Tāmaki Makaurau / Auckland Marine Sediment Contaminant Monitoring: Data Report for 2022

Upper Waitematā Harbour, Mahurangi Harbour

Tāmaki Estuary, Whangateau Estuary, East Coast Bays

Hamish Allen

December 2023

Technical Report 2023/15

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Research and Evaluation Unit RIMU

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Cover images
Shell hash and invertebrate feeding tubes at Jamieson Bay, Mahurangi Harbour.
Looking towards Rangitopuni Creek monitoring site, Upper Waitematā Harbour.

Photographs by H Allen.

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Executive summary

Contaminants such as copper, lead, zinc, arsenic, and mercury, can accumulate in the sediments of our harbours, estuaries, and beaches. They can originate from a range of different activities and land uses including vehicle tyre and brake wear, industrial discharges, and the breakdown of some building materials. When it rains, these pollutants are washed into our stormwater networks and waterways, ending up in our marine environment. The build-up of these contaminants can affect ecological health, by reducing the abundance and/or diversity of animals living in the sediment. This can have harmful effects on the natural functioning of these ecosystems and result in degraded communities that are dominated by the remaining few species that are tolerant of higher contaminant levels. Understanding the distribution and level of chemical contaminants in marine sediments provides a useful marker of land use impacts on aquatic receiving environments and ecosystem health.

This document describes the monitoring undertaken at 40 sites in October and November 2022 as part of Auckland Council's Regional Sediment Contaminant Monitoring Programme (RSCMP). Sites were located in the Upper Waitematā Harbour, Tāmaki Estuary, Mahurangi Harbour, the East Coast Bays (including Okura Estuary), and Tāmaki Strait.

The report provides:

- an overview of the RSCMP monitoring programme
- description of the sampling undertaken in 2022
- the sediment contaminant (metals) and particle size distribution (PSD) results obtained for the 2022 samples
- a summary of contaminant (metals) state and changes over time in state
- quality assurance (QA) assessments undertaken to verify the data were acceptable for the purposes of the RSCMP.

Changes in state refer to a change relative to Environmental Response Criteria (ERC) threshold levels only. More sensitive trend analysis (statistical analysis of the monitoring data to obtain the magnitude and direction of change over time) can be found in Mills and Allen (2021).

Samples used for sediment chemistry analysis were processed and analysed for the following metals: copper, lead, zinc, arsenic (a metalloid species), mercury, and at six sites in the Mahurangi Harbour, cadmium. Total recoverable metals, on the <500µm fraction, were analysed. One composite sample from each site was also analysed for PSD.

The quality assurance data analysis indicated that overall, the metals and PSD data obtained in 2022 are largely within acceptance criteria and considered suitable for use in the RSCMP.

Contaminant state is compared with sediment quality guidelines, including the Australian and New Zealand Guidelines for fresh and marine water quality (ANZG), the Auckland Council

Environmental Response Criteria (ERC), and the Threshold Effects Level / Probable Effects Level (TEL/PEL). See section 3.1 for more detail on the sediment quality guidelines used in the RSCMP.

Results from sampling undertaken in 2022 showed a wide range of sediment contamination. Most of the sites sampled (30 out of 40; 75%) were assessed in the conservative ERC-green category. Fewer sites trigger the higher ANZG amber thresholds (only three sites for zinc and two for mercury; 88% are in the ANZG green category). Encouragingly, no sites sampled in 2022 triggered the ANZG red threshold for any metal.

The spatial pattern of contamination remains consistent with previous monitoring, with rural locations recording low levels of metals, while elevated concentrations were observed in the upper reaches of the Tāmaki Estuary and (to a lesser degree) in the Upper Waitematā Harbour.

In the Tāmaki Estuary, zinc remains a key contaminant of concern, exceeding ERC sediment quality guidelines at seven of nine sites. At several of these sites, levels of copper and mercury are also elevated. Previous monitoring has found that higher contaminant concentrations are most prevalent in catchments with intensive industrial and urban areas, particularly where there is a long history of this type of land use. The pressures associated with these land uses have cumulatively had a negative impact on sediment quality, particularly in the upper reaches of the Tāmaki Estuary, where the sheltered, low energy environment tends to accumulate fine sediment and can have a high proportion of mud and metals. Sites in the lower reaches have lower metal and mud content, likely as a reflection of these sites' location in sandier substrate, exposed to higher wave and tidal energy.

Despite the surrounding catchment containing large rural areas, in the Upper Waitematā Harbour several sites trigger conservative copper and mercury thresholds (the ERC and TEL/PEL, respectively). These levels are higher than expected, and the area has a long history of elevated copper, with sites observed above the ERC amber threshold since monitoring began at Paremoremo and Lucas Upper in 1998. The cause or causes of this are unknown, however it is possible that largely historic copper-based pesticide and herbicide use in the surrounding catchment has been a contributing factor.

Cadmium was included in the suite of analytes for sampling conducted in the Mahurangi Harbour. Cadmium has the potential to be elevated in marine sediments of rural areas, because it is an unavoidable contaminant present in phosphate fertiliser. Overall, low levels of cadmium were observed in Mahurangi, with two sites recording concentrations below lab detection limits, and the remaining four sites at concentrations well below guideline thresholds. Results of the other metals tested in Mahurangi were also low, with no sites triggering any of the applied threshold guidelines.

In general, ERC contaminant status (for metals copper, lead and zinc) has remained relatively stable over time at most sites sampled in 2022. Two sites (Awaruku Stream and Lucas Upper) both changed from ERC amber to ERC green for the metal copper. Further monitoring at these sites will be required to determine if these changes remain, or if concentrations are fluctuating above and below guideline values.

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1 Introduction

1.1 Overview

Tāmaki Makaurau is a predominantly marine region, surrounded by numerous sheltered bodies of water and stretches of exposed coastline. Healthy harbours and estuaries play important roles in many ecological processes, helping to regulate climate, supporting rich biodiversity, and providing abundant ecosystem functions and services. Harbours and estuaries are also important areas for people. Many coastal areas are significant for Māori, holding sites that are of strong spiritual and cultural value. They provide places to live, places to work, and space and opportunity for recreation. Over time, pollutants can have both acute and cumulative impacts on the health and quality of our marine environment, and in some places, this can compromise our ability to swim, collect kai moana and interact with nature.

Chemical contaminants can accumulate in the sediments of estuarine and marine receiving environments. They can originate from both natural processes (e.g., the weathering of rocks) and human activities (e.g., industrial processes and building materials) and can be transported into the marine environment in numerous ways, including in stream and riverine systems and in wastewater and stormwater discharge. The build-up of contaminants in marine sediments is of concern because it can adversely affect ecological health, by reducing the abundance and/or diversity of sensitive sediment-dwelling species. This can result in degraded communities dominated by animals that are tolerant of higher contaminant levels. This has the potential to affect both the immediate area, as many species play important roles in the natural functioning of benthic ecosystems, and beyond, as many sediment-dwelling organisms provide a key food source for animals such as fish and birds in higher trophic levels.

Sediment contaminant monitoring, in conjunction with ecological and water quality monitoring, contributes information about land use impacts on the health of aquatic receiving environments, and the effectiveness of resource management initiatives and policies in mitigating adverse effects arising from land use activities.

Auckland Council's Regional Sediment Contaminant Monitoring Programme (RSCMP) conducts regular monitoring across the region's harbours and estuaries (see Mills and Allen (2021) for further details on programme history).

The RSCMP aims to achieve the following objectives:

1. Provide assessment of the state of near shore marine sediment contamination using relevant guidelines where applicable.

2. Maintain regionally representative coverage, with an emphasis on areas undergoing change.
3. Provide data which allows the changes (trends) in sediment quality to be assessed over time.
4. Undertake studies to increase understanding and identify new and developing marine sediment contamination issues.

Information collected in the RSCMP complement those obtained in Auckland Council coastal water quality (Ingley, 2021) and benthic ecology (Drylie, 2021) monitoring programmes, which together aim to provide consistent, long-term information on the quality of Auckland's coastal environment. Data 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.

Monitoring of marine sediment contaminants began with 26 sites in 1998, and the RSCMP has since collected chemical contaminant data from over 120 harbour, estuary, and coastal sites across the region. Today, approximately 80 sites are monitored regularly with a selection of sites monitored per year. The total number of sites monitored in the RSCMP changes over time as new sites are added to provide more spatial coverage and some existing sites are removed from routine monitoring; for example, sites may be dropped if they become physically compromised by mangrove encroachment or poor access.

In addition to sampling carried out as part of the RSCMP, sediment contaminant sampling has also been carried out in conjunction with benthic ecology monitoring in a number of additional estuaries and harbours around the region. In 2022, several sites from the East Coast Estuary and Harbour Ecology monitoring programmes were sampled for chemical contaminants. This included sites within the Whangateau, Okura and Mahurangi estuaries. Monitoring at these locations markedly increases the spatial coverage of our understanding of sediment contaminants across the region and provides for 'checks' in more rural areas where sites in these programmes are typically located. These checks ensure that the expected low level of metal contamination is in fact a reality, and can provide important baseline information for future assessment, especially in estuaries where urban development is planned or underway within the catchment.

Previous data for sites outside the RSCMP can be found in Hailes et al. (2010) and Allen (2021) 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 Ōrewa estuaries, and Lohrer et al. (2012) and Mills (2021) for the Wairoa embayment.

