

# Marine sediment contaminants: Status and trends assessment 1998-2010

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# Marine sediment contaminants: Status and trends assessment 1998-2010

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# **Table of Contents**

1.0	Exe	ecutive Summary	1
2.0	Inti	oduction	5
2	2.1	Background	5
2	2.2	This report	7
3.0	Мо	nitoring programme outline	9
3	8.1	Sites	9
3	8.2	Sampling	10
3	8.3	Constituents measured	11
4.0	Со	ntaminant status: Concentrations and spatial patterns	13
4	.1	Approach used for status assessment	13
4	.2	Overall contaminant status	15
4	.3	Spatial patterns of contamination	20
4	.4	Arsenic, cadmium, mercury, antimony and tin	28
4	.5	Summary of contaminant distributions	35
5.0	Te	mporal trends	39
5	5.1	Trend assessment approach	39
5	5.2	Factors affecting the "robustness" of trend results	45
5	5.3	Trend results	54
5	5.4	Trend monitoring results compared with modelling predictions.	76
5	5.5	Trend summary	78
6.0	Ov	erall assessment	80
7.0	Ac	knowledgements	99
8.0	Re	ferences	100
Арр	endi	x 1. Single Site Reports	104

# **List of Figures**

Figure 2.1 Site locations for the sediment contaminant monitoring programmes	8
Figure 4.1 Contaminant status summary - site ERC status by MRA	. 16
Figure 4.2 Contaminant status summary - contaminant ERC status by MRA.	. 18
Figure 4.3 Concentrations of metals (Cu, Pb, and Zn) and "high molecular weight" PAH (HWPAH	H)
relative to Environmental Response Criteria (ERC)	. 20
Figure 4.4 Potential contaminant sources contributing to metal and PAH contamination of	
Auckland's marine receiving environment. Monitoring sites and their ERC grades are shown	. 21
Figure 4.5 Map of overall contamination status of sediment monitoring sites	. 22
Figure 4.6 Map of copper status	. 23
Figure 4.7 Map of lead status	. 24
Figure 4.8 Map of zinc status.	. 25
Figure 4.9 Map of high molecular weight PAH status.	. 26
Figure 4.10 Concentrations of arsenic (As) at 27 former SoE sites sampled in 2005	. 30
Figure 4.11 Concentrations of mercury (Hg) at SoE sites sampled in 2005	. 32
Figure 4.12 Concentrations of cadmium (Cd) at SoE sites sampled in 2005	. 33
Figure 4.13 Concentrations of antimony (Sb) and tin (Sn) at SoE sites sampled in 2005	. 34
Figure 5.1 Comparison of trends (mg/kg/year) in metals' concentrations over time obtained from	
linear regression analysis (LR) and the Sen Slope Estimate (Sen Slope)	. 42
Figure 5.2 Comparison of trends (mg/kg/year) in high molecular weight PAH (HWPAH)	
concentrations over time obtained from linear regression analysis (LR) and the Sen Slope	
Estimator (Sen Slope). Data are for all sites with $n \ge 4$ samplings	. 43
Figure 5.3 Distribution of trends (Relative Sen Slope; % median per year) in metals.	. 56
Figure 5.4 Distribution of trends (Relative Sen Slope; % median per year) for HWPAH	. 57
Figure 5.5 Trends (Sen Slopes, mg/kg per year) in extractable (2 M HCl, <63 $\mu$ m fraction) and to	otal
recoverable (<500 $\mu m)$ metals, and HWPAH (<500 $\mu m)$ in sediments from SoE, RDP, and UWH	
programmes. Trends for data from all programmes grouped are also shown	. 61
Figure 5.6 Trends (Relative Sen Slopes, % median concentration per year) in extractable (2 M H	ICI,
<63 $\mu m$ fraction) and total recoverable (<500 $\mu m$ ) metals, and HWPAH (<500 $\mu m$ ) in sediments	
from SoE, RDP, and UWH programmes. Trends from all programmes grouped are also shown	. 62
Figure 5.7 Distribution of trends (Relative Sen Slope; % median per year) in metals.	. 63
Figure 5.8 Distribution of trends (Relative Sen Slope; % median per year) in high molecular weig	jht
РАН (НWPAH)	. 64
Figure 5.9 Map of trends in extractable copper (<63 µm fraction)	. 65
Figure 5.10 Map of trends in extractable lead (<63 µm fraction)	. 66
Figure 5.11 Map of trends in extractable zinc (<63 µm fraction)	. 67
Figure 5.12 Map of trends in total recoverable copper (<500 µm fraction)	. 68
Figure 5.13 Map of trends in total recoverable lead (<500 µm fraction)	. 69
Figure 5.14 Map of trends in total recoverable zinc (<500 µm fraction)	. 70
Figure 5.15 Map of trends in high molecular weight PAH (<500 µm fraction)	.71
Figure 5.16 Relationship between trends (Sen Slopes, mg/kg/year) and metals' concentrations	. 75

Figure 5.17 Relationship between trends (Sen Slopes, mg/kg/year) and HWPAH concentrations. 76
Figure 5.18 Trends in Cu and Zn predicted from contaminant accumulation modelling78
Figure 6.1 Trends in extractable copper (<63 $\mu$ m fraction) for sites with n=4 or more samplings with
sites grouped by sampling programme
Figure 6.2 Trends in extractable lead (<63 $\mu$ m fraction) for sites with n=4 or more samplings with
sites grouped by sampling programme
Figure 6.3 Trends in extractable zinc (<63 $\mu$ m fraction) for sites with n=4 or more samplings with
sites grouped by sampling programme83
Figure 6.4 Trends in total copper (<500 $\mu$ m fraction) for sites with n=4 or more samplings with sites
grouped by sampling programme
Figure 6.5 Trends in total lead (<500 $\mu$ m fraction) for sites with n=4 or more samplings with sites
grouped by sampling programme
Figure 6.6 Trends in total zinc (<500 $\mu$ m fraction) for sites with n=4 or more samplings with sites
grouped by sampling programme
Figure 6.7.Trends in high molecular weight PAH (HWPAH; <500 $\mu$ m fraction) for sites with n=4
samplings with sites grouped by sampling programme

# **List of Tables**

Table 4.1 Environmental Response Criteria (ERC) and associated sediment quality guidelines	
(SQGs) 1	3
Table 4.2 Contaminant status summary by MRA1	7
Table 4.3 Concentrations of arsenic (As), cadmium (Cd), mercury (Hg), antimony (Sb) and tin (Sn)	)
in sediments from the 27 SoE programme sites2	29
Table 4.4 Sediment contaminant status by site	36
Table 5.1 A summary of sampling and analysis providers and methods used in the SoE, RDP, and	b
UWH programmes between 1998 and 2010 4	9
Table 5.2 A summary of the data used for trend analysis	53
Table 5.3 Overview of trends detected across all monitoring sites with N ≥4 samplings	55
Table 5.4 Broad-scale trends over time. Data are Sen Slopes (mg/kg/year). N is the no. of sites. 5	59
Table 5.5 Broad-scale trends over time. Data are Relative Sen Slopes (% of median per year). N i	is
the number of sites	30
Table 6.1 Raw trend analysis data for extractable copper (<63 µm)8	38
Table 6.2 Raw trend analysis data for extractable lead (<63 µm)8	39
Table 6.3 Raw trend analysis data for extractable zinc (<63 µm)9	90
Table 6.4 Raw trend analysis data for total copper (<500 µm)9	<del>)</del> 1
Table 6.5 Raw trend analysis data for total lead (<500 µm)9	92
Table 6.6 Raw trend analysis data for total zinc (<500 µm)9	)3
Table 6.7 Raw trend analysis data for High molecular weight PAH (<500 µm)9	94
Table 6.8 Modelling predictions summary for Zinc    9	<i>)</i> 5
Table 6.9 Modelling predictions summary for Copper         9	97

# **1.0 Executive Summary**

#### Background

Estuarine sediments can accumulate chemical contaminants originating from land-based activities. Sediment contamination therefore provides a useful marker of land use impacts on aquatic receiving environments. In addition, the build-up of contaminants can cause changes in the ecological health of an area by reducing the abundance or diversity of sensitive species, leaving degraded communities dominated by species that are tolerant of higher contaminant levels.

Understanding the distribution of contaminants in marine sediments, their potential effects on aquatic ecology, and trends over time in chemical contamination is therefore important for effective resource management of coastal areas.

Marine sediment contamination monitoring, in conjunction with ecology monitoring, has been conducted by Auckland Council (AC) and the former Auckland Regional Council (ARC) since 1998, in three complementary programmes:

- The State of the Environment (SoE) marine sediment monitoring programme, covering 27 sites, monitored every two years since 1998. This programme aimed to provide long-term information on contaminant status and trends across the region;
- 2. The Regional Discharges Project (RDP), which monitored an additional 51 sites, at 2–5 yearly intervals. Monitoring in the RDP began in 2002, and was administered by the ARC on behalf of the region's Territorial Local Authorities (TLAs). This programme was aimed primarily at monitoring the effects of stormwater discharges, as part of the TLA stormwater network discharge consenting programme; and
- The Upper Waitemata Harbour (UWH) benthic ecology programme, which has monitored 14 Upper Waitemata Harbour sites annually since 2005. This programme provides specific information on the effects of predicted urban development on the Upper Waitemata Harbour;

In order to achieve efficiencies and cost savings for Auckland Council the contaminant chemistry components of the SoE, RDP, and UWH programmes have recently been combined into a single programme, the "Regional Sediment Chemistry Monitoring Programme" (RSCMP).

Information collected in the RSCMP is available for a wide range of end users and stakeholders. Uses of the monitoring data include:

- State of the Environment reporting;
- stormwater quality management;
- resource consenting;
- policy development, and
- public education.

The RSCMP data complement those obtained in other AC programmes (Coastal Water Quality, Shellfish Contaminants, and Benthic Ecology), which together aim to provide consistent, long-term information on the quality of Auckland's coastal environment. This enables AC's performance, in respect to its resource management responsibilities for protecting the coastal environment from the effects of land use activities and contaminant discharges, to be assessed.

Information from the Sediment Contaminant Monitoring Programme is also used to measure the success of several strategic directives in the Auckland Plan including: Directive 7.10 "Manage land to support the values of waterbodies by protecting them where they are high and reviving them where they are degraded" and Directive 7.12 "Protect coastal areas - particularly those with high values - from the impacts of use and development, and enhance degraded areas". These outcomes also contribute towards Auckland's vision of becoming the world's most liveable city.

#### This report

This report brings together sediment chemistry monitoring data collected in the three former ARC programmes – the former State of the Environment (SoE) programme, the Regional Discharges Project (RDP), and the Upper Waitemata Harbour Ecological Programme (UWH) – and analyses them to evaluate:

- Chemical contamination "status" in Auckland's estuaries and harbours spatial patterns
  of sediment contamination, and the potential impacts of this contamination on benthic
  ecosystem health, as inferred from comparison of contaminant concentrations with
  sediment quality guidelines<sup>1</sup>; and
- **Temporal trends** in contaminant concentrations between 1998 and 2010 (inclusive), focusing on changes over time in the concentrations of key indicators of urban contamination the heavy metals copper (Cu), lead (Pb), and zinc (Zn), and polycyclic aromatic hydrocarbons (PAH).

#### Key findings

The spatial distribution of contaminants in sediments followed the same patterns reported previously in ARC sediment contaminant monitoring reports. The distribution of metals (Cu, Pb, and Zn, and probably also mercury (Hg), tin (Sn), cadmium (Cd), and antimony (Sb)) follows a well-described spatial pattern. Highest contaminant concentrations are generally found in the muddy upper reaches of estuaries receiving runoff from the older, intensively urbanised and/or industrialised catchments, particularly in the Tamaki Estuary and Central Waitemata Harbour. Lowest concentrations are found in rural/forested catchment estuaries and open coastal beaches.

Regionally, the proportions of monitoring sites included in the current status assessment falling into the ERC Green, Amber and Red ranges were as follows:

<sup>&</sup>lt;sup>1</sup> The sediment quality guidelines used in this report to infer potential adverse effects on ecosystem health are the ARC "Environmental Response Criteria" (ERC; TP168, ARC 2004a). A brief description of the ERC is given in section 4.1.

- 41% were rated as ERC Green, reflecting a relatively low level of chemical contaminant impact. At these sites, effects on benthic ecology from individual metals or PAH are considered unlikely to be significant. Note, however, that benthic health modelling has shown that subtle, but measurable, effects on benthic ecology may be occurring in the ERC green range (Hewitt et al. 2009).
- Approximately 43% of the sites were in the ERC Amber range. These sites are showing signs of chemical contamination, at levels where adverse effects on benthic ecology may begin to appear. Amber sites are widely distributed throughout the central and upper Waitemata Harbour, in Mangere Inlet, and in the Tamaki Estuary.
- Approximately 16% of the sites were rated as ERC Red. These sites are the most highly
  contaminated of the monitored locations. Adverse effects on benthic ecology would be
  expected to occur more frequently at these sites than at the less contaminated ERC Amber
  or Green locations. ERC Red sites were present mostly in the Upper Tamaki Estuary, and
  in the urbanised Central Waitemata Harbour catchment sub-estuaries.

Zinc was the metal that most often reached the ERC Red concentrations, while copper was in the ERC Amber range most frequently.

PAH concentrations at the majority of sites were well below the ERC Amber threshold, and are therefore considered unlikely, on their own, to be causing adverse effects on benthic ecology at most sites. However, it is possible that they may contribute to cumulative effects that might be associated with the presence of multiple contaminants. PAH concentrations were generally correlated with metals' concentrations. Motions and Meola estuaries (in the Central Waitemata Harbour) were notable exceptions, having unusually high PAH levels (indicating additional PAH sources to these estuaries).

Trends over time in metals' and PAH concentrations across the region were generally small, and, on average, little change has occurred over the monitoring period. However, decreases in Pb concentrations have been recorded at most urban sites, which may reflect the effect of removal of Pb from petrol (a key source of Pb) in the mid-1990s. Trends in Cu and Zn were more variable, with no obvious consistent pattern among sites. Where significant changes in Zn concentrations have occurred, these were mainly increases. This supports a commonly held view (and is generally consistent with modelling predictions) that Zn concentrations are likely to increase over time at most urban sites.

While statistically significant trends have been measured at some sites, definitive conclusions regarding the "real-world" significance of these trends cannot be made at this stage. This is because of:

 Uncertainties associated with the analytical data. In particular, a lack of "benchmarking" over time prevents us from assessing whether the observed trends are real, or if some component of the trends is due to analytical variation over time. As a result of the trend assessments carried out in this project, improved benchmarking measures have been added to the monitoring programme's quality assurance protocols. These are detailed in a separate review of the sediment chemistry monitoring programme (Diffuse Sources, in prep.).

• The relatively short length of time that the monitoring programme has so far been conducted, and the small numbers of samplings at many sites. A more robust picture of trends will emerge as the trend record grows with future monitoring.

#### **Concluding remarks**

Despite issues associated with the monitoring data quality (variability and uncertain consistency over time), the sediment contaminant monitoring programmes have delivered a wealth of useful information on the spatial distribution and general trends in key urban contaminants in Auckland's marine sediments.

The monitoring data clearly identify areas with differing levels of contamination, and now provide a comprehensive spatial picture of contaminant levels in the Auckland coastal zone. This has provided a better understanding of the impacts of land use on receiving environments, and (via integration with ecological health monitoring and modelling<sup>2</sup>) the potential ecological impacts of this contamination.

The overall picture obtained from trend analysis is that while there is considerable complexity (with differences between sites, contaminants, and programmes), broad-scale changes in sediment contamination by metals and PAHs since 1998 have generally been small. A decrease in Pb concentrations at most urban sites has been measured, which may reflect the beneficial effect of removal of a key Pb source (leaded petrol) in the mid-1990s.

The data analysis conducted in this status and trends review has also improved our understanding of the capabilities and limitations of current sediment contaminant monitoring methods. This information is being used to improve the quality of future monitoring data, and hence provide greater certainty for future trend assessments.

Overall, the sediment contaminant monitoring data analysed in this project indicate that the spatial patterns of contamination are broadly the same as reported previously, and that contaminant concentrations in most areas have not changed greatly since 1998. This picture is generally consistent with modelling predictions, and provides some reassurance that rapidly increasing contamination in Auckland's estuaries, as a result, for example, of stormwater discharges, is not a widespread occurrence. However, because of uncertainties associated with the monitoring data, continued monitoring is recommended to provide greater surety in future trend assessments. Furthermore, continued monitoring will allow the success of current and proposed contaminant discharge and land use management policies to be appropriately evaluated.

<sup>&</sup>lt;sup>2</sup>An updated ecological assessment, using the Benthic Health Model (BHM), is to be reported separately in 2012.

# 2.0 Introduction

## 2.1 Background

Sediments accumulate many chemical contaminants originating from land-based activities, and sediment contamination therefore provides a useful marker of land use impacts on aquatic receiving environments and ecosystem health.

In 1998, the Auckland Regional Council (ARC) initiated a sediment contaminant monitoring programme aimed at assessing the spatial distribution and temporal trends in key chemical contaminants across the region's urban estuaries, harbours, and beaches. Key objectives of this "State of the Environment" (SoE) monitoring programme were to assess the effects of catchment land use, in particular urbanisation, on marine environmental quality, and the effectiveness of resource management initiatives and policies in mitigating adverse effects arising from land use activities.

Subsequently, two additional programmes have been used to acquire sediment contaminant data – the "Regional Discharges Project" (RDP), and the "Upper Waitemata Harbour Benthic Ecology Programme" (UWH).

Briefly, these complementary programmes were as follows:

- State of the Environment (SoE) marine sediment monitoring programme, covered 27 sites, monitored every two years since 1998. This programme aimed to provide long-term information on contaminant status and trends across the region;
- Regional Discharges Project (RDP), which monitored an additional 51 sites, at 2–5 yearly intervals (depending on their contamination status; see Kelly 2007). Monitoring in the RDP began in 2002, and was administered by the ARC on behalf of the region's Territorial Local Authorities (TLAs). This programme was aimed primarily at monitoring the effects of stormwater discharges, as part of the TLA stormwater network discharge consenting programme; and
- 3. The UWH programme, which has monitored 14 Upper Waitemata Harbour sites annually over a 4 year period (i.e. 5 samplings), from 2005–2009 (inclusive). This programme provides specific information on the effects of urban development on the Upper Waitemata Harbour;

The locations of the sites monitored in these programmes are shown in Figure 2.1

Details of the monitoring programme design, operation, and results are given in a number of reports, most recently Kelly (2007) and Lundquist et al. (2010).

Data from the former SOE and RPD monitoring programmes have been compiled and reported annually – e.g. Reed and Gadd (2009) for the SoE, Diffuse Sources (2007 to 2011) for the RDP programme.

Every few years, the data and programme operation are reviewed to assess longer-term patterns and trends in contamination, and to assess operational changes that may be required to improve programme performance.

The last review of the SoE programme was conducted in 2002 (Timperley and Mathieson 2002), and covered the initial three-year phase of the programme, from 1998–2001.

The Auckland Council (AC) has continued the former ARC sediment chemistry monitoring programmes, and, in order to achieve efficiencies and cost savings, has integrated the contaminant chemistry components of the SoE, RDP, and UWH programmes into a single programme, the "Regional Sediment Chemistry Monitoring Programme" (RSCMP).

Information collected in the RSCMP is available for a wide range of end users and stakeholders. Uses of the monitoring data include:

- State of the Environment reporting;
- stormwater quality management;
- resource consenting;
- policy development, and
- public education.

The RSCMP data complement those obtained in other AC programmes (Coastal Water Quality, Shellfish Contaminants, and Benthic Ecology), which together aim to provide consistent, long-term information on the quality of Auckland's coastal environment. This enables AC's performance, in respect to its resource management responsibilities for protecting the coastal environment from the effects of land use activities and contaminant discharges, to be assessed.

Information from the Sediment Contaminant Monitoring Programme is also used to measure the success of several strategic directives in the Auckland Plan including: Directive 7.10 "Manage land to support the values of waterbodies by protecting them where they are high and reviving them where they are degraded" and Directive 7.12 "Protect coastal areas - particularly those with high values - from the impacts of use and development, and enhance degraded areas". These outcomes also contribute towards Auckland's vision of becoming the world's most liveable city.

Note that sediment chemistry sampling has also been carried out in conjunction with benthic ecology monitoring in a number of additional estuaries and programmes around Auckland, including the Kaipara and Mahurangi Harbours, and Whangateau, Wairoa, Waiwera, Puhoi, Mangemangeroa, Waikopua, Okura, Turanga, and Orewa estuaries. These programmes are not currently part of the on-going sediment contaminant monitoring programme, so are not reported here. Data for these sites can be found in reports appearing on the Auckland Council website – to date these include: Hailes et al. (2010) for the Kaipara Harbour; Townsend et al. (2010) for the Whangateau Harbour; Halliday and Cummings (2012) for the Mahurangi Estuary; Hewitt and Simpson (2012) for Waiwera, Puhoi, Mangemangeroa, Waikopua, Okura, Turanga, and Orewa estuaries and Lohrer et al. (2012) for the Wairoa embayment.

## 2.2 This report

This report reviews the chemical contaminant monitoring data collected in the RSCMP, using data acquired in the former SoE, RDP, and UWH programmes<sup>3</sup>.

The following areas are addressed in the report:

- 1. Assessment of spatial patterns of sediment contamination across the Auckland area, as defined by SoE, RDP, and UWH monitoring sites;
- 2. Comparison of contaminant concentrations with sediment quality guidelines (ERC), to assess the potential impacts of contaminants on benthic ecosystem health<sup>4</sup>;
- 3. Assessment of temporal trends in contaminant (Cu, Pb, Zn, and PAH) concentrations between 1998 and 2010 (inclusive);
- 4. Brief evaluation of how temporal trends compare with modelling predictions (in areas where modelling has been conducted and output data has been available).

Based on these assessments, recommendations for future monitoring are made. These are discussed further in a separate report (Diffuse Sources; in prep), which reviews operational aspects of the sediment chemistry monitoring programme.

Limiting the accumulation of contaminants over time in the receiving environment has been a key goal for stormwater management in the Auckland region. Contaminant accumulation trends provide feedback on the effects of land use practices and the effectiveness of management policies relating to land use and stormwater discharges. They also enable us to predict what the future may hold, in particular for potential impacts on the health of aquatic ecosystems.

Obtaining a clear, reliable, picture of contaminant trends over time is therefore critical to effective on-going resource management. Evaluation of temporal trends in contaminant concentrations is therefore a major focus of this review.

<sup>&</sup>lt;sup>3</sup>The UWH programme has monitored sediment contaminant chemistry annually since 2005 at sites close to several former RDP sites in the UWH. To minimise duplication, monitoring at nearby former RDP sites has been dropped, and is now covered by the UWH programme.

<sup>&</sup>lt;sup>4</sup> Actual impacts on benthic ecosystem health are reported separately in a benthic health report. See Hewitt et al. 2012 for further information.



Figure 2.1 Site locations for the sediment contaminant monitoring programmes.

# 3.0 Monitoring programme outline

### 3.1 Sites

The locations of the sites monitored in these programmes are shown in Figure 2.1. More detailed location maps are shown in "Single Site Reports" (SSRs) given in Appendix 1.

Monitoring sites are spread across the range of catchment land uses and histories. Because a key focus of the RDP programme was to manage the impacts of urban stormwater, most of the sites are located in areas receiving runoff from predominately urban catchments.

The urban catchments cover a wide range of predominant land use(s) and histories, including:

- old commercial/industrial areas (e.g. Mangere Inlet sites at the Cemetery and Ann's Creek);
- newer mixed industrial/commercial/residential areas (e.g. Whau River, Tamaki Estuary sites);
- older, mainly residential areas (e.g. Hobson Bay at Newmarket, Coxs Bay);
- newer, but well-established, urban areas (e.g. Pakuranga Creek), and
- developing urban catchments (e.g. Weiti at Silverdale).

