Auckland
Regional Council
TE RAUHITANGA TAIAO

Marine Receiving Environment Stormwater Contaminants: Status Report 2007

June 2007 TP333

Auckland Regional Council
Technical Publication No. 333, 2007
ISSN 1175-205X
ISBN -13 : 978-1-877416-71-2
ISBN -10 : 1-877416-71-1
Printed on recycled paper

Marine Receiving Environment Stormwater Contaminants: Status Report 2007

Prepared by: S. Kelly

Peer reviewed by:
Geoff Mills

Date: June 2007

Peer reviewed by:
Megan Stewart

Date: June 2007

Approved for release by:
Grant Barnes

Date: June 2007

Acknowledgements

Samples were collected by the ARC, Geoff Mills (Diffuse Sources Ltd.), and Kingett Mitchell Ltd. Sample processing was carried out by, Geoff Mills (Diffuse Sources Ltd.) NIWA and Hill Laboratories Ltd. Metal analyses were conducted by Hill Laboratories Ltd. NIWA processed all of the ecological samples.

Recommended Citation:

Kelly, S. (2007). Marine Receiving Environment Stormwater Contaminants: Status Report 2007. Auckland Regional Council Technical Publication Number 333.

Contents

1 Executive Summary

The Auckland Regional Council has been monitoring the regional effects of urban stormwater discharges at 72 sites since 2002. The contaminants monitored are concentrations of copper, lead, zinc, and where required, polycyclic aromatic hydrocarbon (PAH) in estuary sediments. Individual sites are monitored at 2 or 5 year intervals, depending on the concentrations of these key contaminants.

Highest concentrations of copper, lead and zinc were obtained from estuary sites adjoining the older urban catchments of Waitakere, Auckland, and Manukau Cities, i.e. Henderson Creek to Coxs Bay along the southern shores of the Waitemata Harbour, upper reaches and side-branches of Tamaki Estuary, and Mangere Inlet. State of the environment (SoE) monitoring indicates that the quality of the worst sites is continuing to degrade rapidly, with the concentrations of copper and zinc increasing fastest. Lead concentrations were more variable over time, reflecting the removal of the major source of lead from urban catchments, i.e. leaded petrol.

With the exception of Mangere Inlet, the concentrations of copper, lead and zinc were below threshold effect levels (i.e. TEL sediment quality guideline values) in the Manukau Harbour, and Orewa and Weiti estuaries. The concentrations of copper and zinc at most SoE monitoring sites in the Manukau Harbour (excluding Mangere Inlet) are relatively stable or slowly increasing. The exception is Pahurehure (Papakura) where zinc increased by 27% between 1998 and 2005. Zinc concentrations at the Weiti monitoring site also increased by 30% between 1998 and 2005. The monitoring record for Orewa is not long enough to evaluate contaminant trends in this estuary.

Copper concentrations were slightly above TEL values at a number of upper Waitemata Harbour sites. However, with the exception of Hellyers Creek, lead and zinc concentrations were below TEL values. However, zinc concentrations are increasing rapidly in Lucas Creek and are likely to exceed TEL values in the near future.

A strong relationship was apparent between copper, lead and zinc concentrations and benthic community structure, indicating that current levels of contamination (or a covariate of copper, lead and zinc) are affecting the ecological function of urban estuaries. In general, the spatial pattern of ecological condition reflected levels of contamination. However, several sites in the upper Waitemata Harbour and south-eastern Manukau Harbour were noteworthy because the condition of their benthic communities was poor relative to the concentrations of copper, lead and zinc at each site. Further investigations may be required to determine the reason(s) for this anomaly.

2 Introduction

The ARC regularly measures contaminant levels at 72 coastal sites subject to urban stormwater runoff. The sites are spread across the region, and have been carefully located to provide a measure of contaminants from diffuse stormwater inputs rather than individual point sources. The purpose of this monitoring is to:

- provide site-specific information on the quality of the urban marine receiving environment and the effects of stormwater runoff;
- assist in the analysis of options for managing urban stormwater quality;
- measure the performance of management initiatives aimed at improving urban stormwater quality and the efficacy of regional stormwater policy and network consent conditions;

In the Auckland Region stormwater quality is managed under a best practical option (BPO) framework. According to this approach, stormwater network operators are required to assess the environmental effects of their discharges and identify the "best practical option" (BPO) for managing those effects. The BPO must take into account: the nature of the discharge and sensitivity of the receiving environment; the financial implications and effects on the environment of alternative options; and the state of technical knowledge and likelihood of success.

A previous report on the status of the marine environment (Williamson and Kelly 2003) compared contaminant concentrations against a three tiered (green, amber, red) system of environmental response criteria (ERC) developed by the ARC (see Appendix 1). The ARC are currently reviewing the use of ERC, and are considering adopting the international sediment quality guideline values produced by Florida Department of Environmental Protection (MacDonald et al. 1996) - Threshold Effects Levels (TELs) and Probable Effects Levels (PELs). Both the ARC and Florida quality rankings are included in this report. Note that the red ERC values for copper, lead and zinc are based on the rounded Effects Range Low (ERL) guideline values of Long and Morgan (1990) and Long et al (1995). Therefore, in this report, the red ERC and ERL are used interchangeably.

The Florida TEL and PEL guideline values were derived from toxicological studies that showed either an effect or no-effect on the test organisms. In most cases the effects/no-effects guideline values tend to be more conservative (i.e. protective) than guideline values based on effects data alone. This is consistent with the ARC's approach of using the guidelines as an early warning of environmental degradation, which allows time for investigations into the causes of contamination to be carried out and options for limiting the extent of degradation to be developed.

Stormwater network operators are encouraged to maintain contaminant concentrations below TEL levels for as long as practicable. If TEL values are exceeded, an ecological

evaluation is carried out. Additional testing may be carried out if discrepancies between the concentrations of the three key metals and ecological condition are observed (i.e. ecological condition is worse than expected given the concentrations of copper, lead and zinc). This may include toxicological testing and the measurement of acid volatile sulphides (AVS), high molecular weight polycyclic aromatic hydrocarbons (HMW-PAH), and/or organochlorines.

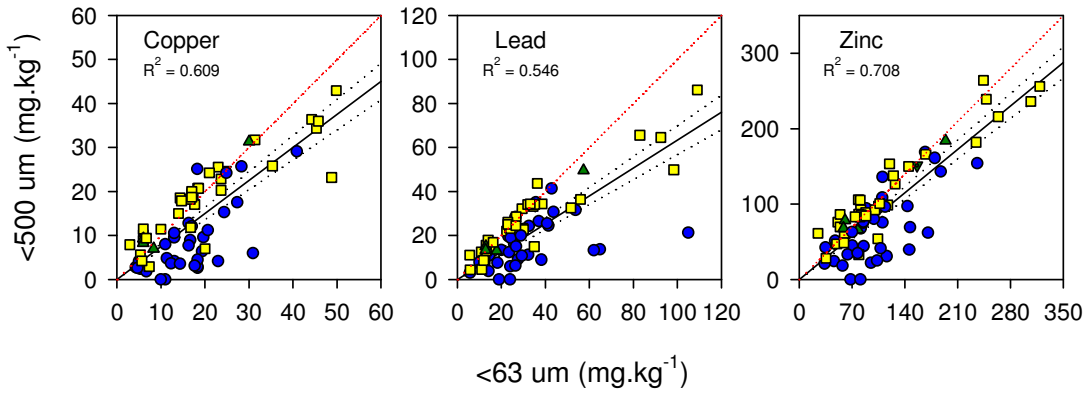
Two types of analyses are carried out for metals. Weak acid digestion of the less than 63 μm sediment fraction provides an estimate of what is nominally considered to be the bioavailable metal concentration. Strong acid digestion of the less than 500 μm sediment fraction provides an estimate of total metal concentrations, which includes metals that were tightly bound to the sediment matrix and therefore biologically unavailable. A strong linear relationship was apparent between the concentrations of bioavailable and total metals, but bioavailable concentrations tend to be slightly higher than total metals (reflecting the strong influence of available surface area (Figure 2.1).

For the purpose of stormwater contaminant monitoring, Auckland's urban marine area has been divided into two types of receiving environments: settling zones and outer zones. Settling zones are areas where most sediment (nominally 75%) and associated contaminants settle out of suspension and become incorporated into bed sediments. Consequently, settling zones are muddy locations, prone to the accumulation of sediment and associated urban stormwater contaminants. Some level of degradation is inevitable in urban settling zones.

Outer zones are wider estuarine or harbour areas either downstream of the settling zone or located in higher energy environments where contaminants are less likely to settle permanently. Outer zones tend to have a more diverse range of organisms than settling zones, and the organisms that live within outer zones are generally considered to be more sensitive.

Sediment quality guidelines are usually compared against total metal concentrations. However, in recognition of differences in habitat quality, ecological value and sensitivity, and physico-chemical characteristics of settling and outer zones, the ARC compares both bioavailable and total metal concentrations against guideline values. For settling zones, guideline values are compared against total metal concentrations obtained by strong acid digestion of the total (<500 μm) sediment fraction. A more protective approach is applied to outer zones, with the guideline values being compared against the greater of: bioavailable, or total metal concentrations. Further information on the rationale for the comparing guideline values against both metal concentrations is contained in Williamson and Kelly (2003) and Anderson et al. (2006).

Figure 2.1: Relationship between metal concentrations obtained from the <63 µm sediment fraction using weak acid digestion (nominally bioavailable metals) and the <500 µm sediment fraction using strong acid digestion (nominally total metals). Linear, least squares regressions with 95% confidence limits are fitted and a 1:1 reference line is provided (red dotted line). Data points are outer zones (blue circles), inner zones (yellow squares) and deposition zones (green triangles).



3 Sampling Methods and Frequency

The stormwater contaminant monitoring programme currently monitors sediment quality at 72 sites spread throughout urban areas of the Auckland Region (Figure 3.1, Appendix 2). The sites have been specifically located to provide a measure of contaminants from diffuse stormwater inputs rather than individual point sources. The location of each site has been recorded on GPS and most are marked with permanent pegs.

Twenty-one of the 72 stormwater contaminant monitoring sites are also included in the ARC's Sediment Contaminant State of the Environment (SoE) Monitoring Programme. That programme is tracks long-term changes in a broader range of contaminants than considered here. Further details on the Sediment Contaminant SoE Monitoring Program are provided in McHugh and Reed (2006).

3.1 Contaminants

Contaminant samples were collected from a rectangular patch within the site, generally running 50 m parallel and 20 m perpendicular to the estuary channel. However, slight variations on this arrangement may have occurred at some sites, depending on the extent of intertidal flats.

On each occasion, three sediment samples were collected from each site using the protocols described in Williamson and Kelly (2003). Briefly, each sample consisted of a composite of ten sub-samples collected from the long-shore margins of the sampling patch. Sub-samples are collected with a polyethylene scoop taken from the top 2 cm of sediments (i.e. recently deposited, surficial sediments). In terms of detecting trends, 2 cm is a compromise between shallower depths that might be biased by recent events and greater depths where recent changes in metal concentrations are diluted by cleaner sediments laid down many years before.

The frequency of sampling is either 2 yearly or 5 yearly, depending on contaminant concentrations. Sites with concentrations of copper, lead and zinc, below TEL levels are monitored for contaminants at 5 yearly intervals. Sites with copper, lead and zinc above TEL levels are monitored for contaminants and benthic ecology at 2 yearly intervals. Sampling is spread across a number of years, with approximately half of the sites with contaminant levels above TEL levels being sampled in one year and half in the next. Sampling of sites with contaminant levels below TEL levels is spread across a five year sampling period (see Appendix 2).

3.1.1 Contaminant Sample Processing

Metal concentrations were obtained from the <500 μm sediment fraction using strong acid digestion and the < 63 μm fraction using weak acid digestion. Slightly different

methods of extraction were used for samples from the State of the Environment Monitoring (SoE) sites, which are also used in this programme. NIWA extracted metals from SoE samples, whereas Hill Laboratories extracted metals from the remaining samples. Differences in metal concentrations obtained using the two extraction methods are considered to be minor, but NIWA's method of preparing <500 µm samples is probably better than Hill Laboratories, because freeze drying and sieving means there is no risk of crushing up larger debris (especially shell hash) which might lower metal concentrations. Details of the extraction methods and subsequent analyses are provided below. All of the analyses were done by Hill Laboratories.

3.1.1.1 State of the Environment samples: extraction by NIWA

Sediment samples for weak-acid extraction were prepared by wet-sieving approximately 60 mL of sample through a 63 µm plastic mesh with 300 mL of deionised water. The filtrate was centrifuged at 3000 rpm for 20 minutes before the supernatant liquid was decanted. Approximately 2.5 g of sediment residue was placed in 50 mL polypropylene centrifuge tubes. Separate samples were dried at 60 °C overnight for moisture-content determination. To each tube 40 mL of 2M HCl was added to extract the reactive fraction of metals. The tubes were placed on their sides on a shaking table at 100 rpm for 24 hours. Samples were then centrifuged at 3000 rpm for 15 minutes and the supernatant was decanted into new tubes for analysis by Hill Laboratories, as described below.

Sediment samples for hot acid digestion were freeze-dried and sieved through 500 µm mesh. Composite samples of approximately 1g were prepared from the 3 replicates of each site. These were digested for 3 hours at 100 °C in 10 mL of 3:1 HCl:HNO_3. A further 5 mL of concentrated HNO_3 was added to each tube and the digestions continued for another hour (or until the digests cleared and the remaining grains appeared clean). The samples were then cooled, diluted to 50 mL and centrifuged at 2500 rpm for 10 minutes to remove the remaining debris. The extracts were decanted into clean tubes and analysed by Hill Laboratories, as described below.

Quality assurance is provided by including archived samples, which have been repeatedly tested for metal concentrations, with each batch of samples analysed (see McHugh and Reed 2006).

3.1.1.2 Stormwater contaminant monitoring programme samples: extraction and analysis by Hill Laboratories

The sediment samples for the total recoverable digestion are dried in a 35°C oven overnight (minimum of 4 hours). Once dried, the samples are gently ground and sieved through a 500µm sieve. A worksheet of 48 samples was prepared that includes 2 procedural blanks, in-house QC samples at the start and end of each run, a Standard Reference Material (SRM) QC, a random sample digested in duplicate, and a routine repeat sample. 1.0g of each sample was weighed into a polypropylene graduated vial. 14mL of an acid solution (1:1:5 nitric acid: hydrochloric acid: type 1 water) was added to

each sample and a lid secured firmly on top. The samples were digested at 120°C on a block, to achieve a temperature of 95°C in the closed vial, for 50 minutes. The samples were removed from the block and left to cool for 5 minutes at room temperature before being placed in a cold water bath (for about 15-20 minutes) until the contents were at room temperature. Once cool, the samples were diluted to 20mL, then inverted or vortexed to ensure complete mixing. Following this they were centrifuged at 1500 rpm for 10 minutes to separate the insoluble material from the soluble. Due to the long, skinny nature of the vials used there was no need to decant. Samples were then diluted 10-fold with 1% HNO3 by an automated diluter, into clean polystyrene tubes and analysed for trace level copper, lead and zinc by Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS). The concentrations for metals were reported on as $mg.kg^{-1}$ on a dry weight basis.

The <63μm fraction samples were prepared by sieving approximately 50g of a wet, thoroughly mixed, portion of sample through a 63μm nylon mesh into a plastic pan, with 50mL of type 1 water. The plastic pan and sieve apparatus were shaken on an orbital shaker for 5 minutes at 150rpm. A further 50mL of type 1 water was added and again shaken for 5 minutes. A final 50mL of type 1 water was added and the samples shaken for a further 5 minutes. The plastic pan was removed from the bottom of the sieve and placed in a 35°C oven for at least 2 days until all free water had evaporated leaving the dried sample. The dried samples were ground with a pestle in the plastic container to break up any clumps and ensure the sample was as homogeneous as possible. 0.5g of each dried <63μm sample was weighed into a 50mL polycarbonate centrifuge vial. 2 blanks were run with each batch of samples, these contained the extraction fluid only. Also included with each batch of samples was a sample extracted in duplicate, an in house QC, a SRM QC and a spiked sample. To each vial, including blanks 25mL of 2M HCl was added. To the sample to be spiked, 0.2mL of an in-house multi-element solution is added. This contains As, Cd, Cr, Cu, Fe, Ni, Pb, and Zn. The samples were extracted for 24 hours at 30 rpm in an end-over-end shaker. Following extraction the samples were centrifuged for 10 minutes at 2000rpm. The extracts were diluted 20-fold with 1% HNO3 by an automated diluter into clean polystyrene tubes. The samples are analysed for copper, lead and zinc by ICP-MS. The reported concentrations for metals are reported as $mg.kg^{-1}$ on a dry weight basis.