In 2022, a review of the RSCMP took place, focussing on site selection, sampling frequency and programme structure (Allen, 2022). This included a review of all sites in the RSCMP network, a region wide gap analysis with an emphasis on areas where no/limited monitoring takes place and urban development is either planned or already underway, and an assessment of the current sampling frequency. As a result of the review several changes have been enacted, including establishing a temporally nested monitoring approach and extending sampling frequency, along with annual sampling focussing on specific locations, allowing more complete reporting of an area each year to take place. A report of the review documenting the process and outcomes is available on request.

1.2 Sampling

The sampling protocols used in the RSCMP are outlined in Mills and Allen (2021). Briefly, this involves the collection of five replicate samples from a plot (plot dimensions are typically 50m x 20m) at each location, with each replicate being made up of several sub-samples. The sampling depth is 0-2cm, providing a depth-integrated mixture of freshly deposited material and older sediment from slightly deeper in the profile. The sampling is designed to 'smooth out' spatial and short-term temporal variations in contaminant levels to facilitate trend detection. The multiple replicates taken from each site enables robust measures of annual 'average' concentrations to be calculated (medians are generally used for data analyses), as well as providing information on within-year data variability.

Sampling is usually conducted in October-November each year to align with optimal timing for benthic ecology sampling which is conducted at the same time as the contaminant sampling. Sampling benthic ecology in October-November avoids major recruitment periods for most species, and sampling at regular times within a year increases the ability to detect real change in community composition over time (Hewitt, 2000). 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).

At least 100g of dry, <500µm sieved sediment is retained from each sediment sample for archiving. The purpose of the sample archive is to provide sufficient sediment in case future reanalysis is required, for example for checking trends or analysis of historical samples for new contaminants that have not been routinely monitored.

1.3 Analytes

1.3.1 Metals

The contaminants routinely analysed in the RSCMP are currently limited to total recoverable metals – copper (Cu), lead (Pb), zinc (Zn), arsenic (As; a metalloid species), and mercury (Hg). Copper, lead, and zinc are commonly associated with urban activities, and are often present at elevated concentrations in urban stormwater. Copper and zinc concentrations have generally been predicted to increase in sediments receiving urban stormwater runoff, while lead is anticipated to decrease as its use has declined over time, particularly since the mid-1990s when it was removed from petrol. Arsenic and mercury are toxic contaminants sometimes present at elevated concentrations in Auckland marine sediments. Sources and trends for arsenic and mercury are currently unclear, so routine analysis was instituted in 2012 to obtain more information. Concentrations of total recoverable cadmium (Cd) were also analysed at sites in Mahurangi Harbour. Cadmium is an unavoidable contaminant in phosphate fertiliser, and while small amounts are found naturally in soil, sustained application can lead to an accumulation in agricultural areas, negatively impacting soil health (Gray and Cavanagh, 2022; Loganathan et al., 2003). If elevated levels of cadmium are present in coastal environments, they can be toxic to aquatic organisms. Chronic exposure causes a range of adverse effects on growth, reproduction, and development, while acute exposure can cause an increase in mortality (Environmental Protection Agency, 2022). Monitoring of cadmium was included in the 2022 sampling round to serve as a 'check' on this metal contaminant in the Mahurangi Harbour which has a largely rural catchment.

Total recoverable metals are extracted from the sediment by hot, strong acid digestion (HNO_3/HCl, USEPA, 2010 – Method 200.2). Samples are analysed on the <500µm (<0.5mm) fraction. This approximates the total sediment and allows for larger coarse particles – e.g., shell hash and gravel – to be removed to reduce data variability.

Prior to 2015, weak acid extractable metals in the <63µm fraction were also routinely analysed at all sites. Quality assurance (QA) data accumulated since 2011, and field results from earlier monitoring, have indicated that year-to-year analytical variability for extractable metals was too high for reliable use in trend monitoring. The QA data indicated that total recoverable metals results have been more consistent, and therefore better suited for ongoing monitoring. Extractable metals are therefore no longer routinely analysed at RSCMP sites. The <63µm fraction metals' data may be of value at some sites where trends in fine sediment contamination in variable-textured sediments are a particular focus (e.g., Long Bay stream sites), or in more detailed investigations at more contaminated sites (e.g., following the Australian and New Zealand Guidelines for fresh and marine water quality (ANZG, 2018) tiered evaluation protocols).

1.3.2 Organic contaminants

Persistent organic pollutants (POPs) such as polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides (OCPs), and polychlorinated biphenyls (PCBs) have also been analysed at times in the past. These contaminants are now scheduled to be analysed much less frequently than for metals and only at selected 'at risk' sites (see Mills 2014a and 2014b). This is because the analyses are much more expensive to reliably perform than for metals, ecosystem health is expected to be less sensitive to POPs than metals at most sites, and the concentrations are not anticipated to increase much over time.

1.3.3 Emerging organic contaminants and microplastics

Emerging Organic Contaminants (EOCs) are a very broad range of chemicals that are not yet routinely monitored in the environment but have potential to cause adverse ecological and/or human health effects. The main sources of EOCs have been found to include municipal sewage treatment plant effluent and associated biosolids, landfill leachate, urban stormwater, and agricultural/horticultural runoff. A scoping study of sediments from estuarine locations around Auckland has been previously undertaken, finding concentrations largely similar to those reported internationally, with elevated concentrations observed around wastewater discharge and sewage overflows (Stewart et al., 2014).

Microplastics (plastic particles <5mm in size) are increasingly being reported as contaminants in sediments and surface waters globally. Sources are many and varied and can include synthetic textiles, vehicle tyre wear, packaging, pre-production pellets, personal care products, and as a result of degraded larger plastic waste. International research indicates that microplastics are widespread and persistent in the environment, with the potential to cause harmful ecological impacts (e.g., Gola et al., 2021). A study identifying quantity and characteristics of microplastics in sediment was undertaken at 39 coastal sites across Auckland, finding microplastic contamination at the majority of locations studied (Bridson et al., 2020).

Currently, work is underway with a national research programme centred in the Whau Estuary in the Waitematā Harbour. The outcomes of this work will help to further guide and determine the future EOC and microplastic monitoring direction and priorities in the region. Given that these contaminants are not currently an integral component of routine RSCMP monitoring, they are not discussed in further detail in this report.

1.3.4 Particle size distribution

Particle size distribution (PSD) is presented as percentage composition of gravel/shell hash (>2mm), coarse sand (500-2000µm), medium sand (250-500µm), fine sand (125-250µm), very fine sand (62.5-125µm), silt (3.9-62.5µm) and clay (<3.9µm).

PSD has been determined by two different methods in the past. The primary method used up to 2008, was laser particle size analysis. At sites in the Upper Waitematā, PSD was determined by wet sieving/pipette analysis (Lundquist et al., 2010). Since 2009 the wet sieving/pipette method has been applied across all sediment contaminant sites and is also the method used in Auckland Council benthic ecology programmes.

The particle size distribution data are used in the RSCMP primarily to assess whether there have been changes in mud content (i.e., proportion of the sediment in the <63µm range; the sum of silt and clay particle size content) that may affect interpretation of the total metals results. Finer grained sediments (i.e., muddier) generally have higher metals' concentrations than coarser (i.e., sandy) material. This is due to several factors: low energy, muddy zones are more likely to trap and accumulate contaminants attached to fine particles; the large surface area of numerous very small particles provides more space for contaminants to adhere to; metals are strongly attracted to ionic exchange sites that are associated with the iron and manganese coatings common on clay and silt particles (Ongley, 1996). Trends in metals and PSD therefore need to be considered together to assess the possible contribution of changing PSD to trends in metals over time (see Mills and Allen (2021) for trends in PSD up to 2019).

1.4 Data and reporting

1.4.1 Data reporting

A data report is produced for each RSCMP monitoring round. This provides a summary of the sampling and analyses undertaken (sites, dates, analytes), an overall QA and state assessment and the monitoring data (metals and PSD) in tabular form. This current report is a data report covering sampling carried out in October and November 2022.

1.4.2 State and trend reporting

Every few years, when sufficient temporal and spatial data have been collected to support more detailed analysis, data have been analysed to assess spatial distribution (state) and temporal trends in contamination. State and trends in metals and PAH were reported by Mills et al. (2012), covering monitoring data collected between 1998 and 2010 (inclusive). Organochlorines – organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) – and emerging contaminants were reviewed in Mills (2014a and 2014b). Mills and Allen (2021) includes state and trends in metals and mud concentrations for the period 2004 to 2019.

1.4.3 Land, Air, Water Aotearoa (LAWA)

The Land, Air, Water Aotearoa (LAWA) data portal (https://www.lawa.org.nz/) displays sediment contaminant information for sites in the Auckland region under the 'Estuary Health' topic. Data is displayed at all sites where sampling has taken place since 2010. The LAWA portal also describes estuary and individual site characteristics, and broadly outlines contaminant impact in estuaries and monitoring methodology. Results can be viewed alongside a range of different sediment quality guidelines including the Auckland specific Environmental Response Criteria. Site results are updated annually, available for download, and can be viewed dating back to 2010 where data is available.

1.4.4 Programme operations

General programme operation including field practices, sample processing and QA/QC, is detailed in an internal 'working' protocol. Further details of the monitoring programme design and operation are given in a number of reports, including ARC (1999 and 2004), Kelly (2007), Lundquist et al. (2010), Townsend et al. (2015), Mills and Williamson (2014), Mills (2016), and Mills and Allen (2021).

