8	1.5
Pakuranga Creek (Greenmount Drive)	12	2	7.4	3.1	3.9	0.6
Papakura Stream	12	1.4	200.0	2.9	19.2	16.4
Puhinui Stream	12	1.4	49.0	4.3	7.8	3.8
Rangitopuni River (NIWA operated)	not measured at this site					
Riverhead Forest Stream	12	1.9	7.8	4.0	4.1	0.5
Vaughan Stream	12	0.4	23.0	3.9	5.0	1.7
Wairoa River	12	2.6	230.0	6.0	24.4	18.7
Wairoa Tributary	12	1.4	16.0	2.3	3.6	1.2
Waitangi River	12	0.4	14.0	1.8	2.6	1.1
Waiwera River	12	2.4	23.0	5.4	6.9	1.6
West Hoe Stream	12	1.2	44.0	5.7	11.3	4.5
Whangamaire Stream	12	0.3	14.0	1.5	2.6	1.1

Table 13
Turbidity (NTU)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	1.4	14.3	3.5	5.5	1.3
Hoteo River (NIWA operated)	12	5.1	16.5	7.8	9.3	1.1
Kaukapakapa River	12	7.3	38.1	12.4	14.9	2.6
Kumeu River	11	5.4	34.0	9.4	12.8	2.7
Lucas Creek	12	4.0	24.6	7.7	9.6	1.7
Mahurangi River (Forestry HQ)	12	4.3	31.4	7.1	11.6	2.8
Mahurangi River (Water Supply)	12	1.5	52.5	9.4	14.6	4.6
Makarau River	12	5.3	67.5	8.3	16.1	5.1
Matakana River	12	2.5	36.6	5.7	8.8	2.7
Ngakaroa Stream	12	1.3	46.6	2.4	6.5	3.7
Oakley Creek	12	2.5	30.8	3.2	5.8	2.3
Okura Creek	12	13.3	31.7	22.0	22.0	1.6
Omaru Creek	12	2.6	7.1	4.5	4.6	0.4
Opanuku Stream	12	2.1	20.1	6.4	8.4	1.7
Otaki Creek	12	5.0	13.1	8.3	8.6	0.6
Otara Creek (East Tamaki)	12	2.0	23.0	5.7	7.0	1.6
Otara Creek (Kennell Hill)	12	3.8	14.3	5.9	7.4	1.1
Oteha Stream	12	2.4	32.3	8.2	12.9	3.1
Pakuranga Creek (Botany Rd)	12	5.6	24.2	8.5	10.2	1.5
Pakuranga Creek (Greenmount Drive)	12	3.4	10.6	5.3	5.8	0.6
Papakura Stream	12	1.8	198.0	4.0	21.1	16.1
Puhinui Stream	12	2.3	72.0	6.5	12.0	5.5
Rangitopuni River (NIWA operated)	12	4.1	16.1	6.6	7.7	0.9
Riverhead Forest Stream	12	5.4	22.5	9.8	12.7	1.9
Vaughan Stream	12	3.0	36.4	9.2	10.4	2.6
Wairoa River	12	4.1	281.0	7.6	31.5	22.7
Wairoa Tributary	12	3.2	55.5	5.9	10.1	4.2
Waitangi River	12	0.9	47.1	1.4	5.3	3.8
Waiwera River	12	5.5	46.7	10.5	14.5	3.3
West Hoe Stream	12	5.1	21.6	9.4	10.9	1.4
Whangamaire Stream	12	0.6	46.2	1.1	5.0	3.8

Table 14Ammoniacal Nitrogen (mg N l⁻¹)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	0.003	0.010	0.004	0.005	0.001
Hoteo River (NIWA operated)	12	0.002	0.051	0.011	0.016	0.004
Kaukapakapa River	12	0.003	0.079	0.047	0.042	0.006
Kumeu River	11	0.014	0.052	0.025	0.029	0.004
Lucas Creek	12	0.003	0.124	0.026	0.036	0.009
Mahurangi River (Forestry HQ)	12	0.003	0.127	0.022	0.036	0.010
Mahurangi River (Water Supply)	12	0.003	0.104	0.015	0.026	0.008
Makarau River	12	0.003	0.040	0.029	0.025	0.004
Matakana River	12	0.003	0.046	0.017	0.020	0.004
Ngakaroa Stream	12	0.003	0.095	0.013	0.029	0.010
Oakley Creek	12	0.003	0.092	0.023	0.032	0.008
Okura Creek	12	0.003	0.263	0.031	0.055	0.020
Omaru Creek	12	0.014	0.413	0.034	0.062	0.032
Opanuku Stream	12	0.003	0.031	0.012	0.013	0.002
Otaki Creek	12	0.006	0.166	0.074	0.078	0.013
Otara Creek (East Tamaki)	12	0.003	0.041	0.021	0.022	0.003
Otara Creek (Kennell Hill)	12	0.020	0.049	0.025	0.028	0.003
Oteha Stream	12	0.003	0.175	0.036	0.054	0.015
Pakuranga Creek (Botany Rd)	12	0.020	0.097	0.047	0.055	0.008
Pakuranga Creek (Greenmount Drive)	12	0.083	0.474	0.215	0.244	0.039
Papakura Stream	12	0.003	0.444	0.052	0.087	0.035
Puhinui Stream	12	0.003	0.067	0.025	0.029	0.007
Rangitopuni River (NIWA operated)	12	0.017	0.038	0.022	0.024	0.002
Riverhead Forest Stream	12	0.003	0.057	0.013	0.023	0.005
Vaughan Stream	12	0.003	0.167	0.023	0.035	0.012
Wairoa River	12	0.003	0.104	0.029	0.037	0.009
Wairoa Tributary	12	0.003	0.061	0.006	0.011	0.005
Waitangi River	12	0.003	0.051	0.019	0.020	0.004
Waiwera River	12	0.003	0.064	0.030	0.028	0.005
West Hoe Stream	12	0.003	0.154	0.009	0.026	0.013
Whangamaire Stream	12	0.003	0.067	0.014	0.023	0.006