Blind duplicate quality assurance samples are included to check the precision of the lab analysis. In 2004 and 2005, these provided "within batch" precision assessments. In 2006, archived samples from 2004 were also included as "between batch" blind duplicates to check analysis precision over time.

3.1.2 Statistical Analyses

Contaminant data were tested for statistically significant trends (95% C.I.) by conducting linear regressions between the sampling date and metal concentration for each site. The linear equations from these analyses also provided a measure of copper, lead and zinc accumulation rates.

3.2 Ecology

Ecological samples were collected from the sites with contaminant levels greater than TEL concentrations in October of each sampling year. The size of the sampling plot varied depending on the space available on the intertidal flats: ranging from 1,000 m^2 (20 m x 50 m) to 10,000 m^2 (100 m x 100 m). Ten, core samples (13 cm diameter x 15 cm deep) were collected from stratified random positions in each site. Stratification was used to avoid clumping of random samples.

3.2.1 Ecological sample processing

Ecological samples were sieved through a 0.5 mm mesh and preserved in isopropanol (70% v/v). Sample sorting and taxonomic identification was carried out by NIWA Hamilton, with taxa being identified and enumerated to the lowest taxonomic level practical.

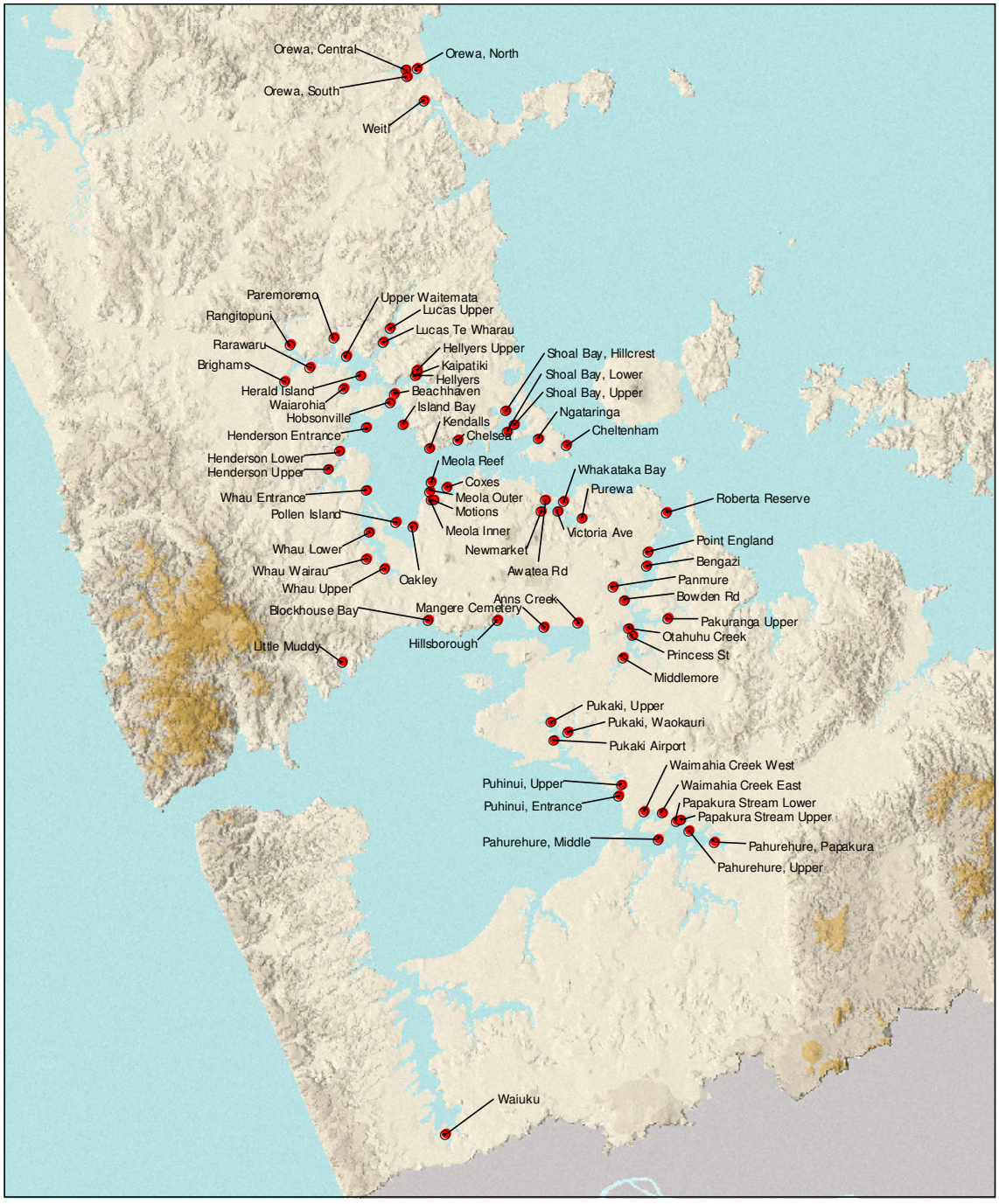
3.2.2 Ecological analysis

Full details of the ecological analyses are provided in Anderson et al. (2006). Briefly, ecological effects are assessed against a regional index of ecological condition, which was derived from a study of the ecology, contaminant concentrations and physical characteristics of 84 sites spread throughout the Auckland region (Anderson et al. 2006). The multivariate analysis technique, canonical analysis of principle coordinates (or CAP), forms the basis for this analysis, which ranks the health of benthic communities from 1 (= healthy) to 5 (= degraded). The contamination values used in the analyses were derived from the combined (using principal component analysis (PCA)) concentrations of copper, lead and zinc.

The index used to rank benthic health varies according to sediment texture and exposure:

- Samples collected from sheltered areas with predominantly fine sediments (nominally settling zones) are ranked using an index obtained from the relationship between benthic communities and total contaminant concentrations from the <500 μm sediment fraction.
- Samples collected from relatively exposed areas with predominantly coarse sediments (nominally outer zones) are scored using 1) an index derived from the relationship between benthic communities and total contaminant concentrations from the <500 μm sediment fraction, and 2) an index derived from the relationship between benthic communities and "bioavailable" contaminant concentrations from the <63 μm sediment fraction. The benthic health ranking for the site is taken as the larger (i.e. worst) of these two scores.

Figure 3.1: Location of stormwater contaminant monitoring sites.



4 Results

4.1 Contaminant Overview

The greatest proportion of sites with copper, lead and/or zinc concentrations above TEL values are adjacent to Auckland City Council (ACC) catchments (Figure 4.1). Twenty of the 29 sites receiving stormwater runoff from ACC catchments had concentrations of at least one metal above TEL values (i.e. 69 % of sites). Two ACC sites have zinc concentrations in the <63 µm sediment fractions that exceed PEL concentrations. In contrast:

- Rodney had 3 sites that exceeded TEL values out of the 8 sites monitored (38%);
- NSCC had 7 sites that exceeded TEL values out of the 15 sites monitored (46%);
- Waitakere had 7 sites that exceeded TEL values out of the 13 sites monitored (47%);
- Manukau had 2 sites that exceeded TEL values out of the 11 sites monitored (18%);
- Papakura had no sites that exceeded TEL values out of the 5 sites monitored;
- Franklin has a single monitoring site, which was below TEL values (Table 4-1).

Note, that some sites are subject to runoff from more than one territorial authority hence the sum of sites given above is greater than 72.

Table 4-1 and Figure 4.2 to Figure 4.7 compare copper, lead and zinc concentrations against international guideline values for each stormwater contaminant monitoring site, grouped by local council. Key points of note are:

Rodney District Council (RDC): Lead and zinc concentrations were below sediment quality guidelines in all sites associated with RDC. Copper concentrations were above TEL values in Paremoremo, Brighams and Rangitopuni inlets in the upper Waitemata Harbour.

North Shore City Council (NSCC): Copper, lead and zinc concentrations exceeded TEL values in Hellyers Creek (which includes the Kaipatiki side branch). Copper concentrations were slightly above TEL values in Lucas Creek and Paremoremo. Both copper and lead concentrations fluctuated around TEL values in parts of Shoal Bay (Hillcrest) and in the fine sediment fraction at Island Bay.

Waitakere City Council (WCC): Copper, lead and zinc concentrations were below TEL values in all Upper Waitemata Harbour sites adjoining Waitakere catchments. All three metals were elevated above TEL values in Henderson Creek, with zinc concentrations exceeding ERL values at the Upper Henderson site. Whau estuary has some of the

highest metal concentrations in the region, with all three metals exceeding ERL values, and zinc approaching PEL values at the upper Whau site.

Auckland City Council (ACC): Marine receiving environments adjoining ACC catchments are among the most contaminated in the region. High concentrations of all three metals were recorded in all of the southern Waitemata Harbour settling zones monitored between Whau Estuary and Coxs Bay. One or more of the key metals also exceeded TEL values in either the <500 μm or <63 μm sediment fraction at all of the Hobson Bay, inner Tamaki (upstream from Panmure) and Mangere Inlet sites. Sediment quality was reasonably good at the outer Tamaki sites, and sites in outer parts of Meola reef.

Manukau City Council (MCC): MCC sites in the upper Tamaki (upper Pakuranga and Middlemore) had high concentrations of all three metals. Zinc concentrations in the <63 μm sediment fraction were particularly high at the upper Pakuranga site where they exceeded PEL values. Metal concentrations at all of the MCC Manukau Harbour sites were below TEL concentrations.

Papakura (PDC) and Franklin District Councils (FDC): All sites associated with PDC and FDC had metal contaminant concentrations below TEL values.

Table 4-1: Most recent estimates of copper (Cu), lead (Pb), and zinc (Zn) concentrations in the total (<500 µm) and fine (<63 µm) sediment fractions of stormwater contaminant monitoring sites. Metals in the <500 µm sediment fraction were extracted using strong acid digestion, while metals in the <63 µm fraction were extracted using weak acid digestion. The year of sampling, type of zone, and adjacent local authority are indicated for each site (OZ = outer zone, DZ = deposition zone, SZ = settling zone). Colours related to the ERC categories previously used by the ARC, with the addition of blue for concentrations above the PEL (Green = <TEL, Amber = TEL to ERL, Red = ERL to PEL, Blue = >PEL). Sites that are also included in the ARC's State of the Environment Monitoring Programme (SoE) are indicated with a tick.

Name	Total	Zone	SoE Site	Rodney	North Shore	Waitakere	Auckland	Manukau	Papakura	Franklin	<500 Cu	<500 Pb	<500 Zn	<63 Cu	<63 Pb	<63 Zn
Orewa-Orewa, North	2002	SZ									2.9	4.6	32.9	7.3	11.2	79.0
Orewa-Orewa, Central	2002	OZ									2.6	3.0	21.0	4.7	5.8	33.7
Orewa-Orewa, South	2002	SZ									4.2	4.4	28.1	5.7	5.9	35.3
Weiti-Weiti	2005	SZ	✓								11.8	8.7	48.7	16.8	12.0	59.3
East Coast Bays-Cheltenham	2005	OZ	✓								2.8	10.9	42.4	4.3	14.5	34.7
Waitemata-Ngataringa	2002	OZ									8.0	20.0	63.0	11.0	29.0	70.0
Waitemata-Shoal Bay, Lower	2005	OZ									3.6	9.2	34.9	14.3	27.6	77.3
Waitemata-Shoal Bay, Upper	2004	OZ									4.5	10.8	41.1	18.3	29.3	108.0
Waitemata-Shoal Bay, Hillcrest	2004	SZ									17.9	34.3	100.5	14.7	33.2	106.7
Waitemata-Chelsea	2004	OZ									4.8	12.3	44.7	11.3	23.6	70.3
Waitemata-Beachhaven	2002	SZ									18.5	32.2	105.3	14.3	29.4	80.7
Waitemata-Kendalls	2004	OZ									3.6	7.5	33.0	12.3	18.2	64.0
Waitemata-Island Bay	2002	SZ									7.0	15.0	54.0	20.0	35.0	104.0
Waitemata-Kaipatiki	2005	SZ	✓								24.2	34.1	137.7	21.0	35.2	124.7
Waitemata-Hellyers	2005	OZ									15.3	24.5	96.9	24.4	41.5	143.5
Waitemata-Hellyers Upper	2005	SZ									17.0	23.3	97.1	17.7	29.8	105.0
Waitemata-Lucas Te Wharau	2004	SZ									20.7	28.5	92.4	18.3	26.8	100.3
Waitemata-Lucas Upper	2005	SZ	✓								20.3	22.7	98.8	23.7	30.1	117.3
Waitemata-Paremoremo	2005	SZ	✓								20.7	23.5	86.6	18.5	23.8	78.9
Waitemata-Upper Waitemata	2002	SZ									15.0	25.0	83.0	14.0	23.0	74.0
Waitemata-Brighams	2005	SZ									19.5	22.0	88.9	17.0	22.4	88.0
Waitemata-Rangitopuni	2002	SZ									20.0	26.0	86.0	17.0	23.0	82.0
Waitemata-Rarawaru	2005	SZ									18.2	23.2	82.7	16.7	24.1	80.3
Waitemata-Herald Island	2005	OZ									7.7	15.1	75.3	16.3	26.7	84.7
Waitemata-Waiarohia	2005	SZ									18.7	24.5	84.3	17.0	26.6	88.3
Waitemata-Hobsonville	2005	OZ									2.6	5.9	21.8	18.3	24.1	95.0
Waitemata-Henderson Entrance	2004	OZ									6.4	18.9	69.1	19.3	24.3	147.0
Waitemata-Henderson Lower	2004	SZ									25.5	34.1	126.7	23.0	32.1	127.3

Table 4.1 cont.: Most recent estimates of copper (Cu), lead (Pb), and zinc (Zn) concentrations in the total (<500 μm) and fine (<63 μm) sediment fractions of stormwater contaminant monitoring sites. Metals in the <500 μm sediment fraction were extracted using strong acid digestion, while metals in the <63 μm fraction were extracted using weak acid digestion. The year of sampling, type of zone, and adjacent local authority are indicated for each site (OZ = outer zone, DZ = deposition zone, SZ = settling zone). Colours related to the ERC categories previously used by the ARC, with the addition of blue for concentrations above the PEL (Green = <TEL, Amber = TEL to ERL, Red = ERL to PEL, Blue = >PEL). Sites that are also included in the ARC's State of the Environment Monitoring Programme (SoE) are indicated with a tick.