1.4.5 Quality control / quality assurance reports

Additional reports include quality control checks conducted by R J Hill Laboratories, to ensure that the results have met the laboratory's in-house quality standards. The laboratory is required to provide a QA/QC report for each batch of RSCMP data. In addition, the sample processing laboratory (NIWA, Hamilton) undertakes an assessment of the data provided by the analytical laboratory, including their QA/QC results and the variability of the results reported for the five replicates analysed at each site. Additional QA/QC reports are available on request.

Laboratory quality control data – analysis of procedural blanks, blind duplicate samples, Certified Reference Material (CRM; AGAL-10) and 'in-house' reference sediment from R J Hill Laboratories (Hamilton), are available in PDF or excel format on request.

1.4.6 Data

Once the quality of the analytical results has been verified by the QA protocol, they are imported into Auckland Council's electronic databases (KiECO and KiWQM). Raw data is available on request (requests can be made via the environmental data portal)

2 Sampling conducted in 2022

2.1 Sites and programmes

Sediments from a total of 40 sites were sampled for chemical contaminant analysis. Sampling was undertaken in the following locations:

- nine sites in Upper Waitematā Harbour
- nine sites in Tāmaki Estuary
- seven sites in Whangateau Estuary
- six sites in Mahurangi Harbour
- five sites on the East Coast Bays
- three sites in Okura Estuary
- one site from Te Matuku Bay, Waiheke Island.

The majority of sampling was undertaken by the National Institute of Water and Atmospheric Research (NIWA), except for six sites which were sampled by Auckland Council. Samples were taken between October 6th and November 15, 2022.

The locations of the 40 sites monitored in 2022 (and the remaining RSCMP sites not sampled) are shown in Figure 2-1.

In addition to data collected as part of the RSCMP, samples were also collected from the East Coast Estuary Ecology (10 sites) and Harbour Ecology (five sites) programmes. Some sites, such as several in the Upper Waitematā Harbour, serve as both RSCMP and ecology monitoring sites, sampled regularly for ecology, and less frequently for chemical contaminants. Ecology programmes assess surface sediment characteristics and macrofauna community composition and abundance to gauge the ecological health of intertidal sandflats. Sampling for sediment contaminants at these sites is done much less frequently than at RSCMP sites, and as such the data are not yet sufficient for trend assessment. However, they are suitable for inclusion in 'state' assessment, broadening the spatial coverage of contaminant distribution across the region, particularly in more rural areas.

A list of sites, coordinates, sampling dates, associated programme, and analyses conducted at each site are shown in Appendix A: Monitoring site details.

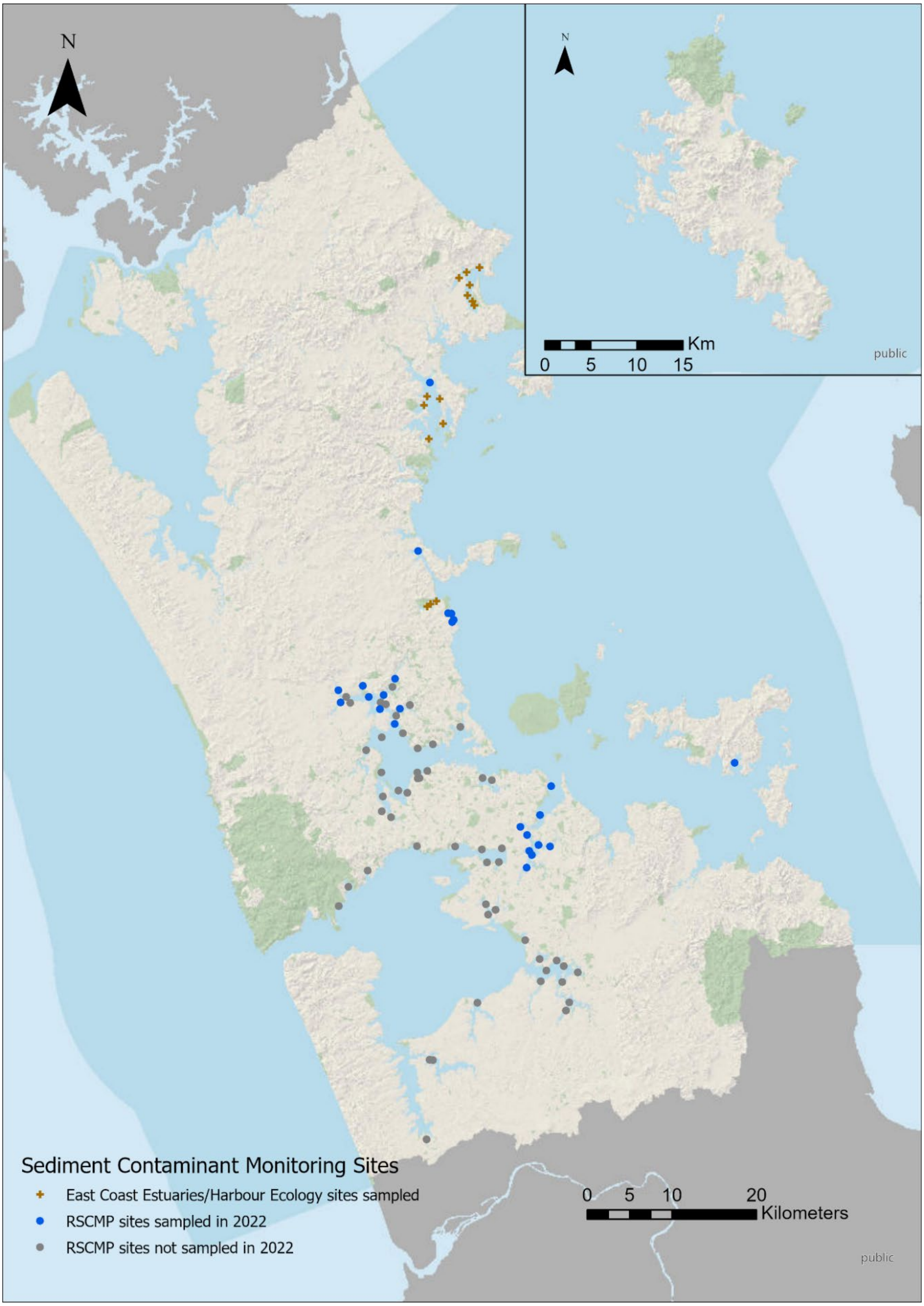

Figure 2-1. Location of sites sampled for sediment contaminant analysis in 2022.

2.2 Sediment chemistry samples

Five replicate samples (each replicate consists of 10 sub-samples) for sediment chemistry analysis were taken at each site, using the protocol described in ARC (2004). All five replicates from each site were processed by homogenisation, freeze-drying, and sieving (<500µm) at NIWA Hamilton.

A sub-sample of each of the five replicates of the sieved and freeze-dried samples (<500µm) from each site was provided to R J Hill Laboratories (Hamilton) by NIWA for metal analysis. Sediment samples were analysed for total recoverable metals – copper, lead, zinc, arsenic (a metalloid species), cadmium, and mercury – on the <500µm sediment fraction (all replicate data is presented in Appendix B: Sediment contaminant data).

Approximately 100g of the remaining freeze-dried <500µm sieved sediment from each replicate was placed in glass jars and archived.

2.3 Particle size distribution samples

A composite sample from each site was used for particle size distribution (PSD) analysis. Each composite sample consisted of 10 sub-samples, each sub-sample being taken from the top 2cm immediately adjacent to a sediment chemistry sample, i.e., the PSD composite was therefore equivalent to a sediment chemistry replicate sample. The PSD samples were analysed by NIWA using wet sieving/pipette separation into seven size fractions, followed by oven drying each fraction to constant weight (all PSD data is presented in Appendix C: Particle size distribution).

2.4 Benthic ecology

Benthic ecology sampling was undertaken at all sites monitored in 2022. Briefly, this involves the collection of 10 large cores (13cm diameter, 15cm depth) from across the site, which are then sieved over a 500µm mesh, and specific taxa enumerated during later laboratory analysis (see Drylie (2021) for further detail). The number of cores collected per site varies depending on the associated programme (e.g., 10 cores are collected in the RSCMP, 12 cores are collected in the Harbour Ecology programme). Ecology data will be analysed and reported separately to this report (see Drylie (2021) for the most recent report).

2.5 Concentration units for metals

Concentrations for metals are presented in milligrams per kilogram (mg/kg) freeze-dry weight of sediment in the <500µm (<0.5mm) fraction. As for the RSCMP monitoring conducted since 2013, the sediment samples provided to R J Hill Laboratories for metal analysis were freeze-dried. No correction for residual moisture in the freeze-dried samples has been made. NIWA staff (G. Olsen, personal communication, May 2014) have indicated that their freeze-dried sediments (including fine, organic-rich sediment) typically have moisture contents of <2%, and usually <1% for sandy marine sediments. NIWA's analyses have found that the weighing errors for moisture correction are often higher than the mass difference measured between wet weight and oven-dry weight (overnight at 103°C). Therefore, moisture correction of the freeze-dried sediment results is not warranted and has not been undertaken for the 2022 sample data reported here.