Table 15Total oxidised Nitrogen (mg N l⁻¹)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	0.001	0.054	0.022	0.023	0.005
Hoteo River (NIWA operated)	12	0.038	0.532	0.240	0.265	0.053
Kaukapakapa River	12	0.044	0.612	0.252	0.260	0.043
Kumeu River	11	0.129	0.699	0.464	0.385	0.062
Lucas Creek	12	0.086	1.180	0.231	0.394	0.101
Mahurangi River (Forestry HQ)	12	0.028	0.306	0.077	0.107	0.028
Mahurangi River (Water Supply)	12	0.024	0.361	0.182	0.166	0.033
Makarau River	12	0.025	0.479	0.159	0.161	0.041
Matakana River	12	0.021	0.372	0.054	0.096	0.030
Ngakaroa Stream	12	1.900	3.490	2.810	2.747	0.137
Oakley Creek	12	1.200	1.610	1.415	1.414	0.038
Okura Creek	12	0.146	1.390	0.441	0.462	0.097
Omaru Creek	12	0.160	1.390	0.578	0.604	0.102
Opanuku Stream	12	0.036	0.645	0.118	0.146	0.048
Otaki Creek	12	0.205	1.950	0.776	0.872	0.142
Otara Creek (East Tamaki)	12	0.397	1.720	0.848	0.910	0.121
Otara Creek (Kennell Hill)	12	0.034	0.812	0.325	0.361	0.077
Oteha Stream	12	0.072	0.598	0.376	0.355	0.046
Pakuranga Creek (Botany Rd)	12	0.214	0.981	0.626	0.604	0.070
Pakuranga Creek (Greenmount Drive)	12	0.206	0.699	0.406	0.415	0.044
Papakura Stream	12	0.037	2.220	0.210	0.477	0.181
Puhinui Stream	12	0.083	1.420	0.518	0.551	0.119
Rangitopuni River (NIWA operated)	12	0.044	0.358	0.163	0.168	0.030
Riverhead Forest Stream	12	0.060	0.156	0.084	0.093	0.009
Vaughan Stream	12	0.012	0.126	0.067	0.063	0.011
Wairoa River	12	0.127	1.740	0.411	0.549	0.132
Wairoa Tributary	12	0.003	0.406	0.064	0.096	0.030
Waitangi River	12	0.295	2.790	1.695	1.576	0.255
Waiwera River	12	0.025	0.602	0.172	0.189	0.048
West Hoe Stream	12	0.008	0.047	0.016	0.020	0.004
Whangamaire Stream	12	7.450	16.400	14.700	13.399	0.910

Table 16Kjeldhal Nitrogen by calculation (mg N l⁻¹)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	0.01	0.18	0.05	0.08	0.02
Hoteo River (NIWA operated)	12	0.18	0.45	0.28	0.28	0.02
Kaukapakapa River	12	0.43	0.93	0.72	0.67	0.05
Kumeu River	11	0.12	0.80	0.44	0.50	0.07
Lucas Creek	12	0.12	1.03	0.30	0.40	0.08
Mahurangi River (Forestry HQ)	12	0.07	0.56	0.24	0.27	0.05
Mahurangi River (Water Supply)	12	0.20	0.72	0.37	0.39	0.05
Makarau River	12	0.16	0.73	0.44	0.41	0.05
Matakana River	12	0.01	0.62	0.29	0.28	0.04
Ngakaroa Stream	12	0.28	1.71	0.42	0.61	0.13
Oakley Creek	12	0.09	0.99	0.46	0.44	0.08
Okura Creek	12	0.29	2.08	0.53	0.67	0.14
Omaru Creek	12	0.19	1.68	0.31	0.44	0.12
Opanuku Stream	12	0.03	0.36	0.24	0.23	0.03
Otaki Creek	12	0.02	1.44	0.47	0.48	0.10
Otara Creek (East Tamaki)	12	0.13	0.52	0.30	0.32	0.04
Otara Creek (Kennell Hill)	12	0.06	0.65	0.36	0.33	0.05
Oteha Stream	12	0.22	1.92	0.40	0.54	0.14
Pakuranga Creek (Botany Rd)	12	0.31	1.39	0.42	0.52	0.09
Pakuranga Creek (Greenmount Drive)	12	0.37	0.82	0.54	0.58	0.04
Papakura Stream	12	0.43	1.49	0.64	0.76	0.10
Puhinui Stream	12	0.16	0.98	0.40	0.43	0.07
Rangitopuni River (NIWA operated)	12	0.34	0.79	0.44	0.46	0.03
Riverhead Forest Stream	12	0.14	0.67	0.33	0.35	0.05
Vaughan Stream	12	0.24	1.92	0.44	0.57	0.13
Wairoa River	12	0.07	1.16	0.37	0.47	0.09
Wairoa Tributary	12	0.02	0.17	0.05	0.06	0.01
Waitangi River	12	0.00	1.02	0.39	0.41	0.07
Waiwera River	12	0.20	0.65	0.38	0.38	0.03
West Hoe Stream	12	0.01	1.38	0.11	0.28	0.12
Whangamaire Stream	12	0.20	6.40	1.05	1.45	0.49