Name	Total	Zone	SoE Site	Rodney	North Shore	Waitakere	Auckland	Manukau	Papakura	Franklin	<500 Cu	<500 Pb	<500 Zn	<63 Cu	<63 Pb	<63 Zn
Waitemata-Henderson Upper	2005	SZ	✓								31.7	34.3	166.0	31.4	38.6	167.6
Waitemata-Whau Entrance	2004	OZ									3.1	6.3	24.9	17.7	26.5	103.3
Waitemata-Whau Lower	2005	OZ	✓								24.2	41.3	161.0	24.8	42.9	179.7
Waitemata-Whau Wairau	2005	SZ	✓								42.9	64.6	216.0	49.8	92.5	263.8
Waitemata-Whau Upper	2005	SZ	✓								36.0	65.6	256.0	45.8	83.0	318.9
Waitemata-Pollen Island	2005	OZ									10.5	21.3	76.2	13.0	27.1	85.0
Waitemata-Oakley	2005	DZ	✓								31.3	49.6	184.0	30.0	57.4	193.8
Waitemata-Meola Outer	2004	OZ									2.9	9.0	30.7	18.3	38.3	116.0
Waitemata-Meola Reef	2005	OZ	✓								11.2	25.5	96.4	20.7	40.8	113.8
Waitemata-Meola Inner	2005	SZ	✓								23.2	49.9	239.0	48.8	98.4	247.8
Waitemata-Motions	2005	SZ	✓								36.4	86.1	264.0	44.2	109.0	244.2
Waitemata-Coxs	2004	OZ									4.2	13.3	61.8	23.0	62.1	170.7
Hobson Bay-Awatea Rd	2004	OZ									12.8	30.7	108.6	16.3	43.7	110.0
Hobson Bay-Newmarket	2005	OZ	✓								6.0	13.7	39.5	30.9	64.9	145.8
Hobson Bay-Victoria Ave	2004	OZ									4.2	11.2	44.1	13.0	32.3	85.3
Hobson Bay-Purewa	2004	SZ									18.2	43.7	153.3	17.3	36.4	119.7
Hobson Bay-Whakataka Bay	2005	OZ									8.9	24.3	94.4	16.7	32.6	88.7
Tamaki-Point England	2004	OZ									12.1	19.7	80.3	17.0	23.2	99.0
Tamaki-Benghazi	2004	OZ									9.6	16.2	75.4	19.7	26.0	110.3
Tamaki-Roberta Reserve	2002	OZ									0.0	0.0	0.0	10.0	24.0	81.0
Tamaki-Panmure	2004	SZ									22.8	33.2	150.0	23.7	34.5	145.0
Tamaki-Bowden Rd	2004	OZ									25.7	35.0	168.7	28.3	35.7	167.0
Tamaki-Pakuranga Upper	2005	SZ	✓								34.4	36.4	236.0	45.4	56.0	307.0
Tamaki-Princess St	2004	OZ									17.5	26.5	143.0	27.3	37.1	187.7
Tamaki-Otahuhu Creek	2004	DZ									24.9	33.8	151.3	24.7	35.4	156.0
Tamaki-Middlemore	2005	SZ	✓								25.8	32.6	182.0	35.3	51.6	234.4
Manukau-Anns Creek	2005	OZ	✓								29.1	31.5	154.0	40.9	53.7	235.8
Manukau-Mangere Cemetery	2005	OZ	✓								25.1	28.3	136.0	18.3	26.5	110.3
Manukau-Pukaki Airport	2005	SZ									7.9	11.1	61.2	2.9	5.7	24.8
Manukau-Pukaki, Upper	2002	SZ	✓								5.6	9.1	47.3	5.3	12.7	49.7
Manukau-Pukaki, Waitekauri	2002	SZ									8.8	13.1	69.6	6.0	13.3	54.3

Table 4.1 cont.: Most recent estimates of copper (Cu), lead (Pb), and zinc (Zn) concentrations in the total (<500 μm) and fine (<63 μm) sediment fractions of stormwater contaminant monitoring sites. Metals in the <500 μm sediment fraction were extracted using strong acid digestion, while metals in the <63 μm fraction were extracted using weak acid digestion. The year of sampling, type of zone, and adjacent local authority are indicated for each site (OZ = outer zone, DZ = deposition zone, SZ = settling zone). Colours related to the ERC categories previously used by the ARC, with the addition of blue for concentrations above the PEL (Green = <TEL, Amber = TEL to ERL, Red = ERL to PEL, Blue = >PEL). Sites that are also included in the ARC's State of the Environment Monitoring Programme (SoE) are indicated with a tick.

Name	Total	Zone	SoE Site	Rodney	North Shore	Waitakere	Auckland	Manukau	Papakura	Franklin	<500 Cu	<500 Pb	<500 Zn	<63 Cu	<63 Pb	<63 Zn
Manukau-Puhinui, Entrance	2002	OZ									4.1	7.8	51.3	5.0	10.1	47.7
Manukau-Puhinui, Upper	2005	SZ	✓								9.2	12.5	106.0	6.1	10.9	78.6
Manukau-Waimahia Creek East	2002	DZ									9.3	15.0	78.3	6.0	13.0	60.7
Manukau-Waimahia Creek West	2002	DZ									8.3	13.4	67.8	6.0	12.9	58.7
Manukau-Pahurehure, Middle	2002	OZ									2.4	5.9	24.4	5.3	11.7	46.0
Manukau-Pahurehure, Papakura	2005	DZ	✓								7.0	13.0	66.1	8.3	17.9	78.0
Manukau-Pahurehure, Upper	2002	OZ									1.8	3.8	18.0	6.7	14.2	57.3
Manukau-Papakura Stream Lower	2002	SZ									10.1	15.7	76.0	6.0	13.1	51.3
Manukau-Papakura Stream Upper	2002	SZ									11.5	17.8	86.2	6.0	14.0	54.0
Manukau-Waiuku	2002	SZ									9.4	17.0	92.6	6.7	16.3	81.3
Manukau-Blockhouse Bay	2002	OZ									0.0	0.0	0.0	11.0	19.0	68.0
Manukau-Little Muddy	2002	SZ									11.4	14.9	60.9	10.0	14.8	59.7
Manukau-Hillsborough	2004	OZ									9.5	13.4	67.6	13.0	20.0	81.3

Figure 4.1: Relative concentrations of copper, lead and zinc in the <500 μm sediment fraction extracted using strong acid digestion. Relative concentration is indicated by the bubble size and colour (green = <TEL, orange = >TEL and < ERL, red = > ERL).

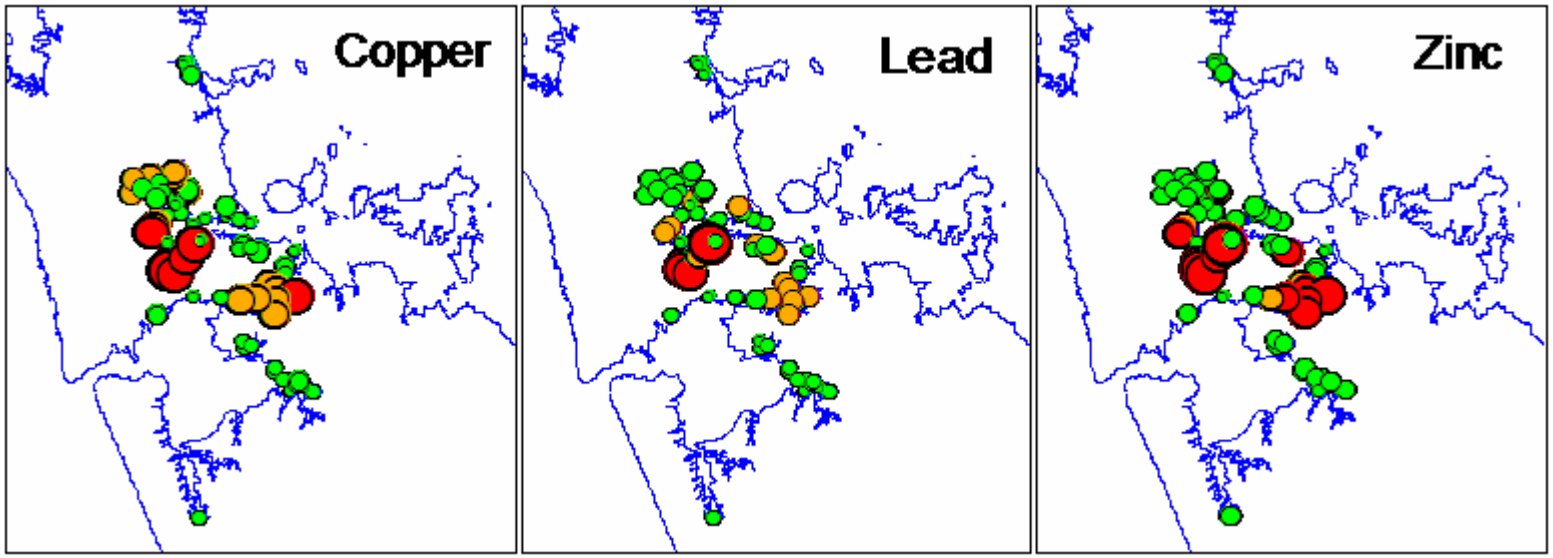


Figure 4.2: Concentrations (mg.kg^{-1}) of copper, lead and zinc in Rodney District marine sediments measured from the <500 µm sediment fraction extracted using strong acid digestion. Reference lines indicate PEL (blue), ERL (red) and TEL (green) sediment quality guideline values.

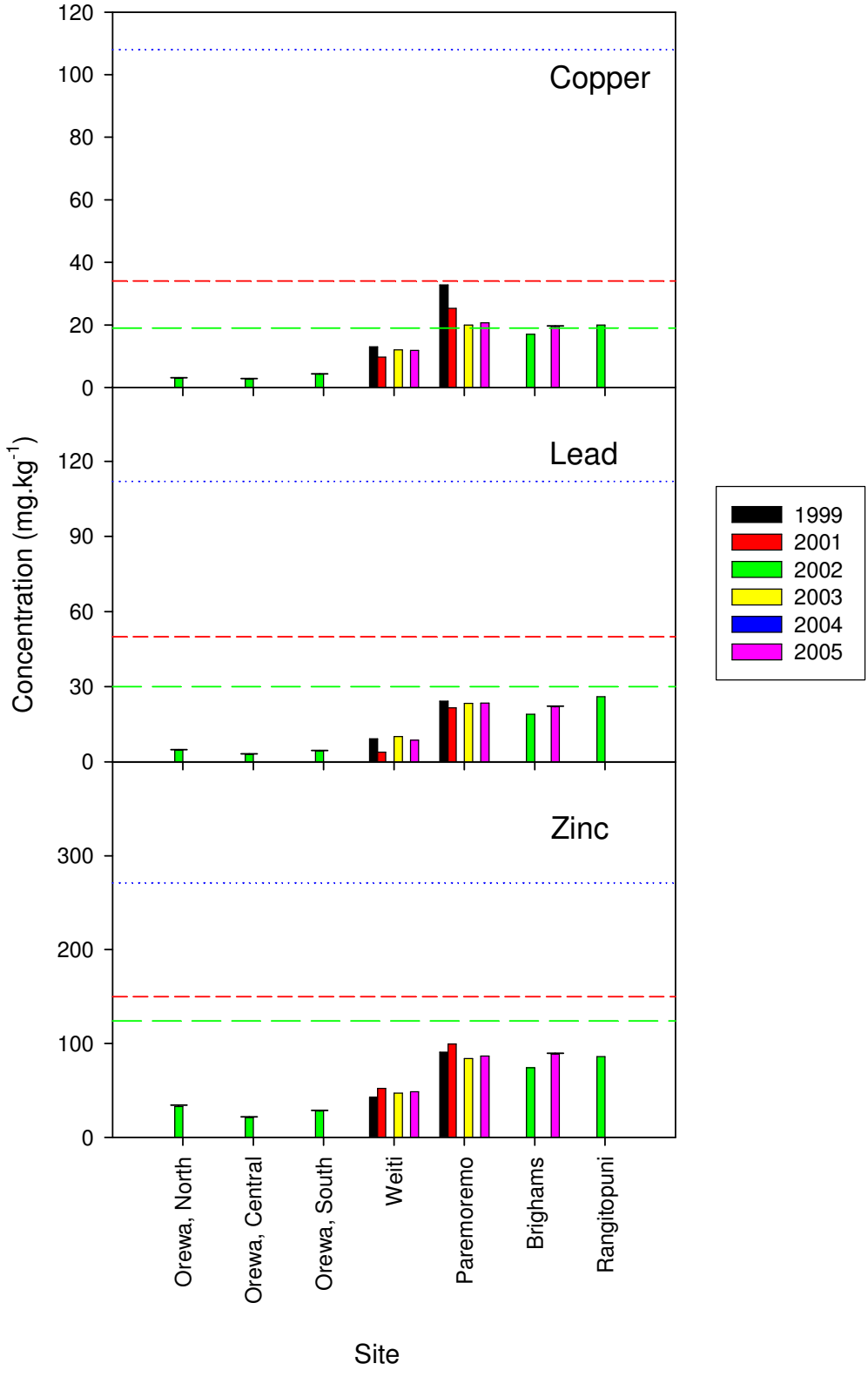


Figure 4.3: Concentrations (mg.kg^{-1}) of copper, lead and zinc in North Shore City marine sediments measured from the <500 µm sediment fraction extracted using strong acid digestion. Reference lines indicate PEL (blue), ERL (red) and TEL (green) sediment quality guideline values.

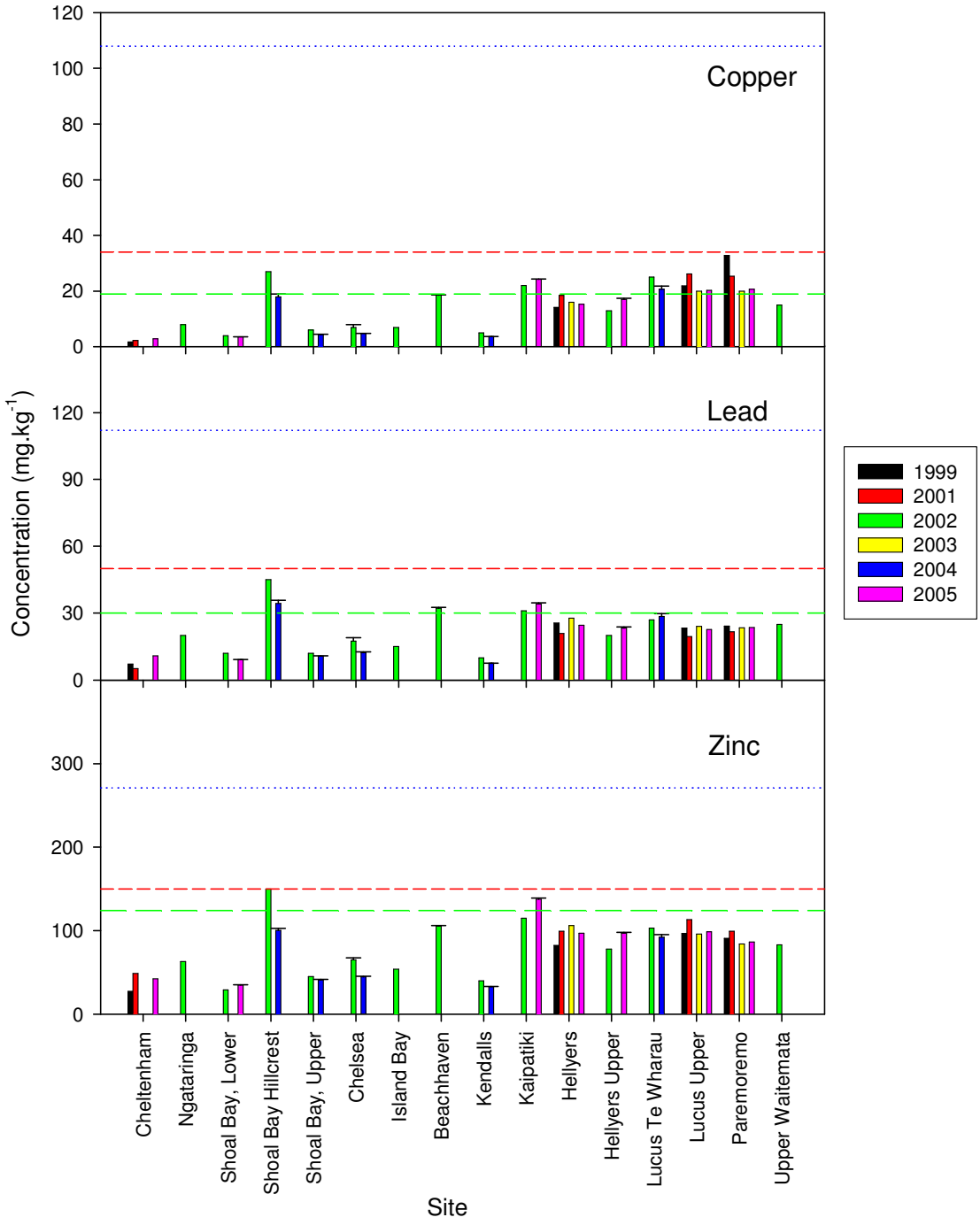


Figure 4.4: Concentrations (mg.kg^{-1}) of copper, lead and zinc in Waitakere City marine sediments measured from the <500 µm sediment fraction extracted using strong acid digestion. Reference lines indicate PEL (blue), ERL (red) and TEL (green) sediment quality guideline values.