2.6 Quality assurance

A robust quality assurance process is conducted to ensure that the RSCMP data are 'fit for purpose' and suitable for use in the RSCMP. Analysis of Certified Reference Material (CRM) and Bulk Reference Sediments (BRS) showed that 2022 monitoring data for total recoverable metals and PSD were similar in quality to those obtained in previous years. The elevated Zn issue observed in data from 2017 to 2019 appears to be resolved, and trend analysis in BRS samples are continuing to show improved results (i.e., a reduced percent annual change compared with 2021 results). Overall, the metals and mud content data from 2022 are considered acceptable for use in the RSCMP status and trend assessment programme. For a detailed description and results of the quality assurance process see Appendix D: Quality assurance analysis.

3 Contaminant state at sites sampled in 2022

3.1 State assessment

The contaminant state is a measure of the likelihood of adverse ecological effects occurring, specifically relating to benthic organisms residing in the sediment.

Contaminant concentrations are compared with sediment quality guidelines (SQGs), using the Australian and New Zealand Guidelines for fresh and marine water quality (ANZG, 2018), the Auckland Council Environmental Response Criteria (ERC; ARC, 2004) for copper lead and zinc, and the Threshold Effects Level / Probable Effects Level (TEL/PEL; MacDonald et al., 1996) for mercury and cadmium. Specific values used in the SQGs are shown in Table 3-1 and described further below.

3.1.1 Australian and New Zealand Guidelines for fresh and marine water quality (ANZG)

The ANZG values relevant to the monitoring conducted in 2022 are summarised in Table 3-1. Details of the origins of these values, and their relationship to other SQGs is provided in ANZG (2018). The ANZG provides default guideline values (DGV), which indicate the concentrations below which there is a low risk of ecological effects occurring, and in contrast, 'upper' guideline values (GV-high), which indicate concentrations where you might expect to observe adverse toxicity-related effects.

3.1.2 Environmental Response Criteria (ERC)

The ERC are considered to be conservative thresholds, developed and refined specifically for the Auckland region (ARC, 2004). The ERC are the guidelines predominantly used in assessment of sediment contaminant levels in the RSCMP for copper, lead and zinc. The rationale for selecting lower contaminant thresholds (when compared with the ANZG) is to provide an early warning of environmental degradation, allowing time for further investigations to take place and/or management responses to be properly assessed and implemented before more serious degradation can occur. The ERC values relevant to the monitoring conducted in 2022 are summarised in Table 3-1.

A summary of the meaning of the ERC are as follows (ARC, 2004):

- ERC Green conditions reflect a low level of impact.
- ERC Amber sites are showing signs of contamination, having one or more contaminants above a level at which adverse effects on benthic ecology may be expected to appear.
- ERC Red sites are higher impact sites where significant degradation may already have occurred.

3.1.3 Threshold Effects Level (TEL)/ Probable Effects Level (PEL)

The TEL/PEL were established by McDonald et al. (1996). The TEL is a sediment contamination concentration at which a toxic response has started to be observed in benthic organisms and is intended to estimate the concentration of a chemical below which adverse effects only rarely occur. Conversely, the PEL is intended to provide an estimate of the concentration above which adverse effects frequently occur to a large percentage of the benthic population. The TEL/PEL serve as more conservative guidelines, in line with the ERC. These have been applied to the metals mercury and cadmium, for which no ERC guidelines exist. The TEL/PEL values for mercury and cadmium relevant to the monitoring conducted in 2022 are summarised in Table 3-1.

Table 3-1. Environmental Response Criteria (ERC), Threshold Effects Level /Probable Effects Level (TEL/PEL) and Australian and New Zealand Guidelines (ANZG) for metals. DGV = default guideline values, GV-high = guideline value high.

	ERC (mg/kg)			ANZG (mg/kg)			TEL/PEL (mg/kg)		
Metals	Green	Amber	Red	DGV		GV-high	TEL		PEL
Copper	<19	19 - 34	>34	<65	65 - 270	>270	Not applicable		
Lead	<30	30 - 50	>50	<50	50 - 220	>220	Not applicable		
Zinc	<124	124 - 150	>150	<200	200 - 410	>410	Not applicable		
Arsenic	No ERC values			<20	20 - 70	>70	Not applicable		
Mercury	No ERC values			<0.15	0.15 - 1	>1	<0.13	0.13 - 0.7	>0.7
Cadmium	No ERC values			<1.5	1.5 - 10	>10	<0.68	0.68 - 4.21	>4.21

The ANZG DGV for copper (65 mg/kg) and zinc (200 mg/kg) are higher than the ERC-red values (34 and 150 mg/kg respectively), while for lead the ANZG DGV (50 mg/kg) is the same as the ERC-red threshold. The ANZG DGVs are all higher than the ERC green-amber threshold values for copper, lead and zinc, and the TEL thresholds for mercury and cadmium. Fewer sites will therefore trigger the ANZG guideline thresholds for adverse ecological effects than the ERC or TEL/PEL.

A note on arsenic: The application of more conservative guidelines (such as the TEL/PEL) for the metalloid arsenic are not deemed suitable for Auckland, as guideline values can sit below what is found to occur naturally or as 'background' concentrations in the region. As such, arsenic is compared with ANZG guidelines only.

3.2 State of sites sampled in 2022

3.2.1 Overall summary

The contaminant state of sites sampled in 2022 was assessed from median concentrations (from five replicates) of total recoverable metals in the <500µm fraction.

Figure 3-1 shows the current Environmental Response Criteria (ERC) contaminant state for all sites sampled in the Regional Sediment Contaminant Monitoring Programme. This includes sites sampled in 2022 (denoted with a circle), and sites sampled in previous years (denoted with a triangle).

There is a wide range of metal contamination across the monitored locations in 2022. Most of the sites sampled (30 out of 40; 75%) were assessed in the ERC-green category, with rural locations recording low levels of all metals tested, while sites that have higher contaminant levels are located mostly in the Tāmaki Estuary, and to a lesser degree, in the Upper Waitematā Harbour, where several sites trigger conservative zinc, copper and mercury thresholds (the ERC and TEL respectively; see Table 3-3). Far fewer sites fall into the ANZG DGV-amber category (only three sites for zinc and two for mercury), and encouragingly, no sites sampled in 2022 triggered the ANZG red threshold for any metal (see Table 3-2).

Due to the varying nature and high number of locations sampled in 2022, each area will be briefly described, and results presented individually for Whangateau Estuary, Mahurangi Harbour, East Coast Bays, Upper Waitematā Harbour, and Tāmaki Estuary in following sections.

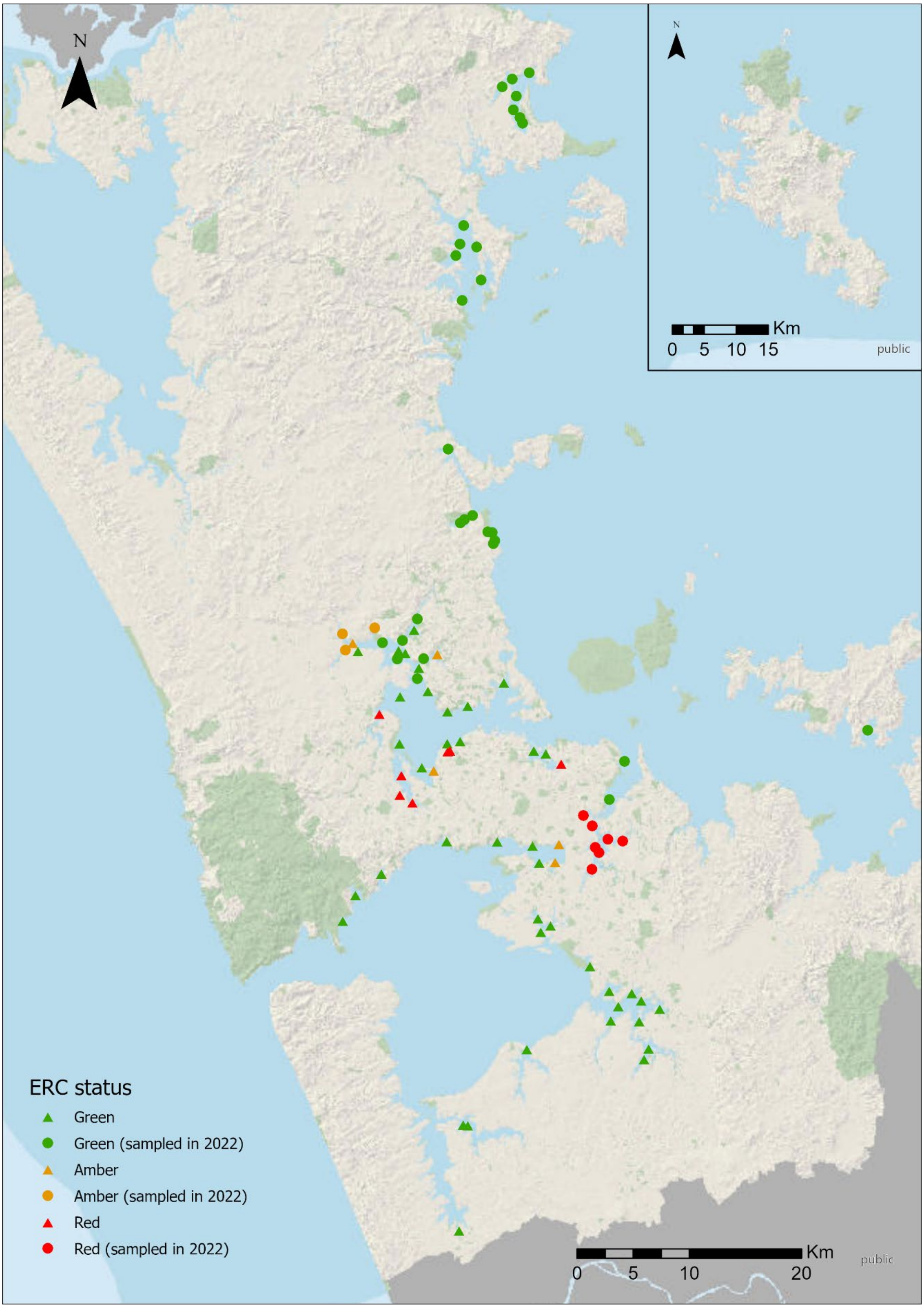

Figure 3-1. Current Environmental Response Criteria (ERC) contaminant state for all sites sampled in the Regional Sediment Contaminant Monitoring Programme. Sites sampled in 2022 are shown with a circle (●), sites sampled in previous years are shown with a triangle (▲).