Predominantly rural catchment sites are less represented, but include several in the Upper Waitemata Harbour such as Brighams, Paremoremo, Rangitopuni, and Rarawaru Creeks.

Reference sites (rural catchments having very little urban activity and catchment land cover dominated by regenerating bush and/or pasture) include Te Matuku Bay on Waiheke Island, and Big Muddy Creek in the outer reaches of the Manukau Harbour.

Sediment contaminant concentrations generally reflect the predominant land use in the surrounding catchment, with older, intensively developed catchment sites having highest levels, and rural/reference sites the lowest contaminant levels.

The sites are located in the intertidal zone, and cover a broad range of sediment textures. Many sites are soft and "muddy" with a significant proportion of silt and clay (particles <63  $\mu$ m) and very fine sand (63–125  $\mu$ m). The dominant representation by muddy sites reflects the accumulation of fine sediment in many estuarine locations as a consequence of historical land development. These muddy zones are more likely to trap and accumulate contaminants, and hence they are useful as sentinel sites for assessing the effects of runoff from upstream catchments.

Firmer, sandier textured sites include the East Coast beach sites (Browns Bay, Cheltenham, Long Bay beaches at the Awaruku and Vaughan's Stream mouths), Mill Bay and Blockhouse Bay (Manukau Harbour), "outer zone" (OZ) sites in the main body of the Waitemata Harbour (e.g. Henderson Entrance, Meola Outer, Hobsonville, Herald Island), some locations in Hobson Bay (e.g. Hobson Newmarket) and Te Matuku Bay (Waiheke Island).

Sediment texture (summarised as the mud content % <63  $\mu$ m) is given for each site in the SSRs (Appendix 1).

### 3.2 Sampling

Sampling at both the former SoE and RDP programme sites is carried out using protocols detailed in the monitoring "blueprint" document, ARC Technical Publication 168 (TP168, ARC 2004a). Briefly this involves taking 5 replicate sediment samples from an approximately 50 x 20 m plot<sup>5</sup> marked out at each monitoring site. Each replicate is made up from 10 sub-samples taken at regular intervals (approximately every 2 metres) along two designated longitudinal transects within the sampling plot. The sampling depth is 0–2 cm.

Sampling in the UWH programme is undertaken using a different protocol (Lundquist et al. 2010). Briefly, this involves collection of at least three replicate cores (5 cm diameter, 0-2 cm depth) from three random locations within the site. This generates 3 replicate samples, each sample made up from at least 3 sub-samples.

Samples are analysed for chemical contaminants and particle size distribution, with the number of replicates analysed varying between contaminants and monitoring programmes (as described in section 3.3).

Generally, three of the replicates are analysed for metals (Cu, Pb, and Zn) and polycyclic aromatic hydrocarbons (PAH), and one replicate (or a single composite made up from equal amounts of three replicates) is used for particle size analysis or for "special" non-routine surveys of other contaminants (e.g. organochlorines, mercury and other heavy metals). The remaining two replicates are kept frozen in case unusual results require checking. A portion of each of three replicates is also retained for long-term archiving. The archived samples are freeze-dried, sieved (<0.5 mm), and stored in glass jars.

Sampling frequency is biannual (i.e. every 2 years) at former SoE programme sites, and 2–5 yearly for former RDP programme sites – more highly contaminated sites are monitored more frequently than cleaner sites. UWH programme sites have been sampled annually from 2005 (data from 2005 to 2009 inclusive was available for this report). The SSRs in Appendix 1 show the data obtained for each site.

Sample collection in the former SoE programme was undertaken between April and September in 1998 and 1999, and in August for 2001–2007. Sampling in the RDP programme (and for SoE sites in 2009) was conducted in October each year. Sampling in the UWH programme has been undertaken in November each year.

The timing of the chemical contaminant sampling is not considered critical, because concentrations are not expected to vary greatly over relatively short time intervals (e.g. weeks-to-months), and the focus of the monitoring is long-term trends (several years-to-decades). In addition, samples are taken from the top 2 cm of the sediment profile. This provides an integrated mixture of freshly deposited material and older sediment from deeper in the profile, the sediments being mixed by biological (bioturbation) and physical processes. This mixing is likely to "smooth" out short-term variations in contaminant levels in the samples taken for analysis.

<sup>&</sup>lt;sup>5</sup>Some sites, generally in the broader outer harbour locations, are 100 x 100 m. These sites are sampled in the same ways as the smaller 50 x 20 m upper estuary sites.

### 3.3 Constituents measured

The chemical contaminants and sediment physical properties monitored are described briefly below:

**Extractable metals** – copper (Cu), lead (Pb), and zinc (Zn) – are measured on the <63  $\mu$ m sediment fraction. Extraction is via cold 2 M HCl, a weaker extraction medium than that used in total recoverable digestion for "total metals". This more closely approximates the "reactive", and potentially more bioavailable, metal fraction. This method was developed "in-house" at NIWA. The use of the <63  $\mu$ m fraction reduces variability associated with particle size variations, improving the comparability between sites and over time. The extractable metals are therefore the preferred metals' indicators for temporal trend assessment.

**Total recoverable metals** – Cu, Pb, and Zn – are determined from hot, strong acid digestion (HNO<sub>3</sub>/HCl, USEPA Method 200.2). Samples are analysed on the <500  $\mu$ m (<0.5 mm) fraction, which approximates the total sediment (with larger coarse particles – e.g. shell hash, gravel – removed to reduce variability). The total metal results are used to compare with sediment quality guidelines (SQG), which have generally been derived using metals' concentrations obtained via strong acid digests of total sediment samples.

**Polycyclic aromatic hydrocarbons** (PAH), **total organic carbon** (TOC), **organochlorine pesticides** (OCP), and **polychlorinated biphenyls** (PCB) are measured on freeze-dried, sieved (<500 μm) samples. TOC is used for calculating TOC-normalised concentrations, the units used for organic contaminant SQG (usually expressed as ng/g at 1% TOC). This reduces the variability associated with differences in the organic matter (the primary organic contaminant binding phase in sediments) content between samples and/or sites. Note that PAH and TOC data are presented in this report (see SSRs in Appendix 1). A review of other organic contaminant data (PCBs, OCP, emerging contaminants) is to be undertaken in 2012.

Particle size distribution (PSD) has been determined by two different methods. The method used in the SoE and RDP programmes, up to 2008, was laser particle size analysis. Samples were analysed in the 0-300 µm size range, and also in the 2-600 µm size range for sediments with significant amounts of coarse particles >300 µm. Data for particle areas, volumes, and numbers were obtained in several different ranges within the  $0-300 \,\mu\text{m}$  (or  $2-600 \,\mu\text{m}$ ) range. Since 2009, PSD has been determined by wet sieving/pipette analysis (Lundquist et al. 2010). This is the method used in ARC/AC benthic ecology programmes, including the UWH programme. The particle size distribution data are used primarily to assess whether there have been changes in texture over time (e.g. increasing muddiness) that may influence contaminant concentrations or affect benthic fauna; e.g. increasing amounts of fine muddy sediment could increase the total metals' concentrations and could change the benthic faunal assemblage. The SSRs (Appendix 1) provide a summary of the "mud content" of the sediments at each site. The data used are the % total area <63 µm (determined from laser PSD analysis) and (for the UWH sites and SoE/RDP sites in 2009 and 2010) the % by weight <63 µm (from pipette/sieving method). These <63 µm fraction measures were found to be well correlated overall, with, on average, a 1:1 linear relationship (Diffuse Sources, in prep). However, the relationship showed considerable scatter, and therefore there may be substantial differences between the two different measures of mud content at individual sites, especially at sandier sites, where the proportions of mud are low. Where both laser PSD data and pipette/sieving method data were available from the same site and year, the results were averaged. The PSD trend results shown for each site in Appendix 1 are therefore best viewed as indicative at sites where changes in analysis method in 2009 occurred (SoE and RDP sites).

Three of the five replicates collected in each sampling round are used for chemical analysis, and two are retained in case checking of unusual results is required. Where only a single sample is analysed (e.g. for total metals in the SoE programme before 2009, or for PSD), this is usually a composite sample prepared from equal amounts of the 3 replicates used for other chemical analyses.

The following constituents have been measured in special "one off" surveys at the SoE sites:

- The toxic elements mercury (Hg), arsenic (As), tin (Sn), cadmium (Cd), and antimony (Sb), which were analysed in samples taken in 2005 (McHugh and Reed 2006);
- Organochlorine pesticides (OCPs), including DDTs, dieldrin, chlordanes, lindane, and endosulfans, which were analysed in samples collected in 2003 and 2007 (Reed and Webster 2004, and Reed and Gadd 2009 respectively); and
- Polychlorinated biphenyls (PCBs), which were analysed in samples taken in 2003 (Reed and Webster 2004).

These constituents were analysed in the <0.5 mm (<500  $\mu$ m) sediment fraction.

The organic contaminant data is the subject of a separate review, to be undertaken in 2012, so has not been reported here. The Hg, As, Cd, and Sb data are summarised in section 4.4.

# 4.0 Contaminant status: Concentrations and spatial patterns

### 4.1 Approach used for status assessment

The assessment of contaminant status aims to provide an up-to-date picture of the concentrations of metals and PAH across the region's "marine reporting areas" (MRAs), which are used for communicating "State of Auckland" report card information to the public and Auckland Council local boards<sup>6</sup>:

Contaminant concentrations are compared with sediment quality guidelines (SQG), using the ARC Environmental Response Criteria (ERC; ARC 2004a) to provide an indication of the potential effects of these contaminants on benthic ecology. Those relevant to this report are summarised in Table 4.1. The basis for these guidelines and their relationship to other SQGs is described in ARC (2004a).

**Table 4.1** Environmental Response Criteria (ERC) and associated sediment quality guidelines (SQGs). Units are mg/kg dry weight for copper, lead, and zinc, and mg/kg at 1% Total Organic Carbon (TOC) for high molecular weight polycyclic aromatic hydrocarbons (HWPAH).

	ERC (ARC 2004a) <sup>1</sup>			MacDonald et al. (1996)		Long and Morgan (1990)		ANZECC (2000)	
Substance	Green	Amber	Red	TEL	PEL	ERL	ERM	ISQG-Low	ISQG-High
Copper	<19	19–34	>34	18.7	108.2	34	270	65	270
Lead	<30	30–50	>50	30.2	112.2	47	218	50	220
Zinc	<124	124–150	>150	124	271	150	410	200	410
HWPAH <sup>2</sup>	<0.66	0.66–1.7	>1.7	0.66	6.7	1.7	9.6	1.7	9.6

<sup>1</sup> Values for metals are for total recoverable metals in the <0.5 mm fraction in the settling zone (SZ), and the greater of the total recoverable metals in the <0.5 mm fraction or the weak acid extractable metals in the mud fraction (<63  $\mu$ m) within the outer zone (OZ).

<sup>2</sup> Guidelines for organic contaminants are given in concentrations "normalised" to a sediment organic carbon content of 1%. High Molecular Weight (HW) PAH is the sum of the concentrations of benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene (as defined in ANZECC 2000).

Each set of SQGs provides:

• a lower range of contaminant concentrations (TEL, ERL, or ISQG-Low), below which adverse effects on benthic ecological health are unlikely to occur; and

<sup>&</sup>lt;sup>6</sup>More information on the MRAs and report cards can be found at: <u>http://stateofauckland.aucklandcouncil.govt.nz/</u>

• a higher range of concentrations (PEL, ERM, ISQG-High), above which marked adverse effects on a substantial proportion of benthic species is expected.

The MacDonald et al. (1996) guidelines, developed for use in Florida, are the "Threshold Effects Level" (TEL) and "Probable Effects Level" (PEL). The Long and Morgan (1990) SQGs are "Effects Range Low" (ERL) and "Effects Range Median" (ERM). ANZECC (2000) provides "Interim Sediment Quality Guideline – Low" (ISQG-Low) and ISQG-High.

The ARC green/amber ERC threshold is essentially the TEL (MacDonald et al. 1996). The TEL and PEL guideline values were derived from toxicological studies that included both "effect" and "no-effect" results on 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 (e.g. Long and Morgan ERL and ERM values). This is consistent with the use of 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.

The amber/red ERC threshold is essentially the ERL (Long and Morgan 1990). This is still a relatively sensitive SQG, with contaminant concentrations well below those at which "marked adverse effects" (e.g. PEL or ERM) would be expected to occur.

ERC Green conditions reflect a low level of impact. Further investigations are not required unless significant changes in upstream catchment land use occur. The status is reassessed every 5 years.

ERC Amber sites are showing signs of contamination, having one or more contaminants above a level at which adverse effects on benthic ecology may begin to show (the TEL). Ecological evaluation is required to assess the actual biological impacts occurring. Depending on the outcome of this monitoring, further chemical testing may be required. Management actions taken as early as possible are likely to be most effective at limiting further degradation. These sites present the best opportunity to make a difference to the future quality of the receiving environment.

ERC Red sites are higher impact sites where significant degradation has already occurred, and remedial opportunities are often more limited. Restoration of the site may not be feasible in the short term, but actions should be taken to slow the rate of decline and limit the spread of contaminants.

To provide as robust and up-to-date an assessment as possible, the contaminant data were selected as follows:

- Metals' data were used only from sampling conducted in the past 5 years (2006–2010). Of these data, the most recent sediment chemistry data at each site were used.
- The latest available PAH data were used, but because PAH have been less frequently monitored than metals, data were taken from any sampling date (not just the past 5 years, as done for metals). Both PAH (as HWPAH<sup>7</sup>) and TOC data are required to determine

<sup>&</sup>lt;sup>7</sup>HWPAH have been used to assess the status of PAH, as detailed in ARC (2004a). Briefly, this is because these "high molecular weight" PAH compounds are more accumulative and persistent in sediments, and less prone to losses during sample analysis, than lower molecular weight species. The compounds making up the HWPAH group are listed in the footnote to Table 4.1.

HWPAH normalised to1% TOC, which is the concentration unit required for comparison with ERC guidelines.

- Sites were selected to provide best overall spatial coverage without having overrepresentation in any one small area where more than one site is located in the same location, with similar sediment chemistry, the site with the most recent data was selected.
- The median concentrations at each site were used for status assessment. Medians and means were generally similar (and give the same ERC grades across all sites).

Medians were chosen because some monitoring results have 2 replicates with very similar concentrations, and 1 replicate with a reasonably different value. The median therefore probably provides a more robust indicator of "average" or "typical" value under these circumstances (being less affected by outlying values).

Overall, 81 sites were selected for status assessment, with the following allocations between the seven Marine Reporting Areas (MRAs)

- 26 sites in the Central Waitemata Harbour MRA;
- 18 sites in the Manukau Harbour;
- 10 in Tamaki Estuary;
- 19 in the Upper Waitemata Harbour;
- 3 in East Coast Bays;
- 4 in Hibiscus Coast; and
- 1 in the Tamaki Strait MRA (on Waiheke Island)

The sites selected are shown in the "status" maps in Figures 4.5 to 4.9. Data are tabulated at the end of this chapter (Table 4.4).

The distribution of sites between the three ERC classes ("green", "amber", and "red") has been summarised in Figure 4.1, which plots the number of sites within each ERC class, and the percentages of sites in each ERC class for all the sites and for each MRA.

### 4.2 Overall contaminant status

The overall status of sediment contamination – the numbers and percentages of monitoring sites within each of the ERC green, amber, and red ranges – is summarised in Figure 4.1, and in Table 4.2.

The numbers and proportions of individual contaminant concentrations within each ERC range are shown in Figure 4.2.





Numbers and percentages of sites with contaminant concentrations within the Environmental Response Criteria (ERC) green, amber, and red ranges for all contaminants combined. Sites are grouped by location (Marine Reporting Area; MRA) and for all sites selected for status assessment (overall).

#### Table 4.2 Contaminant status summary by MRA.

Numbers and percentages of monitoring sites within the Environmental Response Criteria (ERC) green, amber, and red ranges. These data are shown spatially in the map given in Figure 4.5.

	Numbers of sites			% of sites			
Marine Reporting Area	Green	Amber	Red	Green	Amber	Red	
Central Waitemata Harbour	4	15	7	15.4	57.7	26.9	
East Coast Bays	2	1	0	67.0	33.0	0.0	
Hibiscus Coast	4	0	0	100.0	0.0	0.0	
Tamaki Estuary	2	2	6	20.0	20.0	60.0	
Manukau Harbour	15	3	0	83.3	16.7	0.0	
Tamaki Strait	1	0	0	100.0	0.0	0.0	
Upper Waitemata Harbour	5	14	0	26.3	73.7	0.0	
Overall	33	35	13	40.7	43.2	16.1	

Overall, approximately 41% of the monitoring sites selected for status assessment are rated as "ERC-Green" – i.e. having no contaminants (Cu, Pb, Zn or HWPAH) present at concentrations exceeding the green/amber ERC threshold. Contaminants in these areas should pose only a low level of risk to benthic fauna. However, ARC's Benthic Health Model (BHM; see Anderson et al. 2006, Hewitt et al. 2009 and Hewitt et al. 2012) indicates that adverse effects on benthic community health are being found in the "ERC-green" range of metals' concentrations, and hence conclusions on the effects of the metals based solely on comparisons with ERC must, at this stage, be treated with some caution.

Approximately 43% of the sites are rated as "ERC-amber", i.e. where at least one of the four contaminants falls in the ERC-amber concentration range. Many of the "amber" sites are located in the Central Waitemata Harbour (mostly associated with slightly elevated Cu and Pb), Tamaki Estuary (Cu and Pb) and Upper Waitemata Harbour (slightly elevated Cu).

High contaminant concentrations, i.e. where at least one of the four contaminants falls in the ERC-Red range, were found at 13 sites (16%); 7 sites in the Central Waitemata Harbour, and 6 in the Tamaki Estuary. Of the ERC-Red threshold exceedances, 12 were for Zn, 3 for Pb, 3 for PAH, and 2 for Cu. The most contaminated sites, with more than one contaminant exceeding the ERC-Red threshold were Meola Inner, Motions (Inner), Whau Upper, and Whau Wairau – all in the Central Waitemata Harbour. Whau Upper and Whau Wairau were the only sites with all three metals (Cu, Pb, and Zn) in the ERC-Red range, while Meola Inner exceeded ERC-Red for Pb, Zn, and PAH (Cu was amber at this site).

The Tamaki Estuary (in its upper reaches and the older urbanised sub-estuaries) and Central Waitemata Harbour have the highest proportions of amber and red sites and are therefore potentially the most biologically impacted receiving environments.



Figure 4.2 Contaminant status summary - contaminant ERC status by MRA.

Numbers and proportions of sites with contaminant concentrations within the Environmental Response Criteria (ERC) green, amber, and red ranges for each contaminant. Sites are grouped by location (Marine Reporting Area; MRA) and for all sites selected for status assessment (overall).

Zinc concentrations exceed ERC red levels more commonly than Cu or Pb. Amber thresholds are exceeded most frequently overall by Cu. In the Central Waitemata Harbour, Pb was noticeably elevated, exceeding the amber ERC threshold at 77% of the sites, compared with only 38% for Zn.

At most sites, PAH concentrations were fairly low, well below the ERC-amber threshold. Elevated PAH concentrations (ERC-Red or Amber) were present in relatively few locations:

- Motions, Meola Inner, and Chelsea (all Central Waitemata Harbour), which exceeded the ERC-Red threshold; and
- Hobson Bay at Newmarket, and Cheltenham Beach, which exceeded the ERC-Amber level.

Examination of correlations between PAH and metals' concentrations revealed that these sites were well separated from the other sites, with higher PAH concentrations than would be predicted from their metals' concentrations.

The unusually elevated PAH at these sites is consistent with a significant contribution to PAH concentrations from an atypical source (not "normal" urban stormwater runoff). The high concentrations at Motions and Meola inner are possibly a result of historical contamination by coal tar residues used in roading before the 1960s–1970s (Depree 2003, Ahrens and Depree 2006; Depree and Ahrens 2007a; Depree and Ahrens 2007b). Leachate from the adjacent historical landfill is also a possible contributor to PAH (and other elevated contaminant) levels at these sites.

The ERC-amber PAH levels at Newmarket and Cheltenham are partly a consequence of the sediment quality guidelines for PAH (and other organic contaminants) being expressed in terms of "Total Organic Carbon normalised" concentrations, where the contaminant concentration is calculated on the basis of the sediment containing 1% TOC. Newmarket and Cheltenham are both sandy sites, with low TOC content (approximately 0.2%). The presence of moderate PAH concentrations combined with the low TOC content at these sites results in relatively high TOC-normalised concentrations and hence exceedance of the ERC trigger value.

The ecological implications of the elevated PAH levels at these sites are uncertain. PAH concentrations at most sites are too low to be the sole cause of adverse effects on benthic ecology. Bioavailability may also be low (Ahrens and Depree 2006), which may further reduce potential impacts. However, along with other urban contaminants, PAH may contribute to "multiple stressor" effects associated with the presence of multiple contaminants that may cumulatively cause toxicity. The role that PAH may play in multi-stressor effects is currently unknown.

Contaminant concentrations, as used for ERC status assessment, for all the sites grouped, and for each MRA, are shown in Figure 4.3.



**Figure 4.3** Concentrations of metals (Cu, Pb, and Zn) and "high molecular weight" PAH (HWPAH) relative to Environmental Response Criteria (ERC).

Data are shown for all sites ("All") and for each Marine Reporting Area (MRA): Central Waitemata Harbour (CWH), East Coast Bays (ECB), Hibiscus Coast (Hib), Manukau Harbour (Man), Tamaki Estuary (TamE), Tamaki Strait (TamS), and Upper Waitemata Harbour (UWH).

### 4.3 Spatial patterns of contamination

A wide range and number of potential contamination sources potentially influence the levels and spatial distribution of chemical contaminants present in Auckland's marine receiving environment. These include urban stormwater (the major "diffuse" pollution source from the urbanised land area), runoff from ex-horticultural land, landfill leachate, contaminated sites, industrial processes, marinas, and boat mooring areas. The distribution of some of these potential contaminant sources is shown in Figure 4.4.

The overall contaminant ERC status of the monitoring sites is shown in Figure 4.5. The spatial distribution of ERC grades for each contaminant are shown in Figures 4.6 (Cu), 4.7 (Pb), 4.8 (Zn), and 4.9 (PAH).



# and location of sediment sampling sites

Auckland Council

Figure 4.4 Potential contaminant sources contributing to metal and PAH contamination of Auckland's marine receiving environment. Monitoring sites and their ERC grades are shown.



Figure 4.5 Map of overall contamination status of sediment monitoring sites.

Colour coding refers to the ARC Environmental Response Criteria (see Table 4.1). <500  $\mu$ m fraction metals' concentrations are compared with ERC for Settling Zone (SZ) sites while the greater of the <63  $\mu$ m or <500  $\mu$ m fraction data are used for Outer Zone (OZ) sites.



#### Figure 4.6 Map of copper status.

Colour coding denotes ARC ERC (green, amber, and red) status (Table 4.1). The concentrations are proportional to the symbol size. <500  $\mu$ m fraction metals' concentrations are compared with ERC for Settling Zone (SZ) sites while the greater of the <63  $\mu$ m or <500  $\mu$ m fraction data are used for Outer Zone (OZ) sites.

Marine sediment contaminants: Status and trends assessment 1998-2010



#### Figure 4.7 Map of lead status.

Colour coding denotes ARC ERC (green, amber, and red) status (Table 4.1). The concentrations are proportional to the symbol size. <500  $\mu$ m fraction metals' concentrations are compared with ERC for Settling Zone (SZ) sites while the greater of the <63  $\mu$ m or <500  $\mu$ m fraction data are used for Outer Zone (OZ) sites.

Marine sediment contaminants: Status and trends assessment 1998-2010



#### Figure 4.8 Map of zinc status.

Colour coding denotes ARC ERC (green, amber, and red) status (Table 4.1). The concentrations are proportional to the symbol size. <500  $\mu$ m fraction metals' concentrations are compared with ERC for Settling Zone (SZ) sites while the greater of the <63  $\mu$ m or <500  $\mu$ m fraction data are used for Outer Zone (OZ) sites.