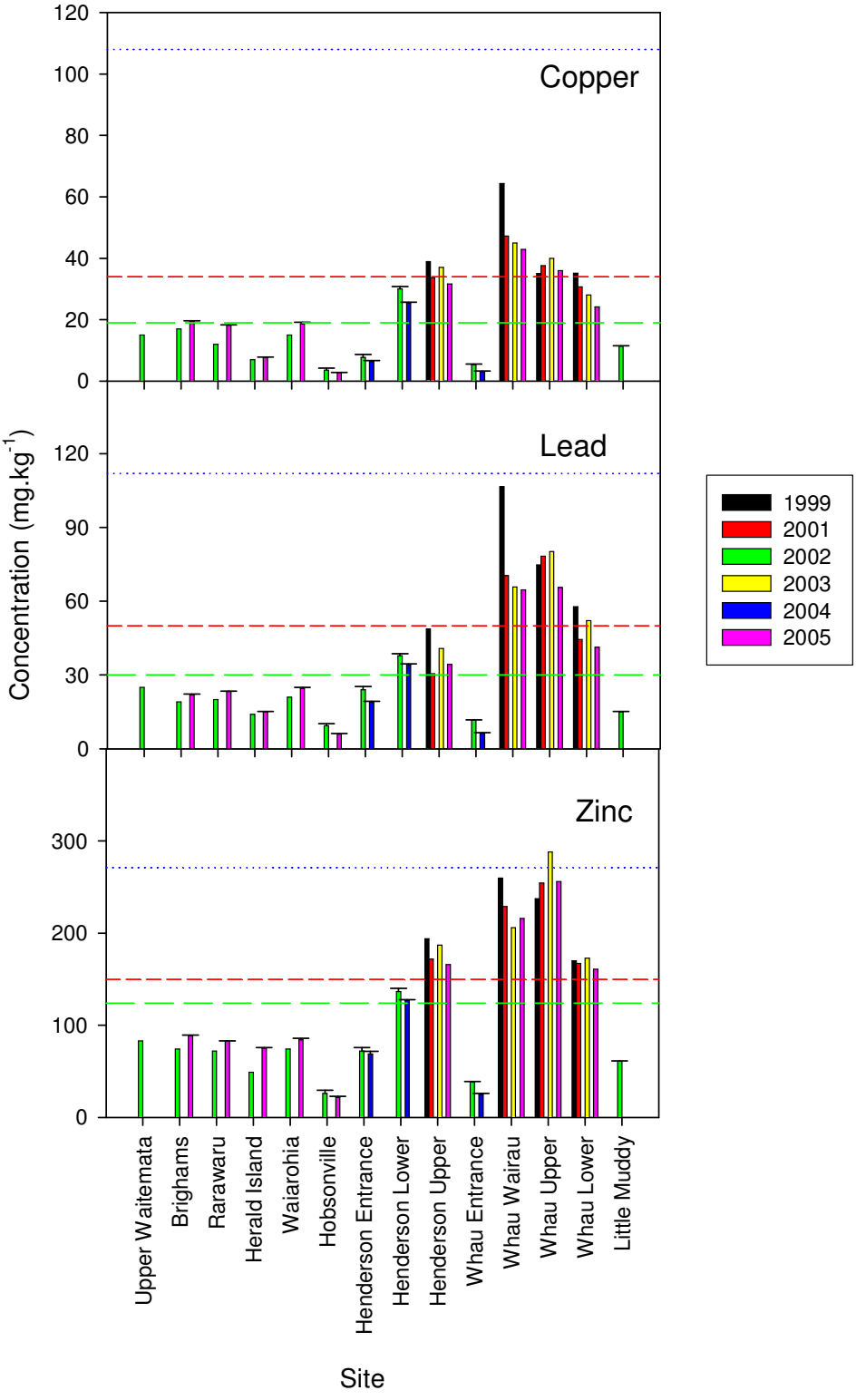


Figure 4.5: Concentrations (mg.kg^{-1}) of copper, lead and zinc in Auckland City marine sediments measured from the <500 µm sediment fraction extracted using strong acid digestion. Reference lines indicate PEL (blue), ERL (red) and TEL (green) sediment quality guideline values.

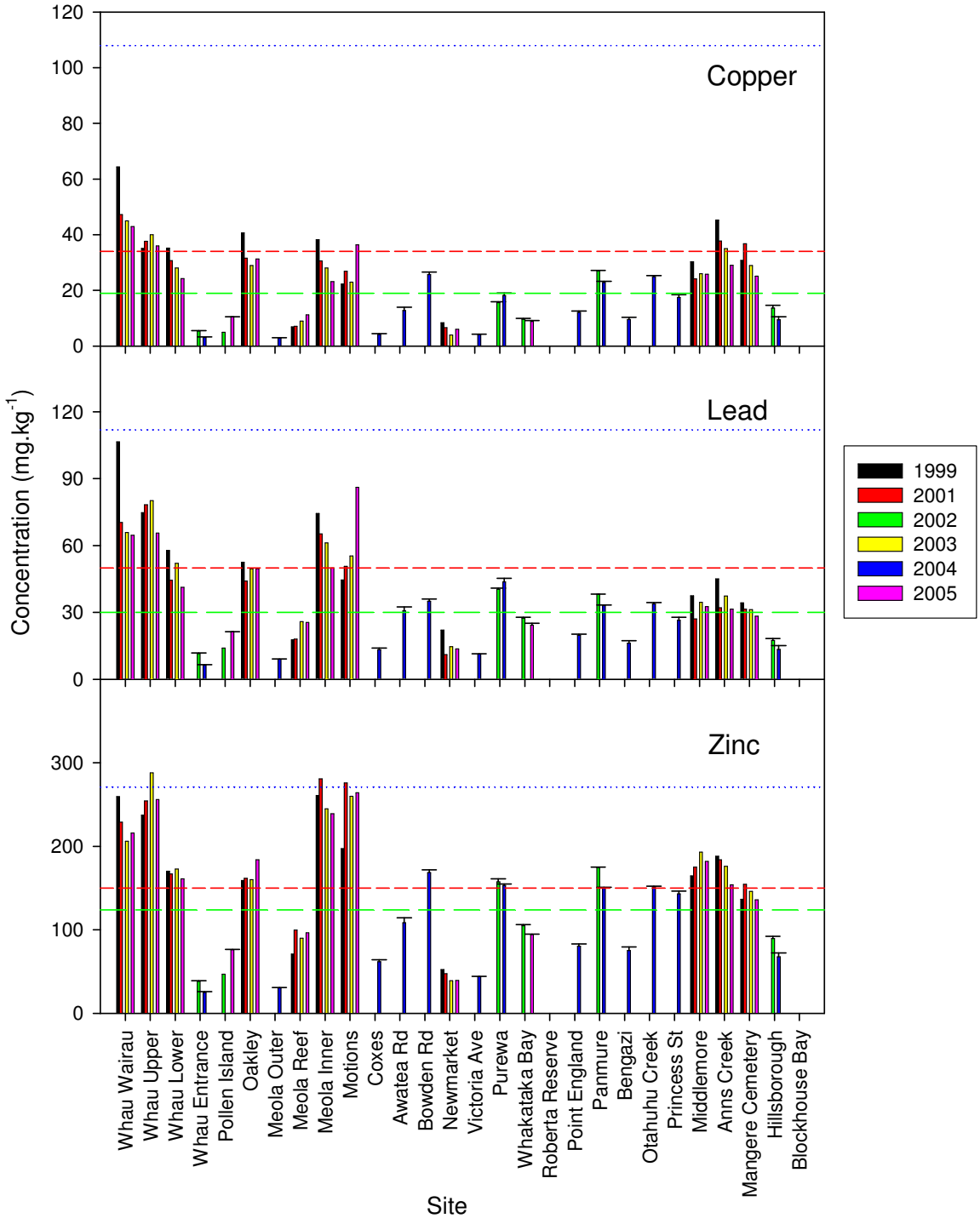


Figure 4.6: Concentrations (mg.kg^{-1}) of copper, lead and zinc in Manukau City marine sediments measured from the <500 µm sediment fraction extracted using strong acid digestion. Reference lines indicate PEL (blue), ERL (red) and TEL (green) sediment quality guideline values.

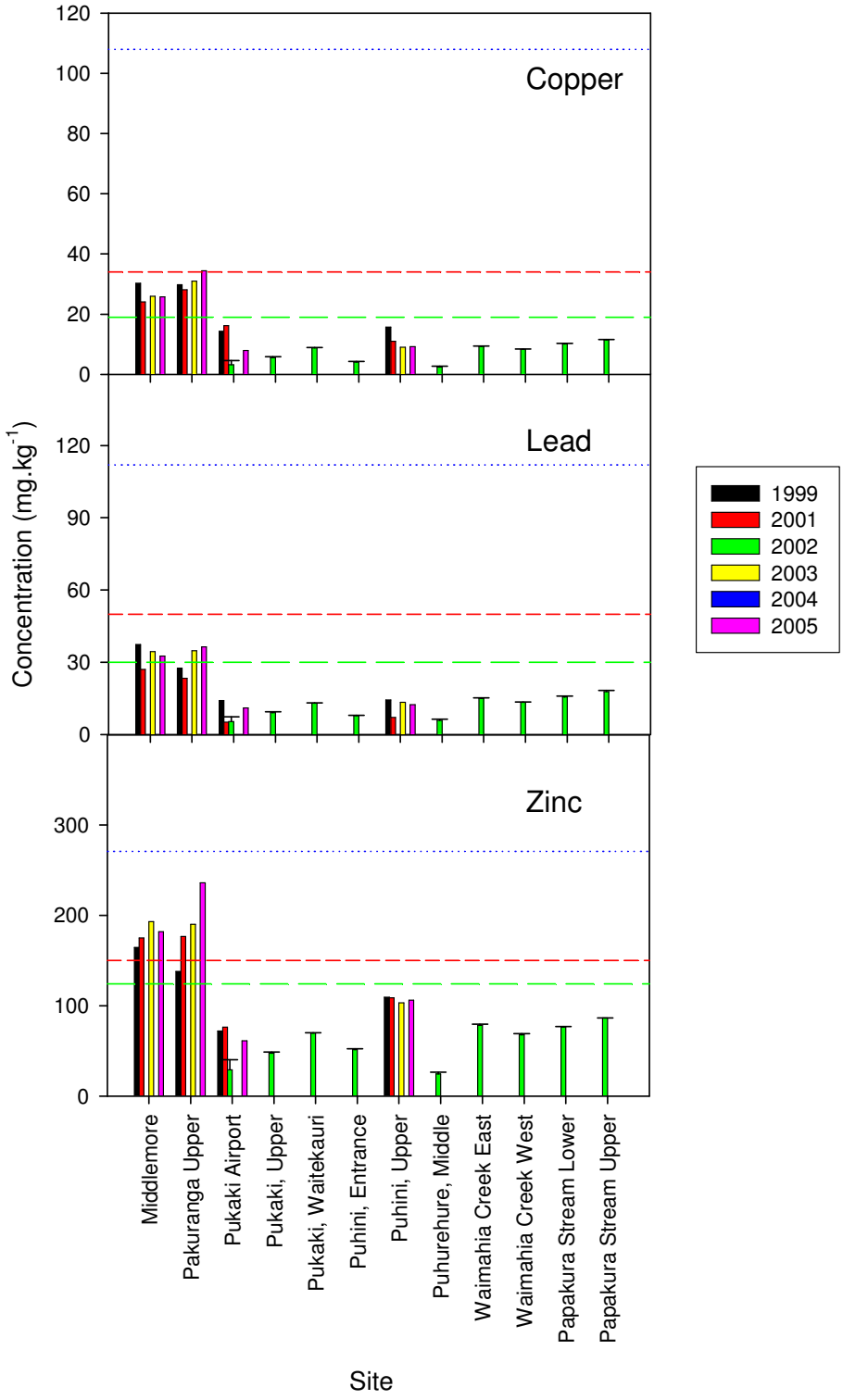
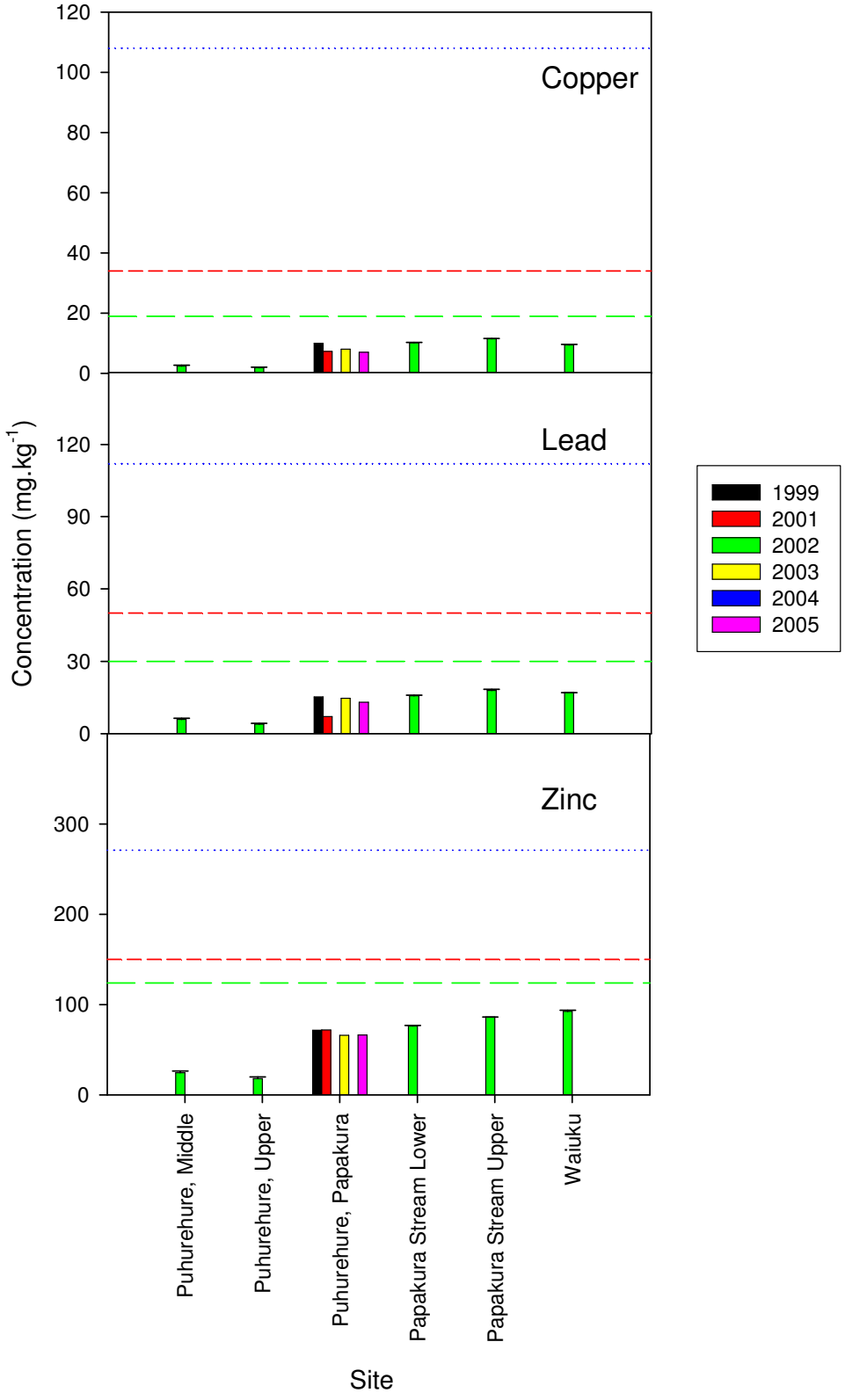


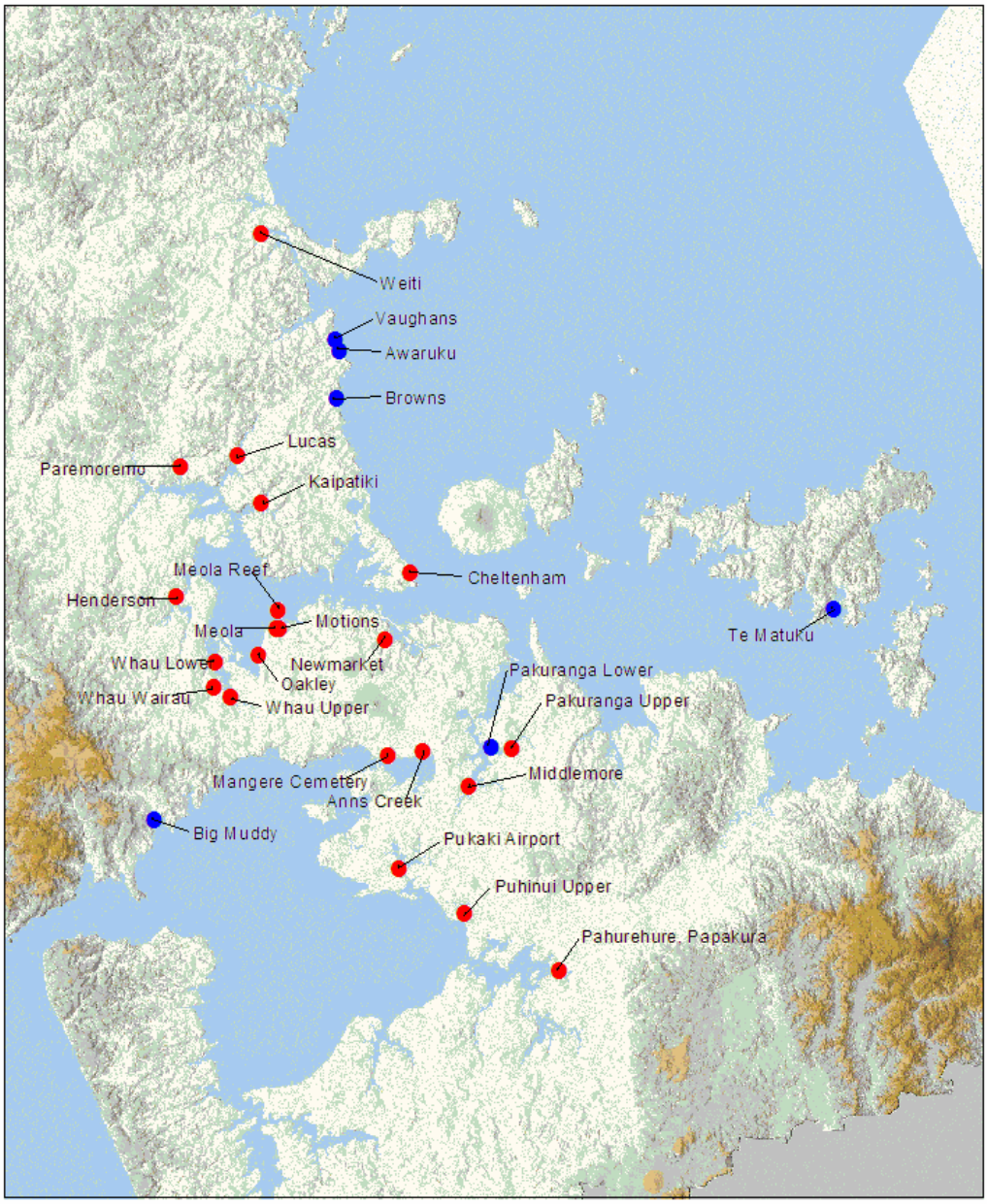
Figure 4.7: Concentrations (mg.kg^{-1}) of copper, lead and zinc in Papakura District and Franklin District marine sediments measured from the <500 µm sediment fraction extracted using strong acid digestion. Reference lines indicate PEL (blue), ERL (red) and TEL (green) sediment quality guideline values.