Table 3-2. Australian and New Zealand Guidelines (ANZG) contaminant state at sites sampled in 2022. Metals' concentrations are medians of five replicates.

Site	Location	Status ANZG	Mud Content % <63 um	Total Recoverable metals, mg/kg <500 mm Cu	Pb	Zn	As	Hg	Cd
Whangateau Estuary 1	Whangateau Estuary		1.9	0.7	0.8	7.5	1.46	<0.02	
Whangateau Estuary 2	Whangateau Estuary		0.3	0.4	0.6	5.6	1.35	<0.02	
Whangateau Estuary 3	Whangateau Estuary		5.0	1.4	1.2	11.0	2.47	<0.02	
Whangateau Estuary 4	Whangateau Estuary		1.7	1.0	0.9	9.6	2.58	<0.02	
Whangateau Estuary 5	Whangateau Estuary		13.0	3.6	2.3	24.7	4.11	<0.02	
Whangateau Estuary 6	Whangateau Estuary		7.4	2.2	1.6	14.7	3.02	<0.02	
Whangateau Estuary 7	Whangateau Estuary		9.2	3.0	1.5	16.5	2.80	<0.02	
Hamilton Landing	Mahurangi Harbour		46.0	6.3	5.2	34.0	10.91	0.030	0.017
Cowans Bay	Mahurangi Harbour		25.7	3.7	3.3	28.4	10.08	0.014	<0.01
Dyers Creek	Mahurangi Harbour		7.4	2.4	1.9	17.6	4.79	<0.02	<0.01
Jamiesons Bay	Mahurangi Harbour		4.8	6.1	5.3	37.4	7.95	0.010	0.016
Mid Harbour	Mahurangi Harbour		11.1	6.1	5.8	43.4	15.87	0.024	0.016
Te Kapa Inlet	Mahurangi Harbour		21.6	5.6	4.1	35.6	9.65	0.014	0.017
Weiti	Weiti River		22.6	11.9	9.6	60.1	8.26	0.041	
Okura Estuary 3	Okura Estuary		5.06	2.1	3.1	19.1	5.06	<0.02	
Okura Estuary 7	Okura Estuary		11.6	3.2	4.3	25.0	5.36	<0.02	
Okura Estuary 9	Okura Estuary		23.7	4.8	5.9	34.7	6.53	0.029	
Awaruku Beach	Long Bay		0.1	1.7	3.3	22.4	12.12	0.008	
Awaruku Stream	Long Bay		69.9	16.3	9.2	33.9	3.67	0.050	
Vaughan Beach	Long Bay		0.0	1.4	2.7	21.0	10.55	0.003	
Vaughan Stream	Long Bay		46.1	11.4	6.1	48.5	6.50	0.031	
Brigham Creek	Upper Waitematā		93.2	22.8	24.7	117.1	12.09	0.152	
Central Main Channel	Upper Waitematā		34.3	13.1	25.2	116.3	14.27	0.129	
Hellyers Creek	Upper Waitematā		53.4	13.9	19.0	91.8	8.11	0.123	
Herald Island Waiarohia	Upper Waitematā		15.2	4.7	8.1	31.4	3.73	0.044	
Lucas Creek	Upper Waitematā		37.6	13.9	21.9	105.7	17.57	0.104	
Rangitopuni Creek	Upper Waitematā		96.3	24.3	23.8	114.0	10.65	0.139	
Hobsonville	Upper Waitematā		3.1	2.8	6.0	24.5	4.05	0.027	
Paremoremo	Upper Waitematā		93.9	21.9	22.7	102.0	12.16	0.132	
Lucas Upper	Upper Waitematā		58.4	17.0	18.7	110.8	9.70	0.108	
Benghazi	Tāmaki Estuary		13.0	7.4	11.8	80.6	6.80	0.060	
Bowden	Tāmaki Estuary		43.4	18.3	23.8	216.5	10.43	0.133	
Middlemore	Tāmaki Estuary		74.4	33.2	31.7	253.0	9.95	0.148	
Ōtāhuhu	Tāmaki Estuary		94.2	29.3	27.6	184.8	9.28	0.149	
Panmure	Tāmaki Estuary		84.9	24.4	26.8	171.1	8.84	0.155	
Roberta Reserve	Tāmaki Estuary		6.6	3.8	7.0	42.6	8.37	0.029	
Pakuranga Lower	Tāmaki Estuary		44.2	17.2	19.2	158.4	8.08	0.096	
Pakuranga Upper	Tāmaki Estuary		73.7	27.6	26.8	231.8	9.50	0.120	
Princes St	Tāmaki Estuary		51.8	21.2	23.8	172.0	9.53	0.133	
Te Matuku	Tāmaki Strait		15.6	2.9	7.1	32.0	5.05	0.034	

Table 3-3. Environmental Response Criteria (ERC) contaminant state for metals copper (Cu), lead (Pb), and zinc (Zn), and Threshold Effects Level/Probable Effects Level (TEL/PEL) state for mercury (Hg) and cadmium (Cd) at sites sampled in 2022. Metals' concentrations are medians of five replicates.

				Total Recoverable metals, mg/kg <500 mm				
			Mud Content	ERC			TEL	
Site	Location	Status ERC/TEL	% <63 um	Cu	Pb	Zn	Hg	Cd
Whangateau Estuary 1	Whangateau Estuary		1.9	0.7	0.8	7.5	<0.02	
Whangateau Estuary 2	Whangateau Estuary		0.3	0.4	0.6	5.6	<0.02	
Whangateau Estuary 3	Whangateau Estuary		5.0	1.4	1.2	11.0	<0.02	
Whangateau Estuary 4	Whangateau Estuary		1.7	1.0	0.9	9.6	<0.02	
Whangateau Estuary 5	Whangateau Estuary		13.0	3.6	2.3	24.7	<0.02	
Whangateau Estuary 6	Whangateau Estuary		7.4	2.2	1.6	14.7	<0.02	
Whangateau Estuary 7	Whangateau Estuary		9.2	3.0	1.5	16.5	<0.02	
Hamilton Landing	Mahurangi Harbour		46.0	6.3	5.2	34.0	0.030	0.017
Cowans Bay	Mahurangi Harbour		25.7	3.7	3.3	28.4	0.014	<0.01
Dyers Creek	Mahurangi Harbour		7.4	2.4	1.9	17.6	<0.02	<0.01
Jamiesons Bay	Mahurangi Harbour		4.8	6.1	5.3	37.4	0.010	0.016
Mid Harbour	Mahurangi Harbour		11.1	6.1	5.8	43.4	0.024	0.016
Te Kapa Inlet	Mahurangi Harbour		21.6	5.6	4.1	35.6	0.014	0.017
Weiti	Weiti River		22.6	11.9	9.6	60.1	0.041	
Okura Estuary 3	Okura Estuary		5.06	2.1	3.1	19.1	<0.02	
Okura Estuary 7	Okura Estuary		11.6	3.2	4.3	25.0	<0.02	
Okura Estuary 9	Okura Estuary		23.7	4.8	5.9	34.7	0.029	
Awaruku Beach	Long Bay		0.1	1.7	3.3	22.4	0.008	
Awaruku Stream	Long Bay		69.9	16.3	9.2	33.9	0.050	
Vaughan Beach	Long Bay		0.0	1.4	2.7	21.0	0.003	
Vaughan Stream	Long Bay		46.1	11.4	6.1	48.5	0.031	
Brigham Creek	Upper Waitematā		93.2	22.8	24.7	117.1	0.152	
Central Main Channel	Upper Waitematā		34.3	13.1	25.2	116.3	0.129	
Hellyers Creek	Upper Waitematā		53.4	13.9	19.0	91.8	0.123	
Herald Island Waiarohia	Upper Waitematā		15.2	4.7	8.1	31.4	0.044	
Lucas Creek	Upper Waitematā		37.6	13.9	21.9	105.7	0.104	
Rangitopuni Creek	Upper Waitematā		96.3	24.3	23.8	114.0	0.139	
Hobsonville	Upper Waitematā		3.1	2.8	6.0	24.5	0.027	
Paremoremo	Upper Waitematā		93.9	21.9	22.7	102.0	0.132	
Lucas Upper	Upper Waitematā		58.4	17.0	18.7	110.8	0.108	
Benghazi	Tāmaki Estuary		13.0	7.4	11.8	80.6	0.060	
Bowden	Tāmaki Estuary		43.4	18.3	23.8	216.5	0.133	
Middlemore	Tāmaki Estuary		74.4	33.2	31.7	253.0	0.148	
Ōtāhuhu	Tāmaki Estuary		94.2	29.3	27.6	184.8	0.149	
Panmure	Tāmaki Estuary		84.9	24.4	26.8	171.1	0.155	
Roberta Reserve	Tāmaki Estuary		6.6	3.8	7.0	42.6	0.029	
Pakuranga Lower	Tāmaki Estuary		44.2	17.2	19.2	158.4	0.096	
Pakuranga Upper	Tāmaki Estuary		73.7	27.6	26.8	231.8	0.120	
Princes St	Tāmaki Estuary		51.8	21.2	23.8	172.0	0.133	
Te Matuku	Tāmaki Strait		15.6	2.9	7.1	32.0	0.034	