Table 17Total Nitrogen by calculation (mg N l⁻¹)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	0.01	0.21	0.07	0.10	0.02
Hoteo River (NIWA operated)	12	0.22	0.95	0.52	0.55	0.07
Kaukapakapa River	12	0.62	1.50	0.83	0.93	0.08
Kumeu River	11	0.57	1.50	0.82	0.89	0.08
Lucas Creek	12	0.27	1.60	0.65	0.79	0.13
Mahurangi River (Forestry HQ)	12	0.18	0.73	0.34	0.37	0.05
Mahurangi River (Water Supply)	12	0.25	1.00	0.49	0.55	0.07
Makarau River	12	0.29	1.00	0.52	0.57	0.06
Matakana River	12	0.20	0.65	0.36	0.38	0.04
Ngakaroa Stream	12	2.30	5.20	3.35	3.36	0.23
Oakley Creek	12	1.50	2.60	1.80	1.86	0.09
Okura Creek	12	0.44	2.60	1.00	1.13	0.19
Omaru Creek	12	0.38	2.30	0.93	1.04	0.16
Opanuku Stream	12	0.20	0.73	0.36	0.37	0.04
Otaki Creek	12	0.77	2.40	1.30	1.36	0.15
Otara Creek (East Tamaki)	12	0.56	1.90	1.30	1.23	0.12
Otara Creek (Kennell Hill)	12	0.45	1.10	0.65	0.69	0.06
Oteha Stream	12	0.29	2.30	0.80	0.90	0.15
Pakuranga Creek (Botany Rd)	12	0.67	1.60	1.10	1.13	0.08
Pakuranga Creek (Greenmount Drive)	12	0.71	1.30	0.98	0.99	0.06
Papakura Stream	12	0.49	3.30	1.05	1.24	0.24
Puhinui Stream	12	0.35	2.40	0.82	0.99	0.16
Rangitopuni River (NIWA operated)	12	0.38	1.15	0.58	0.63	0.06
Riverhead Forest Stream	12	0.20	0.75	0.43	0.45	0.05
Vaughan Stream	12	0.31	2.00	0.50	0.63	0.13
Wairoa River	12	0.42	2.90	0.86	1.02	0.20
Wairoa Tributary	12	0.07	0.48	0.13	0.16	0.03
Waitangi River	12	0.71	3.30	1.95	1.99	0.27
Waiwera River	12	0.33	1.00	0.54	0.57	0.06
West Hoe Stream	12	0.02	1.40	0.13	0.30	0.12
Whangamaire Stream	12	8.10	21.00	15.50	14.85	1.11

Table 18Soluble reactive Phosphorus (mg P l⁻¹)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	0.003	0.020	0.016	0.013	0.002
Hoteo River (NIWA operated)	12	0.008	0.033	0.013	0.017	0.002
Kaukapakapa River	12	0.015	0.052	0.030	0.030	0.003
Kumeu River	11	0.003	0.029	0.015	0.016	0.002
Lucas Creek	12	0.009	0.019	0.014	0.014	0.001
Mahurangi River (Forestry HQ)	12	0.003	0.013	0.008	0.007	0.001
Mahurangi River (Water Supply)	12	0.003	0.019	0.012	0.011	0.001
Makarau River	12	0.003	0.047	0.013	0.017	0.004
Matakana River	12	0.005	0.021	0.013	0.014	0.001
Ngakaroa Stream	12	0.003	0.010	0.008	0.007	0.001
Oakley Creek	12	0.017	0.051	0.027	0.029	0.002
Okura Creek	12	0.011	0.077	0.021	0.033	0.007
Omaru Creek	12	0.017	0.089	0.025	0.033	0.006
Opanuku Stream	12	0.003	0.015	0.009	0.009	0.001
Otaki Creek	12	0.005	0.027	0.019	0.017	0.002
Otara Creek (East Tamaki)	12	0.005	0.030	0.014	0.015	0.002
Otara Creek (Kennell Hill)	12	0.009	0.120	0.017	0.026	0.009
Oteha Stream	12	0.008	0.025	0.015	0.016	0.001
Pakuranga Creek (Botany Rd)	12	0.005	0.047	0.014	0.018	0.003
Pakuranga Creek (Greenmount Drive)	12	0.016	0.034	0.029	0.028	0.002
Papakura Stream	12	0.022	0.082	0.034	0.039	0.005
Puhinui Stream	12	0.010	0.398	0.018	0.050	0.032
Rangitopuni River (NIWA operated)	12	0.010	0.025	0.015	0.016	0.001
Riverhead Forest Stream	12	0.003	0.014	0.008	0.008	0.001
Vaughan Stream	12	0.009	0.020	0.014	0.015	0.001
Wairoa River	12	0.010	0.028	0.020	0.019	0.002
Wairoa Tributary	12	0.015	0.037	0.031	0.030	0.002
Waitangi River	12	0.006	0.015	0.008	0.009	0.001
Waiwera River	12	0.004	0.021	0.012	0.012	0.001
West Hoe Stream	12	0.003	0.013	0.008	0.008	0.001
Whangamaire Stream	12	0.006	0.032	0.008	0.010	0.002