4.2 Trends in Copper, Lead and Zinc

Sufficient time series data for trend detection was only available for 21 of the 72 regional stormwater monitoring sites. These sites are also included in the ARC's SoE monitoring programme which has measured metal concentrations at 1-2 year intervals since 1998. The SoE sediment contaminant monitoring programme contains a total of 27 sites (Figure 4.8). For completeness, data from all 27 SoE monitoring sites are presented here.

Figure 4.8: Location of ARC's state of the environment sediment contaminant monitoring sites. Red sites are also regional stormwater monitoring sites, blue sites are sites not included in the regional stormwater monitoring programme.



Zinc and copper levels tended to increase at 20 and 22 of the 27 SoE sites respectively, whereas lead accumulation rates were highly variable among sites (Figure 4.9). Concentrations of copper and zinc increased most rapidly in sheltered side-branches of the Waitemata Harbour and Tamaki Estuary. Relatively rapid accumulation of these metals has also occurred at the entrance to Anns Creek in Mangere Inlet, but accumulation rates were relatively slow at the other Manukau Harbour sites. Plots showing trends in copper lead and zinc at the 27 SoE monitoring sites are presented in Figure 4.10 to Figure 4.12. Overall, copper and zinc accumulation rates were greatest at sites with high existing concentrations of contaminants and least at "uncontaminated" sites (Figure 4.13). Accordingly, the contaminated sites (i.e. those of the southern Waitemata Harbour, Tamaki Estuary and Mangere Inlet) are rapidly getting worse, whereas the quality of relatively clean sites tends to be either stable or deteriorating only slowly. However, the zinc accumulation rates recorded from several "clean" sites are worth noting. Between 1998 and 2005 zinc concentrations increased by:

- 51% in Kaipatiki (a side branch of Hellyers creek);
- 55% in Lucas (upper);
- 33% in Weiti; and,
- 31% in Pahurehure (Papakura).

Substantial, reductions in copper and zinc concentrations have occurred on exposed East Coast Bays beaches (i.e. at the entrance to Awaruku Stream on Long Bay, Browns Bay and Cheltenham Beach), which is most likely to be due to the redispersal of sediments rather than reductions in contaminant loads. Note that of these sites, Cheltenham is the only one included in the regional stormwater monitoring programme. With the exception of copper at Pukaki (airport), reductions at the other sites were not statistically significant from 1998 to 2005. Copper concentrations at Pukaki (airport) have changed from 4.6 $mg.kg^{-1}$ to 2.9 $mg.kg^{-1}$.

Figure 4.9: Measured accumulation rates (mg/kg/yr) of copper, lead and zinc at state of the environment monitoring sites from 1998 to 2005.

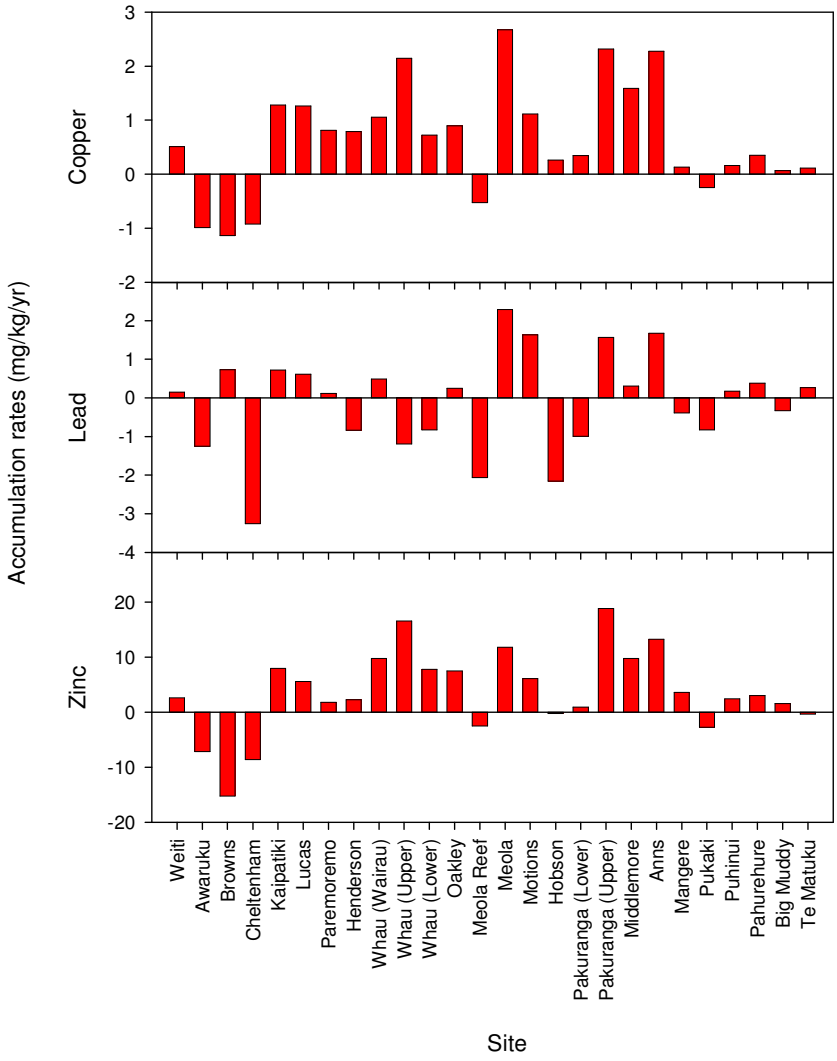


Figure 4.10: Changes in the concentration of copper (<63 μm sediment fraction using weak acid digestion) at the 27 ARC state of the environment monitoring sites from 1998 to 2005. Local councils adjoining each site are indicated (RDC = Rodney, NSCC = North Shore, WCC = Waitakere, ACC = Auckland, MCC = Manukau, & PDC = Papakura). Threshold and probable effects level sediment quality guideline values are also indicated by dashed and dotted reference lines respectively. Sites with statistically significant trends are indicated with an asterisk.

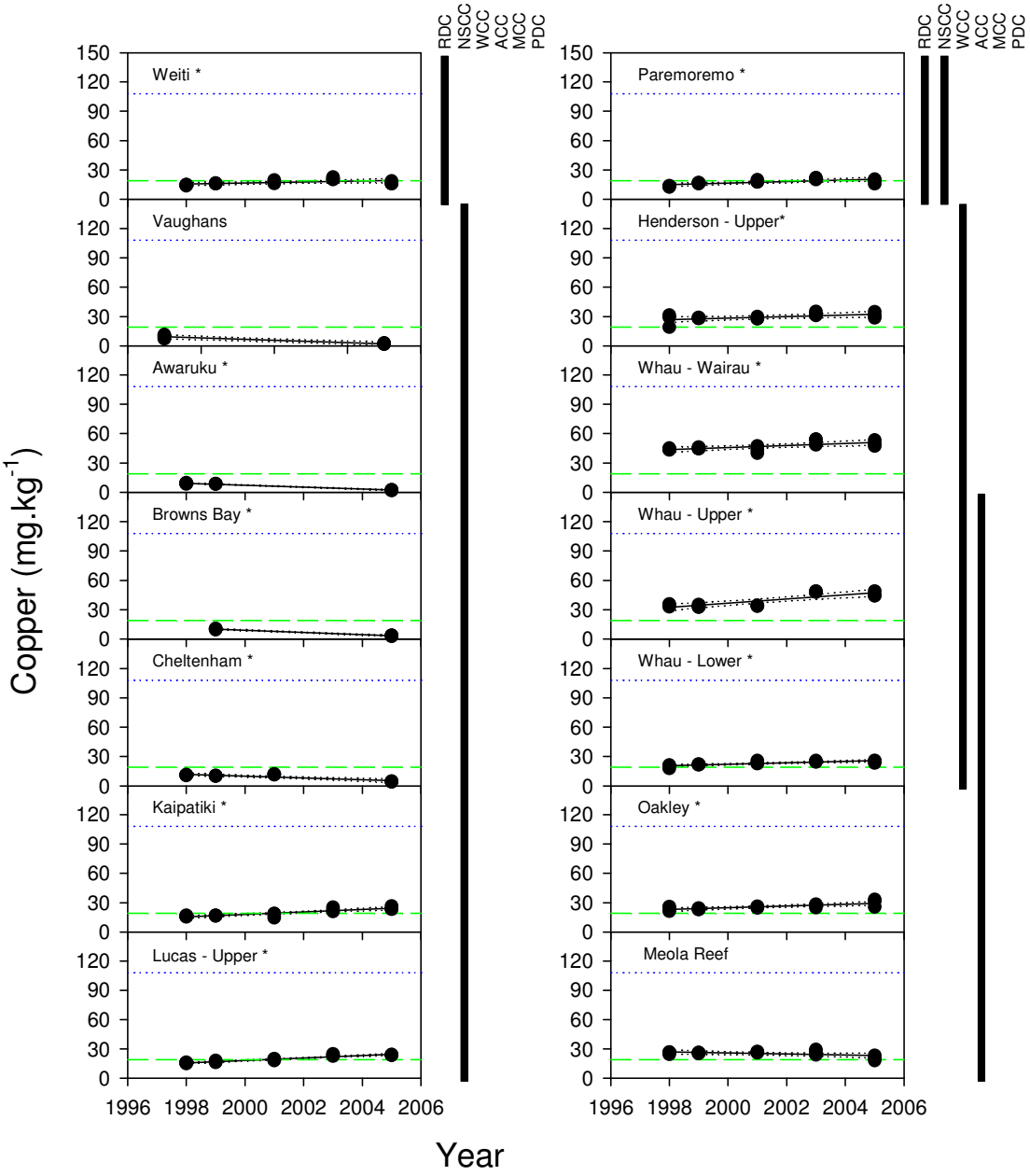


Figure 5.10 cont.: Changes in the concentration of copper (<63 µm sediment fraction using weak acid digestion) at the 27 ARC state of the environment monitoring sites from 1998 to 2005. Local councils adjoining each site are indicated (RDC = Rodney, NSCC = North Shore, WCC = Waitakere, ACC = Auckland, MCC = Manukau, & PDC = Papakura). Threshold and probable effects level sediment quality guideline values are also indicated by dashed and dotted reference lines respectively. Sites with statistically significant trends are indicated with an asterisk.

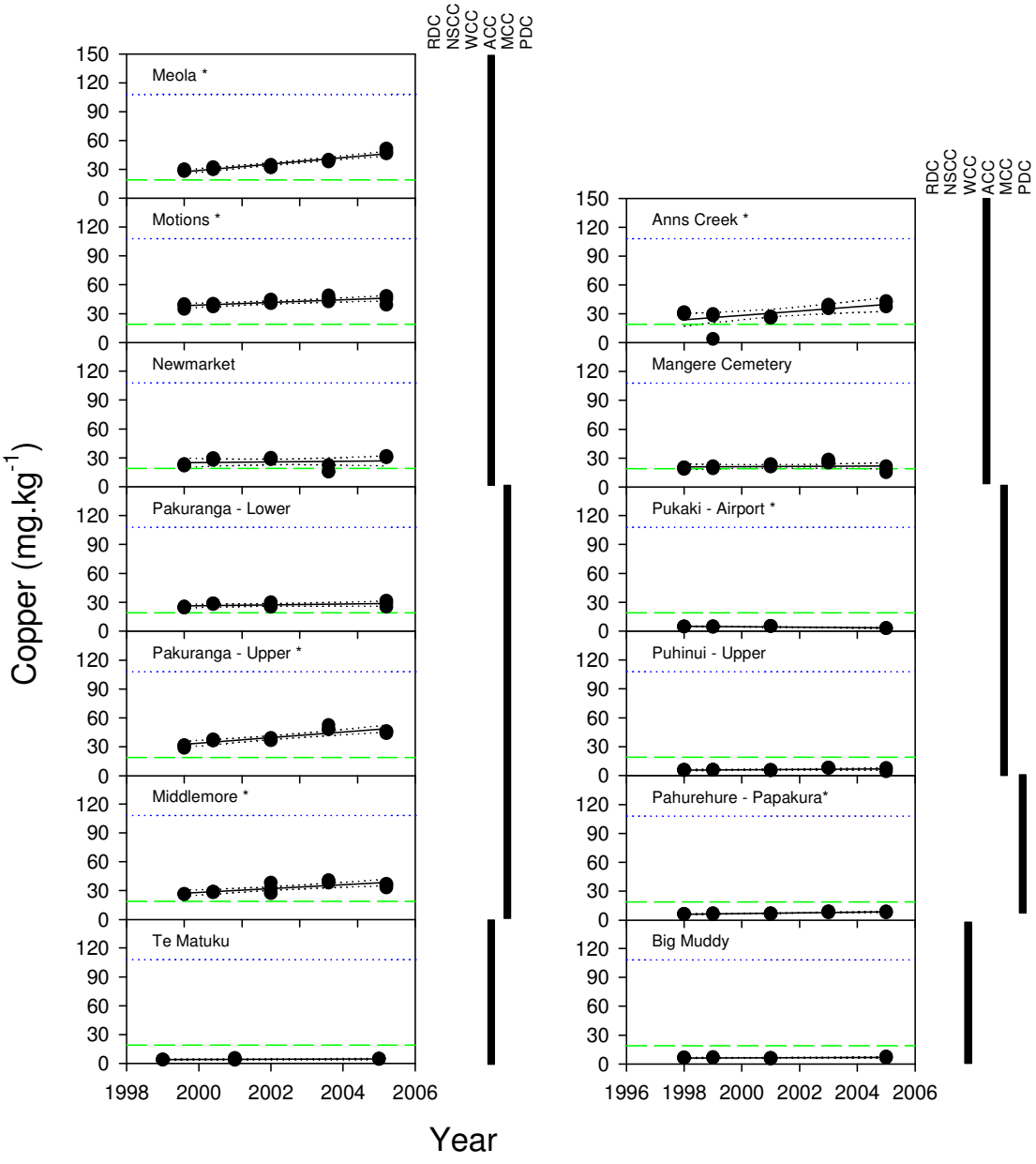


Figure 4.11: Changes in the concentration of lead (<63 μm sediment fraction using weak acid digestion) at the 27 ARC state of the environment monitoring sites from 1998 to 2005. Local councils adjoining each site are indicated (RDC = Rodney, NSCC = North Shore, WCC = Waitakere, ACC = Auckland, MCC = Manukau, & PDC = Papakura). Threshold and probable effects level sediment quality guideline values are also indicated by dashed and dotted reference lines respectively. Sites with statistically significant trends are indicated with an asterisk.