3.2.2 Whangateau Estuary

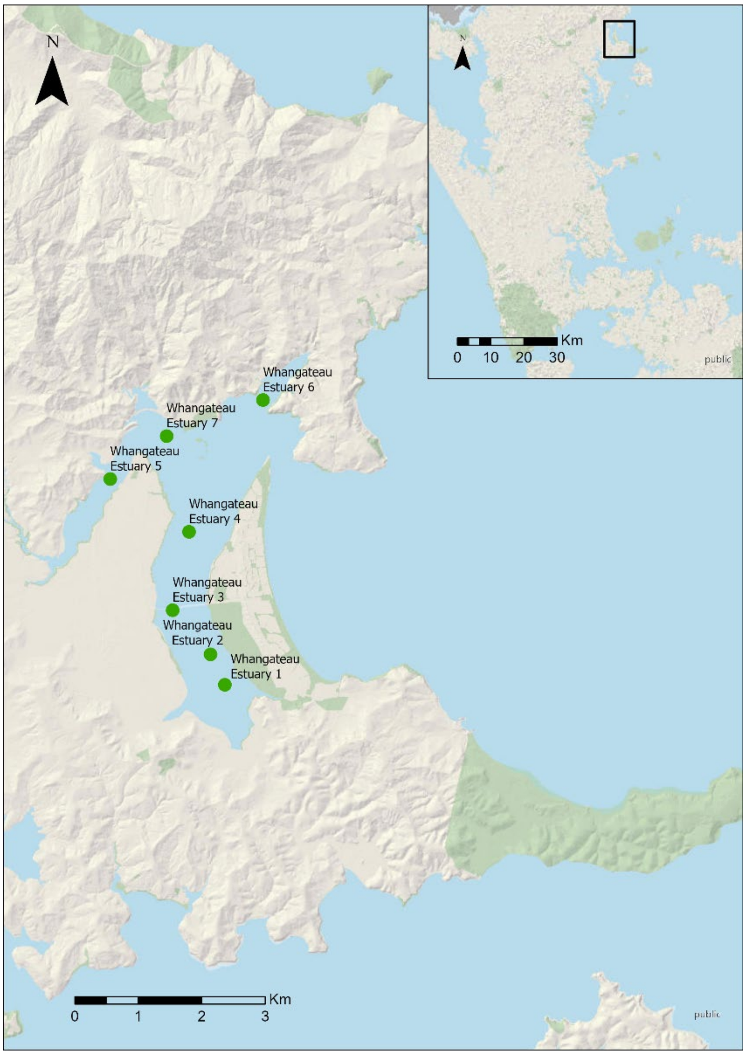

Figure 3-2. Environmental Response Criteria (ERC) contaminant state for metals copper, lead and zinc, ANZG state for arsenic, and Threshold Effects Level (TEL) state for mercury at sites monitored in the Whangateau Estuary, 2022. Inset map shows regional location.

This permanently open tidal lagoon is located in the region's north-east coast and is highly valuable for wildlife. The upper reach of the estuary features significant sequences of fringing vegetation, from intertidal seagrass to coastal forest. The catchment is comprised of native forest, exotic forest, and rural land use.

The seven sites are spread throughout the two arms of the estuary (see Figure 3-2) and are associated with the East Coast Estuary ecology programme.

Results in 2022 showed very low levels of all contaminants measured (some of the lowest levels recorded in the region; mercury levels were below lab detection limits at all sites), well below thresholds where impacts on benthic ecology might be expected.

3.2.3 Mahurangi Harbour

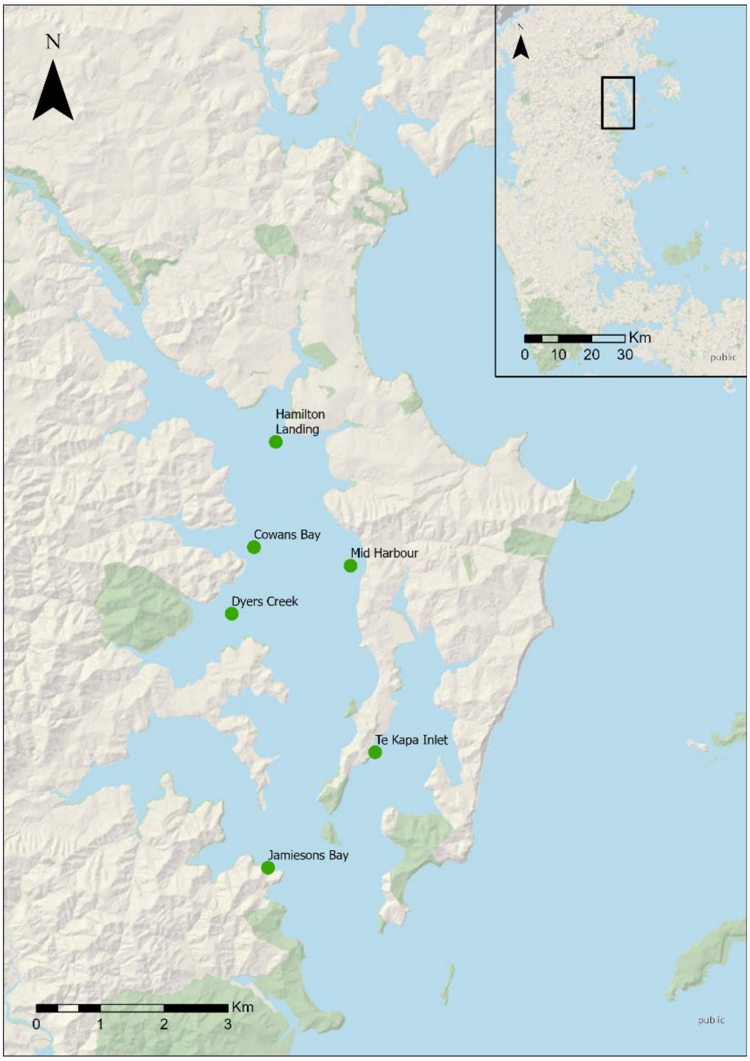

Figure 3-3. Environmental Response Criteria (ERC) contaminant state for metals copper, lead and zinc, ANZG state for arsenic, and Threshold Effects Level (TEL) state for mercury and cadmium at sites monitored in the Mahurangi Harbour, 2022. Inset map shows regional location.

Mahurangi Harbour is a shallow drowned valley estuary on Auckland's north-east coast. The harbour has a variety of habitats, with mud flats fringed by mangroves in the upper reaches, while sandy beaches and rock platforms are present towards the harbour mouth. The majority of the 11,500 ha catchment is rural, however the town of Warkworth is within the catchment, and various areas of expanding urban development are currently underway.

The heavy metal cadmium (Cd) was included in analysis for sites in the Mahurangi, due to the largely rural catchment and the potential for this metal to be present in marine sediment due to its presence as an impurity in phosphate fertiliser.

The six sites sampled in the Mahurangi Harbour (see Figure 3-3) are part of the Harbour Ecology Programme, aside from one site, Hamilton Landing (located in the upper reaches of the harbour) which is now also included in the RSCMP.

Results of contaminant concentrations in Mahurangi were low, with no sites triggering any of the applied threshold guidelines. Cadmium levels were below lab detection levels at two sites, and at the remaining sites were below levels where any impact on ecology would be expected.

3.2.4 East Coast Bays

The East Coast Bays are located on Auckland's north shore. One monitoring site is located in Weiti River, three in Okura Estuary (associated with the East Coast Estuary Ecology programme) and four at Long Bay (Figure 3-4). The Weiti River and Okura Estuary are both permanently open tidal lagoons that drain into Karepiro Bay, south of Whangaparāoa Peninsula. The catchment surrounding these estuaries is a mix of urban and rural land uses, with large areas having undergone urban development in recent years, including areas within the Weiti River catchment.