Marine sediment contaminants: Status and trends assessment 1998-2010



Figure 4.9 Map of high molecular weight PAH status.

Colour coding denotes ARC ERC (green, amber, and red) status (Table 4.1). The concentrations are proportional to the symbol size. HWPAH status is assessed from concentrations in the <500  $\mu$ m fraction, normalised to 1% TOC.

The spatial patterns in contaminant concentrations shown in Figures 4.5 to 4.9 are broadly the same as those detailed in previous reports (e.g. Williamson and Kelly 2003; Diffuse Sources 2004; Kelly 2007). In summary:

- Highest concentrations of metals are present at muddy upper estuary sites receiving runoff from the older urban and industrial catchments – Henderson Creek to Coxs Bay along the southern shores of the Waitemata Harbour (including Whau, Motions, and Meola estuaries), in Hobson Bay (Purewa), the upper reaches and side-branches of the Tamaki Estuary (e.g. Middlemore, Panmure, Otahuhu, and Pakuranga) and, to a lesser degree, Mangere Inlet in the Manukau Harbour.
- The Central Waitemata Harbour is widely contaminated. Contamination gradients extend out from settling zones (where concentrations are generally highest) into adjacent outer zones, metals being transported by resuspension and dispersal of fine particulates. The inner reaches of the Meola, Motions, and Whau estuaries are probably the most contaminated sites routinely monitored in Auckland, having very high concentrations of Zn, Pb, and (for Motions and Meola inner) PAH.
- Concentrations in the Upper Waitemata Harbour are mostly below ERC thresholds, but are higher than expected for the predominately rural surrounding land use, especially for Cu (and possibly also for Pb). The causes for elevated Cu are, as yet, unknown.
- The concentrations of metals and PAH are generally low in most areas of the Manukau Harbour. Concentrations are moderately elevated in Mangere Inlet, which may be partly related to historical industrial pollution. The reasons for the predominantly low concentrations in the bulk of the Manukau are a mixture of factors, including the large size of the harbour, relatively small watershed with a small proportion of urban area, and relatively recent urbanisation.
- The Tamaki Estuary has relatively highly contaminated areas in its older, densely urbanised, headwater zones (e.g. Middlemore, Pakuranga, Otahuhu, and Panmure). Contamination falls with distance away from these areas, so that the lower reaches of the estuary (e.g. Roberta Reserve, Glendowie) are relatively uncontaminated. A high proportion of upper estuary sites had Zn levels in the ERC-Red range, indicating that Zn is a key contaminant for potential ecological impacts in the Tamaki. Management aimed at reducing Zn loads to the estuary may therefore be worthwhile.
- Estuaries to the north of Auckland e.g. Orewa and Weiti have relatively low levels of contamination, although Zn is slightly elevated.
- The East Coast Bays' sites are located on open coastal beaches. Contaminant build up is limited by the relatively high wave energy, which tends to disperse fine sediments and their associated contaminants. Contaminant concentrations are therefore low at these sites.
- The Tamaki Strait MRA is represented by only one site, Te Matuku Bay on Waiheke Island. This estuary has a relatively undeveloped rural catchment, and the monitoring site acts as a "reference" site. Contaminant concentrations are low.

### 4.4 Arsenic, cadmium, mercury, antimony and tin

Arsenic (As), cadmium (Cd), mercury (Hg), antimony (Sb), and tin (Sn) were measured in 2005, at the 27 former SoE sites. Analyses were conducted on a single composite sample (<500  $\mu$ m fraction) from each site. Concentrations of these elements are tabulated and compared with sediment quality guidelines in Table 4.3.

All these elements, except As, were correlated with Cu, Pb, and Zn (Pearson's "r" values 0.65–0.92) and with PAH (r = 0.51). This indicates spatial patterns for these elements are similar to those described above for Cu, Pb, and Zn, and suggests common sources for these contaminants (except As).

Arsenic concentrations showed no significant correlation with Cu, Pb, or Zn (r = 0.005-0.058), nor with Hg, Cd, Sb, or Sn (r = -0.118-0.065). It therefore seems unlikely that As is a primarily urban stormwater-derived contaminant, as is generally accepted for Cu, Pb, and Zn. Arsenic is discussed further in section 4.4.1 below.

There was also a correlation between all the metals (including As) and sediment organic carbon (TOC) content, which is usually also correlated with the proportion of fine particles – e.g. mud – in the sediment. This suggests that organic matter content (and particle size) are co-varying factors influencing the concentrations of metals. PAH and TOC were more weakly correlated (r = 0.38) than might be expected because of the very high PAH concentrations at Motions and Meola Inner (much higher than their TOC contents would "predict").

Note that there are no ERC values for As, Cd, Hg, Sb, or Sn. To assess potential effects on benthic ecology, comparisons of concentrations have been made with ANZECC (2000) ISQG-low and high values, and also the TEL/PEL guidelines (MacDonald et al. 1996). These were briefly explained in section 4.1.

**Table 4.3** Concentrations of arsenic (As), cadmium (Cd), mercury (Hg), antimony (Sb) and tin (Sn) in sediments from the 27 SoE programme sites.

Concentrations are in mg/kg, in the <500 µm fraction. There are no ERC for these contaminants, and therefore ISQG values (ANZECC 2000) and TEL/PEL sediment quality guidelines (MacDonald et al. 1996) are shown for comparison. **Bolded and underlined** values exceed the ANZECC ISQG-low, <u>underlined</u> values exceed the TEL.

Site	As	Cd	Hg	Sb	Sn
Anns	<u>10.9</u>	0.23	0.12	0.21	2.8
Awaruku	<u>14.9</u>	<0.01	0.01	<0.04	0.3
Big Muddy	<u>13.3</u>	0.04	0.03	0.10	1.1
Browns	<u>10.4</u>	<0.01	<0.01	<0.04	0.2
Cheltenham	<u>16.2</u>	0.02	0.02	0.05	0.6
Hellyers	<u>10.8</u>	0.05	0.10	0.12	1.1
Henderson Upper	<u>11.9</u>	0.11	0.11	0.17	2.3
Hobson Newmarket	2.8	0.03	0.04	0.07	1.0
Lucas Upper	<u>11.2</u>	0.06	<u>0.13</u>	0.11	1.4
Mangere Cemetery	<u>11.7</u>	0.19	0.08	0.24	2.8
Meola Inner	6.9	0.39	<u>0.20</u>	0.36	3.2
Meola Reef	6.8	0.13	0.11	0.09	1.1
Motions	<u>11</u>	0.29	<u>0.31</u>	0.45	3.6
Oakley	<u>13.1</u>	0.1	<u>0.15</u>	0.23	2.7
Pahurehure	<u>9.8</u>	0.05	0.04	0.10	1.0
Pakuranga Lower	<u>8.7</u>	0.09	0.12	0.14	1.4
Pakuranga Upper	<u>9.1</u>	0.13	0.12	0.40	2.3
Paremoremo	<u>10.2</u>	0.06	<u>0.16</u>	0.10	1.6
Puhinui Upper	<u>12</u>	0.07	0.03	0.10	1.0
Pukaki at Airport	<u>11.8</u>	0.05	0.03	0.10	1.0
Middlemore	<u>7.9</u>	0.14	<u>0.16</u>	0.19	2.0
Te Matuku	4.7	0.02	0.02	<0.04	0.2
Vaughans	<u>10.4</u>	<0.01	<0.01	<0.04	0.2
Weiti	5.9	0.04	0.04	0.05	0.5
Whau Lower	<u>10.8</u>	0.06	<u>0.17</u>	0.12	2.1
Whau Upper	<u>10.7</u>	0.21	<u>0.15</u>	0.31	2.6
Whau Wairau	<u>10.4</u>	0.11	<u>0.16</u>	0.22	3.1
Mean	<u>10.2</u>	0.11	0.10	0.18	1.6
Range	2.8–16	<0.01–0.39	<0.01–0.31	<0.04–0.45	0.2–3.6
ANZECC ISQG-low	<u>20</u>	<u>1.5</u>	<u>0.15</u>	<u>2</u>	no value
ANZECC ISQQG-high	70	10	1	25	no value
TEL	<u>7.24</u>	<u>0.68</u>	<u>0.13</u>	no value	no value
PEL	41.6	4.21	0.7	no value	no value

### 4.4.1 Arsenic

Arsenic concentrations were below the ANZECC ISQG-low (20 mg/kg), but were above the TEL (7.24 mg/kg) at nearly all (22/27) SoE sites (Figure 4.10). The exceedance of TEL at most sites suggests that As may be contributing to adverse ecological effects at a broad range of sites, possibly including "non-urbanised" estuary sites.



Arsenic: 2005

**Figure 4.10** Concentrations of arsenic (As) at 27 former SoE sites sampled in 2005. The sediment quality guideline shown is the TEL (7.24 mg/kg). The ANZECC ISQG-low (20 mg/kg) is off scale.

Arsenic concentrations were not obviously related to levels of estuary catchment urbanisation, or to the levels of urban contaminants such as Zn, with some of the highest concentrations being found at "cleaner" sites (e.g. Big Muddy, Browns Bay, Awaruku, and Cheltenham). Lowest concentrations were found at Hobson Newmarket, and Te Matuku Bay.

Arsenic concentrations showed no significant correlation with Cu, Pb, or Zn (r = 0.005-0.058) or with Cd, Hg, Sb, or Sn (r = -0.118-0.065). It therefore seems unlikely that As is a primarily urban stormwater-derived contaminant, in the same way as Cu, Pb, and Zn are generally accepted to be.

The possibility of As being sourced from Copper-Chromium-Arsenic (CCA) treated timber (e.g. mooring posts) has been raised, and hence the relationship between Cu and As was examined further.
As outlined above, the overall correlation, for all 27 SoE sites, between Cu and As was very weak. Examination of correlations for each "harbour" were conducted to assess whether any relationships could be found within more defined spatial areas.

The 27 SoE sites are distributed between "harbours" as follows:

- East Coast Bays 4 sites, all sandy beaches
- Manukau Harbour 6 sites, all muddy
- Tamaki Estuary 3 sites, all muddy
- Tamaki Strait 1 site, Te Matuku (reference), muddy sand
- Waitemata Harbour 12 sites, 3 upper harbor sites, 9 central harbour. Hobson Newmarket is sandy, all others muddy.
- Hibiscus Coast 1 site, Weiti, muddy.

Within these "harbour" groups, only the Waitemata Harbour sites showed a significant correlation between As and Cu (linear regression;  $r^2 = 0.39$ , p = 0.018, n = 12). This might suggest a weak relationship between Cu and As in the Waitemata, and hence possibly evidence of some common sources (possibly related to activities such as boating).

However, As was more strongly correlated with TOC at the Waitemata Harbour sites (linear regression;  $r^2 = 0.78$ , p <0.001, n = 12) than with Cu. This strongly suggests that variation in As concentrations within the harbor are largely related to variation in sediment organic matter content (and probably particle size), rather than due to association with Cu.

Background As concentrations in Auckland region soils are reported to be in the 0.4–12 mg/kg range, with geometric means across different soil types ranging from 1.65 to 6.51 mg/kg (ARC 2001). The As concentrations recorded in the SoE site marine sediments are generally within the background soil range, with the mean concentration (10.2 mg/kg) lying towards the upper end of this background range. The slightly elevated concentrations found in the SoE marine sediments may, at least in part, reflect differences in analysis procedures used in the soils' study and the SoE monitoring – e.g. the SoE sediments are sieved to <0.5 mm before analysis, whereas the soils were 2 mm sieved.

Another possible source of As is combustion of CCA-treated timber. Elemental analysis by GNS Sciences of particulate matter samples collected at Auckland Council ambient air quality monitoring sites associated elevated arsenic concentrations with domestic fire emissions, as a result of copper chrome arsenate treated timber being used as fuel (Davy et al. 2012).

Overall, based on the correlative assessment summarised above, it would appear that the As found in the SoE site sediments is not strongly associated with urban stormwater inputs (as judged by correlation with known stormwater contaminants). However, the exceedance of the TEL guideline at most sites indicates that As may be relevant with regard to ecological impacts. Further investigations are required to better understand the spatial distribution of As in Auckland's estuaries and to identify possible sources (including catchment soils, mooring and marina areas and air-borne emissions).

#### 4.4.2 Mercury

Mercury (Hg) was present at, or just above, the ANZECC ISQG-low (0.15 mg/kg) at 8 of the 27 SoE sites (Figure 4.11). No sites approached the ISQG-high level of 1 mg/kg, the highest concentration being 0.31 mg/kg, found at Motions Creek. These results indicate that Hg concentrations may contribute to adverse effects on benthic fauna at the more contaminated urban sites, but would not be expected to be the primary cause of marked impacts.

Highest levels of Hg were found at Motions Creek, followed by the nearby Meola Inner estuary site. Leachate from the adjacent historical landfill is a possible contributor to Hg (and other elevated contaminant) levels at these sites.

The only "non-urban" site with a moderately elevated Hg concentration was Paremoremo, which is a predominately rural sub-catchment estuary of the Upper Waitemata Harbour. The reason for this is unknown. The Paremoremo Village and prison may be sources of Hg to this estuary.

Mercury concentrations were correlated with Zn (linear regression,  $R^2$ =0.718, p<0.0001, n=27) and other metals (except As), and also with PAH, suggesting similar sources of these contaminants (probably urban stormwater).



#### Mercury: 2005

**Figure 4.11** Concentrations of mercury (Hg) at SoE sites sampled in 2005. The sediment quality guidelines shown are the TEL (0.13mg/kg) and the ANZECC ISQG-low (0.15 mg/kg). The ISQG-high is off scale at 1 mg/kg.

### 4.4.3 Cadmium

Cadmium (Cd) concentrations were well below the ISQG-low (1.5 mg/kg) and TEL (0.68 mg/kg) at all sites (Figure 4.12). The highest concentration was found at Meola Inner, at 0.39 mg/kg. As found for Hg, Cd was well correlated with other metals (e.g. with Zn; linear regression,  $R^2$ =0.627, p<0.0001).



Cadmium: 2005

**Figure 4.12** Concentrations of cadmium (Cd) at SoE sites sampled in 2005. The sediment quality guidelines ANZECC ISQG-low (1.5 mg/kg), TEL (0.68 mg/kg), and ISQG-high (10 mg/kg) are all off-scale.

#### 4.4.4 Antimony and tin

Antimony (Sb) and tin (Sn) concentrations showed the strongest correlations of the "other metals" with Zn (linear regression,  $R^2$ =0.836 for Sn and 0.847 for Sb, p<0.0001), strongly indicating common sources for these metals.

Concentrations of Sb were well below the ISQG-low (2 mg/kg) at all sites, with the highest concentration of 0.45 mg/kg being found at Motions Creek. There are no ANZECC sediment quality guidelines for Sn, and no TEL values for Sb or Sn. The highest Sn concentration was 3.6 mg/kg, also at Motions Creek. Figure 4.13 shows the concentrations of these metals at the SoE sites.



**Figure 4.13** Concentrations of antimony (Sb) and tin (Sn) at SoE sites sampled in 2005. The ANZECC ISQG-low for Sb (2 mg/kg) is off scale. There are no guideline values for Sn.

# 4.5 Summary of contaminant distributions

The preceding sections have summarised the current status of metals and PAH in Auckland's marine sediments.

Monitoring to date (2010) has shown:

- The distribution of metals (Cu, Pb, Zn, and probably also Hg, Sn, Cd, and Sb) follows a well-described spatial pattern. Highest concentrations are generally found in estuaries receiving runoff from the older, intensively urbanised and/or industrialised catchments, particularly in the Tamaki Estuary and Waitemata Harbour. Lowest concentrations are found in rural/forested catchment estuaries, and at open coastal beaches.
- Concentrations of metals in most locations are in the "ERC green" range, indicating effects on benthic ecology from metals are unlikely to be significant. Note, however, that benthic health modelling shows measurable effects on benthic ecology at metals' concentrations in the ERC green range (Hewitt et al. 2009). Regionally, a relatively small proportion of locations have metals' concentrations in the ERC amber/red range. The exceptions are in the Upper Tamaki Estuary, and in the urbanised Central Waitemata Harbour catchment estuaries, where a substantial proportion of monitoring sites have metals' concentrations in the ERC amber/red range. Zn concentrations most often exceed the ERC red threshold, indicating it may be the metal of most concern for potential ecological impacts in these areas. The most overall exceedances of the ERC-amber threshold were observed for Cu, suggesting it may be a significant contaminant for broad-scale impacts on benthic ecology in the Tamaki Estuary and Central and Upper Waitemata Harbours, where concentrations are moderately elevated.
- PAH concentrations are correlated with the general level of urban-sourced contamination, as reflected by metals' concentrations. The most notable exceptions are at Motions and Meola Inner, which have unusually high PAH levels, indicating additional sources to these estuaries. PAH concentrations at the majority of sites are well below the ERC-amber threshold, and are therefore unlikely, on their own, to be causing adverse effects on benthic ecology at most sites. However, it is possible that they may contribute to cumulative contaminant "multi-stressor" effects at some sites.

#### **Table 4.4** Sediment contaminant status by site.

Concentrations of metals are in mg/kg. High molecular weight PAH (HWPAH) are in mg/kg normalised to 1% Total Organic Carbon (TOC). Data are medians (n=3).Colour coding denotes ARC ERC (green, amber, and red) status. Note that the <500 µm fraction metals' concentrations are compared with ERC for muddy Settling Zone (SZ) sites while the greater of the <63 µm or <500 µm fraction data are used for Outer Zone (OZ) sites. Unshaded values are for metals in the alternate particle size fraction (i.e. not the size fraction appropriate for the ERC comparison for that site). Marine Reporting Areas (MRA): Central Waitemata Harbour (CWH); East Coast Bays (ECB); Hibiscus Coast (Hib); Manukau Harbour (Man); Tamaki Estuary (TamE); Tamaki Straits (TamS); Upper Waitemata harbour (UWH).

				Coordinates NZTM		Data	Year	<63 µm fraction			<500 µm fraction			
Site	MRA	Туре	Programme	East	North	Metals	PAH	Cu	Pb	Zn	Cu	Pb	Zn	HWPAH
Chelsea	CWH	OZ	RDP	1754161	5923677	2010	2004	20.0	25.0	94.0	7.0	15.3	53.0	2.356
Coxs	CWH	OZ	RDP	1753479	5920531	2010		25.0	48.0	131.0	5.0	14.1	75.0	
Henderson Entrance	CWH	OZ	RDP	1748127	5924512	2010	2002	22.0	28.0	113.0	5.0	18.1	68.0	0.179
Henderson Lower	CWH	SZ	RDP	1746287	5922955	2010	2002	21.0	28.0	125.0	28.0	33.0	149.0	0.169
Henderson Upper	CWH	SZ	SoE	1745597	5921791	2009	2005	27.0	34.0	160.0	28.0	33.0	150.0	0.169
Hobson Awatea	CWH	OZ	RDP	1760037	5919688	2008		14.0	36.0	95.0	12.0	33.0	100.0	
Hobson Newmarket	CWH	OZ	SoE	1759826	5918942	2009	2005	22.0	48.0	110.0	4.9	12.0	40.0	1.366
Hobson Victoria	CWH	OZ	RDP	1760854	5918935	2008		13.0	31.0	82.0	3.8	11.0	39.0	
Hobson Whakataka	CWH	OZ	RDP	1761114	5919424	2009	2002	15.0	30.0	93.0	7.2	19.0	85.0	0.076
Island Bay	CWH	OZ	RDP	1750607	5924995	2007		16.0	21.0	74.0	6.2	13.0	54.0	
Kendall	CWH	OZ	RDP	1752352	5923186	2010		13.1	17.8	69.0	4.0	7.4	32.0	
Meola Inner	CWH	SZ	SoE	1752369	5919629	2009	2005	29.0	63.0	180.0	29.0	54.0	230.0	2.330
Meola Outer	CWH	OZ	RDP	1752317	5920334	2010		18.6	28.0	103.0	3.0	9.3	34.0	
Meola Reef TeTokaroa	CWH	OZ	SoE	1752452	5920868	2009	2005	21.0	43.0	120.0	9.6	21.0	90.0	0.463
Motions	CWH	SZ	SoE	1752573	5919704	2009		32.0	65.0	170.0	16.0	34.0	220.0	2.045
Ngataringa	CWH	OZ	RDP	1759696	5923743	2007		16.0	34.3	105.0	22.1	37.9	123.0	
Oakley	CWH	SZ	SoE	1751121	5917912	2009		23.0	47.0	160.0	25.0	41.0	150.0	0.335
Pollen Island	CWH	OZ	RDP	1750065	5918198	2009	2002	17.0	34.0	100.0	9.1	17.0	78.0	0.085
Purewa	CWH	SZ	RDP	1762482	5918521	2010	2002	20.0	40.0	126.0	14.0	36.0	165.0	0.428
Shoal Hillcrest	CWH	SZ	RDP	1757375	5925746	2010		14.5	32.0	99.0	17.0	32.0	113.0	
Shoal Lower	CWH	OZ	RDP	1757533	5924310	2009		16.0	28.0	87.0	5.4	11.0	46.0	
Shoal Upper	CWH	OZ	RDP	1757834	5924722	2008		20.0	34.0	100.0	4.6	12.0	44.0	
Whau Entrance	CWH	OZ	RDP	1748081	5920325	2010		20.0	32.0	118.0	3.0	7.6	34.0	

				Coordinates NZTM		Data Year		<63 µm fraction			<500 µm fraction			
Site	MRA	Туре	Programme	East	North	Metals	PAH	Cu	Pb	Zn	Cu	Pb	Zn	HWPAH
Whau Lower	CWH	SZ	SoE	1748243	5917496	2009	2005	21.0	37.0	170.0	26.0	42.0	180.0	0.338
Whau Upper	CWH	SZ	SoE	1749226	5915064	2009	2005	35.0	68.0	270.0	35.0	63.0	280.0	0.379
Whau Wairau	CWH	SZ	SoE	1748106	5915757	2009	2005	40.0	63.0	250.0	39.0	53.0	220.0	0.424
Awaruku	ECB	OZ	SoE	1756571	5938381	2010	2005	1.5	1.2	10.0	2.0	3.7	25.0	0.070
Cheltenham	ECB	OZ	SoE	1761382	5923325	2009	2005	3.6	14.0	44.0	2.5	9.1	37.0	1.689
Vaughans	ECB	OZ	SoE	1756335	5939102	2010	2005	1.6	0.8	6.0	2.0	3.0	21.0	0.043
Orewa Central	Hib	OZ	RDP	1750700	5948609	2006		6.0	6.6	36.0	2.7	2.8	21.9	
Orewa North	Hib	OZ	RDP	1751433	5948585	2006		7.0	8.4	58.0	4.1	4.8	39.6	
Orewa South	Hib	SZ	RDP	1750772	5948071	2006		5.0	5.1	29.0	4.4	4.1	29.8	
Weiti	Hib	SZ	SoE	1752400	5946536	2009	2005	18.0	11.0	65.0	13.0	9.0	54.0	0.196
Anns	Man	OZ	SoE	1762281	5911361	2009	2005	14.0	22.0	110.0	19.0	24.0	130.0	0.154
Big Muddy	Man	SZ	SoE	1744153	5906819	2009	2005	6.0	9.1	46.0	8.5	9.3	51.0	0.156
Blockhouse Bay	Man	OZ	RDP	1752283	5911623	2009		9.2	18.0	84.0	5.0	11.0	67.0	
Harania	Man	SZ	RDP	1761945	5909753	2010		12.7	19.1	99.0	18.0	24.0	133.0	
Hillsborough	Man	OZ	RDP	1756786	5911590	2010		11.2	17.8	88.0	7.0	11.9	71.0	
Little Muddy	Man	SZ	RDP	1746459	5908737	2009		12.0	16.0	70.0	12.0	15.0	70.0	
Mangere Cemetery	Man	OZ	SoE	1759928	5911221	2009	2005	13.0	22.0	98.0	18.0	23.0	110.0	0.152
Mill Bay	Man	OZ	RDP	1743018	5904528	2010		7.9	10.3	56.0	4.0	10.1	66.0	
Pahurehure Middle	Man	OZ	RDP	1767570	5896927	2008		5.0	11.0	55.0	2.0	6.7	32.0	
Pahurehure Papakura	Man	DZ	SoE	1771260	5896689	2009	2005	7.3	17.0	82.0	5.8	10.0	64.0	0.071
Pahurehure Upper	Man	OZ	RDP	1769613	5897426	2008		4.2	10.0	53.0	9.0	14.0	81.0	
Papakura Lower	Man	SZ	RDP	1768772	5898091	2008		4.2	10.0	53.0	10.0	16.0	76.0	
Puhinui Entrance	Man	OZ	RDP	1764948	5899773	2009	2002	7.3	13.0	97.0	8.8	13.0	110.0	0.023
Puhinui Upper	Man	SZ	SoE	1765048	5900492	2009		8.0	13.0	110.0	9.5	13.0	110.0	0.052
Pukaki Airport	Man	SZ	SoE	1760665	5903547	2009		6.0	10.0	60.0	8.1	11.0	65.0	0.055
Tararata	Man	SZ	RDP	1760526	5909707	2010		11.0	17.4	95.0	17.0	23.0	126.0	
Waimahia East	Man	SZ	RDP	1767782	5898654	2008	2002	4.8	11.0	58.0	11.0	16.0	88.0	0.047
Waimahia West	Man	SZ	RDP	1766610	5898779	2008	2002	4.0	9.7	51.0	9.3	13.0	74.0	0.050
Benghazi	TamE	OZ	RDP	1766790	5915326	2010		25.0	24.0	106.0	9.0	14.6	75.0	
Bowden	TamE	OZ	RDP	1765251	5912952	2010		25.0	29.0	146.0	27.0	34.0	210.0	
Middlemore	TamE	SZ	SoE	1765216	5909093	2009	2005	30.0	43.0	220.0	25.0	32.0	190.0	0.530