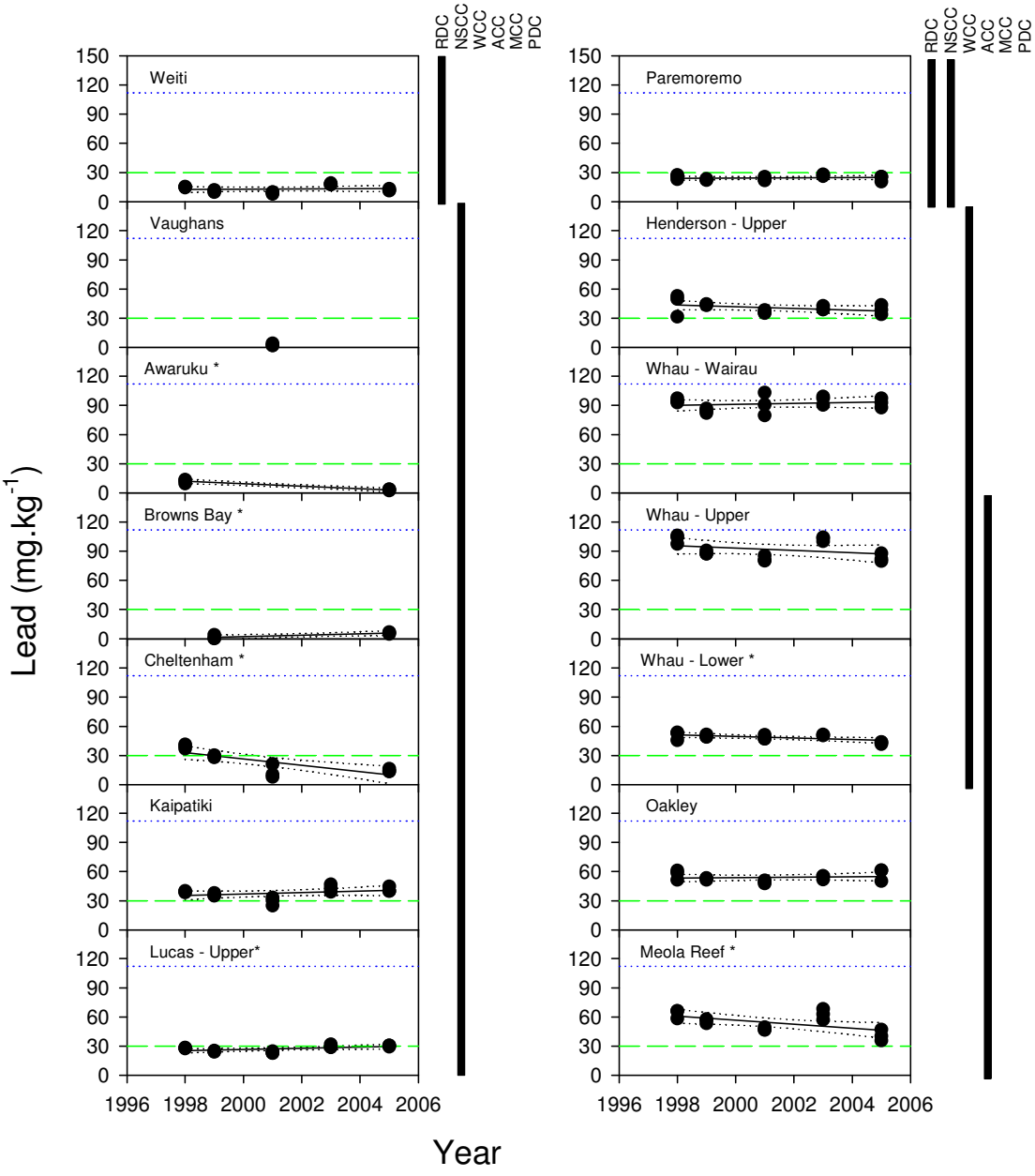


Figure 5.11 cont.: Changes in the concentration of lead (<63 µm sediment fraction using weak acid digestion) at the 27 ARC state of the environment monitoring sites from 1998 to 2005. Local councils adjoining each site are indicated (RDC = Rodney, NSCC = North Shore, WCC = Waitakere, ACC = Auckland, MCC = Manukau, & PDC = Papakura). Threshold and probable effects level sediment quality guideline values are also indicated by dashed and dotted reference lines respectively. Sites with statistically significant trends are indicated with an asterisk.

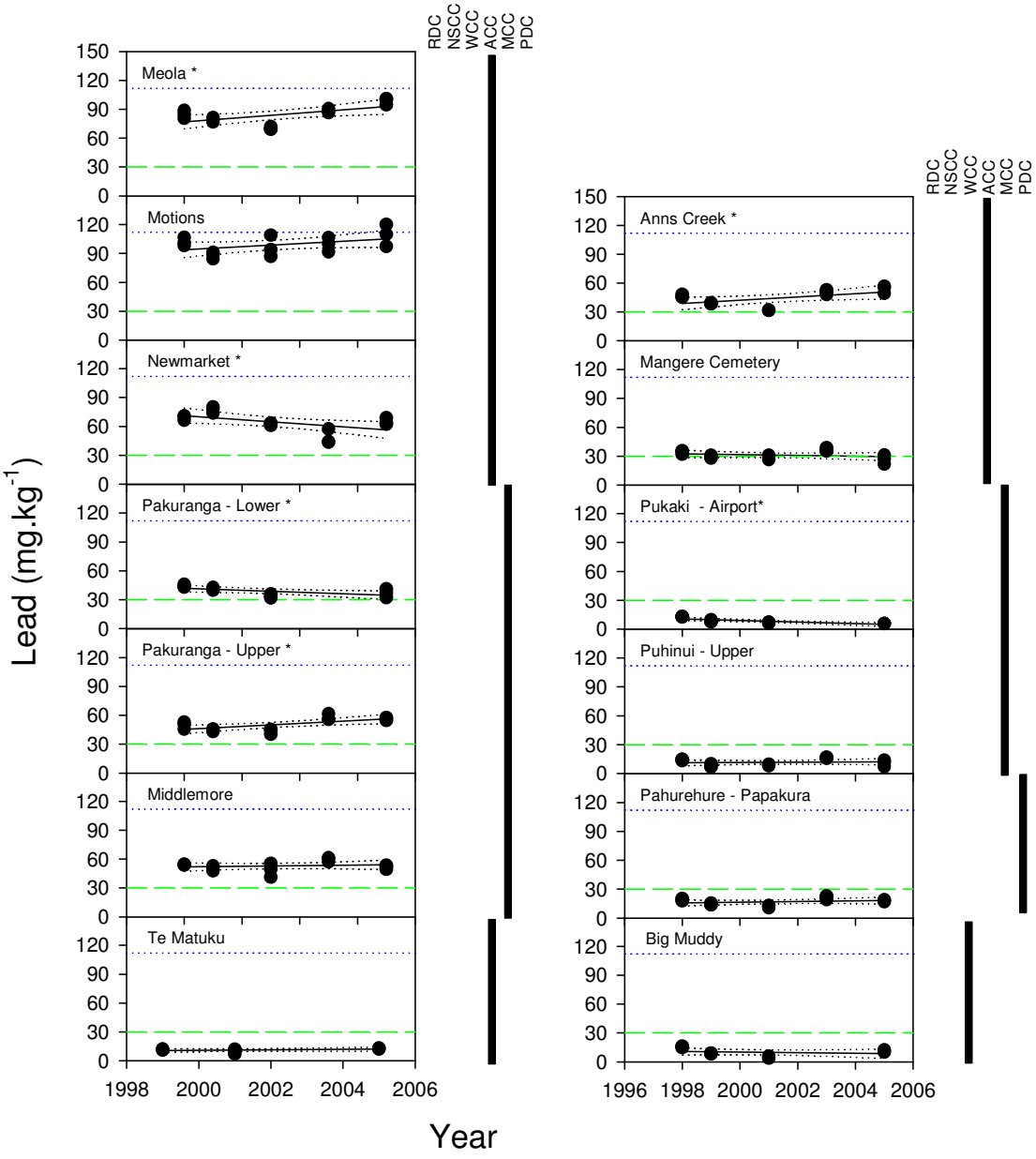


Figure 4.12: Changes in the concentration of zinc (<63 µm sediment fraction using weak acid digestion) at the 27 ARC state of the environment monitoring sites from 1998 to 2005. Local councils adjoining each site are indicated (RDC = Rodney, NSCC = North Shore, WCC = Waitakere, ACC = Auckland, MCC = Manukau, & PDC = Papakura). Threshold and probable effects level sediment quality guideline values are also indicated by dashed and dotted reference lines respectively. Sites with statistically significant trends are indicated with an asterisk.

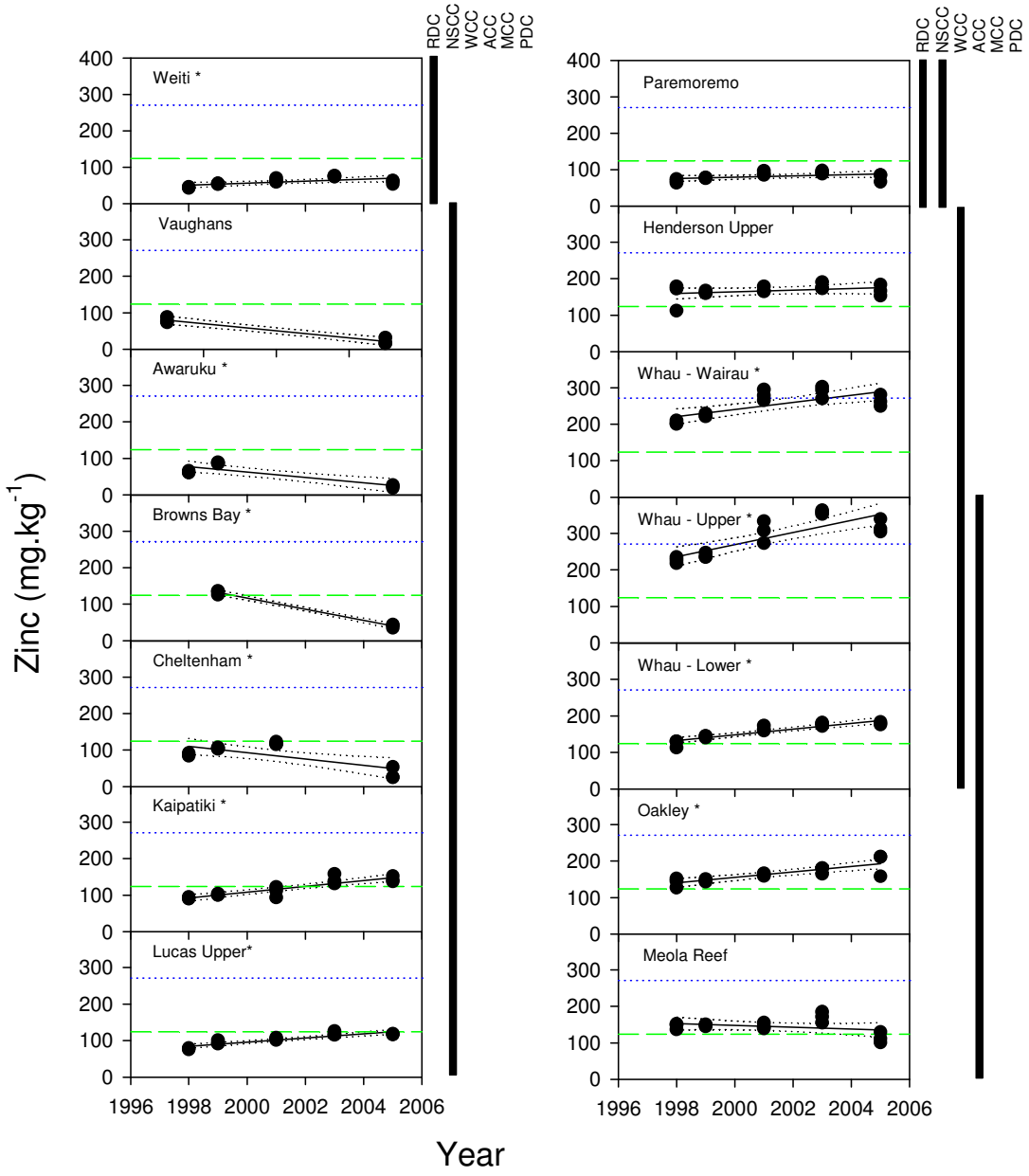


Figure 5.12 cont.: Changes in the concentration of zinc (<63 µm sediment fraction using weak acid digestion) at the 27 ARC state of the environment monitoring sites from 1998 to 2005. Local councils adjoining each site are indicated (RDC = Rodney, NSCC = North Shore, WCC = Waitakere, ACC = Auckland, MCC = Manukau, & PDC = Papakura). Threshold and probable effects level sediment quality guideline values are also indicated by dashed and dotted reference lines respectively. Sites with statistically significant trends are indicated with an asterisk.

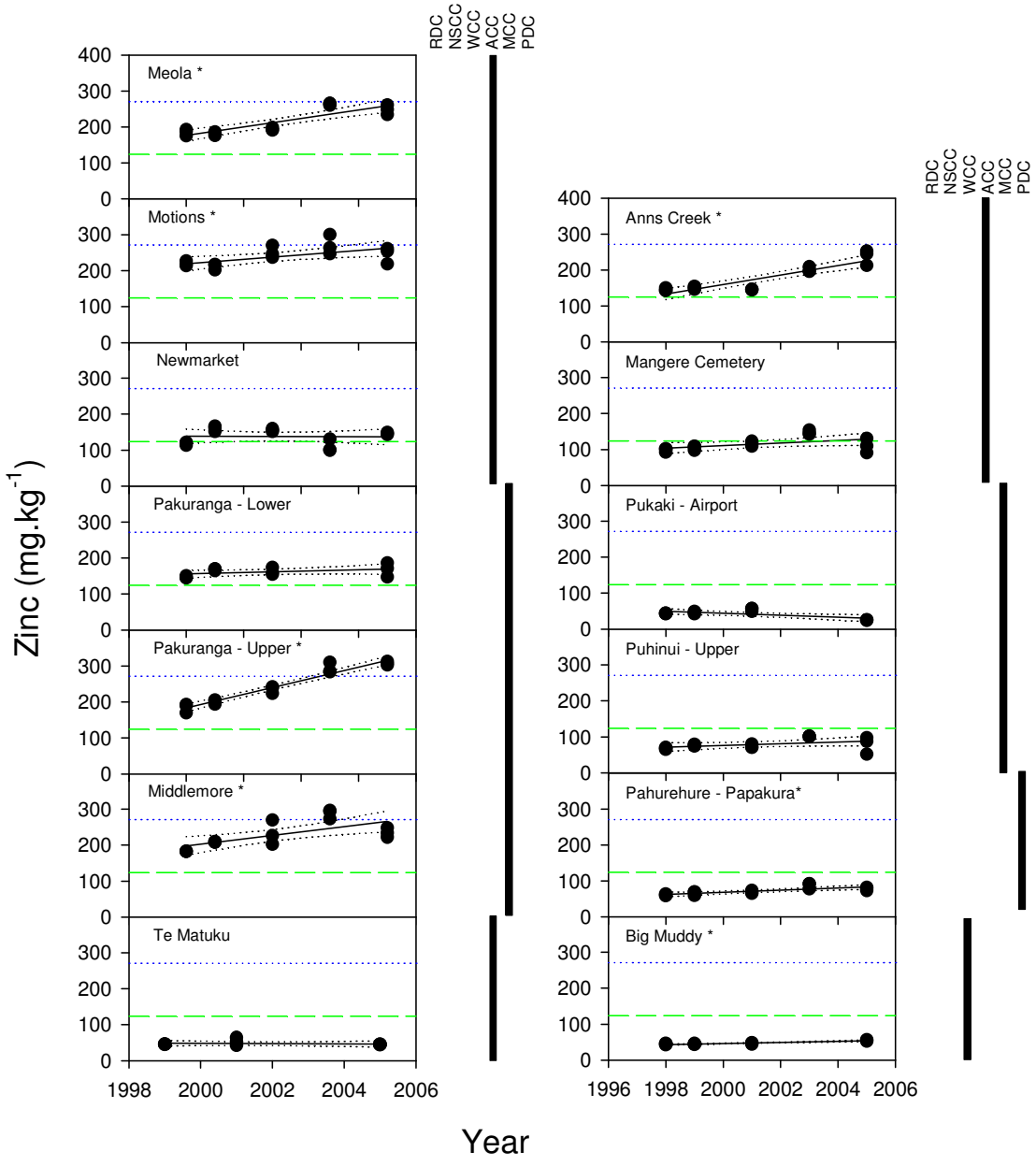
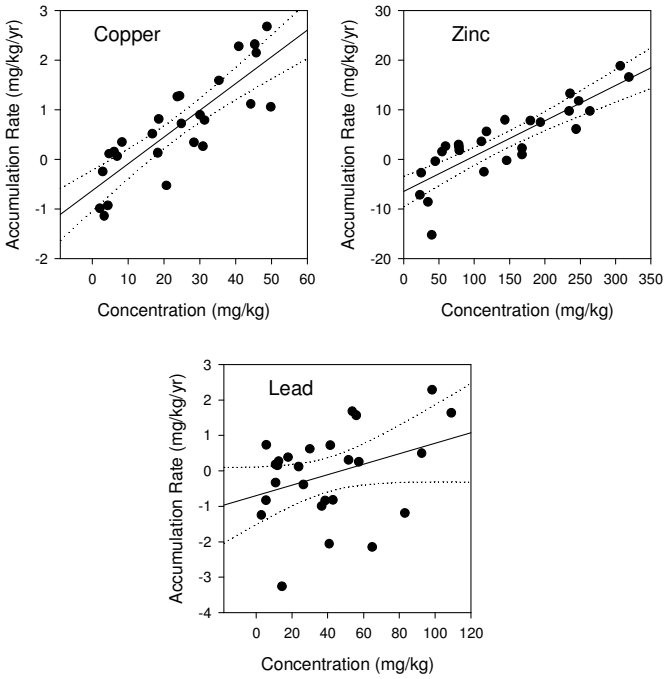


Figure 4.13: Relationship between existing concentrations of copper, zinc and lead in the <63 μm sediment fraction and their accumulation rate at ARC state of the environment monitoring sites. Linear regression and 95 % confidence intervals are shown.