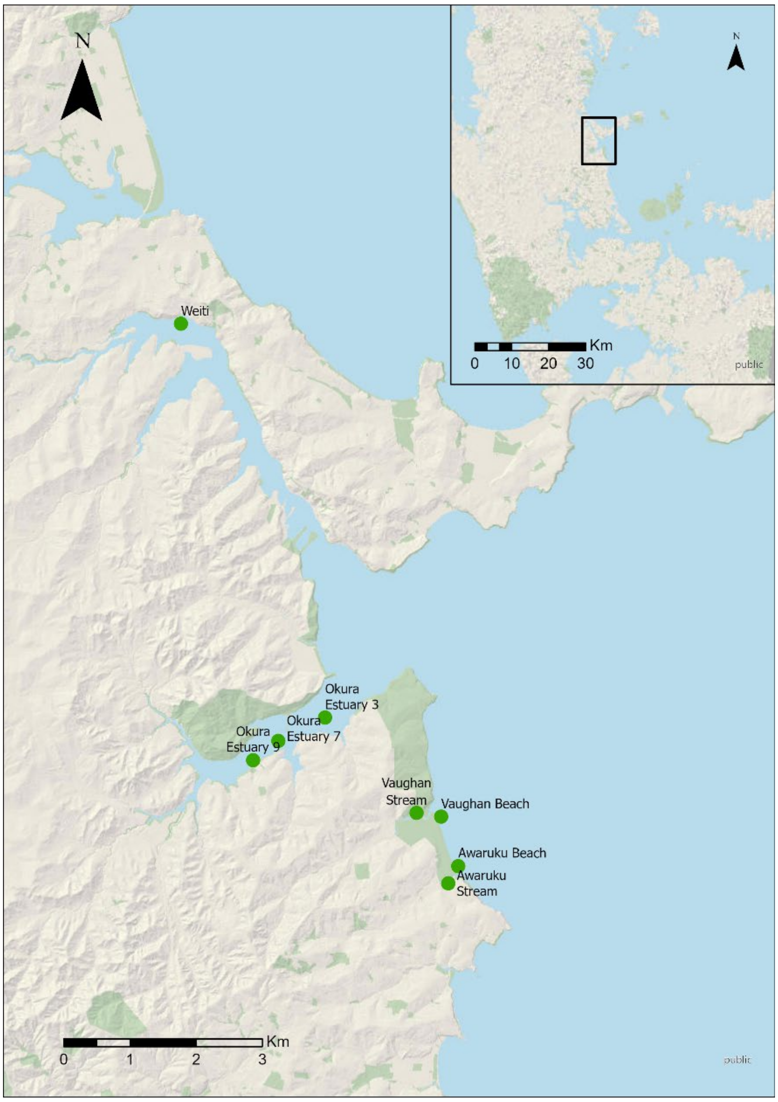

Figure 3-4. Environmental Response Criteria (ERC) contaminant state for metals copper, lead and zinc, ANZG state for arsenic, and Threshold Effects Level (TEL) state for mercury at sites monitored in the East Coast Bays, 2022. Inset map shows regional location.

Long Bay is a relatively exposed stretch of coastline south of the Okura Estuary. The Long Bay beach and surrounds are a popular regional park, and the adjacent marine environment is a protected reserve. Monitoring at Long Bay was initiated in 1998 due to concerns over large scale urban development in the surrounding catchment. Sampling at Long Bay includes sites in the Awaruku and Vaughan Streams, as well as from the adjacent beach. No benthic ecology samples are collected at beach sites in Long Bay, due to the high energy and low composition of benthic macrofauna present.

Results at sites in Okura Estuary showed low concentrations. Slightly higher levels of metals (although still well below guideline thresholds) are observed at site 'Okura Estuary 9' towards the estuary's upper reaches. This site is also muddier than the other two sites sampled (23.7% mud content compared with 11.6 and 5.06%).

Weiti River recorded low levels with no sites triggering guideline thresholds. Results are comparable with concentrations observed during the most recent monitoring at this site in 2020.

At Long Bay, both beach sites (Awaruku Beach and Vaughan Beach) showed very low mud and metal content. Stream sites showed higher metal content, however no sites triggered any of the applied sediment quality guidelines. The metal copper has previously been recorded at levels above the ERC amber threshold (including when last sampled in 2018;

19.5 mg/kg, just above the 19 mg/kg threshold), however in 2022 this had decreased to a median concentration of 16.3 mg/kg. All other metals at both stream sites fall below ERC and TEL/PEL guideline values.

3.2.5 Upper Waitematā Harbour

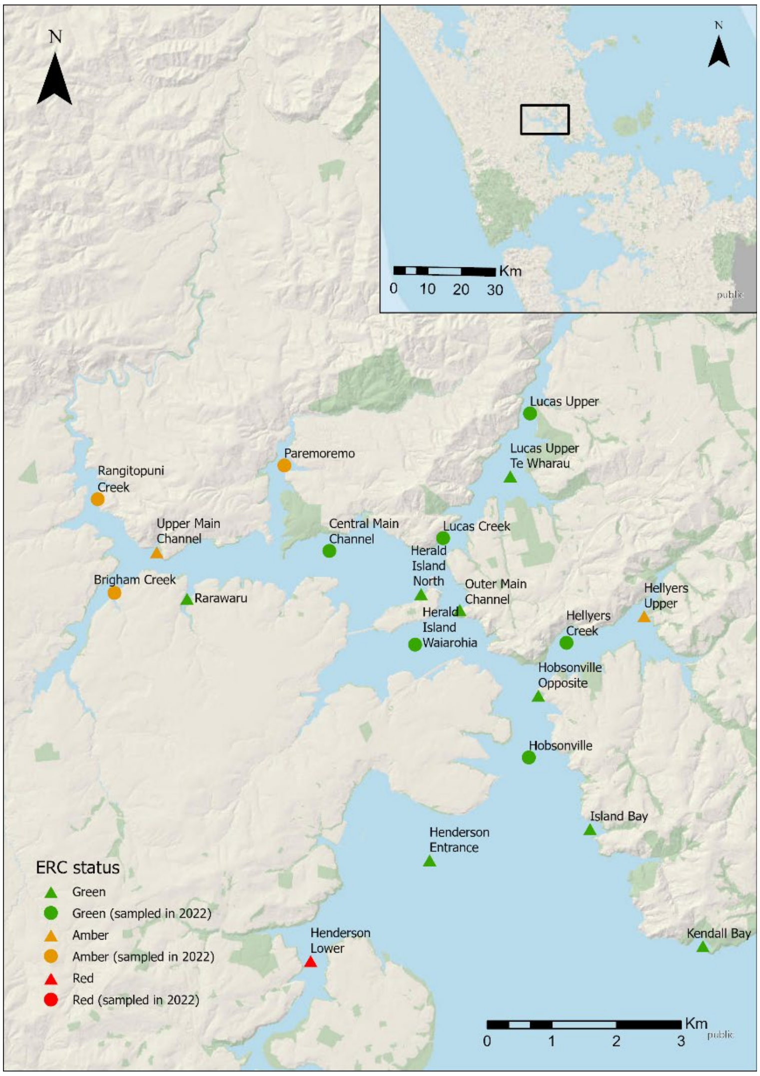

Figure 3-5. Environmental Response Criteria (ERC) contaminant state for metals copper, lead and zinc, ANZG state for arsenic, and Threshold Effects Level (TEL) state for mercury at sites monitored in the Upper Waitematā Harbour. Sites sampled in 2022 are shown with a circle (●), sites sampled in previous years are shown with a triangle (▲). Inset map shows regional location.

The Upper Waitematā Harbour consists of several tidal creeks and inlets that converge into a main channel that enters into the Central Waitematā via a narrow outlet. Some of the tidal creeks contain ecologically valuable areas of coastal vegetation, including sequences of mangroves to coastal forest. The catchment surrounding the Upper Waitematā is a mix of urban and rural land use. The nine sites sampled in the Upper Waitematā in 2022 comprise a mix of RSCMP (two sites) and sites monitored under the Upper Waitematā Harbour Ecology programme (seven sites).

Results for sites in the Upper Waitematā show mostly low levels of contamination. The exception to this is the metals copper and mercury, which reach the amber category at three sites (Figure 3-5). Just one site (Brigham Creek) had concentrations high enough to trigger the ANZG amber category, and this was only for the metal mercury.

3.2.6 Tāmaki Estuary and Tāmaki Strait

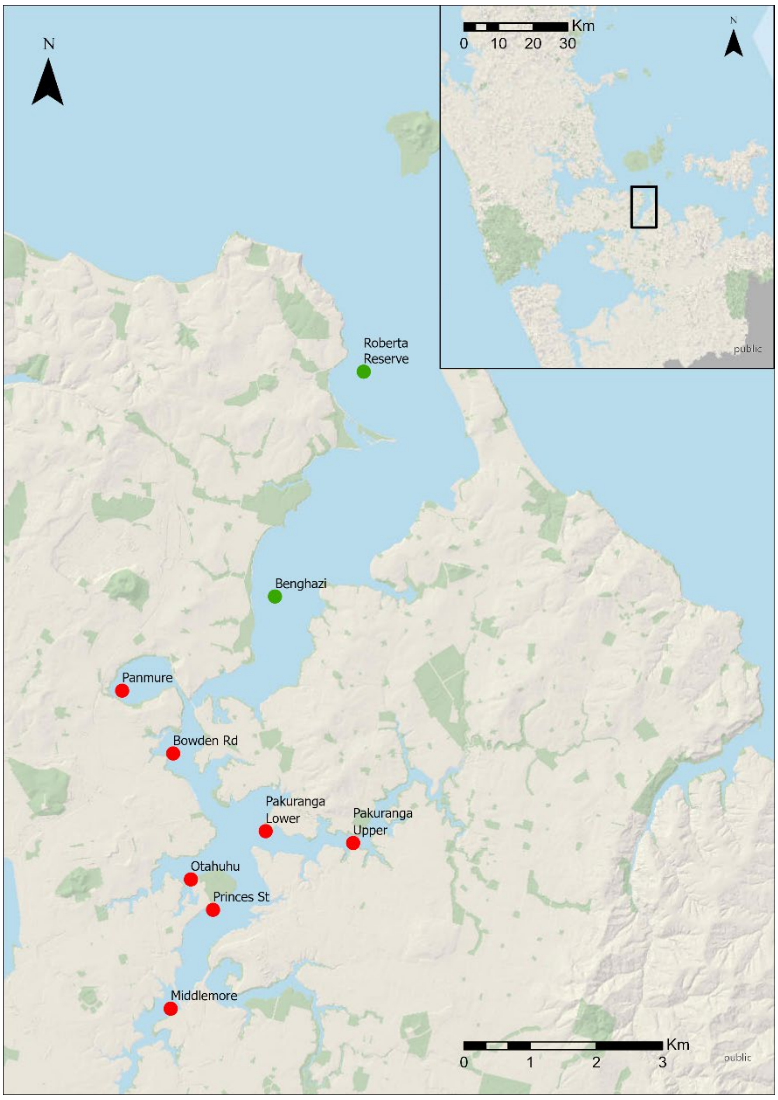

Figure 3-6. Environmental Response Criteria (ERC) contaminant state for metals copper, lead and zinc, ANZG state for arsenic, and Threshold Effects Level (TEL) state for mercury at sites monitored in the Tāmaki Estuary, 2022. Inset map shows region.