Table 19Total Phosphorus (mg P l⁻¹)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	12	0.010	0.103	0.018	0.025	0.007
Hoteo River (NIWA operated)	12	0.037	0.084	0.051	0.053	0.004
Kaukapakapa River	12	0.048	0.142	0.078	0.082	0.008
Kumeu River	11	0.024	0.070	0.052	0.048	0.005
Lucas Creek	12	0.016	0.053	0.030	0.031	0.003
Mahurangi River (Forestry HQ)	12	0.008	0.044	0.024	0.024	0.004
Mahurangi River (Water Supply)	12	0.017	0.080	0.029	0.035	0.005
Makarau River	12	0.022	0.095	0.029	0.039	0.006
Matakana River	12	0.020	0.073	0.030	0.036	0.004
Ngakaroa Stream	12	0.005	0.112	0.012	0.020	0.009
Oakley Creek	12	0.022	0.133	0.054	0.056	0.008
Okura Creek	12	0.023	0.143	0.058	0.071	0.012
Omaru Creek	12	0.028	0.193	0.051	0.069	0.013
Opanuku Stream	12	0.011	0.037	0.021	0.022	0.002
Otaki Creek	12	0.020	0.091	0.062	0.058	0.006
Otara Creek (East Tamaki)	12	0.017	0.063	0.026	0.031	0.004
Otara Creek (Kennell Hill)	12	0.023	0.159	0.055	0.062	0.010
Oteha Stream	12	0.025	0.058	0.047	0.046	0.003
Pakuranga Creek (Botany Rd)	12	0.021	0.181	0.051	0.065	0.013
Pakuranga Creek (Greenmount Drive)	12	0.055	0.150	0.088	0.096	0.009
Papakura Stream	12	0.051	0.414	0.074	0.108	0.029
Puhinui Stream	12	0.030	0.464	0.046	0.092	0.035
Rangitopuni River (NIWA operated)	12	0.038	0.084	0.058	0.060	0.004
Riverhead Forest Stream	12	0.007	0.071	0.017	0.022	0.005
Vaughan Stream	12	0.016	0.080	0.034	0.041	0.006
Wairoa River	12	0.029	0.349	0.046	0.070	0.026
Wairoa Tributary	12	0.029	0.069	0.040	0.041	0.003
Waitangi River	12	0.005	0.125	0.013	0.025	0.010
Waiwera River	12	0.027	0.058	0.034	0.038	0.003
West Hoe Stream	12	0.005	0.091	0.015	0.019	0.007
Whangamaire Stream	12	0.005	0.112	0.012	0.022	0.009

Table 20Soluble Copper ($\mu\text{g l}^{-1}$)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	2	0.12	0.44	0.28	0.28	0.16
Hoteo River (NIWA operated)	Not measured at this site					
Kaukapakapa River	2	0.63	0.80	0.72	0.72	0.09
Kumeu River	2	0.60	0.70	0.65	0.65	0.05
Lucas Creek	12	0.40	3.10	0.98	1.40	0.27
Mahurangi River (Forestry HQ)	2	0.41	0.65	0.53	0.53	0.12
Mahurangi River (Water Supply)	2	0.32	0.48	0.40	0.40	0.08
Makarau River	2	0.25	0.79	0.52	0.52	0.27
Matakana River	2	0.55	0.90	0.73	0.73	0.18
Ngakaroa Stream	2	0.05	0.27	0.16	0.16	0.11
Oakley Creek	12	0.66	3.80	1.20	1.38	0.24
Okura Creek	12	0.32	1.70	0.90	0.90	0.13
Omaru Creek	12	0.72	2.10	1.15	1.30	0.12
Opanuku Stream	2	0.33	0.72	0.53	0.53	0.20
Otaki Creek	12	0.37	3.00	1.10	1.16	0.19
Otara Creek (East Tamaki)	12	0.55	2.70	0.88	1.04	0.17
Otara Creek (Kennell Hill)	12	0.60	1.40	0.85	0.95	0.08
Oteha Stream	12	0.58	3.50	1.20	1.47	0.25
Pakuranga Creek (Botany Rd)	12	0.57	1.60	1.05	1.07	0.09
Pakuranga Creek (Greenmount Drive)	12	1.10	2.80	1.60	1.66	0.14
Papakura Stream	2	0.93	0.99	0.96	0.96	0.03
Puhinui Stream	12	0.53	2.30	1.05	1.15	0.14
Rangitopuni River (NIWA operated)	Not measured at this site					
Riverhead Forest Stream	2	0.21	0.26	0.24	0.24	0.03
Vaughan Stream	12	0.11	1.40	0.43	0.60	0.13
Wairoa River	2	0.27	1.30	0.79	0.79	0.52
Wairoa Tributary	2	0.05	0.23	0.14	0.14	0.09
Waitangi River	2	0.39	0.39	0.39	0.39	0.00
Waiwera River	2	0.58	2.60	1.59	1.59	1.01
West Hoe Stream	2	0.05	0.36	0.21	0.21	0.16
Whangamaire Stream	2	0.11	0.46	0.29	0.29	0.18

Table 21Total Copper ($\mu\text{g l}^{-1}$)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	2	0.84	1.30	1.07	1.07	0.23
Hoteo River (NIWA operated)	Not measured at this site					
Kaukapakapa River	2	1.20	1.30	1.25	1.25	0.05
Kumeu River	2	1.20	1.30	1.25	1.25	0.05
Lucas Creek	12	0.95	4.40	1.75	2.16	0.36
Mahurangi River (Forestry HQ)	2	1.00	1.10	1.05	1.05	0.05
Mahurangi River (Water Supply)	2	0.86	1.80	1.33	1.33	0.47
Makarau River	2	0.84	2.60	1.72	1.72	0.88
Matakana River	2	1.00	1.90	1.45	1.45	0.45
Ngakaroa Stream	2	0.39	0.42	0.41	0.41	0.02
Oakley Creek	12	1.30	7.10	2.15	2.43	0.44
Okura Creek	12	0.99	3.10	1.45	1.75	0.20
Omaru Creek	12	1.70	4.30	2.50	2.62	0.22
Opanuku Stream	2	0.85	1.30	1.08	1.08	0.23
Otaki Creek	12	1.30	6.50	2.35	2.51	0.39
Otara Creek (East Tamaki)	12	0.95	3.90	1.45	1.73	0.23
Otara Creek (Kennell Hill)	12	1.10	6.50	1.60	1.98	0.42
Oteha Stream	12	0.95	5.50	1.95	2.53	0.42
Pakuranga Creek (Botany Rd)	12	1.10	3.10	2.15	2.08	0.18
Pakuranga Creek (Greenmount Drive)	12	2.00	5.50	2.70	3.06	0.31
Papakura Stream	2	1.30	1.70	1.50	1.50	0.20
Puhinui Stream	12	0.85	5.50	1.95	2.35	0.36
Rangitopuni River (NIWA operated)	Not measured at this site					
Riverhead Forest Stream	2	0.68	1.00	0.84	0.84	0.16
Vaughan Stream	12	0.20	2.20	0.74	0.97	0.18
Wairoa River	2	0.97	1.20	1.09	1.09	0.12
Wairoa Tributary	2	0.46	0.47	0.47	0.47	0.00
Waitangi River	2	0.76	0.81	0.79	0.79	0.03
Waiwera River	2	1.70	3.20	2.45	2.45	0.75
West Hoe Stream	2	0.40	0.64	0.52	0.52	0.12
Whangamaire Stream	2	0.57	0.66	0.62	0.62	0.05