				Coordinates NZTM		Data Year		<63 µm fraction		tion	<500 µm fraction			
Site	MRA	Туре	Programme	East	North	Metals	PAH	Cu	Pb	Zn	Cu	Pb	Zn	HWPAH
Otahuhu	TamE	SZ	RDP	1765518	5911051	2010		22.0	27.0	146.0	27.0	32.0	176.0	
Pakuranga Lower	TamE	SZ	SoE	1766648	5911776	2009	2005	25.0	34.0	170.0	17.0	21.0	150.0	0.235
Pakuranga Upper	TamE	SZ	SoE	1767969	5911598	2009	2005	32.0	44.0	230.0	24.0	26.0	190.0	0.145
Panmure	TamE	SZ	RDP	1764477	5913898	2010	2002	22.0	30.0	139.0	25.0	33.0	181.0	0.492
Point England	TamE	OZ	RDP	1766861	5916213	2010		16.8	22.0	98.0	12.0	20.0	92.0	
Princes	TamE	OZ	RDP	1765853	5910587	2010		25.0	35.0	184.0	15.0	22.0	146.0	
Roberta Reserve	TamE	OZ	RDP	1768127	5918726	2006		12.0	24.0	77.0	2.8	6.3	30.4	
Te Matuku	TamS	SZ	SoE	1789785	5921484	2009	2005	5.2	13.0	50.0	3.0	7.2	34.0	0.019
Brighams (UWH)	UWH	SZ	UWH	1743254	5928631	2009	2009	18.9	25.0	89.0	19.3	28.0	107.0	0.101
Central Main Channel	UWH	OZ	UWH	1746577	5929280	2009	2009	17.9	30.0	98.0	11.2	27.0	103.0	0.214
Central Waitemata East	UWH	OZ	UWH	1749807	5927056	2009	2009	16.7	30.0	97.0	21.0	32.0	112.0	0.150
Hellyers SoE	UWH	OZ	SoE	1751385	5928242	2009	2005	17.0	32.0	110.0	11.0	20.0	86.0	0.201
Hellyers Upper RDP	UWH	SZ	RDP	1751499	5928413	2007		17.0	27.9	107.0	15.0	21.0	93.6	
Hellyers (UWH)	UWH	OZ	UWH	1750242	5927860	2009	2009	14.1	26.0	74.0	13.5	22.0	82.0	0.208
Herald Island North	UWH	OZ	UWH	1747994	5928628	2009	2009	22.0	32.0	105.0	5.3	14.0	41.0	0.087
Herald Island Waiarohia	UWH	OZ	UWH	1747901	5927833	2009	2009	19.6	28.0	100.0	3.6	6.3	22.0	0.097
Hobsonville	UWH	OZ	UWH	1749660	5926258	2009	2009	16.4	28.0	103.0	2.7	6.6	23.0	0.137
Kaipatiki	UWH	SZ	RDP	1751493	5928185	2009		20.0	32.0	120.0	20.0	31.0	120.0	
Lucas Te Wharau (UWH)	UWH	SZ	UWH	1749374	5930448	2009	2009	18.4	29.0	103.0	21.0	26.0	97.0	0.094
Lucas Upper	UWH	SZ	SoE	1749681	5931407	2007	2005	14.8	19.8	89.9	20.0	22.0	100.0	0.204
Lucas (UWH)	UWH	SZ	UWH	1748335	5929477	2009	2009	16.9	27.0	94.0	13.5	24.0	89.0	0.135
Outer Main Channel	UWH	OZ	UWH	1748592	5928382	2009	2009	19.5	29.0	99.0	13.2	22.0	79.0	0.121
Paremoremo (UWH)	UWH	SZ	UWH	1745753	5930371	2008	2007	17.7	28.0	93.0	23.0	29.0	103.0	0.078
Rangitopuni (UWH)	UWH	SZ	UWH	1742996	5930079	2009		20.0	26.0	97.0	24.0	25.0	102.0	0.059
Rarawaru	UWH	SZ	RDP	1744369	5928559	2010		15.4	22.0	84.0	17.0	24.0	88.0	
Upper Main Channel	UWH	OZ	UWH	1743908	5929274	2009	2009	17.0	24.0	87.0	23.0	26.0	102.0	0.083
Waiarohia	UWH	SZ	RDP	1746623	5927140	2010		16.2	25.0	88.0	19.0	26.0	95.0	

# 5.0 Temporal trends

A key component of the sediment contaminant monitoring programme is the assessment of changes in contaminant concentrations over time – "temporal trends".

Trend assessment aims to determine whether contaminant concentrations in receiving water sediments are increasing, decreasing, or remaining fairly constant over time. This provides a better indicator of the effects of land use over time on receiving waters, and of the effectiveness of catchment land use and water resource management activities.

The following sections describe the trends that have emerged from the SoE, RDP, and UWH programmes to the end of 2010. The key aims are to:

- Assess broad-scale changes in sediment contamination over time;
- Identify sites where greatest changes have occurred; and
- Briefly compare the results obtained from monitoring with those predicted from contaminant accumulation modelling.

The information obtained from these assessments will be used to refine monitoring protocols and goals. This is to be included in the programme review report (Diffuse Sources, in prep.).

The trend assessment described here is aimed at determining "*statistically significant*" changes over time, by applying trend analysis tests to the monitoring data.

Assessing whether these trends are "*meaningful*" – that is, whether they have "real world" significance or relevance – requires a broader analysis and interpretation that is beyond the scope of this report. For example, changes might be considered "meaningful" if they are linked with changes in ecological health, if they can be associated with known changes in catchment land use or management, or if the rates of change exceed those required to exceed defined triggers (e.g. ERC) within nominated time frames.

The trend analysis results presented here form one part of the information matrix required to assess "real world" relevance. When combined with other information components (e.g. trends in ecological health, catchment land use changes, contaminant management activities, targets or triggers for rates of change in contaminant levels), the real "meaningfulness "of the contaminant trends will be able to be better interpreted.

# 5.1 Trend assessment approach

Assessing the nature and magnitude of temporal trends in environmental monitoring data is not necessarily straightforward. Many environmental data do not necessarily follow simple trends or patterns (e.g. linear changes over time) that can be described using simple descriptive parameters (e.g. linear "regression slopes" or "rates of change"). Rather, trends can change in magnitude and/or direction over time in response to the combinations of many influential variables, both

natural and anthropogenic (e.g. climatic variation, catchment development, implementation of management interventions such as stormwater treatment). This potential complexity needs to be considered when interpreting the trend analysis results.

In addition, the "robustness" of trend monitoring results may be affected by factors associated with the monitoring itself – for example; analytical variability, length of monitoring period, consistency in sampling and analysis methods over time, and monitoring site disturbance.

Ideally, the trend monitoring data would all have been acquired over the same time period, at the same frequency, using the same sampling methodology, and the samples analysed by exactly the same methods. This is not the case for the sediment contaminant monitoring undertaken to date. This is partly because the three monitoring programmes have different primary objectives (e.g. SoE mainly aimed at long-term status and trends assessment, RDP for stormwater impacts assessment, and UWH primarily focused on ecological health monitoring).

Bringing together the sediment chemistry data from these programmes to assess trends therefore presents some challenges and complicates the interpretation of trends, as outlined in section 5.2.

#### 5.1.1 Trend analysis and presentation

Trend analysis was conducted at sites with four or more sets of sampling data (i.e.  $n\geq4$ ). Trends could, in theory, be measured from only three samplings. However, using so few data points was considered unwise for the current assessment because of limitations in the monitoring data, as described in section 5.2. As discussed in section 5.2, even four samplings represents a minimal data set for trend analysis.

Trends were assessed by two methods:

- 1. The non-parametric Mann-Kendall (MK) trend test. This is the most commonly used trend analysis method for environmental data. It does not rely on the data having any particular underlying distributional form (e.g. normality) and accommodates missing values and "less than detection limit" values well. The test tells you whether there is a significant trend or not. The magnitude of the trend (or "rate of change") was obtained using the "Sen Slope Estimate" (SSE), another non-parametric test method. The SSE can be expressed in absolute concentration units per unit time (e.g. mg/kg/year) or in relative terms (e.g. as a percentage of the median concentration per year). The MK and SSE (or "Relative Sen Slope Estimate"; RSSE) were determined using the "Time Trends" software package (NIWA and Jowett Consulting, version 3.31). A trend was considered statistically significant if the MK test p values were p<0.05.</p>
- 2. Linear regression (LR) was also used to provide indicative trends for use in "Single Site Reports" (SSRs, Appendix 1), which give a numerical and graphical summary of the monitoring data at each site. Linear regression, rather than the MK and Sen Slope tests, was used in the SSRs because the MK and Sen Slope tests are not currently available in Microsoft Excel, which was used to generate the SSRs. Linear regression analyses were conducted using Excel and Data Desk (version 6.1, Data Description Inc.).

The MK/Sen Slope and LR tests generally gave trends that were of similar magnitude and direction (Figure 5.1). Differences in the results from these two approaches were of practical significance only at sites where data were limited (n=4 samplings, the smallest number used in the trend assessment) and/or highly variable. Differences between the two methods were also sometimes observed where the magnitude of trends was very small, but in this situation, the differences between these test results are not considered important.

For **total metals**, the linear regression trend slopes (rate of change) were, on average, very similar to the Sen Slopes:

- Copper: LR trend = 1.011 x Sen Slope 0.021 (R<sup>2</sup>=0.959)
- Lead: LR trend = 1.042 x Sen Slope 0.0029 (R<sup>2</sup>=0.908)
- Zinc: LR trend = 0.944 x Sen Slope + 0.178 (R<sup>2</sup>=0.943)

For **extractable metals**, the linear regression trend slopes (rate of change) were, on average, slightly smaller than the Sen Slopes. The data also showed more scatter than for total metals:

- Copper: LR slope = 0.865 x Sen Slope 0.0484 (R<sup>2</sup>=0.778)
- Lead: LR slope= 0.844 x Sen Slope 0.0026 (R<sup>2</sup>=0.893)
- Zinc: LR slope= 0.781 x Sen Slope 0.377 (R<sup>2</sup>=0.786)

All the above regressions were highly significant ( $p \le 0.0001$ ).

The greatest outliers were observed for:

- Herald Island North (HIN) in the UWH programme, for extractable Cu;
- Cheltenham (SoE programme), for extractable Pb and Zn, and
- Central Waitemata East (site "OHbv", UWH programme) for extractable Zn.

For Herald Island North (HIN), the LR trend for extractable Cu was 1 mg/kg/year and the Sen Slope was 0. The Cu data for HIN showed an abnormally high value for one replicate in 2006 (48 mg/kg, compared with the median of 22 mg/kg). If this was removed from the dataset, the LR trend became -0.1 mg/kg/year, which is close to the MK trend result.

For Cheltenham (a sandy outer zone beach site), extractable metals' data were highly variable (possibly because of the low mud fraction content in these sandy sediments), and there were only 4 sets of sampling data. Substantial differences between trends measured by the two approaches were therefore not surprising.

At Central Waitemata East (OHbv, UWH programme), the metals' trend profiles showed a marked "hump" with relatively low values in 2005, high values in 2006, then decreasing values to 2009. Data showed little scatter within each year. The LR trend for extractable Zn was -1.7 mg/kg/year, and the Sen Slope was -5.7 mg/kg/year. Presumably, the combination of a markedly non-linear trend profile and a relatively short time period (only 4 years) resulted in the marked difference between the two trend estimates.



**Figure 5.1** Comparison of trends (mg/kg/year) in metals' concentrations over time obtained from linear regression analysis (LR) and the Sen Slope Estimate (Sen Slope).

Data are for all sites with  $n \ge 4$  samplings, excluding 2002 data from RDP sites, and 2003–2007 extractable metals data (<63 µm fraction) from SoE sites.

For High Molecular Weight PAH (HWPAH), there was also a good correlation between LR and Sen Slopes (Figure 5.2):

• HWPAH: LR slope = 0.834 x Sen Slope+ 0.003 R<sup>2</sup>=0.808 (n=41, p≤0.0001)



**Figure 5.2** Comparison of trends (mg/kg/year) in high molecular weight PAH (HWPAH) concentrations over time obtained from linear regression analysis (LR) and the Sen Slope Estimator (Sen Slope). Data are for all sites with  $n \ge 4$  samplings.

This assessment indicates that trends determined by the LR and MK/Sen Slope tests gave generally comparable results overall, but at a few individual sites the results can differ markedly between the test methods. This is particularly noticeable where the data series is short, with few samplings, and data are variable (including outliers). Extractable metals seemed to be more affected than total metals (possibly because a substantial proportion of the extractable metals data were removed from the trend series for SoE sites, because of as yet unresolved quality assurance uncertainties, as discussed later in section 5.2).

This highlights an important "rule"; in any meaningful trend assessment, the data need to be examined visually to assess whether factors such as high variability or unusual trend profiles could be influencing the trend analysis results. Data for individual sites can be viewed graphically in the "single site reports" (SSRs) in Appendix 1.

Unless noted, the summary of trends given in the following sections is based on the results from the MK and Sen Slope test analyses. A trend was considered statistically significant if the MK p values were p<0.05. Trend magnitudes have been given in absolute terms (units of mg/kg per year) and in relative terms, by dividing the absolute trend by the median concentration over the time interval of the trend measurement (units used are % of median concentration per year). A positive trend value indicates an increase in concentration over time, while a negative value indicates a decreasing concentration. The larger the number, the greater the increasing/decreasing rate of change.

Trends (Sen Slopes) have been divided into three groups for summarising the "strength" and possible "real world" significance of the changes, and for use as trend indicators in the "single site reports" (SSRs, Appendix 1):

- <±1% per annum change probably indicates no (or very little) trend. Changes in this range are unlikely to have any "real world" significance, and have been assigned as "no change";
- ±1–2% per annum indicates a small, or emerging, trend. Changes of this magnitude could be largely associated with analytical and/or sampling variation, so trends in this range may not have any "real world" significance. Trends in this range have been assigned as "possibly increasing/decreasing" trends; and
- >±2% indicates a stronger trend, equivalent to > ±20 % per decade, which is probably worth investigating further to better understand possible causes. These changes have been termed "probably increasing/decreasing" trends.

This grouping is somewhat subjective, but provides a basis for identifying locations with trends that may be worth investigating further. The 2% per year trend is also approximately the rate of change required to increase the average Zn concentration across all sites (approximately 100 mg/kg) to the ERC-amber threshold (124 mg/kg) over 10 years.

Trends have been plotted in Figures 6.1 to 6.7 (appended to Section 6), showing the Sen Slopes (in mg/kg/year, and % of the median concentration per year) for each site and monitoring programme. 95% confidence limits (95% CLs), produced by the Time Trends software, are included in the plots. If the 95% CLs do not cross zero, it is highly likely that the trend is "significantly different" from zero (i.e. "real").

Note that PAH concentrations are generally low at most sites. Because of data rounding, there may be some small differences in how the data is reported with statistics and plots (e.g. where a % trend value (Relative Sen Slope) has been calculated from a low absolute trend and very low median concentration). None of these minor differences change the conclusions drawn from the data.

The plots show the trends for each of the three monitoring programmes separately. As discussed further in section 5.2, this was required because of the differences in monitoring periods, sampling frequencies, and methods employed between the programmes. These differences may mean that the trend data from each programme are not as directly comparable as they would be if exactly the same monitoring had been conducted at all sites.

A more general overview of the trend data has also been provided in section 5.3. The SSRs presented in Appendix 1 provide a visual assessment of the nature (including variability) of the monitoring data and trends at each site.

Trend results at each monitoring site from the MK/Sen Slope analyses are given in Tables 6.1 to 6.7 (appended to Section 6).

# 5.2 Factors affecting the "robustness" of trend results

## 5.2.1 Different monitoring periods and sampling frequencies

Sediment chemistry monitoring data from three programmes were available for assessing temporal trends:



# Monitoring Data for Trend Analysis

- The former SoE programme, which had data from 27 sites, covering an 11 year period (1998–2009). Sampling had been undertaken 5–7 times from most sites (depending on site and metal, as discussed further in section 5.2.4). This was the core programme for status and trend assessment, which has subsequently been expanded by the RDP, and more recently the UWH, programmes.
- The former RDP programme, which had suitable monitoring data for a 6 year period (2004–2010). Adequate data for trend assessment (i.e. at least 4 samplings) was available from 16 of these RDP sites. Some RDP sites (or nearby sites) were sampled in 2002. However, the consistency of the data with later results from these sites was uncertain, and therefore they have been excluded from this trend assessment;
- The UWH programme, which had been monitored annually at 14 sites over a 4 year period (i.e. 5 samplings) from 2005–2009 (inclusive).

The time series record is relatively short, ranging between 11 years (1998–2009) for sites in the former SoE programme, 6 years (2004–2010) for the former RDP programme, and 4 years (2005–2009) for the UWH programme.

The data series from the three programmes span different time periods, and therefore trends obtained from each programme are (strictly) not directly comparable. The measured trends for the shorter monitoring periods may well differ from those measured over longer periods. The shorter time series data are susceptible to greater short-term variability (e.g. due to analysis, sampling, event-related effects) potentially giving an unrealistic picture of "trends". Short-term variability is "averaged out" over longer periods, providing a more robust indication of real patterns and trends.

In addition, monitoring over only a short period would not be expected to be able to reliably detect trends, unless large changes are occurring (which is probably unlikely at most sites).

In the context of the sediment chemistry monitoring programmes, the SoE programme sites offer the best opportunity for reliably assessing trends, because they have the longest time series. However, data quality issues may have affected the SoE data series, as outlined further in section 5.2.4 below). The UWH programme data series covers the shortest period (only 4 years), and therefore detection of trends from these data would not be expected (unless large changes were occurring, which in the relatively undeveloped UWH is considered unlikely). The RDP data (6 year period) fall between the SoE and UWH.

Overall, the programme is probably still in its infancy as far as trend detection is concerned. It is likely that another decade may be required at many sites to be able to clearly detect and quantify trends that are significant (statistically) and meaningful (having real world relevance; e.g. associated with changes in ecological health or with known catchment land use activities).

## 5.2.2 Small, and variable, numbers of samplings

So far the number of samplings (or "data points") in the time series record is small, ranging from:

- a maximum of 7 (for total recoverable metals at most of the 27 sites in the former SoE programme). As outlined in section 5.2.4, extractable metals' data was available from (at most) only 4 samplings at the former SoE programme sites;
- 4–5 samplings at 16 of the former RDP programme sites (an additional approximately 38 RDP sites have been sampled, but only 1–3 times to the end of 2010); and
- 5 samplings for the 14 UWH programme sites.

Because the number of samplings is small, any trends measured are potentially sensitive to the effects of additional data. Future years' monitoring results may change the magnitude, and even direction, of trends at sites where current changes are small. The RDP data series are most susceptible to this (because they have the smallest number of data so far), while total metals' data from the SoE sites are likely to be least affected (having the greatest number of data so far – although lower replication may affect this, as outlined in section 5.2.5).

An example of this effect was observed for Henderson Entrance (RDP site). The trend (Sen Slopes) for extractable Zn (in the <63  $\mu$ m fraction) for 2004–2010 (n=4) was -5.0 mg/kg/year, a strong decreasing trend. This appears to be strongly influenced by a high concentration recorded in 2004. Monitoring data was also obtained in 2002 at this site. When the 2002 data was included in the trend series, the 2004 result more clearly stands out as abnormally elevated, and the revised trend was -1.0 mg/kg/year (a much smaller trend). If the high 2004 result was removed (and 2002 data left in), the trend was +0.1 mg/kg/year. Clearly therefore, some of the current trend results may be sensitive to "atypical" individual monitoring results, especially where the data series is small.

## 5.2.3 Variable providers and procedures

Ideally, to maximise data consistency, a single provider would be used for all (or at least each one of) of the steps involved in the monitoring and sample analysis.

As summarised in Table 5.1, a variety of sampling and analysis providers and methods have previously been used in the three sediment contaminant monitoring programmes. Since 2009 however, most aspects of the programmes have been standardized.

Use of multiple providers and methods is acceptable, provided that quality assurance (QA) data is obtained to verify that the same (or very similar) results are obtained by the various approaches used. While QA data have been acquired within each of the programmes (for example those given in annual reports; e.g. KML 2003, Diffuse Sources 2010), and the sampling and chemical analysis methods are generally very similar, the comparability of the results obtained by the various providers and methods identified in Table 5.1 is still not known. A separate monitoring programme review (Diffuse Sources, in prep.) details these aspects further.

The RDP programme data are likely to be reasonably consistent. The same sampling and chemical analysis methods were used in the RDP between 2004 and 2010, and the 2002 RDP data collected by Kingett Mitchell Ltd for ARC are likely to be consistent with that from 2004–2010. This is because the same sampling methods were used, site locations were mostly very similar, and analysis was conducted by the same laboratory. The QA approach and results obtained in these surveys were also comparable (KML 2003).

Similarly, the UWH programme data for 2005, 2006, and 2007 are likely to be consistent with each other. The 2008 and 2009 samples were processed differently, in that the sieving prior to metals' analysis was undertaken by RJ Hill Laboratories, whereas this was done in previous years by NIWA Hamilton. Whether this has made an appreciable difference to the final results is unknown and is currently being investigated as part of a wider programme review (Diffuse Sources, in prep.).

The SoE programme has gone through a number of changes in analytical procedures/providers since 1998. Analysis of the data from this programme has identified some potential QA uncertainties. As a result, at this stage, some of the extractable metals' data has been excluded for trend analysis (section 5.2.4).

Overall, the absence of definitive QA information to verify the consistency of the monitoring data across, and (to a lesser degree) within, the programmes, means that it is not possible to quantitatively confirm whether differences observed between programme results, or over time within each programme, are "real" or associated with variations in sampling and analysis. It is possible that a significant component of the variability, and year-to-year differences, observed in the monitoring data may be associated with changes in providers and/or methods. This is an issue that must be addressed for future monitoring, to minimise potential artefacts associated with analysis.