4.3 Ecological Condition

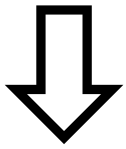
Ecological condition was analysed at 84 sites throughout the Auckland Region to obtain data for the development of ecosystem health models (Anderson et al. 2006). Forty-eight of these sites were stormwater contaminant monitoring sites, of which 10 were sampled twice.

Ecological community structure varied along the contamination gradient obtained from the 84 sites sampled (Figure 4.14), with the strongest relationship between community structure and the combined concentrations of copper, lead and zinc, occurring in the sites with coarse sediments (Figure 4.15) (see Anderson et al. (2006) for details on how sediment texture and exposure were used to group sites). The models are used to rank ecological condition from 1 (healthy) to 5 (degraded) (Table 4-2).

Of the 48 stormwater contaminant monitoring sites included in this assessment:

- 1 site was ranked 1 for ecology;
- 5 sites were ranked 2 for ecology;
- 13 sites were ranked 3 for ecology;
- 20 sites were ranked 4 for ecology, and;
- 9 sites were ranked 5 for ecology.

Good ecological condition



Degraded ecological condition

Note that the above rankings are based on the results from the most recent sampling occasion.

Of the 10 sites that have been sampled on more than one occasion, the ecological rankings of 7 sites have remained the same (i.e. 1 site ranked 3, 2 sites ranked 4, and 4 sites ranked 5), 1 site has shifted from ecological ranking 3 to ranking 4 (Henderson entrance between 2002 and 2004) and 2 sites have shifted from ecological ranking 4 to ranking 5 (Anns Creek and upper Henderson between 2002 and 2005). Note however, that there is scatter around the relationship between contaminants and benthic community structure (see Figure 4.14 and Figure 4.15), so several samples will be required to confirm any trends.

Spatial patterns in ecological condition broadly reflect spatial patterns of contamination. Sites along the southern Waitemata Harbour, in upper reaches of Tamaki Estuary, and on the northern-eastern Manukau had ecological communities with signs of stress. In contrast, open sites on the northern Waitemata Harbour (Chelsea and Kendalls Bay) had good ecological condition. Similarly, the condition of ecological communities in Orewa was excellent.

Of particular note was the relatively poor ecological condition of sites in side-branches of the upper Waitemata Harbour, i.e. Brighams, Rangitopuni and Paremoremo, which have predominantly rural catchments. The condition of ecological communities at two sites in the Manukau Harbour: Pukaki (airport) and upper Puhinui, was also poor, and did not reflect the low concentrations of copper, lead and zinc found at these sites.

Conversely, the Newmarket site was notable for it's good ecological status. This site is situated near the outlet of Newmarket creek which drains a relatively large commercial area. Contaminant load modelling carried for ACC/Metrowater suggests zinc loads going into Newmarket creek are relatively high. Yet, the site has relatively coarse sediments and contaminant concentrations are only elevated in the fine sediment fraction.

Figure 4.14: Relationship between contamination and ecological community structure. The plot includes data from coarse-sediment and fine-sediment sites. Contamination values were derived from a principal components analysis of copper, lead and zinc concentrations obtained from the <500 µm sediment fraction using strong acid digestion. Values for ecological community structure were derived using canonical analysis of principal coordinates (CAP) with Bray-Curtis dissimilarity on square-root transformed count data (see Anderson et al. 2006). Stormwater contaminant monitoring sites are shown in red, while additional sites used in the model are indicated in blue.

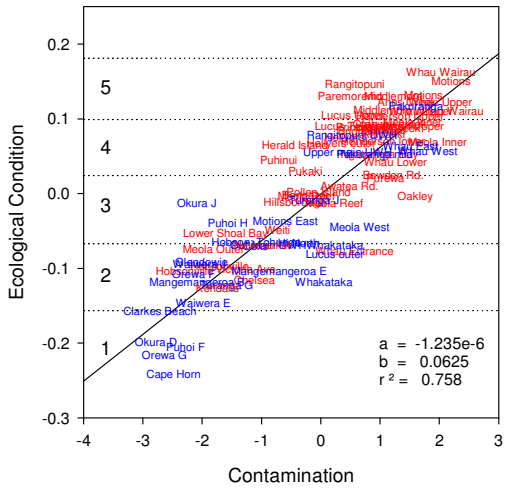


Figure 4.15: Relationship between contamination and ecological community structure at sites with coarse sediments. Contamination values were derived from a principal components analysis of copper, lead and zinc concentrations obtained from the <63 µm sediment fraction using weak acid digestion. Values for ecological community structure were derived using canonical analysis of principal coordinates (CAP) with Bray-Curtis dissimilarity on square-root transformed count data (see Anderson et al. 2006). Stormwater contaminant monitoring sites are shown in red, while additional sites used in the model are indicated in blue.

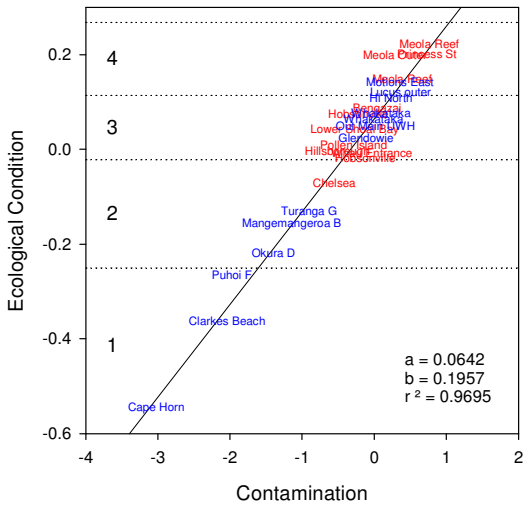


Figure 4.16: Ecological condition of the stormwater contaminant monitoring sites. Condition is ranked from 1 (good) to 5 (degraded). Note that, generally, ecological condition is not assessed until contaminant levels are above TEL values.

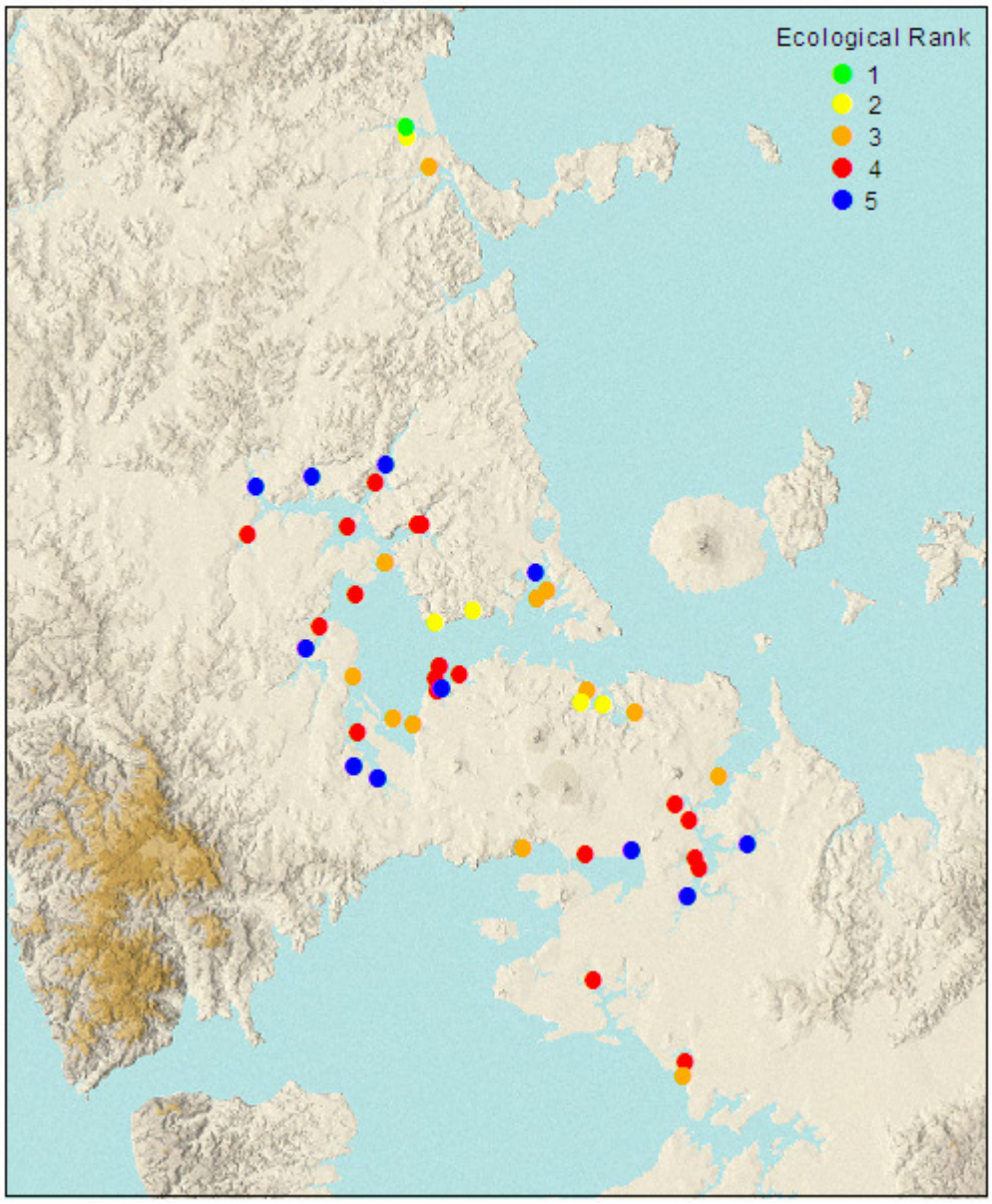


Table 4-2: Analytical grouping of sites based on combined copper, lead and zinc concentrations in the <63 um (bioavailable) and <500 µm (total) sediment fractions and ecological community structure.

Year	Location	Site	Bioavailable Metal Concentrations	Total Metal Concentrations	Overall Ecological Rank	Sediment Characteristics	Zone
2004	Waitemata	Chelsea	2	2	2	C	OZ
2004	Waitemata	Kendalls	2	2	2	C	OZ
2005	Hobson Bay	Newmarket	5	2	2	C	OZ
2005	Waitemata	Hobsonville	3	1	3	C	OZ
2002	Waitemata	Hobsonville	3	2	3	C	OZ
2005	Waitemata	Shoal Bay, Lower	3	2	3	C	OZ
2002	Manukau	Puhinui, Entrance	1	2	3	C	OZ
2004	Waitemata	Shoal Bay, Upper	3	2	3	C	SZ
2004	Tamaki	Benghazi	3	3	3	C	OZ
2004	Waitemata	Henderson Entrance	3	3	3	C	OZ
2004	Manukau	Hillsborough	2	3	3	C	OZ
2005	Waitemata	Pollen Island	3	3	3	C	OZ
2004	Waitemata	Whau Entrance	3	4	3	C	OZ
2004	Waitemata	Coxs	4	2	4	C	OZ
2004	Waitemata	Meola Outer	4	2	4	C	OZ
2002	Waitemata	Henderson Entrance	3	3	4	C	OZ
2002	Waitemata	Meola Reef	4	3	4	C	OZ
2005	Waitemata	Meola Reef	4	3	4	C	OZ
2004	Tamaki	Princess St	4	4	4	C	OZ
2005	Orewa	Orewa Central	1	1	1	F	OZ
2005	Orewa	Orewa South	1	1	2	F	SZ
2004	Hobson Bay	Victoria Ave	3	2	2	F	OZ
2005	Weiti	Weiti	2	3	3	F	SZ
2004	Hobson Bay	Awatea Rd.	4	4	3	F	OZ
2004	Hobson Bay	Purewa	4	4	3	F	SZ
2005	Waitemata	Oakley	5	5	3	F	SZ
2005	Manukau	Puhinui, Upper	1	3	4	F	SZ
2005	Manukau	Pukaki, Airport	2	3	4	F	SZ
2005	Manukau	Anns Creek	5	4	4	F	OZ
2005	Waitemata	Brigham	3	4	4	F	SZ
2005	Waitemata	Hellyers	4	4	4	F	SZ
2004	Waitemata	Henderson lower	4	4	4	F	SZ
2005	Waitemata	Kaipatiki	4	4	4	F	SZ
2004	Waitemata	Lucas Te Wharau	3	4	4	F	SZ
2005	Manukau	Mangere Cemetery	3	4	4	F	OZ
2004	Tamaki	Otahuhu Creek	4	4	4	F	SZ
2004	Tamaki	Panmure	4	4	4	F	SZ
2004	Tamaki	Bowden Rd.	4	5	4	F	OZ

Year	Location	Site	Bioavailable Metal Concentrations	Total Metal Concentrations	Overall Ecological Rank	Sediment Characteristics	Zone
2002	Waitemata	Meola Inner	5	5	4	F	SZ
2005	Waitemata	Meola Inner	5	5	4	F	SZ
2005	Waitemata	Henderson Upper	4	5	4	F	SZ
2005	Waitemata	Herald Island	3	3	4	F	OZ
2005	Waitemata	Whau Lower	4	5	4	F	OZ
2005	Waitemata	Lucas Upper	4	4	5	F	SZ
2002	Tamaki	Middlemore	5	4	5	F	SZ
2005	Waitemata	Paremoremo	3	4	5	F	SZ
2005	Waitemata	Rangitopuni	3	4	5	F	SZ
2004	Waitemata	Shoal Bay, Hillcrest	3	4	5	F	SZ
2002	Manukau	Anns Creek	4	5	5	F	OZ
2002	Waitemata	Henderson Upper	4	5	5	F	SZ
2005	Tamaki	Middlemore	5	5	5	F	SZ
2002	Waitemata	Motions	5	5	5	F	SZ
2005	Waitemata	Motions	5	5	5	F	SZ
2004	Waitemata	Whau Upper	5	5	5	F	SZ
2005	Waitemata	Whau Upper	5	5	5	F	SZ
2002	Waitemata	Whau Wairau	5	5	5	F	SZ
2005	Waitemata	Whau Wairau	5	5	5	F	SZ
2005	Tamaki	Pakuranga Upper	5	5	5	F	SZ

5 Discussion

5.1 Urban Estuaries with Poor Environmental Quality

The most contaminated sites in the region are continuing to degrade rapidly due to the ongoing inputs of copper and zinc. The emphasis for the management of these areas is on slowing the rate of contaminant accumulation and preventing the spread of contaminants from sheltered settling zones to broader harbour areas. However, it is likely that sediment concentrations of these two contaminants will continue to increase in the marine environment, unless loads can be substantially reduced in urban stormwater. It is possible to reduce the rate of contaminant accumulation with stormwater treatment and contaminant source control, but such intervention is costly and technically difficult in fully urbanised catchments. Effective solutions will take time to develop and implement, and the resulting environmental response is likely to be relatively slow, possibly in the order of decades.

The majority of contaminated sites adjoin Auckland City catchments draining into the southern Waitemata, Tamaki Estuary, and northern side of Mangere Inlet. Auckland City Council is currently considering options for stormwater contaminant management, to determine the BPO for addressing the problem. The Council plans a city-wide approach to stormwater management, but targeted initiatives will be required to address "hotspots" of contamination.