Table 22Soluble Zinc ($\mu\text{g l}^{-1}$)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	2	0.56	2.60	1.58	1.58	1.02
Hoteo River (NIWA operated)	Not measured at this site					
Kaukapakapa River	2	2.50	3.40	2.95	2.95	0.45
Kumeu River	2	3.70	4.90	4.30	4.30	0.60
Lucas Creek	12	0.49	13.00	4.35	5.67	1.29
Mahurangi River (Forestry HQ)	2	3.60	13.00	8.30	8.30	4.70
Mahurangi River (Water Supply)	2	1.60	2.30	1.95	1.95	0.35
Makarau River	2	1.90	2.40	2.15	2.15	0.25
Matakana River	2	1.50	16.00	8.75	8.75	7.25
Ngakaroa Stream	2	0.15	39.00	19.58	19.58	19.43
Oakley Creek	12	0.95	38.00	10.25	12.20	2.77
Okura Creek	12	0.33	16.00	1.65	2.92	1.25
Omaru Creek	12	18.00	150.00	62.00	73.92	13.14
Opanuku Stream	2	1.80	2.70	2.25	2.25	0.45
Otaki Creek	12	9.90	53.00	33.50	31.24	3.55
Otara Creek (East Tamaki)	12	4.70	44.00	13.50	18.36	3.53
Otara Creek (Kennell Hill)	12	2.80	13.00	5.50	6.73	0.93
Oteha Stream	12	2.40	41.00	31.00	26.57	3.96
Pakuranga Creek (Botany Rd)	12	2.50	28.00	8.00	10.89	2.09
Pakuranga Creek (Greenmount Drive)	12	3.50	45.00	10.35	13.54	3.30
Papakura Stream	2	8.60	8.70	8.65	8.65	0.05
Puhinui Stream	12	2.20	78.00	14.50	21.28	6.56
Rangitopuni River (NIWA operated)	Not measured at this site					
Riverhead Forest Stream	2	5.90	10.00	7.95	7.95	2.05
Vaughan Stream	12	0.15	25.00	1.85	4.43	2.04
Wairoa River	2	2.60	47.00	24.80	24.80	22.20
Wairoa Tributary	2	0.15	0.15	0.15	0.15	0.00
Waitangi River	2	2.50	4.10	3.30	3.30	0.80
Waiwera River	2	1.20	22.00	11.60	11.60	10.40
West Hoe Stream	2	0.55	1.30	0.93	0.93	0.38
Whangamaire Stream	2	0.72	4.30	2.51	2.51	1.79

Table 23Total Zinc ($\mu\text{g l}^{-1}$)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	2	1.9	2.5	2.2	2.2	0.3
Hoteo River (NIWA operated)	Not measured at this site					
Kaukapakapa River	2	3.5	5.9	4.7	4.7	1.2
Kumeu River	2	7.2	7.9	7.6	7.6	0.4
Lucas Creek	12	0.4	22.0	7.6	9.5	2.2
Mahurangi River (Forestry HQ)	2	7.6	24.0	15.8	15.8	8.2
Mahurangi River (Water Supply)	2	4.3	7.0	5.7	5.7	1.4
Makarau River	2	4.5	7.3	5.9	5.9	1.4
Matakana River	2	2.5	18.0	10.3	10.3	7.8
Ngakaroa Stream	2	0.4	0.7	0.5	0.5	0.2
Oakley Creek	12	1.2	61.0	17.0	19.9	4.4
Okura Creek	12	0.4	44.0	4.6	8.2	3.4
Omaru Creek	12	45.0	180.0	87.5	98.3	13.0
Opanuku Stream	2	3.7	4.8	4.3	4.3	0.6
Otaki Creek	12	23.0	73.0	48.5	45.7	4.6
Otara Creek (East Tamaki)	12	11.0	52.0	23.0	27.2	3.8
Otara Creek (Kennell Hill)	12	5.9	83.0	13.5	18.0	6.1
Oteha Stream	12	2.7	73.0	46.0	41.2	6.7
Pakuranga Creek (Botany Rd)	12	8.9	37.0	21.5	22.6	2.2
Pakuranga Creek (Greenmount Drive)	12	6.9	74.0	21.0	23.8	5.1
Papakura Stream	2	7.8	13.0	10.4	10.4	2.6
Puhinui Stream	12	2.2	120.0	30.0	39.6	9.9
Rangitopuni River (NIWA operated)	Not measured at this site					
Riverhead Forest Stream	2	11.0	12.0	11.5	11.5	0.5
Vaughan Stream	12	0.2	34.0	3.2	7.2	3.0
Wairoa River	2	5.9	44.0	25.0	25.0	19.1
Wairoa Tributary	2	0.3	1.0	0.6	0.6	0.3
Waitangi River	2	2.4	7.4	4.9	4.9	2.5
Waiwera River	2	4.0	19.0	11.5	11.5	7.5
West Hoe Stream	2	0.9	1.9	1.4	1.4	0.5
Whangamaire Stream	2	1.2	5.2	3.2	3.2	2.0