However, analysis of QA data from the RDP programme has provided information on the likely magnitude of variability associated with analysis (detailed in the separate programme review currently being undertaken, and summarised in section 5.2.6 below). In addition, visual assessment of the trend data shown in the SSRs (Appendix 1) provides an indication of the variability in the data record at each site, and allows the trends to be assessed in this context.

Clearly, a comprehensive QA system is required to verify data comparability across, and within, the various sediment contaminant monitoring programmes. Work is underway to design and test

appropriate QA protocols – these are to be documented in the programme review currently being undertaken (Diffuse Sources, in prep.), with a view to implementing them for the next round of monitoring scheduled for the end of 2012.

#### 5.2.4 Exclusion of extractable metals' data from the SoE programme

The data record for the SoE programme sites was reduced for trend assessment by exclusion of extractable metals' data from samplings conducted in 2003, 2005, and 2007, because of quality assurance issues associated with the results from these years. Details are to be provided in the programme review report (Diffuse Sources, in prep.).

Briefly, the extractable metals' data from these years appeared to be higher than usual, including unexpectedly high results from the rural reference site at Big Muddy Creek. Repeat analyses of archived samples from 5 sites gave generally lower results, which were also more consistent with the 2009 data. The reason(s) for the apparently high results from 2003–2007 are, as yet, unknown (and, realistically, may never be known). Until this issue is resolved, it was considered prudent to exclude these results from trend analysis.

Removing the 2003–2007 extractable metals' results left data from 1998, 1999, 2001, and 2009. This represents a minimal series for trend analysis, which is further reduced in "value" by having an "unbalanced" sampling frequency – 3 samplings relatively close together (1998, 1999, and 2001), followed by an 8 year gap, then a single additional sampling in 2009. This is clearly not ideal for robust trend assessment.

Extractable metals have been designated as the primary tool for tracking trends in metals' concentrations over time, because the analysis of the mud fraction reduces the variation associated with changes in sediment particle size distribution. Reducing the sample size from 7 to 4 samplings represents a major reduction in the ability to reliably detect trends at the SoE programme sites using extractable metals in the <63 µm fraction as the primary trend indicator.

#### 5.2.5 Differences in replication between monitoring programmes

At the RDP and UWH programme sites, 3 replicates per site were analysed for both extractable and total metals. At the SoE sites, 3 replicates were analysed for extractable metals, but only a single replicate (or composite sample) was analysed for total recoverable metals between 1998 and 2007 (3 replicates were analysed in 2009, to bring it into line with the RDP programme). The trend record for total metals at the former SoE sites, while longer, therefore lacks the higher level of replication undertaken at the RDP and UWH sites.

Table 5.1 A summary of sampling and analysis providers and methods used in the SoE, RDP, and UWH programmes between 1998 and 2010.

				Metals			
Programme	Years	Sampling <sup>a</sup>	Sieving <sup>b</sup>	Digestion <sup>b</sup>	Analysis <sup>c</sup>	PAH <sup>b</sup>	PSD <sup>d</sup>
SoE	1998-2001	ARC	NIWA-H	NIWA-H	NIWA: AAS	NIWA-H	NIWA: Laser
	2003–2007	ARC	NIWA-A	NIWA-A	RJ Hill: ICP-MS	NIWA-H	NIWA: Laser
	2009	DSL	RJ Hill	RJ Hill	RJ Hill: ICP-MS	n/a	NIWA: Sieve
RDP	2002	ARC and KML	RJ Hill	RJ Hill	RJ Hill	NIWA-H	RJ Hill: Sieve
	2004–2008	DSL	RJ Hill	RJ Hill	RJ Hill	n/a	NIWA: Laser
	2009–2010	DSL	RJ Hill	RJ Hill	RJ Hill	n/a	NIWA: Sieve
UWH	2005–2007	NIWA	NIWA-H	RJ Hill	RJ Hill	RJ Hill	NIWA: Sieve
	2008–2009	NIWA	RJ Hill	RJ Hill	RJ Hill	RJ Hill	NIWA: Sieve

a. Sampling providers: Auckland Regional Council (ARC), Kingett Mitchell Ltd (KML), Diffuse Sources Ltd (DSL).

b. Analytical providers: NIWA Hamilton (NIWA-H), NIWA Auckland (NIWA-A), RJ Hill Laboratories.

c. Metals' analysis methods: "Atomic Absorption Spectroscopy" (AAS), "Inductively Coupled Plasma Mass Spectrometry" (ICP-MS)

d. PSD analysis: Particle Size Distribution analysis methods – Laser particle size analyser (Galai instrument at NIWA); Sieve – wet sieving and pipette analysis into 6 size fractions (NIWA), or wet sieving into 3 size fractions (RJ Hill).

Note that sediment contaminant data was also collected in 2002 by NIWA (for Auckland City Council/Metrowater) and URS (for North Shore City Council). However, the data from these projects has not been included in this trend assessment exercise, because of differences/uncertainties in site locations and/or clear differences in analytical methods and results compared with later RDP results.

#### 5.2.6 Analytical variability

An assessment of the influence of analytical variability on results from the sediment chemistry monitoring programmes is currently being undertaken as part of the programme operational review (Diffuse Sources, in prep.). The results reviewed to date indicate that the variability associated with sample analysis may be a significant contributor to the overall variability in the final monitoring data.

Within-batch repeatability for analysis of samples from the same year (when analysed in the same analytical batch) is generally good, with reasonable agreement between individual replicates – approximately 80% of the metals' values lay within  $\pm 10-15\%$  of each other. However, differences between individual sample duplicates can occasionally be large, up to around  $\pm 40\%$ .

Between-batch variability (i.e. differences between samples taken in the same year, but analysed in different years) is higher than that for within-batch duplicates. Approximately 80% of the between-batch duplicate values for metals lie within  $\pm 20-25\%$  of each other, which is approximately double the difference observed for the within-batch duplicates. Differences between individual between-batch duplicate samples can be large, up to around 60%.

The analysis of monitoring programme variability undertaken to date suggests that differences in individual sample metals' concentrations between years of less than about  $\pm 20\%$  could largely be due to analytically-sourced variability. This is just a general rule – variability is likely to vary from site to site, and with the monitoring period and sampling frequency. Monitoring results need to be considered in this light.

While the differences between individual duplicate samples taken from different years may be reasonably large, the trend analysis is conducted using yearly median data (n=3 samples per year). There is no QA information on how greatly median concentrations in blind replicate samples vary from year-to-year, as this has not been included in QA protocols to date. However, analysis of multiple replicates of Certified Reference Material (CRM) for metals has been conducted each year in the RDP programme. The results (Diffuse Sources, in prep.) suggest that the analytical contribution to trends over time for metals has been small – significant trends have only been recorded for total Cu, and these were small (approximately +0.6% per year)<sup>8</sup>.

The lack of "benchmarking", from analysis of consistent QA samples over time, prevents us from quantitatively assessing exactly what proportion of any observed trends is likely to be sourced from analytical variation. A QA system including on-going analysis of "Bulk Reference Sediment" (BRS)<sup>9</sup>

<sup>&</sup>lt;sup>8</sup>Note that the CRM analysis conducted for the RDP programme did not include the sediment preparation steps of sieving and drying prior to digestion and ICP-MS analysis. These steps may potentially introduce significant variability, and therefore the CRM results may not completely reflect the total variation for field sediment sample analyses.

<sup>&</sup>lt;sup>9</sup>Bulk Reference Sediments (BRS) from two Auckland sites have been prepared, and initial characterisation undertaken. It is intended that the BRS will be introduced for QA assessment for the sampling to be conducted in late 2012.

for year-to-year benchmarking, is currently being developed for future monitoring. The programme operational review (Diffuse Sources, in prep.) will detail the revised QA protocols.

## 5.2.7 Uncertainties with 2002 data for RDP sites

Monitoring was undertaken in 2002 by ARC (KML 2003), North Shore City Council (URS 2002), and Auckland City/Metrowater (Webster et al. 2004), at a range of locations across the region, with some sites close to those later sampled in the routine RDP programme. The exact location of some of these sites is uncertain, and (as outlined above) the comparability of the analytical results with later RDP data could generally not be checked.

Therefore, it was considered inappropriate to include the 2002 results in detailed trend analysis. However, single site reports (Appendix 1) have included 2002 results for those sites with locations comparable to those sampled in later years, and where quality assurance data and analytical methodologies were consistent with 2004–2010; essentially only the KML (2003) dataset.

## 5.2.8 Particle size distribution

Particle size distribution (PSD) has been measured by different methods in the SoE, RDP, and UWH programmes, and the methods have (in the SoE and RDP programmes) changed over time. The different methods (principally laser particle size analysis and sieving/pipetting/weighing) provide generally similar results (Diffuse Sources, in prep.), but correlation between them is not good enough at each site to provide reliable trend records at individual sites.

In addition, the number of replicates analysed for PSD each year has generally been only one (on a composite sample, for the former RDP and UWH programme sites, and for sampling undertaken in 1998 and 2009 in the SoE programme). Three replicates per year were analysed in the SoE programme between 1999 and 2007.

Given the variable nature of the PSD data, no detailed statistical assessment of trends has been conducted. However, changes in PSD over time are shown in the SSRs (Appendix 1).

Note that a single, consistent, PSD analysis protocol (wet sieving/pipette analysis) is now being used across all programmes, so more detailed analysis should be able to be conducted in future.

## 5.2.9 Polycyclic aromatic hydrocarbons (PAHs)

PAHs have been measured on four occasions (1998, 1999, 2001, and 2005) at 26 sites in the SoE programme (only three times at Te Matuku, as sampling did not begin here until 1999).

In the RDP programme, 18 sites have had PAHs analysed. However, these were all undertaken on only one occasion (in 2002), except for Chelsea, which was analysed in 2002 and 2004. There are therefore no PAH trend data from RDP sites.

In the UWH programme, 13 sites have had PAHs measured on four occasions (2005, 2006, 2007, and 2009), and one (Paremoremo UWH) on three occasions (2005, 2006, and 2007).

PAH trends have therefore been assessed for 26 of the 27 SoE sites (1998–2005) and 13 of the UWH sites (2005–2009).

Trends in PAH have been assessed using "high molecular weight PAH" (HWPAH)<sup>10</sup>. TOCnormalised<sup>11</sup> PAH data would usually be used for trend analysis, to reduce variability associated with changes in particle size and organic matter content. However, there were no TOC data for SoE samples analysed for PAH, and therefore TOC-normalisation could not be conducted. To be consistent with the SoE sample results, trends in PAH at the UWH sites were also conducted on "non-normalised" data.

## 5.2.10 Trends at beach sites

The SoE programme beach sites (Awaruku, Vaughans, Te Matuku, Cheltenham, and Browns Bay) have coarse, sandy textures, and therefore low "mud content". Contaminants, which tend to associate with the finer sediment fractions, are therefore unlikely to accumulate for significant periods at these sites. Because of the low mud content in these sediments, analysis for extractable metals in the <63  $\mu$ m fraction is difficult, and the results generated to date have been highly variable.

The ARC monitoring blueprint (TP168, ARC 2004a, section 3.2.1) recommends that sediments with <5% mud content not be analysed for metals in the mud fraction. Of the five SoE beach sites, only Te Matuku has a mud content significantly above 5% (median of 11%). However, after removal of the 2003–2007 data (for QA reasons, as outlined previously), there are only 3 sets of extractable metals' data for this site. Awaruku, Vaughans, and Browns Bay sites have lower, and variable, mud fraction content, with median levels ranging between approximately 3 and 6%. Extractable metals' data were therefore not assessed for trends at these sites.

Cheltenham Beach, which had a median mud content of 6.3 %, and n=4 samplings (excluding 2003–2007 data), was the only beach site assessed for trends. However, extractable metals at this site are expected to be variable due to the low proportion of mud, and this site has only been included to check whether on-going analysis at beach sites is worthwhile.

## 5.2.11 Data used for trend assessment

In summary therefore, the data used for temporal trend analysis are as tabulated in Table 5.2.

Apart from the total metals at the SoE sites, the data record is therefore marginal for reliable trend assessment. Note, however, that the total metals' data are also probably not ideal for trend analysis because of potential PSD variation effects.

<sup>&</sup>lt;sup>10</sup>HWPAH is defined in the ANZECC (2000) guidelines as the sum of the concentrations of six dominant high molecular weight PAH compounds: fluoranthene, pyrene, benzo[a]pyrene, benzo[a]anthracene, dibenz[a,h]anthracene, and chrysene. Being higher molecular weight species, they are more likely to accumulate in sediments, and are less prone to losses during sample analysis than lower molecular weight compounds, and therefore are likely to provide more robust measure of PAH for trend assessment purposes.

<sup>&</sup>lt;sup>11</sup>PAH concentrations expressed in mg/kg at a sediment TOC concentration of 1%, as used to compare PAH concentrations with sediment quality guidelines (e.g. ERC).

Because the current data record is short, with relatively few data points, trend results for many sites may be sensitive to new results obtained from future monitoring. Because of this, the trend analysis only applies to the available data, in a "retrospective sense". Trends determined from monitoring to date do not necessarily mean that these will continue into the future.

		Extractable Metals		Total M	etals	HWP	۹H
Programme	Period	Samplings	Sites	Samplings	Sites	Samplings	Sites
SoE	1998–2009 <sup>a</sup>	4	21	5–7 <sup>b</sup>	27	4	26
RDP	2004–2010	4	16	4	16	No trend	data <sup>d</sup>
UWH	2005–2009	5°	14	5	14	4	13

**Table 5.2** A summary of the data used for trend analysis

- a. 1998, 1999, 2001, and 2009 only for extractable metals (due to quality assurance uncertainties). 1998–2005 for HWPAH.
- b. Most sites (19 of 27) have total metals' data from 7 samplings. Others have 5 or 6 samplings.
- c. Except Paremoremo, which has had 4 samplings between 2005 and 2008 for metals, and 3 samplings for PAH (2005–2007).
- d. PAH have been analysed at 18 RDP sites (in 2002), but only at 1 site have they been analysed more than once (Chelsea, in 2002 and 2004). Therefore trend assessment for PAH at RDP sites was not possible.

While the trend record is currently limited, and there are a variety of potentially problematic factors associated with the monitoring data, trends were still considered worth analysing. The process of undertaking the trend assessment has helped inform the programme review project, in particular in identifying improvements required to deliver more robust results in future. It also provides an indication of the scale of changes occurring to date, and the variability inherent in the monitoring data. This is a useful "reality check" for assessing what level of change in receiving environments is likely to be measurable.

#### 5.2.12 Interpreting trend data: A cautionary note

For all the reasons outlined above, it is very important **not** to put too much emphasis on the exact magnitude of trends, nor to analyse or interpret the results in too much detail.

Rather, it is more appropriate to use the data to provide a broader assessment about the general direction and magnitude of changes in sediment contamination. The trend monitoring results have therefore been presented and discussed within this context.

If detailed assessment of trends at individual sites is required, or the "real world" significance of trends at a particular site is of great importance, the "single site" data summary reports provided in Appendix 1 should be consulted, to check the nature of the data, in particular the data variability and the presence of any unusual data that may be influencing the trend results.

# 5.3 Trend results

#### 5.3.1 General overview of regional trends

This section provides an overview of the key results obtained from trend analysis. For the reasons outlined above, the level of analysis has been kept relatively broad. More detailed assessment can be obtained from examination of the SSRs (Appendix 1), the trend data table (Tables 6.1 to 6.7, appended to Section 6), and Figures 5.11 to 5.17 (trends at individual sites, which are also summarised in section 5.3.3).

The distribution of trends within each of the trend magnitude groups described previously in section 5.1.1 are tabulated in Table 5.3 and summarised graphically in Figures 5.3 (for metals) and 5.4 (for PAH).

Key features of these results are:

- The number of sites showing statistically significant trends (MK test, p<0.05) were relatively few. This reflects the combination of the small numbers of samplings conducted at most sites to date, the moderately variable results at many sites, and fairly small changes at most sites. Only extractable Pb showed significant trends at greater than a third of the sites (23/51 sites).
- The clearest consistent trend signal was observed for Pb, especially extractable Pb in the <63 µm fraction, which showed significant decreases in concentration at most sites; 22/23 sites where significant trends were measured showed possibly or probably decreasing trends (or 40/51 sites including both significant and non-significant changes). These data indicate that Pb concentrations are generally decreasing over time. This is probably consistent with expectations, given the removal of a major source of Pb (leaded petrol) some 15 years ago. The rate of decrease in Pb is likely to vary between sites, as the amounts, and removal rates, of Pb remaining in catchment soils will vary between catchments.</li>
- Significant changes for Zn were relatively fewer than for Pb; 20/51 sites showed no significant trend. Where significant trends were measured, these were generally increases; 13/15 sites with significant trends in extractable Zn showed increasing trends. This suggests that where changes are occurring, Zn is increasing more often than decreasing.
- Copper results were mixed, with extractable Cu showing both increases and decreases (but most sites having no significant change), while total Cu showed more sites decreasing than increasing. Copper concentrations are lower than Zn or Pb, and the less definitive trend picture shown for Cu to date may be partly attributable to this.
- HWPAH showed few significant trends (7/39 sites); 5/7 of these sites showed increases, and 2/7 decreases. HWPAH concentrations were generally low, and showed moderate variability. Also the numbers of samplings was small (n=4). A lack of a definitive trend pattern is therefore not unexpected.

Overall, therefore, most sites have shown no significant changes. Where significant trends have occurred, they appear to be following a generally "accepted" pattern – Pb has mostly decreased, Zn seems to have generally increased, and changes in Cu and HWPAH have been largely indeterminate.

**Table 5.3** Overview of trends detected across all monitoring sites with N  $\geq$ 4 samplings.

A. All trends, both "significant" (MK, p<0.05) and "non-significant" (MK p≥0.05)

	Extractable Metals			Total Metals			
Sites and trend categories	Cu	Pb	Zn	Cu	Pb	Zn	HWPAH
Total trend sites (n ≥ 4 samplings)	51	51	51	57	57	57	39
"Probably decreasing" trend (<-2% per year)	11	31	8	22	19	5	8
"Possibly decreasing "trends (-1 to -2% per year)	10	9	6	7	2	12	3
Sites with "no change" (-1 to +1% per year)	17	5	20	15	24	17	12
"Possibly increasing" trend (1-2% per year)	7	4	9	6	4	7	5
"Probably increasing" trend ( >2% per year)	6	2	8	7	8	16	11

#### B. "Significant" trends only (MK, p<0.05)

	Extractable Metals			Тс	otal Meta	als	
Sites and trend categories	Cu	Pb	Zn	Cu	Pb	Zn	HWPAH
Total trend sites (n ≥ 4 samplings)	51	51	51	57	57	57	39
Total sites with significant trend (MK test; p<0.05)	9	23	15	15	13	19	7
"Probably decreasing" trend ( <-2% per year)	3	19	2	12	11	2	2
"Possibly decreasing "trends (-1 to -2% per year)	1	3	0	0	0	3	0
Sites with "no change" (-1 to +1% per year)	0	0	0	0	0	1	0
"Possibly increasing" trend (1-2% per year)	2	0	5	1	0	2	0
"Probably increasing" trend ( >2% per year)	3	1	8	2	2	11	5



**Figure 5.3** Distribution of trends (Relative Sen Slope; % median per year) in metals. Trends are subdivided into "significant" (sig.; MK, p<0.05) and "not significant" (n.s.; MK p≥0.05).



**Figure 5.4** Distribution of trends (Relative Sen Slope; % median per year) for HWPAH. Trends are subdivided into "significant" (sig.; MK, p<0.05) and "not significant" (n.s.; MK p≥0.05).

#### 5.3.2 Magnitude of trends across the region

The overall rates of change in sediment contamination across the "region" (i.e. the areas covered by the monitoring sites used in the trend assessment) can be obtained by calculating the trends at each site, then assessing summary statistics based on these individual site trend results (e.g. average or median rates of change, smallest, largest etc). This assessment maybe affected by differences in monitoring periods and sample numbers at different sites, but it does provide a useful broad-scale indicator of trends.

Trend values are tabulated in Table 5.4 (Sen Slopes, mg/kg/year) and Table 5.5 (Relative Sen Slopes, % of median concentration per year), and presented graphically in Figures 5.5 and 5.6. Results are shown for all monitoring data, and also the trends for the SoE, RDP, and UWH programme sites separately. Histograms (providing greater detail of trends than those given in Figures 5.3 and 5.4) shown in Figures 5.7 and 5.8 show the distribution of trends at each site, including their significance (MK test, where "significant" is p<0.05).

#### Metals

For all programme data, including both significant and non-significant trends, the median rates of change for all metals were small decreases (ranging from -0.1% to -2.4% per year), except for Total Zn, which showed a small increase over time (approximately 0.4% per year). This suggests that there has been no marked broad-scale change in sediment contamination over the past decade.

The results also show that there is a wide range of trends at individual sites. For example, total Zn trends range from -5.7 mg/kg/year (-3.7% per year) to +6.6 mg/kg/year (+7.1% per year). Therefore, while the overall average (or median) change may be near zero, there are sites with significant increases, and decreases, in metal levels.

There are also differences between programmes, as shown in Figures 5.5 and 5.6. These differences between the programmes vary with no obvious consistent pattern. Because the average trends are relatively small, this may reflect data variability rather than anything meaningful.

One feature which does appear reasonably consistent is that the trends for extractable Pb in all programmes are, on average, negative (i.e. small decreasing trends over time). Cu and Zn are sometimes positive, sometimes negative. This is also observed in the plots of trends for each site (Figures 6.1 to 6.7, appended to Section 6).

#### PAH

There are fewer PAH data than for metals, with trend data available from only the SoE programme (1998, 1999, 2001, and 2005) and the UWH programme (2005–2009).

Trends from all the data grouped give an overall median rate of change in "high molecular weight PAH" (HWPAH) of 0.0005 mg/kg per year.

For the SoE programme only, the median trend was +0.001 mg/kg/year, and for the UWH programme -0.001 mg/kg/year.

On average, therefore, there has been very little change in HWPAH concentrations over time. Overall, the trends in PAH were not significantly different from "zero", which reflects the relatively high variability in concentrations within each year, relatively low PAH concentrations at most sites, and that only n=4 years of trend data are available to date. It is considered unlikely that the changes in PAH measured to date represent any "real" meaningful trends over time. Table 5.4 Broad-scale trends over time. Data are Sen Slopes (mg/kg/year). N is the no. of sites.

Analyte (fraction analysed)	N	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	51	-0.16	-0.04	-1.52	1.32	-0.65	0.31
Extractable Pb (<63 µm)	51	-0.88	-0.75	-3.17	0.85	-2.39	0.28
Extractable Zn (<63 µm)	51	-0.09	-0.14	-6.00	6.59	-4.11	4.03
Total Cu (<500 μm)	57	-0.25	-0.14	-2.44	0.88	-0.88	0.33
Total Pb (<500 µm)	57	-0.31	-0.03	-2.77	0.96	-1.56	0.33
Total Zn (<500 μm)	57	0.73	0.41	-5.70	6.58	-1.82	3.90
HWPAH (<500 μm)	39	-0.0017	0.0005	-0.0827	0.0222	-0.0123	0.0084

A. Data from all monitoring sites

B. Data from SoE programme sites(1998–2009 for metals, 1998–2005 for HWPAH).

Analyte (fraction analysed)	Ν	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	21	-0.08	-0.01	-1.40	0.39	-0.53	0.36
Extractable Pb (<63 µm)	21	-1.44	-1.03	-3.17	-0.11	-2.97	-0.26
Extractable Zn (<63 µm)	21	1.55	1.67	-3.53	6.59	-2.56	5.81
Total Cu (<500 μm)	27	-0.47	-0.40	-2.44	0.27	-1.28	0.05
Total Pb (<500 μm)	27	-0.71	-0.28	-2.77	0.23	-2.07	0.08
Total Zn (<500 μm)	27	-0.62	-0.44	-5.70	3.31	-3.90	1.52
HWPAH (<500 μm)	26	-0.0013	0.0010	-0.0827	0.0222	-0.0127	0.0082

C. Data from RDP programme sites(2004–2010; no trend data for HWPAH).

Analyte (fraction analysed)	Ν	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	16	0.04	0.06	-0.50	1.32	-0.50	0.48
Extractable Pb (<63 µm)	16	-0.39	-0.41	-1.94	0.85	-1.32	0.49
Extractable Zn (<63 µm)	16	-0.56	-0.54	-5.05	4.34	-4.76	2.06
Total Cu (<500 μm)	16	0.07	0.10	-0.66	0.55	-0.40	0.40
Total Pb (<500 µm)	16	-0.04	0.06	-1.01	0.45	-0.60	0.32
Total Zn (<500 μm)	16	2.10	1.93	-1.06	6.58	-0.35	6.07
HWPAH (<500 μm)	0	-	-	-	-	-	-

D. Data from UWH programme sites(2005–2009).

Analyte (fraction analysed)	Ν	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	14	-0.51	-0.36	-1.52	0.00	-1.20	0.00
Extractable Pb (<63 µm)	14	-0.59	-0.50	-1.57	0.32	-1.44	0.14
Extractable Zn (<63 µm)	14	-2.02	-1.53	-6.00	0.71	-5.88	0.45
Total Cu (<500 µm)	14	-0.19	-0.31	-0.90	0.88	-0.72	0.58
Total Pb (<500 μm)	14	0.14	0.00	-0.60	0.96	-0.43	0.82
Total Zn (<500 μm)	14	1.77	2.20	-2.00	5.04	-1.04	4.14
HWPAH (<500 μm)	13	-0.0027	-0.0010	-0.0283	0.0184	-0.0141	0.0105

**Table 5.5** Broad-scale trends over time. Data are Relative Sen Slopes (% of median per year). N is the number of sites.