Manukau City has two known hotspots of contamination: Pakuranga Creek and Middlemore (although the Middlemore site is likely to be influenced by stormwater inputs from both Manukau and Auckland Cities). Both are located in Tamaki estuary. Manukau City Council is currently considering options for managing stormwater contaminants in the Papatoetoe catchment, which is likely to contribute significant loads of copper and zinc to the Middlemore site. Work has not begun on assessing issues and options for stormwater contaminant management in the Pakuranga catchment. It should also be noted that the southern shore of Mangere Inlet is not monitored. The surrounding catchment contains significant areas of commercial and industrial landuse, so contaminant levels are likely to be elevated in marine sediments. Additional monitoring sites are therefore warranted in this area.

Waitakere City shares some hotspots of contamination with Auckland City, i.e. sites in Whau Estuary. Another Waitakere site with relatively high contaminant levels is Henderson Creek. Project Twin Streams is a Waitakere City Council initiative to achieve better stream and stormwater management, and improve water quality in the catchments draining to the Henderson Creek and Huruhuru Creek (a side-branch of Henderson Creek). Integrated catchment management plans (ICMP's), which address contaminant (and other) issues, will be developed for these catchments, nominally by 2009-10. New Lynn East is the only Waitakere catchment draining into Whau Estuary

that has a completed ICMP. Integrated catchment management plans for the other Whau catchments will be developed after the Project Twin Streams ICMP's are complete. In the interim, WCC has an ongoing capital works programme aimed at improving stormwater quality in Whau catchments. Funding will, in the main, be used to construct stormwater quality devices, especially in brownfields catchments.

Although, contaminant levels on the North Shore are relatively low, concentrations of zinc are increasing rapidly in Lucas and Hellyers Creeks. For instance, zinc concentrations in the fine sediment fraction increased by 55% and 51% respectively at the Upper Lucas Creek and Hellyers Kaipatiki sites between 1998 – 2005. Zinc concentrations at these sites are now approaching (Lucas) or exceed (Kaipatiki) TEL values. Predictions of future trends indicate that concentrations are likely to continue to increase rapidly in these estuaries (Green et al 2004a, Green et al. 2004b). North Shore City Council has developed a city wide integrated catchment management plan for stormwater, but is yet to gain approval for their contaminant management strategy.

5.2 Urban Estuaries with Good Environmental Quality

The condition of most sites with low copper, lead and zinc concentrations has largely been maintained since monitoring commenced. The exceptions are a few SoE and stormwater contaminant monitoring sites which have shown marked increases, particularly in zinc concentration. Besides Lucas and Hellyers Creeks (discussed above) zinc concentrations have increased by 33% at the Weiti, and 27 % at the Pahurehure (Papakura) sites. Although concentrations remain well below TEL values in these two sites, development is occurring in the surrounding catchments, so close attention should be paid to future trends.

Many of the sites with good environmental quality have adjoining catchments with sufficient public open space or undeveloped land to allow a more comprehensive approach to be taken to stormwater management. Consequently, options for managing stormwater quality into the future are greater in greenfield or partially developed catchments than in fully urbanised catchments. The emphasis for the management of these areas is therefore on maintaining the long-term quality of the marine environment by:

- providing adequate treatment for stormwater quality, particularly during catchment development and/or redevelopment;
- future proofing against changing landuse, by designating stormwater management areas in local planning documents;
- regularly maintaining treatment devices to ensure their ongoing performance; and where possible,
- controlling contaminants at source.

5.3 Anomalies

Unusual results were obtained from a number of sites:

1. The ecological condition of some sites in the upper Waitemata Harbour and Manukau Harbour was worse than expected from contaminant levels;
2. The condition of some sites in Hobson Bay were better than expected given the level of urbanisation and commercial development in the adjacent catchment.

5.3.1 Ecological condition of the upper Waitemata Harbour, Puhinui and Pukaki

The Brigham, Rangitopuni, and Paremoremo sites in the upper Waitemata Harbour, Puhinui (upper) and Pukaki (airport site) were ranked either 4 or 5 for benthic community structure, indicating that copper, lead, zinc, and/or another variable that is correlated with these contaminants is adversely affecting ecological "health". Note that the analysis of ecological condition reduces the influence of sediment texture and exposure by grouping sites according to their sediment and exposure characteristics.

Similar observations of poor ecological condition at some upper Waitemata Harbour sites were highlighted by Hewitt et al. (2007) and Cummings et al. (2002). Hewitt et al. (2007) indicated that the low diversity they observed was not necessarily related to mud content, with 67% of the variability in community composition among sites in the upper Waitemata Harbour being explained by organic content, zinc concentration in the fine sediment fraction, sediment accumulation rate, and the percentage of fine and medium sand. The results of stormwater contaminant monitoring indicate that copper concentrations are slightly elevated at many of the upper Waitemata Harbour sites. State of the environment monitoring also indicates that mercury concentrations are above TEL and ERL guideline values at the Paremoremo site. In contrast, sediment concentrations of commonly measured organic contaminants are low at the Paremoremo site (Reed and Webster 2004, McHugh and Reed 2006). Further investigation is required to the confirm the reason(s) for the poor ecological condition of upper Waitemata Harbour sites. These investigations should also: establish the source(s) of copper in the upper Waitemata Harbour; confirm the results for mercury at Paremoremo; and, determine if mercury levels are high in other parts of the upper harbour.

The ecological condition of Pukaki (airport) and Puhinui (upper) was also degraded despite low concentrations of copper, lead and zinc (ecological rank 4). Sediment concentrations of commonly measured organic contaminants are known to be relatively low at both of these sites (Reed and Webster 2004, McHugh and Reed 2006). Further investigation is therefore required to determine the reasons for the degraded ecological condition. However, it is recommended that this work is not undertaken until the results of the ecological analysis have been confirmed in the next sampling round.

5.3.2 Contaminant concentrations in Hobson Bay

The comparatively good ecological condition and relatively low concentration of metals in the <500 µm sediment fraction of the Newmarket site in Hobson Bay was somewhat surprising because:

- the site receives runoff from an old, relatively large urban catchment with significant areas of commercial landuse.
- modelling of zinc loads carried out for Auckland City Council suggests that zinc inputs from the Newmarket catchment are relatively high;
- the sheltered, enclosed nature of Hobson Bay suggests that sediments and associated contaminants would be readily trapped.

Further investigation into the reasons for low zinc concentrations and ecological condition would be informative, but is not warranted at this stage, given that metal contamination of Hobson Bay does not appear to be causing significant problems.

6 Conclusions

Sediment concentrations of the key stormwater contaminants, copper, lead and zinc are greatest in sheltered receiving systems adjoining older urban and industrial parts of Auckland City, Waitakere City and Manukau City. Furthermore, the quality of many old urban areas is continuing to degrade fairly rapidly due to the continuing accumulation of copper and zinc.

In contrast, contaminant concentrations in receiving systems with newer urban catchments tend to be below TEL guideline values, and in most cases copper and zinc concentrations are stable or increasing only slowly. Trends in lead concentrations are more variable. The exceptions are in estuary systems that receive stormwater runoff from catchments where recent, large-scale urban development has occurred, such as Lucas and Hellyers Creeks. Copper and zinc are accumulating more rapidly at these sites.

An evaluation of benthic community structure suggests that contamination is having an effect on the organisms living in estuaries subject to stormwater contamination. In some cases (three upper Waitemata Harbour and two Manukau sites) the ecological condition was worse than expected from existing concentrations of copper, lead and zinc. Further investigation may be required to determine the reason(s) for the poor ecological ranking at these sites.

6.1 Recommendations

Upper Waitemata Harbour: Determine the cause of the poor ecological condition at upper Waitemata sites. Among other things, the investigation should consider the source and consequences of elevated copper at the sites, confirm the mercury concentrations recorded at Paremoremo, and determine if elevated mercury concentrations are widespread in the upper harbour.

Pukaki (airport) and Puhinui (upper): Confirm the ecological status of these sites during the next sampling round.

Southern Mangere Inlet: Establish sampling site(s) on the southern side of Mangere Inlet to assess and monitor the effects of stormwater discharges from the predominantly commercial/industrial catchments adjoining this area.

7 References

Anderson M.J., Hewitt J.E., Ford R.B., Thrush S.F. (2006) Regional models of benthic ecosystem health: predicting pollution gradients from biological data. Auckland Regional Council, TP317, Auckland,103 pp.

Cummings, V, Hatton, S, Nichlolls, P. (2002) Upper Waitemata Harbour benthic habitat survey. Auckland Regional Council, TP219, Auckland, 58pp.

Green M, Timperley M, Collins R, Senior A, Adams R, A. S, Williamson RB, Mills GN (2004a) Prediction of contaminant accumulation in the Upper Waitemata Harbour - Results: Zinc. Auckland Regional Council, TP260, Auckland, 96 pp.

Green M, Timperley M, Collins R, Williamson RB (2004b) Upper Waitemata Harbour Contaminant Study: Summary. Auckland Regional Council, TP250, Auckland, New Zealand, 49 pp.

Hewitt, J., Lundquist, C., Halliday, J., Hickey, C. (2007) Upper Waitemata Harbour ecological monitoring programme: 2005 - 2006. Auckland Regional Council, TP331, Auckland 62 pp.

Long ER, MacDonald DD, Smith SL, Calder FD (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19: 81-97

Long ER, Morgan LG (1990) The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. National Oceanic and Atmospheric Administration, NOAA Technical Memorandum, NOS OMA 52, Seattle, Washington, 175 pp.

MacDonald DD, Carr RS, Calder FD, Long ER, Ingersoll CG (1996) Development and evaluation of sediment quality guidelines for Florida coastal waters. Ecotoxicology 5: 253-278

McHugh M, Reed J (2006) Marine sediment monitoring programme: 2005 results. Auckland Regional Council, TP316, Auckland, 195 pp.

Reed J, Webster K (2004) Marine Sediment Monitoring Programme - 2003 Results. Auckland Regional Council, TP246, Auckland, 146 pp.

Williamson RB, Kelly S (2003) Regional Discharges Project marine receiving environment status report 2003. Auckland Regional Council, TP203, Auckland, 53 pp.

8 Appendix 1: Sediment Quality Guidelines

Sediment quality guideline values referred to in the report. All values are given in $mg.kg^{-1}$.

Source	ARC			MacDonald et al. (1996)		Long and Morgan (1990)	
Guideline	Green	Amber	Red	TEL	PEL	ERL	ERM
Copper	<18	18-34	>34	18.7	108.2	34	270
Lead	<30	30-50	>50	30.2	112.2	47	218
Zinc	<124	124-150	>150	124	271	150	410

9 Appendix 2: Monitoring site details

Harbour	Site	X NZTM	Y NZTM	Zone	Latest Sample	Next Sampling Year	Sampling Interval (years)
Orewa	Orewa, North	1751461	5948632	SZ	2002	2006	5
Orewa	Orewa, Central	1750704	5948584	OZ	2002	2006	5
Orewa	Orewa, South	1750783	5948061	SZ	2002	2006	5
Weiti	Weiti	1751931	5946517	SZ	2005	2005	2
East Coast Bays	Cheltenham	1761384	5923321	OZ	2005	2005	2
Waitemata	Ngataringa	1759558	5923807	OZ	2002	2007	5
Waitemata	Shoal Bay, Lower	1757533	5924310	OZ	2005	2007	2
Waitemata	Shoal Bay, Upper	1757914	5924713	OZ	2004	2006	2
Waitemata	Shoal Bay, Hillcrest	1757379	5925667	SZ	2004	2006	2
Waitemata	Chelsea	1754160	5923688	OZ	2004	2006	2
Waitemata	Beachhaven	1750022	5926837	SZ	2002	2006	2
Waitemata	Kendalls	1752318	5923141	OZ	2004	2006	2
Waitemata	Island Bay	1750556	5924788	SZ	2002	2007	5
Waitemata	Kaipatiki	1751493	5928185	SZ	2005	2007	2
Waitemata	Hellyers	1751357	5928057	OZ	2005	2005	2
Waitemata	Hellyers, Upper	1751499	5928413	SZ	2005	2007	5
Waitemata	Lucas, Te Wharau	1749230	5930235	SZ	2004	2006	2
Waitemata	Lucas, Upper	1749697	5931253	SZ	2005	2007	2
Waitemata	Paremoremo	1745909	5930562	SZ	2005	2007	2
Waitemata	Upper Waitemata	1746747	5929380	SZ	2002	2007	5
Waitemata	Brighams	1742634	5927684	SZ	2005	2010	5
Waitemata	Rangitopuni	1742996	5930079	SZ	2002	2007	5
Waitemata	Rarawaru	1744369	5928559	SZ	2005	2010	5
Waitemata	Herald Island	1747703	5928010	OZ	2005	2010	5
Waitemata	Waiarohia	1746623	5927140	SZ	2005	2010	5
Waitemata	Hobsonville	1749660	5926258	OZ	2005	2010	5
Waitemata	Henderson, Entrance	1748148	5924527	OZ	2004	2006	2
Waitemata	Henderson, Lower	1746276	5922925	SZ	2004	2006	2
Waitemata	Henderson, Upper	1745581	5921754	SZ	2005	2007	2
Waitemata	Whau, Entrance	1748081	5920323	OZ	2004	2006	2
Waitemata	Whau, Lower	1748262	5917476	OZ	2005	2007	2
Waitemata	Whau, Wairau	1748097	5915742	SZ	2005	2007	2
Waitemata	Whau, Upper	1749308	5915109	SZ	2005	2006	2
Waitemata	Pollen Island	1750065	5918198	OZ	2005	2007	2
Waitemata	Oakley	1751160	5917908	DZ	2005	2007	2
Waitemata	Meola Outer	1752316	5920286	OZ	2004	2006	2
Waitemata	Meola Reef	1752458	5920875	OZ	2005	2007	2
Waitemata	Meola Inner	1752380	5919674	SZ	2005	2007	2

Harbour	Site	X NZTM	Y NZTM	Zone	Latest Sample	Next Sampling Year	Sampling Interval (years)
Waitemata	Motions	1752584	5919701	SZ	2005	2007	2
Waitemata	Coxs	1753479	5920533	OZ	2004	2006	2
Hobson Bay	Awatea Rd	1760032	5919666	OZ	2004	2006	2
Hobson Bay	Newmarket	1759728	5918969	OZ	2005	2007	2
Hobson Bay	Victoria Ave	1760836	5918947	OZ	2004	2006	2
Hobson Bay	Purewa	1762474	5918496	SZ	2004	2006	2
Hobson Bay	Whakataka Bay	1761250	5919537	OZ	2005	2007	2
Tamaki	Point England	1766859	5916213	OZ	2004	2006	2
Tamaki	Benghazi	1766817	5915306	OZ	2004	2006	2
Tamaki	Roberta Reserve	1768102	5918846	OZ	2002	2006	5
Tamaki	Panmure	1764512	5913867	SZ	2004	2006	2
Tamaki	Bowden Rd	1765249	5912959	OZ	2004	2006	2
Tamaki	Pakuranga, Upper	1768173	5911686	SZ	2005	2007	2
Tamaki	Princess St	1765814	5910530	OZ	2004	2006	2
Tamaki	Otahuhu Creek	1765554	5911076	DZ	2004	2006	2
Tamaki	Middlemore	1765179	5909106	SZ	2005	2007	2
Manukau	Anns Creek	1762214	5911375	OZ	2005	2007	2
Manukau	Mangere Cemetery	1759965	5911179	OZ	2005	2007	2
Manukau	Pukaki Airport	1760623	5903545	SZ	2005	2005	2
Manukau	Pukaki, Upper	1760410	5904750	SZ	2002	2009	5
Manukau	Pukaki, Waitekauri	1761535	5904107	SZ	2002	2009	5
Manukau	Puhinui, Entrance	1764945	5899795	OZ	2002	2009	5
Manukau	Puhinui, Upper	1765064	5900551	SZ	2005	2005	2
Manukau	Waimahia Creek East	1767789	5898668	DZ	2002	2008	5
Manukau	Waimahia Creek West	1766612	5898765	DZ	2002	2008	5
Manukau	Pahurehure, Middle	1767561	5896924	OZ	2002	2008	5
Manukau	Pahurehure, Papakura	1771307	5896717	DZ	2005	2005	2
Manukau	Pahurehure, Upper	1769610	5897428	OZ	2002	2008	5
Manukau	Papakura Stream, Lower	1768760	5898075	SZ	2002	2008	5
Manukau	Papakura Stream, Upper	1769006	5898214	SZ	2002	2008	5
Manukau	Waiuku	1753313	5877050	SZ	2002	2009	5
Manukau	Blockhouse Bay	1752272	5911617	OZ	2002	2009	5
Manukau	Little Muddy	1746483	5908784	SZ	2002	2009	5
Manukau	Hillsborough	1756792	5911582	OZ	2004	2006	2