Table 24Soluble Lead ($\mu\text{g l}^{-1}$)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	2	0.025	0.025	0.025	0.025	0.000
Hoteo River (NIWA operated)	Not measured at this site					
Kaukapakapa River	2	0.025	0.025	0.025	0.025	0.000
Kumeu River	2	0.025	0.025	0.025	0.025	0.000
Lucas Creek	12	0.025	0.130	0.025	0.046	0.010
Mahurangi River (Forestry HQ)	2	0.025	0.025	0.025	0.025	0.000
Mahurangi River (Water Supply)	2	0.025	0.050	0.038	0.038	0.013
Makarau River	2	0.025	0.060	0.043	0.043	0.018
Matakana River	2	0.025	0.025	0.025	0.025	0.000
Ngakaroa Stream	2	0.025	0.025	0.025	0.025	0.000
Oakley Creek	12	0.025	0.610	0.075	0.144	0.051
Okura Creek	12	0.025	0.180	0.048	0.068	0.017
Omaru Creek	12	0.025	0.110	0.025	0.048	0.010
Opanuku Stream	2	0.025	0.050	0.038	0.038	0.013
Otaki Creek	12	0.025	0.250	0.025	0.058	0.020
Otara Creek (East Tamaki)	12	0.025	0.130	0.025	0.047	0.011
Otara Creek (Kennell Hill)	12	0.025	0.070	0.025	0.034	0.005
Oteha Stream	12	0.025	0.130	0.025	0.041	0.009
Pakuranga Creek (Botany Rd)	12	0.025	0.090	0.025	0.033	0.006
Pakuranga Creek (Greenmount Drive)	12	0.025	0.025	0.025	0.025	0.000
Papakura Stream	2	0.050	0.050	0.050	0.050	0.000
Puhinui Stream	12	0.025	0.180	0.100	0.093	0.013
Rangitopuni River (NIWA operated)	Not measured at this site					
Riverhead Forest Stream	2	0.025	0.025	0.025	0.025	0.000
Vaughan Stream	12	0.025	0.070	0.025	0.033	0.005
Wairoa River	2	0.025	0.280	0.153	0.153	0.128
Wairoa Tributary	2	0.025	0.025	0.025	0.025	0.000
Waitangi River	2	0.025	0.025	0.025	0.025	0.000
Waiwera River	2	0.025	0.025	0.025	0.025	0.000
West Hoe Stream	2	0.025	0.025	0.025	0.025	0.000
Whangamaire Stream	2	0.025	0.025	0.025	0.025	0.000

Table 25Total Lead ($\mu\text{g l}^{-1}$)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	2	0.07	0.10	0.09	0.09	0.02
Hoteo River (NIWA operated)	Not measured at this site					
Kaukapakapa River	2	0.16	0.22	0.19	0.19	0.03
Kumeu River	2	0.30	0.34	0.32	0.32	0.02
Lucas Creek	12	0.06	13.00	0.42	1.52	1.05
Mahurangi River (Forestry HQ)	2	0.17	0.21	0.19	0.19	0.02
Mahurangi River (Water Supply)	2	0.12	0.77	0.45	0.45	0.33
Makarau River	2	0.10	0.44	0.27	0.27	0.17
Matakana River	2	0.14	0.40	0.27	0.27	0.13
Ngakaroa Stream	2	0.03	0.10	0.06	0.06	0.04
Oakley Creek	12	0.55	3.20	0.66	0.86	0.21
Okura Creek	12	0.15	0.63	0.41	0.40	0.04
Omaru Creek	12	0.31	1.90	0.47	0.67	0.13
Opanuku Stream	2	0.16	0.20	0.18	0.18	0.02
Otaki Creek	12	0.39	2.00	1.04	1.06	0.16
Otara Creek (East Tamaki)	12	0.20	3.50	0.34	0.67	0.26
Otara Creek (Kennell Hill)	12	0.20	6.10	0.44	0.92	0.48
Oteha Stream	12	0.12	0.91	0.24	0.40	0.08
Pakuranga Creek (Botany Rd)	12	0.11	0.59	0.27	0.32	0.05
Pakuranga Creek (Greenmount Drive)	12	0.12	0.70	0.36	0.36	0.06
Papakura Stream	2	0.15	0.18	0.17	0.17	0.02
Puhinui Stream	12	0.37	2.70	0.63	0.79	0.18
Rangitopuni River (NIWA operated)	Not measured at this site					
Riverhead Forest Stream	2	0.13	0.15	0.14	0.14	0.01
Vaughan Stream	12	0.03	0.64	0.12	0.22	0.06
Wairoa River	2	0.22	0.35	0.29	0.29	0.07
Wairoa Tributary	2	0.06	0.10	0.08	0.08	0.02
Waitangi River	2	0.03	0.11	0.07	0.07	0.04
Waiwera River	2	0.59	0.91	0.75	0.75	0.16
West Hoe Stream	2	0.03	0.11	0.07	0.07	0.04
Whangamaire Stream	2	0.03	0.14	0.08	0.08	0.06

Table 26*Escherichia coli* (cfu/100ml)