A. Data nom all monitori	19 31103						
Analyte(fraction analysed)	Ν	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	51	-0.63	-0.30	-7.20	8.50	-4.14	2.18
Extractable Pb (<63 µm)	51	-2.35	-2.40	-11.50	2.90	-4.14	1.10
Extractable Zn (<63 µm)	51	-0.05	-0.10	-5.60	5.10	-3.00	2.86
Total Cu (<500 µm)	57	-1.57	-1.20	-14.20	6.70	-6.30	2.56
Total Pb (<500 µm)	57	-0.69	-0.10	-6.00	4.70	-4.22	2.54
Total Zn (<500 μm)	57	0.66	0.40	-3.70	7.10	-1.90	3.60
HWPAH (<500 μm)	39	0.81	0.60	-17.80	13.40	-4.48	9.42

#### A. Data from all monitoring sites

B. Data from SoE programme sites(1998–2009 for metals, 1998–2005 for HWPAH).

Analyte(fraction analysed)	Ν	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	21	-0.14	0.00	-5.20	3.10	-3.60	2.30
Extractable Pb (<63 µm)	21	-3.68	-3.00	-11.50	-1.00	-8.80	-1.44
Extractable Zn (<63 µm)	21	1.29	1.20	-2.00	4.70	-1.60	3.94
Total Cu (<500 μm)	27	-1.95	-1.90	-8.40	3.00	-5.40	2.16
Total Pb (<500 μm)	27	-1.74	-2.00	-6.00	3.00	-4.46	0.96
Total Zn (<500 μm)	27	-0.61	-0.70	-3.70	1.70	-2.48	1.20
HWPAH (<500 μm)	26	1.65	0.90	-4.00	10.00	-2.14	7.85

C. Data from RDP programme sites(2004–2010; no trend data for HWPAH).

Analyte(fraction analysed)	Ν	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	16	0.46	0.30	-2.30	8.50	-2.00	2.46
Extractable Pb (<63 µm)	16	-1.03	-1.85	-4.10	2.90	-3.56	1.97
Extractable Zn (<63 µm)	16	-0.17	-0.45	-4.50	5.10	-3.14	1.90
Total Cu (<500 μm)	16	0.31	0.95	-9.40	6.40	-3.07	2.89
Total Pb (<500 μm)	16	0.11	0.25	-5.10	3.50	-2.82	3.29
Total Zn (<500 μm)	16	1.90	2.45	-1.60	5.10	-1.14	3.70
HWPAH (<500 μm)	0	-	_	-	-	-	-

D. Data from UWH programme sites(2005–2009).

Analyte(fraction analysed)	Ν	Mean	Median	Min	Max	10%ile	90%ile
Extractable Cu (<63 µm)	14	-2.61	-1.90	-7.20	0.00	-6.30	0.00
Extractable Pb (<63 µm)	14	-1.87	-1.75	-5.20	1.20	-4.30	0.48
Extractable Zn (<63 µm)	14	-1.91	-1.55	-5.60	0.70	-5.60	0.43
Total Cu (<500 µm)	14	-2.99	-1.85	-14.20	6.70	-11.59	2.83
Total Pb (<500 µm)	14	0.41	0.00	-2.90	4.70	-2.36	2.99
Total Zn (<500 μm)	14	1.71	2.25	-2.00	7.10	-1.91	4.40
HWPAH (<500 μm)	13	-0.88	-0.60	-17.80	13.40	-10.44	10.68



**Figure 5.5** Trends (Sen Slopes, mg/kg per year) in extractable (2 M HCl, <63  $\mu$ m fraction) and total recoverable (<500  $\mu$ m) metals, and HWPAH (<500  $\mu$ m) in sediments from SoE, RDP, and UWH programmes. Trends for data from all programmes grouped are also shown.



**Figure 5.6** Trends (Relative Sen Slopes, % median concentration per year) in extractable (2 M HCl, <63  $\mu$ m fraction) and total recoverable (<500  $\mu$ m) metals, and HWPAH (<500  $\mu$ m) in sediments from SoE, RDP, and UWH programmes. Trends from all programmes grouped are also shown.



Extractable Lead (<63 µm)

p<0.05

p>0.05 

10 12 14

14

12

10

8

6

4

2

0

-14 -12 -10 -8

-6 -4 -2 0

2 4 6 8

Trend (% of median per year)

Number of sites

Total Recoverable Copper (<500 μm) 10 p<0.05 p>0.05 8 Number of sites 6 4 2 0 -10 -15 -5 0 5 10 15 Trend (% of median per year)





Figure 5.7 Distribution of trends (Relative Sen Slope; % median per year) in metals.

8



**Figure 5.8** Distribution of trends (Relative Sen Slope; % median per year) in high molecular weight PAH (HWPAH).

#### 5.3.3 Spatial patterns and trends at individual sites

Spatial patterns in trends are shown in the maps of Figures 5.9 to 5.15, and trends at individual monitoring sites are plotted in Figures 6.1 to 6.7 (appended to Section 6). Raw trend data are also tabulated in Table 6.1 to 6.7 (appended to Section 6).



Figure 5.9 Map of trends in extractable copper (<63 µm fraction)



Figure 5.10 Map of trends in extractable lead (<63 µm fraction)


Figure 5.11 Map of trends in extractable zinc (<63  $\mu$ m fraction)



Figure 5.12 Map of trends in total recoverable copper (<500 µm fraction)



Figure 5.13 Map of trends in total recoverable lead (<500 µm fraction)



Figure 5.14 Map of trends in total recoverable zinc (<500 µm fraction)



Figure 5.15 Map of trends in high molecular weight PAH (<500 µm fraction)

As discussed earlier (section 5.3.1), apart from Pb, there are relatively few consistent significant trends. A detailed assessment of spatial patterns cannot, therefore, be reliably made. Inspection of the maps and plots reveals the following general indications of where major changes have occurred:

## Lead

Most urban sites with significant trends in Pb have shown decreases (>-2% per year), or possible decreases (-1 to -2% per year) over time. Sites in the Central Waitemata Harbour, Tamaki Estuary and Mangere Inlet generally showed decreasing trends. The lower (urban influenced) site in Lucas Creek in the Upper Waitemata Harbour (UWH) also showed a significant decreasing trend, but the record at this site is still relatively short (4 years). The mostly rural sites in the UWH showed no significant changes.

Only two sites, Whau Entrance and Chelsea, both sandy Outer Zone (OZ) RDP sites in the Central Waitemata Harbour, have shown significant increases. At Whau Entrance, the increase was approximately 0.8 mg/kg/year extractable Pb in the <63  $\mu$ m fraction (ca. 3% per year), and about 0.2 mg/kg/year in the <500  $\mu$ m fraction. At Chelsea, the change in extractable Pb (<63  $\mu$ m) was about 2% per year (although not significant; MK test, p=0.19), but in the <500  $\mu$ m fraction the increase was significant at approximately 3.5% per year (ca. 0.45 mg/kg/year). The reasons for the increasing Pb levels at these two sites are unknown.

As discussed previously, therefore, the overall picture for Pb is one of generally decreasing trends in urban estuaries, particularly in the older developed catchments of the Central Waitemata Harbour, Tamaki Estuary, and Mangere Inlet.

## Copper

Trends in Cu were mixed, with the <63  $\mu$ m and <500  $\mu$ m fractions at many sites showing different patterns. Only Anns Creek (decreasing Cu) and Chelsea (increasing Cu) showed consistent results for both fractions.

Extractable Cu (<63 µm fraction) showed significant increasing trends at 5 sites, and decreases at 4 sites.

Total recoverable Cu (<500  $\mu$ m fraction) showed significant increases at 4 sites, but decreases at 12 sites.

Significant increases in extractable Cu (<63 µm fraction) of >2% per year occurred at three sites – Chelsea (Central Waitemata Harbour), Pukaki Creek (Airport site; Manukau Harbour), and Weiti River (Hibiscus Coast). Two sites had "possible" increases (1–2% per year) – Middlemore (Tamaki Estuary) and Pahurehure Papakura (Manukau Harbour).

Significant increases of >2% per year in Total Cu (<500  $\mu$ m fraction) occurred at Chelsea, Vaughans Beach (East Coast Bays), while Kendall Bay (CWH) showed an increase of 1–2% per year. These are all sandy OZ/beach sites, with low Total Cu concentrations. In absolute terms, the changes are very small (0.05–0.35 mg/kg/year).

The12 significant decreases in Total Cu were observed at sites in the Central and Upper Waitemata and Manukau Harbours, but not at sites in the Tamaki Estuary.

The strongest increasing Cu trend was observed at Chelsea (Central Waitemata Harbour, RDP programme), which showed significant increases in both fractions and also showed increases in Pb and Zn concentrations.

It should be noted that Cu concentrations are generally relatively low compared with Pb and Zn, and therefore relative trends (percentage changes) in Cu were relatively large.

Overall, no consistent spatial pattern of trends was shown for Cu. Based on the total Cu (<500 µm fraction) results, decreases outnumbered increases, suggesting generally decreasing concentrations. For extractable Cu (<63 µm fraction), there were few sites with increases or decreases, suggesting little widespread change.

## Zinc

Zinc trends were mixed, with extractable Zn (<63  $\mu$ m fraction) showing both increases and decreases in all three programmes. At SoE sites, increases outnumbered decreases, while at UWH programme sites decreases were dominant. Total Zn (<500  $\mu$ m fraction) showed increases at nearly all RDP and UWH sites, but mostly decreases at SoE sites.

Overall, where significant trends were recorded, there were more increases in Zn than decreases. For extractable Zn (<63  $\mu$ m fraction), 13/15 sites with significant trends were increasing, and for Total Zn (<500  $\mu$ m fraction) 13/19 were increasing, or possibly increasing.

Decreasing Zn was found at:

- Two sites for extractable Zn (<63 µm fraction) Brighams Creek (UWH), which is a mainly rural catchment estuary, and Coxs Bay (mature urban Central Waitemata Harbour site).
- Five sites for total Zn (<500 µm fraction) Anns Creek and Mangere Cemetery sites in Mangere Inlet (old industrialised catchment in Manukau Harbour), Meola Inner and Henderson Upper (both mature urbanized catchment sites in the Central Waitemata Harbour), and at Big Muddy Creek (rural/reference site in the outer Manukau Harbour).

Trends at some rural/reference sites have occurred. (e.g. Big Muddy – decrease, Brighams UWH – increase, Rangitopuni UWH – increase). Reasons for these changes are unknown.

Generally, Zn seems to have increased in the Whau Estuary (Central Waitemata Harbour) and the Tamaki Estuary, decreased in Mangere Inlet, and mixed changes have occurred elsewhere. Overall, it seems increases have outnumbered decreases, consistent with a generally increasing trend in Zn, but the spatial picture is not yet convincingly clear.

## PAH

Few significant trends were observed for PAH. Only 7 of the 39 sites where trends were assessed showed significant trends; 5 of these sites showed increases, and 2 were decreases.

The two decreasing sites were Central Waitemata East and Herald Island North, both UWH programme sites. These have been monitored for only 4 years, and significant change over such a short period is unexpected.

Of the five sites showing increasing PAH, two were beach sites (Awaruku and Vaughans) with very low PAH concentrations.

The remaining three sites where increasing PAH was observed were Anns Creek (SoE site, Manukau Harbour), Lucas Upper (SoE site, Upper Waitemata Harbour), and Pakuranga Lower (SoE site, Tamaki Estuary). These are all urban catchment sites.

PAH concentrations were generally low, and showed moderate variability. Also the numbers of samplings was small (n=4). A lack of a definitive trend pattern is therefore not unexpected. It is probably too early to be confident that any of the changes in PAH observed to date are real. Analytical variation is likely to be a significant contributor to the observed changes.

## 5.3.4 Relationships between trends and contaminant concentrations

An earlier status and trend assessment (Kelly 2007) reported that increasing trends in Cu and Zn at SoE programme sites were greatest at the most contaminated sites.

The relationships between contaminant concentrations and trends (Sen Slopes; mg/kg/year) from the SoE, RDP, and UWH programmes are shown in Figures 5.16 and 5.17. These results show that there was little consistent change in trend with increasing concentrations of Cu, Zn and HWPAH. An exception may be for Zn in the RDP programme, which does appear to show a substantial decrease in trends with increasing concentrations for extractable Zn, but an increasing trend with concentration for total Zn.

For Pb, larger decreasing trends tend to be found at sites with higher Pb levels, at least at SoE programme sites.

Overall, therefore, it appears that Pb levels at the more contaminated sites are decreasing fastest (which is good news), but no simple conclusion about Cu, Zn or HWPAH can yet be made. A clearer picture may emerge as the time series grows, especially for the UWH and (former) RDP sites, which currently have relatively few data.



Figure 5.16 Relationship between trends (Sen Slopes, mg/kg/year) and metals' concentrations.





# 5.4 Trend monitoring results compared with modelling predictions

Changes in Zn and Cu concentrations over time have been predicted from computer modelling in a variety of locations across Auckland's estuaries. A summary of these studies and the changes in Cu and Zn concentrations are given in Tables 6.8 and 6.9 (appended to Section 6). The data are presented in Figure 5.18.

Modelling results have been summarised as average trends for the period 2001 to 2011. These results show that Cu and Zn concentrations are predicted to increase over time, at varying rates, at most sites. Near-zero rates of change have been predicted for primarily rural estuaries, for example Paremoremo and Brighams estuaries (Upper Waitemata Harbour).

In theory, the modelling predictions could be compared with the sediment chemistry monitoring results to provide benchmarking of the modelling predictions, or alternatively a check on the robustness of the monitoring results. Increased confidence in trend results, either measured or modelled, would result if the two lines of evidence produced a similar picture of trends at a range of locations.

Comparing the modelling and monitoring results is not, however, straightforward. Reasons include:

- The scale of sites/locations/areas sometimes differs between the modelling studies and monitoring. UCS2 and USC3 modelling predicts changes over a much broader spatial scale than the scale that the monitoring sites are generally supposed to represent.
- The nature and assumptions of the modelling procedures means that modelling predicts very broad long-term changes and not short-term changes. In contrast, the monitoring has only been running for, at most, a decade (for SoE programme sites) – a short time period compared with modelling time frames.
- Models make many simplifications and assume relatively simple conditions of transport and deposition over very broad regions. Monitoring will reflect all the processes occurring in the environment, and may be picking up more complex short-term and small-scale processes.

Marine sediment contaminants: Status and trends assessment 1998-2010

• As described earlier, monitoring data may be susceptible to potential errors (including those arising from laboratory analysis, monitoring design and implementation and data analysis) as well as real environmental variability. Modelling "smooths out" all the variation, but may also contain inherent errors in terms of the assumptions built into the models.

Therefore, taking these differences into account, at this time we should only compare modelling and monitoring in a general way, using an "order of magnitude" context. Such a general comparison reveals:

- The changes predicted by modelling and monitoring are of a similar order of magnitude and both are relatively small. This is an important result the modelling and monitoring results are generally consistent in that predicted and measured rates of change are mostly small.
- While there is general agreement, modelling predictions and monitoring trends do not show consistent agreement at all sites. However, given the uncertainties associated with both the monitoring and modelling, this is probably not unexpected.
- In predominantly urban estuaries, modelling predicts increasing trends. In contrast, monitoring sometimes shows decreases in concentrations, especially for Cu. This difference is rather interesting, but it would not be sensible to make conclusive comparisons until a longer monitoring record is obtained – many of the negative trends measured from monitoring may yet be due to data variability (e.g. analytically-sourced changes). It is also possible that this may be highlighting some shortcomings in the models, which do not include processes that lead to decreases in concentrations in sediments.

Overall, the modelling results predict relatively small changes over the monitoring period. Monitoring has also generally found this – overall, trends are mostly small. A longer monitoring period, and possibly more reliable monitoring data, are required before comparisons at each site can be made with confidence. More robust comparisons of modelling and monitoring results would also require additional surveys to obtain sediment chemistry data over spatial scales consistent with modelling predictions.



Figure 5.18 Trends in Cu and Zn predicted from contaminant accumulation modelling.

# 5.5 Trend summary

Overall, it is hard to provide a clear summary of the current trend situation at all sites. Considerable variability is observed within and between sites, between contaminants, between forms of contaminants and between the three (former) monitoring programmes.

Using all the monitoring results from all sites to assess "broad scale" regional changes in sediment quality, it appears that there has been little overall change in concentrations of metals or PAH over the past decade.

However, one generally consistent change in sediment chemistry is a small decreasing trend in Pb across most urban sites. While this might be seen as consistent with the removal of Pb from petrol in the mid-1990s, it may not be consistent with the fact that the urban catchments are still discharging Pb from the "Pb reservoir" remaining within the catchment soils.

Cu and Zn trend results lack consistency, varying between sites and between metal forms (extractable and total). However, where changes in Zn concentrations have occurred, these have mainly been increases, which supports a generally held view that Zn concentrations are likely to increase over time at most urban sites. Changes in Cu are smaller, and subject to greater uncertainty.

Analytical variability, and the relatively small changes occurring to date at most sites, are likely to be significant factors affecting the detection of consistent significant trend results. Variability in the processes that control contaminant concentrations in sediment are also likely to be important. For example, localized or more widespread sources of uncontaminated or more contaminated sediments, varying sedimentation/resuspension conditions, and the extent to which such inputs are mixed downward into the bioturbated zones by physical and biological processes are among the multiple factors that may potentially be influencing observed contaminant accumulation rates.

At this stage, because the trend series have so few data points (samplings), changes at many sites are too small, or variable, to be deemed "significant" or, more importantly, "meaningful" in a realworld sense. A clearer picture is likely to emerge in future, as additional sampling data are added to the existing trend series.

The changes observed to date are generally fairly small and this is consistent with modelling predictions. With such small rates of change, reducing data variability, in particular analytical "between batch" variability, is required to help detection of trends above the background "noise" and to improve confidence that observed changes are "real" rather than analytical artifacts. As detailed in earlier sections some improvements in monitoring and analytical procedures have already occurred and further improvements are the subject of the current programme review (Diffuse Sources, in prep.).

# 6.0 Overall assessment

Despite issues associated with the monitoring data quality (variability and uncertain consistency over time), the sediment contaminant monitoring programmes have delivered a wealth of useful information on the spatial distribution and general trends in key urban contaminants in Auckland's marine sediments.

The monitoring data clearly identify areas with differing levels of contamination, and now provide a comprehensive spatial picture of contaminant levels in the Auckland coastal zone. This has provided a better understanding of the impacts of land use on receiving environments, and (via integration with ecological health monitoring and modelling) the potential ecological impacts of this contamination.

The overall picture obtained from trend analysis is that while there is considerable complexity (with differences between sites, contaminants, and programmes), broad-scale changes in sediment contamination by metals and PAHs since 1998 have generally been small. A decrease in Pb concentrations at most urban sites has been measured, which may reflect the beneficial effect of removal of a key Pb source (leaded petrol) in the mid-1990s.

The data analysis conducted in this status and trends review has also improved our understanding of the capabilities and limitations of current sediment contaminant monitoring methods. This information is being used to improve the quality of future monitoring data, and hence provide greater certainty for future trend assessments.

Overall, the sediment contaminant monitoring data analysed in this project indicate that the spatial patterns of contamination are essentially the same as reported previously, and that contaminant concentrations in most areas have not changed greatly since 1998. This picture is generally consistent with modelling predictions, and provides some reassurance that rapidly increasing contamination in Auckland's estuaries, as a result, for example, of stormwater discharges, is not a widespread occurrence. However, because of uncertainties associated with the monitoring data, continued monitoring is recommended to provide greater surety in future trend assessments.



**Figure 6.1** Trends in extractable copper (<63 µm fraction) for sites with n=4 or more samplings with sites grouped by sampling programme. Trends are: A. Sen Slopes (mg/kg/year) and B. Relative Sen Slopes (% median per year). Error bars are ±95% CLs.



**Figure 6.2** Trends in extractable lead (<63 µm fraction) for sites with n=4 or more samplings with sites grouped by sampling programme. Trends are A. Sen Slopes (mg/kg/year) and B. Relative Sen Slopes (% median per year). Error bars are ±95% CLs



**Figure 6.3** Trends in extractable zinc (<63 µm fraction) for sites with n=4 or more samplings with sites grouped by sampling programme. Trends are A. Sen Slopes (mg/kg/year) and B. Relative Sen Slopes (% median per year). Error bars are ±95% CLs.



**Figure 6.4** Trends in total copper (<500 µm fraction) for sites with n=4 or more samplings with sites grouped by sampling programme. Trends are A. Sen Slopes (mg/kg/year) and B. Relative Sen Slopes (% median per year). Error bars are ±95% CLs.



**Figure 6.5** Trends in total lead (<500 µm fraction) for sites with n=4 or more samplings with sites grouped by sampling programme. Trends are A. Sen Slopes (mg/kg/year) and B. Relative Sen Slopes (% median per year). Error bars are ±95% CLs.



**Figure 6.6** Trends in total zinc (<500 µm fraction) for sites with n=4 or more samplings with sites grouped by sampling programme. Trends are A. Sen Slopes (mg/kg/year) and B. Relative Sen Slopes (% median per year). Error bars are ±95% CLs.



**Figure 6.7.**Trends in high molecular weight PAH (HWPAH; <500 µm fraction) for sites with n=4 samplings with sites grouped by sampling programme. Trends are A. Sen Slopes (mg/kg/year) and B. Relative Sen Slopes (% median per year). Error bars are ±95% CLs.