Site	Count	Minimum	Maximum	Median	Mean	Standard error
Cascades Stream	11	5	270	40	73	23
Hoteo River (NIWA operated)	12	46	461	117	163	35
Kaukapakapa River	12	155	2600	410	880	270
Kumeu River	11	20	1191	340	423	93
Lucas Creek	12	64	850	210	300	65
Mahurangi River (Forestry HQ)	12	40	8400	320	1433	793
Mahurangi River (Water Supply)	12	91	3500	340	573	270
Makarau River	12	190	2200	605	705	156
Matakana River	12	100	710	187	279	59
Ngakaroa Stream	12	80	3800	245	576	296
Oakley Creek	12	460	3500	700	1004	239
Okura Creek	12	173	2300	505	679	167
Omaru Creek	12	150	9500	405	1329	767
Opanuku Stream	12	180	1070	445	439	72
Otaki Creek	12	360	5200	910	1624	422
Otara Creek (East Tamaki)	12	200	6300	850	1389	494
Otara Creek (Kennell Hill)	12	410	3800	790	1409	346
Oteha Stream	12	109	800	285	353	68
Pakuranga Creek (Botany Rd)	12	550	22000	1600	3517	1717
Pakuranga Creek (Greenmount Drive)	12	30	4300	430	753	329
Papakura Stream	12	560	49000	2550	8100	4191
Puhinui Stream	12	60	3900	285	608	304
Rangitopuni River (NIWA operated)	12	105	1203	165	265	87
Riverhead Forest Stream	12	20	2000	110	387	172
Vaughan Stream	12	118	8500	885	1709	676
Wairoa River	12	155	18000	445	1854	1468
Wairoa Tributary	12	10	410	58	120	35
Waitangi River	12	127	3700	460	751	283
Waiwera River	12	155	640	400	414	43
West Hoe Stream	12	10	420	35	83	34
Whangamaire Stream	12	173	3800	425	658	287

4.3 Water Quality Indices and classes

Using the methodology described in Appendix 1, water quality indices and classes were generated for each of the 31 sites (Table 27).

The Opanuku Stream had the best water quality in 2009. The Opanuku Stream, West Hoe Stream, Cascade Stream and Wairoa Tributary were the sites classified as having excellent water quality. Opanuku Stream and West Hoe Stream retained their excellent quality class from 2008, Cascades Stream improved from good in 2008 and Wairoa Tributary is a new site in 2009.

The Puhinui Stream had the worst water quality of the monitoring sites in 2009, with exceedances of the target levels common and often of high magnitudes.

There are 17 sites that changed quality class from 2008 to 2009, which reflects the variable nature of water quality data. However, of these 17, five sites changed by two classes. The change in water quality class at Vaughan Stream (from good to poor) and Hoteo River (from poor to good) reversed the changes in quality class observed from 2007 to 2008. The other sites to show a large change in water quality class were the Otara Creek (both the East Tamaki and Kennell Hill sites) and the Kumeu River; these sites all showed an improvement from poor to good. Such large changes in water quality class are unexpected and these sites should be monitored closely to determine the nature of these water quality changes.

Table 27 indicates that urban sites were typically ranked lower in 2008. To allow the relationship between catchment land cover and water quality to be described in more detail, the mean indices were calculated for all sites within each of the four land use types used in the monitoring programme (Table 28). The native forest sites had the best water quality indices in 2009, with the urban sites having the worst water quality indices, but the same quality class as rural sites (fair). The sites with rural and exotic forest catchments typically had water quality indices intermediate between native forest and urban sites, with the exotic forest site classified as having good water quality and rural sites as having fair water quality.

Table 27

Site based water quality indices and classes based on 2009 data (2008 water quality class is provided for comparison (Neale, 2010))

Rank	Site	Scope	Frequency	Magnitude	Water quality index	2009 water quality class	2008 water quality class
1	Opanuku Stream	0.0	0.0	0.0	100.0	Excellent	Excellent
2	West Hoe Stream	14.3	1.2	0.3	91.7	Excellent	Excellent
3	Cascades Stream	14.3	1.3	0.5	91.7	Excellent	Good
4	Wairoa Tributary	14.3	1.3	1.1	91.7	Excellent	New site
5	Waiwera River	28.6	2.6	0.8	83.4	Good	Fair
6	Makarau River	28.6	2.6	2.0	83.4	Good	New site
7	Hoteo River	28.6	3.6	0.2	83.4	Good	Poor
8	Riverhead Forest Stream	28.6	3.8	0.5	83.4	Good	New site
9	Otara Creek (East Tamaki)	28.6	4.9	0.9	83.3	Good	Poor
10	Rangitopuni River	28.6	7.1	1.5	83.0	Good	Fair
11	Matakana River	42.9	3.8	0.3	75.2	Good	Fair
12	Kumeu River	42.9	4.2	0.6	75.1	Good	Poor
13	Lucas Creek	42.9	5.0	1.5	75.1	Good	Fair
14	Otara Creek (Kennell Hill)	42.9	6.2	2.1	75.0	Good	Poor
15	Mahurangi River (Forestry HQ)	42.9	6.4	1.5	75.0	Good	Good
16	Mahurangi River (Water Supply)	57.1	6.4	2.3	66.8	Fair	Good
17	Waitangi River	57.1	16.7	9.8	65.2	Fair	New site
18	Ngakaroa Stream	57.1	22.7	20.1	62.7	Fair	Good
19	Pakuranga Creek (Greenmount Dr)	57.1	30.9	32.0	58.2	Fair	Poor
20	Oteha Stream	71.4	12.0	5.7	58.0	Fair	Poor
21	Kaukapakapa River	71.4	12.8	4.3	58.0	Fair	New site
22	Omaru at Maybury	71.4	11.1	9.6	57.9	Fair	Poor
23	Wairoa River	71.4	9.0	15.4	57.5	Fair	Fair
24	Oakley Creek	71.4	23.1	6.7	56.5	Fair	Fair
25	Papakura Stream	71.4	16.7	22.4	55.7	Fair	Fair
26	Vaughan Stream	85.7	14.5	5.4	49.7	Poor	Good
27	Okura Creek	85.7	15.7	10.0	49.4	Poor	Fair
28	Otaki Creek	85.7	21.0	7.9	48.8	Poor	Poor
29	Pakuranga Ck Botany	85.7	24.7	5.9	48.4	Poor	Poor
30	Whangamaire Stream	71.4	20.8	60.2	44.7	Poor	New site
31	Puhinui Stream	100.0	21.8	11.2	40.6	Poor	Fair

Table 28

Mean water quality index scores and water quality class for all sites within a catchment land cover type

Land cover (number of sites)	Scope	Frequency	Magnitude	Water quality index	Water quality class
Native forest (3)	14.3	1.3	0.7	91.7	Excellent
Exotic forest (2)	35.7	5.1	1.0	79.2	Good
Rural (13)	51.8	9.9	9.7	68.3	Fair
Urban (11)	65.7	16.1	8.3	60.2	Fair

5 Acknowledgements

The ARC river water quality monitoring has benefitted from the efforts of numerous ARC staff since its inception in 1977.

During 2009, Ross Winterbourn, Mike McMurtry, Peter Williams, Kylie Park, Simon Tredgett, Peter Hancock, Kris Fordham, Matt Hope and Clive Coleman contributed to sample collection and data management. Laboratory analyses were carried out by Watercare Laboratory Services Ltd.

The data from the Rangitopuni River and Hoteo River sites are used under licence from NIWA.

6 Appendix 1

The communication of water quality data is often hampered by the volume of results and the complexity of the information. In this report, a water quality index developed by the Canadian Council of Ministers for the Environment (CCME) (2001) was applied to the river water quality data collected by the ARC to enable improved understanding and communication of the work.

The CCME approach uses water quality results to produce four water quality indices, and these indices can be used to assign a water quality class to each monitoring site. The four indices are;

- Scope – This represents the percentage of parameters that failed to meet the objective at least once during the time period under consideration (the lower this index, the better).
- Frequency – This represents the percentage of all individual tests that failed to meet the objective during the time period under consideration (the lower this index, the better).
- Magnitude – This represents the amount by which failed tests exceeded the objective (the lower this index, the better). This is based on the collective amount by which individual tests are out of compliance with the objectives and is scaled to be between 1 and 100. This is the most complex part of the index derivation and the reader is referred to CCME (2001) for full details.
- WQI – This represents an overall water quality index based on a combination of the three indices described above. It is calculated thus;

$$WQI = 100 - \left[\left\{ \sqrt{(Scope^2 + Frequency^2 + Magnitude^2)} \right\} \div 1.732 \right]$$

The divisor 1.732 normalises the resultant values to a range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality.

The WQI index is used by ARC to assign a water quality class to each site using the following ranges;

- Greater than 90 = excellent water quality
- Between 70 and 90 = good water quality
- Between 50 and 70 = fair water quality
- Lower than 50 – poor water quality

The above indices are calculated for each site based on seven water quality parameters (Table 29). The objectives against which the ARC water quality data are tested (Table 29) are derived from the ranges observed at the two ARC reference sites (Cascades Stream and West Hoe Stream) over the five year preceding this report (2004 to 2008). This represents a change from the 2007 and 2008 reports. It was considered thresholds based on a fixed period (2002 to 2006), whilst providing consistency, would not capture longer term trends in water quality, nor account for improvements in the measurement of parameters (for example, improved meter performance or improvements in detection limits).

The ranges at these reference sites were used as this represents the best achievable water quality in the Auckland region. Therefore, the index represents the deviation from “natural” conditions in the Auckland region, rather than indicating whether the water quality is suitable for a particular purpose.

Table 29

The seven water quality parameters, and their objectives, used to produce the water quality indices.

Parameter	Objective (acceptable if)
Dissolved oxygen (% saturation)	Between 70 and 140%
pH	Between 6.2 and 8.2
Turbidity	Less than 30 NTU
Ammoniacal nitrogen	Less than 0.065 mg N l ⁻¹
Temperature	Less than 21 °C
Total phosphorus	Less than 0.072 mg P l ⁻¹
Total nitrogen	Less than 1.4 mg N l ⁻¹

7 References

- APHA. 2005. *Standard methods for the examination of water and wastewater (21st Edition)*. American Public Health Association.
- ARC. 1982. *Baseline data on water quality in the Auckland Water Region obtained from 1977-1982*. Auckland Regional Water Board Technical Publication 22.
- ARC. 1992. *Tamaki Catchment and Estuary: Review of Water Quality*. Auckland Regional Council Technical Publication 20.
- ARC. 2007. *State of the Environment Monitoring: Rivers & Streams Water Quality Data Report 2005*. Auckland Regional Council Technical Publication 327.
- ARC. 2008. *State of the Environment Monitoring: Rivers & Streams Water Quality Data Report 2006*. Auckland Regional Council Technical Publication 342.
- Canadian Council of Ministers of the Environment. 2001. Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0, User's Manual. In. *Canadian environmental quality guidelines*, 1999, Canadian Council of Ministers of the Environment, Winnipeg.
- Chapman, D. (Ed). 1996. *Water Quality Assessments; a guide to the use of biota, sediments and water in environmental monitoring (2nd Edition)*. E & FN Spon, London.
- Neale, M.W. 2009. *State of the Environment Monitoring: River Water Quality Annual Report 2007*. Auckland Regional Council Technical Report 2009/102.
- Neale, M.W. 2010. *State of the Environment Monitoring: River Water Quality Annual Report 2008*. Auckland Regional Council Technical Report 2010/016.
- Scarsbrook, M. 2007. *River Water Quality; state and trends in the Auckland region*. Auckland Regional Council Technical Publication 336.
- Snelder, T., Biggs, B. & Weatherhead, M. 2004 *New Zealand River Environment Classification User Guide*. Ministry for the Environment, Wellington.
- Snelder, T., Scarsbrook, M. & Larned, S. 2006. Assessment of the national pool of river water quality monitoring sites using the River Environment Classification. Ministry for the Environment, Wellington.
- Storey, R. & Wadhwa, S. 2009. *An assessment of the lengths of permanent, intermittent and ephemeral streams in the Auckland region*. Auckland Regional Council Technical Report 2009/028.