#### Table 6.1 Raw trend analysis data for extractable copper (<63 µm).

				Extractable Copp	oer (<63 um	ı)
			median	Sen Slope	р	RSSE
Site	Programme	MRA	mg/kg	mg/kg/yr		% per yr
Anns	SoE	Manukau	27.7	-1.40	0.001	-5.1
Awaruku	SoE	East Coast				
Benghazi	RDP	Tamaki Estuary	20.0	0.12	0.672	0.6
Big Muddy	SoE	Manukau	6.1	-0.04	0.243	-0.7
Bowden	RDP	Tamaki Estuary	25.0	-0.50	0.118	-2.0
Brighams UWH	UWH	Upper Waitemata	20.0	-0.35	0.102	-1.8
Browns	SoE	East Coast				
Central Main Channel	UWH	Upper Waitemata	18.7	-0.08	0.842	-0.4
Central Waitemata East	UWH	Upper Waitemata	18.4	-1.00	0.175	-5.4
Chelsea	RDP	Central Waitemata	15.5	1.32	0.001	8.5
Cheltenham	SoE	East Coast	10.5	-0.55	0.244	-5.2
Coxs	RDP	Central Waitemata	25.5	0.29	0.329	1.1
Hellyers SoE	SoE	Upper Waitemata	16.7	0.17	0.169	1.0
Hellvers Upper UWH	UWH	Upper Waitemata	21.0	-0.57	0.227	-2.7
Hellvers UWH	UWH	Upper Waitemata	16.2	-0.30	0.455	-1.9
Henderson Entrance	RDP	Central Waitemata	20.0	0.50	0.391	2.5
Henderson Lower	RDP	Central Waitemata	22.0	-0.25	0.111	-1.1
Henderson Upper	SoF	Central Waitemata	28.1	-0.09	0.536	-0.3
Herald Island North	UWH	Upper Waitemata	22.0	0.00	0.644	0.0
Herald Island Wajarohia		Upper Waitemata	19.6	-0.25	0.518	-1.3
Hillsborough	RDP	Manukau	11.3	-0.26	0.266	-2.3
Hohson Newmarket	SoF	Central Waitemata	25.4	-0.01	0.945	0.0
Hobsonville (Central Waitemata West)		Linner Waitemata	21.0	-1 52	0.045	-7.2
Kendall	RDP	Central Waitemata	12.0	0.25	0.007	2.1
			12.0	-0.36	0.250	_1 9
	SoF		15.0	-0.30	0.105	-1.5
			19.6	1 16	0.024	6.2
Mangere Cemetery	SoF		20.3	-0.52	0.024	-0.2
Mada Innor	SOE	Control Waitemata	20.3	-0.32	0.731	-2.0
Meela Outer		Central Waitemata	19.0	0.08	0.030	0.3
Media Duter	RDP	Central Waitemata	18.0	0.00	0.883	0.0
	SUE		25.8	-0.35	0.149	-1.4
Mations	SOE	Control Waitemate	28.4	0.35	0.033	1.2
Niotions	SOE	Central Waitemata	38.9	-0.32	0.732	-0.8
Odkiey	SUE		23.7	-0.03	0.575	-0.1
Otanunu Outer Main Channel			25.5	-0.50	0.401	-2.0
Dater Main Channel		Opper Waitemata	22.0	-0.76	0.213	-3.5
	SUE		0.0	0.10	0.011	1.5
Pakuranga Lower	SOE	Tamaki Estuary	25.7	-0.01	0.945	0.0
Pakuranga Opper	SOE	Tamaki Estuary	34.8	0.13	0.536	0.4
Parimure	RDP	I difiditi Estudiy	23.0	-0.41	0.034	-1.8
Paremoremo	SOE	Upper Waltemata	20.0	0.52	0 1 2 2	2.7
Paremoremo UWH	UWH	Opper waitemata	20.0	-0.53	0.132	-2.7
Point England	RDP		15.5	-0.02	0.945	-0.1
Princes	RDP	Tamaki Estuary	27.5	-0.49	0.078	-1.8
Puninui Opper	SOE	Manukau	5.9	0.18	0.113	3.1
Pukaki Airport	SOE	Manukau	4.9	0.11	0.013	2.3
Purewa	RDP	Central Waltemata	18.9	0.27	0.729	1.4
		Opper waitemata	20.0	0.00	0.960	0.0
		Central waitemata	14.3	0.13	0.576	0.9
	SOE		10.0	0.24	0.264	1.0
Upper Main Channel		Upper Waitemata	19.0	-0.31	0.364	-1.6
vaugnans	SOE	East Coast	10.5	0.55	0.000	
weiti	SOE	Hibiscus Coast	16.2	0.38	0.002	2.3
wnau Entrance	KDP	Central Waitemata	18.5	0.25	0.236	1.4
Whau Lower	SOE	Central Waitemata	21.6	0.39	0.063	1.8
Whau Upper	SOE	Central Waitemata	34.0	0.03	0.680	0.1
Whau Wairau	SOF	Central Waitemata	43.8	-0.33	0.114	-0.8

#### Table 6.2 Raw trend analysis data for extractable lead (<63 µm).

			Extractable Pb (<63 um)			
			median	Sen Slope	р	RSSE
Site	Programme	MRA	mg/kg	mg/kg/yr		% per yr
Anns	SoE	Manukau	35.1	-2.74	0.000	-7.8
Awaruku	SoE	East Coast				
Benghazi	RDP	Tamaki Estuary	24.6	-0.52	0.327	-2.1
Big Muddy	SoE	Manukau	9.0	-0.92	0.244	-10.3
Bowden	RDP	Tamaki Estuary	32.4	-1.05	0.007	-3.2
Brighams UWH	UWH	Upper Waitemata	27.0	-0.37	0.208	-1.4
Browns	SoE	East Coast				
Central Main Channel	UWH	Upper Waitemata	30.6	0.12	0.618	0.4
Central Waitemata East	UWH	Upper Waitemata	33.0	-0.75	0.486	-2.3
Chelsea	RDP	Central Waitemata	25.0	0.50	0.189	2.0
Cheltenham	SoE	East Coast	27.0	-3.10	0.007	-11.5
Coxs	RDP	Central Waitemata	54.6	-1.94	0.016	-3.6
Hellyers SoE	SoE	Upper Waitemata	34.2	-0.86	0.003	-2.5
Hellyers Upper UWH	UWH	Upper Waitemata	35.6	-1.28	0.101	-3.6
Hellyers UWH	UWH	Upper Waitemata	29.0	-0.63	0.518	-2.2
Henderson Entrance	RDP	Central Waitemata	25.7	0.27	0.447	1.1
Henderson Lower	RDP	Central Waitemata	29.5	-0.71	0.005	-2.4
Henderson Upper	SoE	Central Waitemata	38.1	-1.03	0.033	-2.7
Herald Island North	UWH	Upper Waitemata	31.0	0.09	0.960	0.3
Herald Island Waiarohia	UWH	Upper Waitemata	30.0	-0.64	0.099	-2.1
Hillsborough	RDP	Manukau	18.1	-0.30	0.189	-1.7
Hobson Newmarket	SoE	Central Waitemata	64.8	-1.99	0.016	-3.1
Hobsonville (Central Waitemata West)	UWH	Upper Waitemata	34.0	-1.43	0.136	-4.2
Kendall	RDP	Central Waitemata	17.4	0.29	0.732	1.7
Lucas Te Wharau UWH	UWH	Upper Waitemata	29.0	-0.34	0.210	-1.2
Lucas Upper	SoE	Upper Waitemata				
Lucas UWH	UWH	Upper Waitemata	30.0	-1.57	0.011	-5.2
Mangere Cemetery	SoE	Manukau	29.6	-1.03	0.003	-3.5
Meola Inner	SoE	Central Waitemata	74.2	-2.24	0.000	-3.0
Meola Outer	RDP	Central Waitemata	32.7	-1.05	0.054	-3.2
Meola Reef Te Tokaroa	SoE	Central Waitemata	51.2	-2.06	0.000	-4.0
Middlemore	SoE	Tamaki Estuary	50.0	-1.00	0.016	-2.0
Motions	SoE	Central Waitemata	90.0	-2.88	0.024	-3.2
Oakley	SoE	Central Waitemata	51.0	-0.81	0.002	-1.6
Otahuhu	RDP	Tamaki Estuary	33.0	-1.35	0.033	-4.1
Outer Main Channel	UWH	Upper Waitemata	29.8	-0.37	0.519	-1.2
Pahurehure Papakura	SoE	Manukau	16.2	-0.27	0.240	-1.7
Pakuranga Lower	SoE	Tamaki Estuary	37.8	-1.04	0.003	-2.7
Pakuranga Upper	SoE	Tamaki Estuary	44.7	-0.54	0.016	-1.2
Panmure	RDP	Tamaki Estuary	32.0	-0.92	0.014	-2.9
Paremoremo	SoE	Upper Waitemata				
Paremoremo UWH	UWH	Upper Waitemata	30.0	-1.00	0.052	-3.3
Point England	RDP	Tamaki Estuary	22.0	-0.03	0.889	-0.1
Princes	RDP	Tamaki Estuary	36.5	-0.73	0.112	-2.0
Puhinui Upper	SoE	Manukau	11.4	-0.11	0.628	-1.0
Pukaki Airport	SoE	Manukau	9.8	-0.25	0.243	-2.6
Purewa	RDP	Central Waitemata	39.4	0.43	0.730	1.1
Rangitopuni UWH	UWH	Upper Waitemata	26.5	0.32	0.518	1.2
Shoal Hillcrest	RDP	Central Waitemata	32.0	0.00	0.945	0.0
Te Matuku	SoE	Tamaki Strait				
Upper Main Channel	UWH	Upper Waitemata	26.7	-0.37	0.295	-1.4
Vaughans	Soe	East Coast				
Weiti	SoE	Hibiscus Coast	11.0	-0.38	0.146	-3.5
Whau Entrance	RDP	Central Waitemata	29.4	0.85	0.003	2.9
Whau Lower	SoE	Central Waitemata	48.1	-1.22	0.011	-2.5
Whau Upper	SoE	Central Waitemata	86.2	-3.17	0.000	-3.7
Whau Wairau	SoE	Central Waitemata	85.6	-2.61	0.016	-3.1

#### Table 6.3 Raw trend analysis data for extractable zinc (<63 µm).

				Extractable Zn	(<63 um)	
			median	Sen Slope	р	RSSE
Site	Programme	MRA	mg/kg	mg/kg/yr		% per yr
Anns	SoE	Manukau	144.3	-2.89	0.084	-2.0
Awaruku	SoE	East Coast				
Benghazi	RDP	Tamaki Estuary	110.0	-0.99	0.447	-0.9
Big Muddy	SoE	Manukau	45.3	0.15	0.267	0.3
Bowden	RDP	Tamaki Estuary	159.5	-2.72	0.053	-1.7
Brighams UWH	UWH	Upper Waitemata	97.0	-2.75	0.020	-2.8
Browns	SoE	East Coast				
Central Main Channel	UWH	Upper Waitemata	101.0	-0.13	0.921	-0.1
Central Waitemata East	UWH	Upper Waitemata	103.0	-5.75	0.234	-5.6
Chelsea	RDP	Central Waitemata	84.5	4.34	0.006	5.1
Cheltenham	SoE	East Coast	97.2	1.19	1.000	1.2
Coxs	RDP	Central Waitemata	150.0	-4.99	0.028	-3.3
Hellvers SoE	SoE	Upper Waitemata	102.7	1.98	0.016	1.9
Hellvers Upper UWH	UWH	Upper Waitemata	121.0	-1.00	0.728	-0.8
Hellvers UWH	UWH	Upper Waitemata	87.0	-2.00	0.371	-2.3
Henderson Entrance	RDP	Central Waitemata	111.0	-5.05	0.114	-4.5
Henderson Lower	RDP	Central Waitemata	126.0	-0.29	0.576	-0.2
Henderson Loner	SoF	Central Waitemata	165.6	-0.14	0.837	-0.1
Herald Island North		Upper Waitemata	105.0	-1 17	0.037	-1.1
Herald Island Wajarobia		Upper Waitemata	103.0	-1.00	0.720	-1.0
Hillsborough	RDP	Manukau	86.0	1.00	0.000	1.0
Hohson Newmarket	SoF	Central Waitemata	136.5	-0.92	0.115	-0.7
Hobsonville (Central Waitemata West)			130.5	-0.52	0.305	-0.7
Kendall		Central Waitemata	66 5	-5.87	0.074	-4.8
		Uppor Waitemata	00.5	0.17	0.241	1.9
	SoF	Upper Waitemata	98.0	0.17	0.042	0.2
		Upper Waitemata	109.0	6.00	0 102	E C
Mangoro Comotory	SOF		108.0	-0.00	0.102	-5.0
Mada Inner	SOE	Ividilukdu	101.0	0.31	0.057	0.3
Meela Outer	JUE	Central Waitemata	104.9	-0.57	0.751	-0.2
Media Outer	RDP	Central Waltemata	111.0	-1.01	0.447	-0.9
	SOE	Central Waltemata	144.3	-2.34	0.063	-1.6
Matiene	SOE		208.9	3.82	0.011	1.8
Motions	SOE		215.9	-3.53	0.451	-1.6
Oakley	SOE	Central Waltemata	155.3	1.67	0.022	1.1
Otanunu Outan Main Channal	RDP	Tamaki Estuary	161.0	-0.50	0.890	-0.3
Outer Main Channel	UWH	Opper Waitemata	99.0	0.42	0.766	0.4
Panurenure Papakura	SOE	Manukau	67.7	1.81	0.005	2.7
Pakuranga Lower	SOE		162.3	1.76	0.046	1.1
Pakuranga Upper	SOE	Tamaki Estuary	213.9	5.37	0.003	2.5
Panmure	RDP	Tamaki Estuary	144.5	-1.21	0.269	-0.8
Paremoremo	SOE	Upper Waitemata	101 5	2.00	0.270	2.0
Paremoremo UWH	UWH	Opper waitemata	101.5	-2.00	0.370	-2.0
Point England	KUP DDD	Tamaki Estuary	96.5	0.42	0.627	0.4
Princes		Tamaki Estuary	195.5	-1.19	0.534	-0.6
Puninul Opper	SOE	маликай	/5.6	3.52	0.005	4./
Pukaki Airport	SOE	Manukau	48.7	1.51	0.001	3.1
Purewa	RDP	Central Waitemata	124.5	-0.04	1.000	0.0
	UWH	Opper Waitemata	96.0	0./1	0.486	0.7
Shoai Hillcrest	KDP C.F	Central Waitemata	101.5	-0.58	0.783	-0.6
	SOE	Tamaki Strait	05.5		0.477	
Upper Main Channel	UWH	Upper Waitemata	95.0	-1.88	0.457	-2.0
Vaughans	SoE	East Coast				
Weiti	SOE	Hibiscus Coast	57.6	2.12	0.001	3.7
Whau Entrance	RDP	Central Waitemata	110.0	2.12	0.053	1.9
Whau Lower	Soe	Central Waitemata	152.4	6.59	0.001	4.3
Whau Upper	SoE	Central Waitemata	248.7	4.58	0.016	1.8
Whau Wairau	SoE	Central Waitemata	239.4	6.46	0.015	2.7

#### Table 6.4 Raw trend analysis data for total copper (<500 $\mu$ m).

			Total Cu (<500 um)			
			median	Sen Slope	р	RSSE
Site	Programme	MRA	mg/kg	mg/kg/yr		% per yr
Anns	SoE	Manukau	29.1	-2.44	0.000	-8.4
Awaruku	SoE	East Coast	2.0	0.06	0.060	3.00
Benghazi	RDP	Tamaki Estuary	8.2	0.15	0.491	1.8
Big Muddy	SoE	Manukau	9.0	-0.11	0.071	-1.2
Bowden	RDP	Tamaki Estuary	23.6	0.21	0.837	0.9
Brighams UWH	UWH	Upper Waitemata	22.7	-0.70	0.022	-3.1
Browns	SoE	East Coast	2.0	-0.01	0.592	-0.51
Central Main Channel	UWH	Upper Waitemata	12.5	-0.50	0.017	-4.0
Central Waitemata East	UWH	Upper Waitemata	21.0	-0.43	0.149	-2.0
Chelsea	RDP	Central Waitemata	5.5	0.35	0.003	6.4
Cheltenham	SoF	Fast Coast	2.5	0.00	0.452	0.0
Coxs	RDP	Central Waitemata	5.0	0.15	0.332	3.0
Hellvers SoF	SoF	Upper Waitemata	15.0	-0.62	0.012	-4.1
Hellvers Upper UWH	UWH	Upper Waitemata	22.0	-0.26	0.552	-1.2
Hellvers LIWH		Upper Waitemata	13.0	-0.50	0.729	-3.8
Henderson Entrance	RDP	Central Waitemata	6.4	-0.18	0.129	-2.8
Henderson Lower	RDP	Central Waitemata	28.5	0.10	0.125	1.9
Henderson Linner	SoF	Central Waitemata	33.0	-1 28	0.000	-3.0
Herald Island North			53.0	-1.20	0.001	-14.2
Herald Island Wajarobia			0.4	-0.90	0.019	-14.2
Heralu Islanu Walaronia Hillsborough			5.5 7 1	-0.55	0.150	-10.0
Holson Newmarket	KDF SoE	Control Waitemata	7.1	-0.00	0.003	-9.4
Hobson Newmarket	SUE		5.0	-0.16	0.110	-2.9
Kondoll		Opper Waitemata	3.8	-0.43	0.130	-11.3
	RDP		3.9	0.07	0.006	1.8
	UWH Car	Upper Waltemata	16.6	0.00	1.000	0.0
	SOE	Opper Waltemata	20.2	0.00	0.500	0.00
Lucas UWH	UWH	Opper Waltemata	12.7	-0.22	0.520	-1.7
Mangere Cemetery	SOE	Manukau	25.1	-1.38	0.002	-5.5
Media Inner	SOE	Central Waltemata	30.0	-0.82	0.049	-2.7
Meola Outer	RDP	Central Waitemata	3.0	0.03	0.301	1.0
Meola Reef Te Tokaroa	SOE	Central Waitemata	9.0	0.27	0.238	3.0
Middlemore	SOE	Tamaki Estuary	25.0	-0.13	0.381	-0.5
Motions	SOE	Central Waitemata	22.3	-0.93	0.030	-4.2
Oakley	SOE	Central Waitemata	29.0	-0.77	0.001	-2.7
Otahuhu	RDP	Tamaki Estuary	27.8	0.40	0.331	1.4
Outer Main Channel	UWH	Upper Waitemata	13.2	0.88	0.372	6.7
Pahurehure Papakura	SOE	Manukau	7.3	-0.47	0.002	-6.5
Pakuranga Lower	Soe	Tamaki Estuary	20.2	-0.40	0.071	-2.0
Pakuranga Upper	SoE	Tamaki Estuary	28.8	-0.42	0.154	-1.5
Panmure	RDP	Tamaki Estuary	25.0	0.38	0.215	1.5
Paremoremo	SOE	Upper Waitemata	21.9	-0.60	0.102	-2.74
Paremoremo UWH	UWH	Upper Waitemata	23.1	0.10	0.945	0.4
Point England	RDP	Tamaki Estuary	12.3	0.10	0.449	0.8
Princes	RDP	Tamaki Estuary	17.0	-0.10	1.000	-0.6
Puhinui Upper	SoE	Manukau	9.5	-0.14	0.238	-1.5
Pukaki Airport	SoE	Manukau	8.2	-0.41	0.169	-5.0
Purewa	RDP	Central Waitemata	13.8	-0.42	0.449	-3.1
Rangitopuni UWH	UWH	Upper Waitemata	23.0	0.13	0.339	0.6
Shoal Hillcrest	RDP	Central Waitemata	17.5	0.10	0.837	0.6
Te Matuku	SoE	Tamaki Strait	3.0	-0.01	0.500	-0.33
Upper Main Channel	UWH	Upper Waitemata	23.0	0.55	0.209	2.4
Vaughans	SoE	East Coast	1.9	0.05	0.022	2.63
Weiti	SoE	Hibiscus Coast	12.0	0.05	0.130	0.4
Whau Entrance	RDP	Central Waitemata	3.2	-0.01	1.000	-0.3
Whau Lower	SoE	Central Waitemata	26.0	-0.49	0.060	-1.9
Whau Upper	SoE	Central Waitemata	36.0	-0.24	0.060	-0.7
Whau Wairau	SoE	Central Waitemata	43.0	-1.26	0.002	-2.9

#### Table 6.5 Raw trend analysis data for total lead (<500 $\mu$ m).

				Total Pb (<5	00 um)	
			median	Sen Slope	р	RSSE
Site	Programme	MRA	mg/kg	mg/kg/yr		% per yr
Anns	SoE	Manukau	31.5	-1.90	0.001	-6.0
Awaruku	SoE	East Coast	3.6	0.11	0.114	3.03
Benghazi	RDP	Tamaki Estuary	14.5	0.07	0.890	0.5
Big Muddy	SoE	Manukau	9.3	0.02	0.406	0.2
Bowden	RDP	Tamaki Estuary	31.9	-0.03	1.000	-0.1
Brighams UWH	UWH	Upper Waitemata	26.0	0.47	0.133	1.8
Browns	SoE	East Coast	4.6	0.03	0.625	0.66
Central Main Channel	UWH	Upper Waitemata	27.0	0.31	0.295	1.1
Central Waitemata East	UWH	Upper Waitemata	33.0	0.00	1.000	0.0
Chelsea	RDP	Central Waitemata	12.9	0.45	0.015	3.5
Cheltenham	SoE	East Coast	8.9	-0.01	0.500	-0.1
Coxs	RDP	Central Waitemata	14.2	0.33	0.271	2.3
Hellvers SoF	SoF	Upper Waitemata	24.0	-0.56	0.009	-2.3
Hellvers Unner UWH		Upper Waitemata	32.4	-0.41	0.394	-1 3
Hellvers IIWH		Upper Waitemata	22.4	0.00	0.004	0.0
Henderson Entrance	RDP	Central Waitemata	19.4	-0.07	0.500	-0.4
Honderson Lower	RDR	Control Waitemata	24.2	-0.07	0.333	-0.4
Henderson Lipper	SoF	Control Waitemata	24.0	0.15	0.750	1.4
Hendelson Opper			54.0	-0.46	0.208	-1.4
	UWH		14.0	0.00	1.000	0.0
		Napukau	5.9	-0.17	0.428	-2.9
Hillsborougn	RDP		11.9	-0.61	0.271	-5.1
Hobson Newmarket	SOE		13.0	-0.45	0.022	-3.5
Hobsonville (Central Waitemata West)	UWH	Upper Waitemata	7.1	-0.06	1.000	-0.8
Kendall	RDP	Central Waitemata	7.4	-0.01	0.891	-0.1
Lucas Te Wharau UWH	UWH	Upper Waitemata	21.0	0.00	1.000	0.0
Lucas Upper	SoE	Upper Waitemata	22.5	-0.03	0.500	-0.13
Lucas UWH	UWH	Upper Waitemata	26.0	-0.60	0.320	-2.3
Mangere Cemetery	SoE	Manukau	28.3	-1.26	0.000	-4.5
Meola Inner	SoE	Central Waitemata	61.2	-2.11	0.017	-3.4
Meola Outer	RDP	Central Waitemata	9.3	0.13	0.240	1.4
Meola Reef Te Tokaroa	SoE	Central Waitemata	22.0	-0.20	0.272	-0.9
Middlemore	SoE	Tamaki Estuary	32.0	-0.28	0.075	-0.9
Motions	SoE	Central Waitemata	44.5	-2.53	0.030	-5.7
Oakley	SoE	Central Waitemata	45.0	-1.10	0.006	-2.4
Otahuhu	RDP	Tamaki Estuary	33.3	-0.12	0.781	-0.4
Outer Main Channel	UWH	Upper Waitemata	20.5	0.96	0.428	4.7
Pahurehure Papakura	SoE	Manukau	10.0	-0.27	0.381	-2.7
Pakuranga Lower	SoE	Tamaki Estuary	23.9	-0.77	0.024	-3.2
Pakuranga Upper	SoE	Tamaki Estuary	27.5	-1.18	0.075	-4.3
Panmure	RDP	Tamaki Estuary	33.4	0.05	0.729	0.1
Paremoremo	SoE	Upper Waitemata	23.5	-0.12	0.136	-0.51
Paremoremo UWH	UWH	Upper Waitemata	29.0	0.80	0.432	2.8
Point England	RDP	Tamaki Estuary	20.0	0.15	0.405	0.8
Princes	RDP	Tamaki Estuary	24.7	-0.51	0.630	-2.1
Puhinui Upper	SoE	Manukau	12.5	-0.04	0.460	-0.3
Pukaki Airport	SoE	Manukau	10.5	0.08	0.406	0.8
Purewa	RDP	Central Waitemata	35.4	-1.01	0.336	-2.9
Rangitopuni UWH	UWH	Upper Waitemata	26.0	0.14	0.802	0.5
Shoal Hillcrest	RDP	Central Waitemata	32.9	0.18	0.945	0.5
Te Matuku	SoE	Tamaki Strait	7.0	0.07	0.236	1.00
Upper Main Channel	UWH	Upper Waitemata	26.0	0.57	0.307	2.2
Vaughans	SoE	East Coast	3.0	-0.06	0.093	-2.00
Weiti	SoE	Hibiscus Coast	9.0	0.23	0.208	2.6
Whau Entrance	RDP	Central Waitemata	7.0	0.24	0.011	3.4
Whay Lower	SoE	Central Waitemata	42.0	-1.64	0.009	-3.9
Whay Upper	SoF	Central Waitemata	65.6	-1 87	0.002	-29
Whay Wairay	SoE	Central Waitemata	64.6	-2,77	0.000	-4.3
			00	, ,	0.000	

#### Table 6.6 Raw trend analysis data for total zinc (<500 µm).

				Total Zn (<5	00 um)	
			median	Sen Slope	р	RSSE
Site	Programme	MRA	mg/kg	mg/kg/yr		% per yr
Anns	SoE	Manukau	154.0	-5.70	0.001	-3.7
Awaruku	SoE	East Coast	24.4	0.00	0.500	0.00
Benghazi	RDP	Tamaki Estuary	70.8	0.19	0.945	0.3
Big Muddy	SoE	Manukau	54.2	-0.76	0.024	-1.4
Bowden	RDP	Tamaki Estuary	198.5	6.30	0.010	3.2
Brighams UWH	UWH	Upper Waitemata	102.0	3.00	0.003	2.9
Browns	SoE	East Coast	34.0	-0.66	0.325	-1.94
Central Main Channel	UWH	Upper Waitemata	103.0	2.83	0.025	2.7
Central Waitemata East	UWH	Upper Waitemata	116.0	1.00	0.691	0.9
Chelsea	RDP	Central Waitemata	45.7	1.12	0.019	2.5
Cheltenham	SoE	East Coast	38.5	-0.91	0.114	-2.4
Coxs	RDP	Central Waitemata	70.1	2.56	0.028	3.7
Hellvers SoF	SoF	Upper Waitemata	96.9	-0.97	0.238	-1.0
Hellvers Upper UWH	UWH	Upper Waitemata	128.0	3 33	0.123	2.6
Hellvers LIW/H	UWH	Upper Waitemata	86.5	0.08	1 000	0.1
Henderson Entrance	RDP	Central Waitemata	69.8	0.00	0.880	0.1
Henderson Lower	RDP	Central Waitemata	147.5	4.04	0.003	2.7
Honderson Lippor	SoF	Contral Waitemata	171.9	-2.68	0.023	-1.6
Horald Island North			171.8	-2.08	0.017	-1.0
	UWH		47.9	-0.93	0.477	-1.9
		Opper Waitemata	18.7	-0.27	0.729	-1.4
Hillsborougn	RDP		64.8	-1.06	0.731	-1.6
Hobson Newmarket	SOE	Central Waltemata	42.0	-0.61	0.130	-1.5
Hobsonville (Central Waitemata West)	UWH	Upper Waitemata	26.0	0.00	1.000	0.0
Kendall	RDP	Central Waitemata	31.8	-0.41	0.366	-1.3
Lucas Te Wharau UWH	UWH	Upper Waitemata	83.0	1.57	0.518	1.9
Lucas Upper	SoE	Upper Waitemata	97.9	0.34	0.360	0.35
Lucas UWH	UWH	Upper Waitemata	100.0	-2.00	0.427	-2.0
Mangere Cemetery	SoE	Manukau	136.0	-4.00	0.005	-2.9
Meola Inner	SoE	Central Waitemata	240.0	-3.49	0.006	-1.5
Meola Outer	RDP	Central Waitemata	33.5	0.79	0.047	2.4
Meola Reef Te Tokaroa	SoE	Central Waitemata	93.0	-0.64	0.130	-0.7
Middlemore	SoE	Tamaki Estuary	182.0	3.09	0.022	1.7
Motions	SoE	Central Waitemata	230.0	-5.66	0.090	-2.5
Oakley	SoE	Central Waitemata	160.0	-0.31	0.130	-0.2
Otahuhu	RDP	Tamaki Estuary	176.0	3.11	0.237	1.8
Outer Main Channel	UWH	Upper Waitemata	70.7	5.04	0.082	7.1
Pahurehure Papakura	SoE	Manukau	66.0	-0.44	0.238	-0.7
Pakuranga Lower	SoE	Tamaki Estuary	150.0	0.56	0.169	0.4
Pakuranga Upper	SoE	Tamaki Estuary	190.0	1.62	0.179	0.9
Panmure	RDP	Tamaki Estuary	177.5	6.58	0.015	3.7
Paremoremo	SoE	Upper Waitemata	89.0	-1.08	0.235	-1.21
Paremoremo UWH	UWH	Upper Waitemata	102.0	4.04	0.086	4.0
Point England	RDP	Tamaki Estuary	84.1	2.26	0.019	2.7
Princes	RDP	Tamaki Estuary	148.0	2.38	0.373	1.6
Puhinui Upper	SoE	Manukau	109.4	0.77	0.022	0.7
Pukaki Airport	SoE	Manukau	66.5	-0.99	0.114	-1.5
Purewa	RDP	Central Waitemata	155.0	1.01	0.535	0.7
Rangitopuni UWH	UWH	Upper Waitemata	102.0	3.03	0.029	3.0
Shoal Hillcrest	RDP	Central Waitemata	108.5	2.84	0.086	2.6
Te Matuku	SoE	Tamaki Strait	33.0	0.41	0.236	1.24
Upper Main Channel	UWH	Upper Waitemata	98.7	4.04	0.058	4.1
Vaughans	SoE	East Coast	21.2	-0.12	0.090	-0.57
Weiti	SoE	Hibiscus Coast	51.0	0.84	0.075	1.6
Whay Entrance	RDP	Central Waitemata	31.1	1.59	0.011	5.1
What Lower	SoF	Central Waitemata	170.0	1 14	0.060	0.7
What Lower	SoF	Central Waitemata	270.0	2 21	0.000	1.7
Whan Wairan	SoF	Central Waitemata	270.0	0.12	0.009	0.1
ttilda ttulluu	301		220.0	0.12	0.100	0.1

### Table 6.7 Raw trend analysis data for High molecular weight PAH (<500 $\mu$ m).

			HWPAH (<500 um)			
			median	Sen Slope	р	RSSE
Site	Programme	MRA	mg/kg	mg/kg/yr		% per yr
Anns	SoE	Manukau	0.2	0.01	0.034	2.8
Awaruku	SoE	East Coast	0.0	0.00	0.033	4.44
Benghazi	RDP	Tamaki Estuary				
Big Muddy	SoE	Manukau	0.1	0.01	0.732	8.0
Bowden	RDP	Tamaki Estuary				
Brighams UWH	UWH	Upper Waitemata	0.2	0.00	0.729	-0.5
Browns	SoE	East Coast	0.0	0.00	0.732	-3.33
Central Main Channel	UWH	Upper Waitemata	0.2	0.02	0.150	9.9
Central Waitemata East	UWH	Upper Waitemata	0.3	-0.03	0.047	-8.6
Chelsea	RDP	Central Waitemata				
Cheltenham	SoE	East Coast	0.2	0.00	0.631	-1.2
Coxs	RDP	Central Waitemata				
Hellvers SoF	SoF	Upper Waitemata	0.3	0.00	0.373	0.6
Hellvers Upper UWH	UWH	Upper Waitemata	0.3	-0.01	0.680	-3.6
Hellvers LIWH	ШМН	Upper Waitemata	0.2	0.00	0.537	0.6
Henderson Entrance	RDP	Central Waitemata	0.2	0.00	0.557	0.0
Henderson Lower	RDP	Central Waitemata				
Honderson Lippor	SoF	Contral Waitemata	0.4	0.01	0.204	1 /
Herald Island North			0.4	0.01	0.304	17.9
		Upper Waitemata	0.0	-0.01	0.033	-17.8
	UWH	Opper Waitemata	0.0	0.00	0.304	-8.1
Hillsborougn	RDP		0.2	0.04	0.244	10
Hobson Newmarket	SOE	Central Waltemata	0.3	-0.01	0.244	-4.0
Hobsonville (Central Waitemata West)	UWH	Upper Waitemata	0.0	0.00	0.783	10.0
Kendall	RDP	Central Waitemata				
Lucas Te Wharau UWH	UWH	Upper Waitemata	0.2	0.00	1.000	-0.6
Lucas Upper	SoE	Upper Waitemata	0.3	0.02	0.007	8.72
Lucas UWH	UWH	Upper Waitemata	0.1	0.00	1.000	0.0
Mangere Cemetery	SoE	Manukau	0.2	0.01	0.150	2.5
Meola Inner	SoE	Central Waitemata	2.8	-0.01	0.945	-0.2
Meola Outer	RDP	Central Waitemata				
Meola Reef Te Tokaroa	SoE	Central Waitemata	0.3	0.02	0.064	6.5
Middlemore	SoE	Tamaki Estuary	0.7	0.00	0.732	0.7
Motions	SoE	Central Waitemata	5.1	-0.08	0.732	-1.6
Oakley	SoE	Central Waitemata	0.8	-0.02	0.732	-2.2
Otahuhu	RDP	Tamaki Estuary				
Outer Main Channel	UWH	Upper Waitemata	0.1	0.01	0.336	13.4
Pahurehure Papakura	SoE	Manukau	0.1	0.00	0.451	1.7
Pakuranga Lower	SoE	Tamaki Estuary	0.2	0.01	0.047	3.7
Pakuranga Upper	SoE	Tamaki Estuary	0.3	0.01	0.732	1.7
Panmure	RDP	Tamaki Estuary				
Paremoremo	SoE	Upper Waitemata	0.3	0.00	0.945	-0.43
Paremoremo UWH	UWH	Upper Waitemata				
Point England	RDP	Tamaki Estuary				
Princes	RDP	Tamaki Estuary				
Puhinui Upper	SoE	Manukau	0.1	0.00	0.837	0.7
Pukaki Airport	SoE	Manukau	0.1	0.00	0.732	1.3
Purewa	RDP	Central Waitemata				
Rangitopuni UWH	UWH	Upper Waitemata	0.2	-0.01	0.063	-4.8
Shoal Hillcrest	RDP	Central Waitemata				
Te Matuku	SoE	Tamaki Strait				
Upper Main Channel	UWH	Upper Waitemata	0.2	0.00	0.492	-1.4
Vaughans	SoE	East Coast	0.0	0.00	0.012	10.00
Weiti	SoE	Hibiscus Coast	0.1	0.00	0.945	0.7
Whay Entrance	RDP	Central Waitemata		0.00	0.010	
What Lower	SoF	Central Waitemata	0.6	0.01	0 5 2 7	1 1
What Upper	SOF	Central Waitemata	0.0	0.01	1 000	0.1
What Opper	SOF	Central Waitemata	0.9	_0.00	0.722	-0.7
	JUL		0.0	-0.01	0.732	-0.7

Main estuary	Subestuary	Reporting Area	Туре	Reference	Model	Avg rate mg/kg/year	% change per year
Paremoremo	Whole estuary=SZ	Upper Waitemata	SZ	Green et al. 2004a	USC2	-0.11	-0.1
Hobsonville	OZ sand banks	Central Waitemata	OZ	Green 2008a	USC3	0.09	0.1
SW Intertidal	Large OZ Includes Pollen	Central Waitemata	OZ	Green 2008a	USC3	0.30	0.4
Pahurehure basin	Papakura SZ	Manukau	SZ	Green 2008b	USC3	0.32	0.3
UWH Main	Lower	Upper Waitemata	OZ	Green et al. 2004a	USC2	0.44	0.5
Waiarohia	Whole estuary S of Herald	Upper Waitemata	SZ+OZ	Green et al. 2004a	USC2	0.44	1.0
UWH	Waiarohia SZ	Upper Waitemata	SZ	Diffuse Sources 2001	USC1	0.46	0.7
Weiti	Weiti Lower Outer OZ	Hibiscus	OZ	Williamson et al. 2005	USC1	0.47	1.0
Shoal Bay	Shoal Bay OZ/SZ	Central Waitemata	OZ	Green 2008a	USC3	0.50	0.5
PukakiCk	Pukaki+Waokauri	Manukau	Two SZ/OZ	Green 2008b	USC3	0.54	0.7
Pahurehure inner	Pahurehure inner OZ	Manukau	OZ	Green 2008b	USC3	0.67	0.7
PukakiCk	Pukaki Upper SZ	Manukau	SZ	Diffuse Sources2006	USC1	0.70	1.5
Weiti	Weiti Duck SZ	Hibiscus	SZ	Williamson et al. 2005	USC1	0.74	1.2
Papakura	Papakura Stm SZ	Manukau	SZ	Green 2008b	USC3	0.76	0.8
Rarawaru	Whole estuary	Upper Waitemata	SZ	Green et al. 2004a	USC2	0.76	0.8
W Intertidal	Includes Whau OZ	Central Waitemata	OZ	Green 2008a	USC3	0.80	0.8
WaimahiaCk	"Waimahia" SZ/OZ	Manukau	Two SZ/OZ	Green 2008b	USC3	0.82	0.8
Brighams	Whole estuary	Upper Waitemata	SZ	Green et al. 2004a	USC2	0.89	1.0
Motions	Whole SZ/OZ	Central Waitemata	SZ+OZ	Green 2008a	USC3	0.90	1.0
Meola	Whole SZ/OZ	Central Waitemata	SZ+OZ	Green 2008a	USC3	1.00	1.1
NW Intertidal	Includes Henderson OZ	Central Waitemata	OZ	Green 2008a	USC3	1.00	1.5
Little Shoal Bay	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	1.06	1.2
PuhinuiCk	Puhinui Inner/Outer SZ	Manukau	SZ+OZ	Green 2008b	USC3	1.07	1.3
Weiti	Weiti Upper Outer OZ	Hibiscus	OZ	Williamson et al. 2005	USC1	1.08	1.7
Weiti	Weiti Upper SZ	Hibiscus	SZ	Williamson et al.2005	USC1	1.08	1.7
Limeburners	Henderson SZ Outer	Central Waitemata	SZ	Green 2008a	USC3	1.10	1.4
Rangitopuni	Whole estuary	Upper Waitemata	SZ	Green et al. 2004a	USC2	1.22	1.5
Kendalls	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	1.30	1.3
Shoal Bay	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	1.47	1.6
Mangere	Tui SZ	Manukau	SZ	Diffuse Sources 2007b	USC1	1.48	1.3
PukakiCk	Pukaki Lower OZ	Manukau	OZ	Diffuse Sources 2006	USC1	1.59	2.0

### Table 6.8 Modelling predictions summary for Zinc

Marine sediment contaminants: Status and trends assessment 1998-2010

Main estuary	Subestuary	Reporting Area	Туре	Reference	Model	Avg rate mg/kg/year	% change per year
Beachhaven	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	1.59	1.5
Hobson	Whole SZ/OZ	Central Waitemata	Multiple SZ+OZ	Green 2008a	USC3	1.62	2.3
Mangere	Harania SZ	Manukau	SZ	Diffuse Sources 2007b	USC1	1.71	1.5
UWH Main	Middle	Upper Waitemata	OZ	Green et al. 2004	USC2	1.78	1.7
Hellyers	Main body OZ	Upper Waitemata	OZ	Diffuse Sources 2005	USC1	1.80	1.8
Chelsea	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	1.90	1.8
Waterview	Whole - part of "Oakley"	Central Waitemata	SZ/OZ	Green 2008a	USC3	2.00	1.7
PukakiCk	Waokauri SZ	Manukau	SZ	Diffuse Sources 2006	USC1	2.08	2.1
Whau	Whole SZ/OZ	Central Waitemata	SZ+OZ	Green 2008a	USC3	2.20	1.2
UWH Main	Upper	Upper Waitemata	OZ	Green et al 2004	USC2	2.56	2.7
Mangere	Tararata SZ	Manukau	SZ	Diffuse Sources 2007b	USC1	2.63	2.1
Lucas	Te Wharau SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	2.64	2.6
Hellyers	Kaipatiki SZ	Upper Waitemata	SZ	ARC 2004b	USC1	2.82	2.1
Hillcrest	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	2.91	2.0
Soldiers	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	2.93	2.4
Henderson	Henderson SZ Inner	Central Waitemata	SZ	Green 2008a	USC3	3.00	2.0
Hellyers	Upper Hellyers SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	3.08	3.7
Hellyers	Whole estuary	Upper Waitemata	SZ+OZ	Green et al 2004	USC2	3.25	2.8
Hellyers	Kaipatiki SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	3.45	2.6
Lucas	Upper SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	4.75	4.3
Lucas	Whole estuary	Upper Waitemata	SZ+OZ	Green et al 2004a	USC2	5.11	5.3
Motions	SZ	Central Waitemata	SZ	ARC 2004b	USC1	5.24	1.8
Wairau	Whau SZ	Central Waitemata	SZ	ARC 2004b	USC1	5.97	2.3
Pakuranga	SZ	Tamaki	SZ	Williamson and Morrisey 2000	USC1	7.74	3.1

Main estuary	Subestuary	ubestuary Reporting Area Type Reference Mode		Model	Ave Rate	% change	
						mg/kg/year	per year
Beachhaven	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	0.16	0.9
Chelsea	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	0.31	1.4
Henderson	Henderson SZ Inner	Central Waitemata	SZ	Green 2008a	USC3	0.40	1.3
Hillcrest	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	0.31	1.4
Hobson	Whole SZ/OZ	Central Waitemata	Multiple SZ+OZ	Green 2008a	USC3	0.73	7.3
Hobsonville	OZ sand banks	Central Waitemata	OZ	Green 2008a	USC3	0.00	0.0
Kendalls	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	0.28	1.2
Limeburners	Henderson SZ Outer	Central Waitemata	SZ	Green 2008a	USC3	0.40	4.5
Little Shoal	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	0.28	1.2
Meola	Whole SZ/OZ	Central Waitemata	SZ+OZ	Green 2008a	USC3	0.10	1.3
Motions	SZ	Central Waitemata	SZ	ARC 2004b	USC1	0.77	1.8
Motions	Whole SZ/OZ	Central Waitemata	SZ+OZ	Green 2008a	USC3	0.10	1.3
NW Intertidal	Includes Henderson OZ	Central Waitemata	OZ	Green 2008a	USC3	0.20	4.0
Shoal Bay	Shoal Bay OZ/SZ	Central Waitemata	OZ	Green 2008a	USC3	0.10	1.1
Shoal Bay	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	0.16	1.1
Soldiers	SZ	Central Waitemata	SZ	Diffuse Sources 2005	USC1	0.35	1.5
SW Intertidal	OZ Includes Pollen	Central Waitemata	OZ	Green 2008a	USC3	0.00	0.0
W Intertidal	Includes Whau OZ	Central Waitemata	OZ	Green 2008a	USC3	0.10	1.7
Wairau	Whau SZ	Central Waitemata	SZ	ARC 2004b	USC1	0.56	1.3
Waterview	Whole - part of "Oakley"	Central Waitemata	SZ/OZ	Green 2008a	USC3	0.25	1.3
Whau	Whole SZ/OZ	Central Waitemata	SZ+OZ	Green 2008a	USC3	0.20	0.7
Weiti	Weiti Duck SZ	Hibiscus	SZ	Williamson et al. 2005	USC1	0.07	1.3
Weiti	Weiti Lower Outer OZ	Hibiscus	OZ	Williamson et al. 2005	USC1	0.04	1.3
Weiti	Weiti Upper Outer OZ	Hibiscus	OZ	Williamson et al. 2005	USC1	0.09	1.8
Weiti	Weiti Upper SZ	Hibiscus	SZ	Williamson et al. 2005	USC1	0.09	1.7
Mangere	Harania SZ	Manukau	SZ	Diffuse Sources 2007b	USC1	0.11	0.5
Mangere	Tararata SZ	Manukau	SZ	Diffuse Sources 2007b	USC1	0.12	0.6
Mangere	Tui SZ	Manukau	SZ	Diffuse Sources 2007b	USC1	0.24	1.0
Papakura	Papakura Stm SZ	Manukau	SZ	Green 2008b	USC3	0.28	2.3
Pahurehure basin	Papakura? SZ	Manukau	SZ	Green 2008b	USC3	0.39	3.2
Pahurehure inner	Pahurehure inner OZ	Manukau	OZ	Green 2008b	USC3	0.24	2.4

### Table 6.9 Modelling predictions summary for Copper

Marine sediment contaminants: Status and trends assessment 1998-2010

Main actuary	Subactuary	Poporting Area	Туро	Poforonoo	Model	Ave Rate	% change
wan estuary	Subestuary	Reporting Area	туре	Reference	Model	mg/kg/year	per year
PuhinuiCk	Puhinui Inner/Outer SZ	Manukau	SZ+OZ	Green 2008b	USC3	0.23	2.1
PukakiCk	Pukaki Lower OZ	Manukau	OZ	Diffuse Sources 2006	USC1	0.25	2.4
PukakiCk	Pukaki Upper SZ	Manukau	SZ	Diffuse Sources 2006	USC1	0.09	1.4
PukakiCk	Pukaki+Waokauri	Manukau	Two SZ/OZ	Green 2008b	USC3	0.10	0.9
PukakiCk	Waokauri SZ	Manukau	SZ	Diffuse Sources 2006	USC1	0.21	2.1
WaimahiaCk	"Waimahia" SZ/OZ	Manukau	Two SZ/OZ	Green 2008b	USC3	0.26	2.2
Pakuranga	SZ	Tamaki	SZ	Williamson and Morrisey 2000	USC1	1.06	3.0
Brighams	Whole estuary	Upper Waitemata	SZ	Green et al. 2004b	USC2	-0.11	-0.5
Hellyers	Whole estuary	Upper Waitemata	SZ+OZ	Green et al. 2004b	USC2	0.57	2.9
Hellyers	Kaipatiki SZ	Upper Waitemata	SZ	ARC 2004b	USC1	0.51	2.1
Hellyers	Kaipatiki SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	0.34	1.6
Hellyers	Main body OZ	Upper Waitemata	OZ	Diffuse Sources 2005	USC1	0.20	1.1
Hellyers	Upper Hellyers SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	0.43	3.2
Lucas	Te Wharau SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	0.61	2.4
Lucas	Upper SZ	Upper Waitemata	SZ	Diffuse Sources 2005	USC1	0.77	2.9
Lucas	Whole estuary	Upper Waitemata	SZ+OZ	Green et al. 2004b	USC2	0.22	1.2
Paremoremo	Whole estuary	Upper Waitemata	SZ	Green et al. 2004b	USC2	0.00	0.0
Rangitopuni	Whole estuary	Upper Waitemata	SZ	Green et al. 2004b	USC2	0.22	1.2
Rarawaru	Whole estuary	Upper Waitemata	SZ	Green et al. 2004b	USC2	0.22	0.9
UWH	Wairohia SZ	Upper Waitemata	SZ	Diffuse Sources 2001	USC1	0.16	1.3
UWH Main	Lower	Upper Waitemata	OZ	Green et al. 2004b	USC2	0.44	3.4
UWH Main	Middle	Upper Waitemata	OZ	Green et al. 2004b	USC2	0.56	7.9
UWH Main	Upper	Upper Waitemata	OZ	Green et al 2004b	USC2	0.22	1.1
Wairohia	Whole estuary	Upper Waitemata	SZ+OZ	Green et al 2004b	USC2	0.11	0.5

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## **Appendix 1. Single Site Reports**

This Appendix contains seven parts based on the sites and marine reporting areas outlined in section 4.1 and shown on figure 2.1. Due to size constraints each of the seven parts is provided as a separate pdf.

- Part 1 Central Waitemata Harbour
- Part 2 Upper Waitemata Harbour
- Part 3 East Coast Bays
- Part 4 Hibiscus Coast
- Part 5 Tamaki Estuary
- Part 6 Tamaki Strait
- Part 7 Manukau Harbour