The Tāmaki Estuary is a shallow, ~17 km long drowned valley located off the Tāmaki Strait. Large areas of intertidal sand and mudflats along with fringing mangrove forest are present in pockets throughout the estuary. The estuary comprises one main central channel, along with several smaller tributaries. The estuary becomes narrow in its mid reaches, creating a pseudo separation between the sheltered, low energy upper estuary and the more expansive lower estuary. Much of the surrounding catchment is intensively developed and has a long history of urban and industrial use. The nine sites in the Tāmaki Estuary extend from Roberta Reserve near the estuary mouth to Middlemore in the upper reaches and include a site in the Panmure Basin (a semi enclosed small tidal estuary within a volcanic crater), and in the Ōtāhuhu and Pakuranga creeks which branch off the main channel.

One site (Te Matuku; not shown on Figure 3-6, see Figure 3-1 for general location) is monitored on Waiheke Island in the Tāmaki Strait. This site is located in a coastal embayment in the south-east of the island, adjacent to Te Matuku marine reserve. The catchment surrounding the bay is rural, with large tracts of native forest. Te Matuku serves as a relatively unimpacted reference site (i.e., a site that others can be compared against).

All 10 sites (nine in the Tāmaki Estuary and Te Matuku in Tāmaki Strait) are monitored as part of the RSCMP.

Results in 2022 show several sites in the upper reaches of the Tāmaki Estuary (seven out of nine) with levels of zinc in the ERC red category (see Figure 3-6). Several of these sites, including Middlemore, Ōtāhuhu, Panmure, Pakuranga Upper and Princes St, also show levels of copper that fall within the ERC amber threshold. Additionally, five sites trigger the TEL for mercury, and one site (Middlemore) also triggers the ERC amber threshold for lead. When concentrations are compared with the ANZG, only three sites trigger the amber category for zinc (sites Bowden, Middlemore and Pakuranga Lower) and one site is above the amber threshold for mercury (Panmure). Sites Benghazi and Roberta Reserve have concentrations below any guideline thresholds.

Results for site Te Matuku remain low (all metals are well below guideline thresholds) and are comparable to concentrations recorded there during the last time of monitoring in 2020.

Table 3-4. History of Environmental Response Criteria (ERC) state for the metals copper (Cu), lead (Pb), and zinc (Zn) at sites sampled in 2022.

		Year																								
Site	Location	2022	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998
Awaruku Beach	East Coast Bays																									
Awaruku Stream	East Coast Bays					Cu		Zn			Zn		Zn	Zn			Cu		Zn		Zn	Zn	Cu Pb Zn		Cu Zn	
Vaughans Beach	East Coast Bays																									
Vaughans Stream	East Coast Bays																									
Weiti	East Coast Bays																									
Benghazi	Tāmaki Estuary																									
Panmure	Tāmaki Estuary	Zn			Zn		Zn					Zn		Zn		Zn		Zn		Cu Pb Zn		Zn				
Middlemore	Tāmaki Estuary	Zn		Zn		Zn		Zn			Zn		Zn		Zn		Zn		Zn		Zn		Zn		Zn	Cu Pb Zn
Pakuranga Lower	Tāmaki Estuary	Zn		Zn		Zn		Zn			Zn		Zn		Zn		Zn		Cu Zn				Zn		Cu Zn	Cu Zn
Pakuranga Upper	Tāmaki Estuary	Zn				Zn		Zn			Zn		Zn		Zn		Zn		Cu Zn		Zn		Zn		Cu Zn	Zn
Princes St	Tāmaki Estuary	Zn		Zn			Zn		Zn			Zn		Zn		Zn		Zn		Zn						
Bowden	Tāmaki Estuary	Zn					Zn		Zn			Zn		Zn		Zn		Zn		Zn						
Ōtāhuhu	Tāmaki Estuary	Zn					Zn					Zn		Zn		Zn		Zn		Zn						
Roberta Reserve	Tāmaki Estuary																									
Te Matuku	Tāmaki Strait																									
Hobsonville	Upper Waitematā Hbr																									
Brigham Creek	Upper Waitematā Hbr	Cu		Cu		Cu		Cu			Cu		Cu		Cu	Cu	Cu	Cu	Cu							
Central Main Channel	Upper Waitematā Hbr					Zn																				
Hellyers Creek	Upper Waitematā Hbr																									
Herald Island Waiarohia	Upper Waitematā Hbr																									
Lucas Upper	Upper Waitematā Hbr			Cu							Cu		Cu				Cu		Cu		Cu		Cu		Cu	Cu
Lucas Creek	Upper Waitematā Hbr																									
Paremoremo	Upper Waitematā Hbr	Cu		Cu		Cu		Cu			Cu		Cu				Cu		Cu		Cu		Cu		Cu	Cu
Rangitopuni Creek	Upper Waitematā Hbr	Cu		Cu		Cu		Cu			Cu		Cu		Cu	Cu	Cu	Cu	Cu							
Hamilton Landing	Mahurangi Harbour																									
Cowans Bay	Mahurangi Harbour																									
Dyers Creek	Mahurangi Harbour																									
Jamiesons Bay	Mahurangi Harbour																									
Mid Harbour	Mahurangi Harbour																									
Te Kapa Inlet	Mahurangi Harbour																									
Whangateau Estuary 1	Whangateau Estuary																									
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Whangateau Estuary 7	Whangateau Estuary																									
Okura Estuary 3	Okura Estuary																									
Okura Estuary 7	Okura Estuary																									
Okura Estuary 9	Okura Estuary																									

3.3 Discussion

Overall, results from sampling undertaken in 2022 showed a wide range of sediment contamination. Rural locations recorded low levels of all metals tested, in line with previous monitoring at these locations, while sites that have higher contaminant levels are located mostly in the Tāmaki Estuary, and (to a lesser degree) in the Upper Waitematā Harbour.

As has been noted previously (see Mills and Allen, 2021), zinc remains a key contaminant of concern, and the metal most regularly exceeding ERC sediment quality guidelines. In 2022, zinc triggered the ERC red threshold at seven sites, all located within the Tāmaki Estuary. Levels of elevated zinc are most prevalent in catchments with intensive industrial and urban areas, particularly where there is a long history of this type of land use, such as the catchment surrounding the Tāmaki Estuary. The pressures associated with these land uses have cumulatively had a negative impact on sediment quality in the estuary, with several sites triggering amber and/or red threshold levels since monitoring began in 1998 (see State History, Table 3-4). Low levels at sites Benghazi and Roberta Reserve are likely a reflection of these sites' location in the more exposed lower reaches of the estuary. The sheltered upper sub-estuaries, tidal creeks and inlets of harbours tend to accumulate fine sediment and can have a high proportion of mud, and in turn are more likely to trap and accumulate contaminants compared to sandy, open sites exposed to higher wave and tidal energy. Sites Benghazi and Roberta Reserve also have considerably lower mud content levels compared to the other sites in the estuary. The most recently available combined benthic ecological health score[1] for sites in the Tāmaki Estuary follow a similar pattern to that of metal contamination. Fair ecological health is observed at site Benghazi (no results were available for site Roberta Reserve), with either poor or marginal health calculated at all sites located further up the estuary (Drylie, 2021).

Several sites in the Upper Waitematā Harbour trigger ERC amber thresholds for copper. This area has a long history of elevated copper levels, with sites observed above the ERC amber threshold since monitoring began at Paremoremo and Lucas Upper in 1998 (see State History, Table 3-4). Copper concentrations are higher than expected for the predominantly surrounding rural land use. The cause or causes of this are unknown, however it is possible that largely historic copper-based pesticide and herbicide use in the surrounding catchment has been a contributing factor.

Recent state and trend reporting (Mills and Allen, 2021) showed that levels of lead were declining at several sites across Tāmaki Makaurau, continuing a regional trend reported previously (see Mills et al., 2012). This widespread decrease is likely due to removal of lead from petrol in the mid-1990s. Sites across the region are now generally below levels where effects on ecology would be expected, and in 2022 only one site (Middlemore – located in

[1] Combined health scores are a single index which combines the Benthic Health Model (BHM) and Traits Based Index (TBI). The BHM and TBI analyse macrofaunal community composition to assess benthic ecological health.

the upper reaches of Tāmaki Estuary) triggered the ERC amber threshold at 31.7 mg/kg, just above the 30 mg/kg guideline value.

Cadmium was included in the suite of analytes for sampling conducted in the Mahurangi Harbour. Overall, low levels of cadmium were observed in Mahurangi, with two sites recording concentrations below lab detection limits, and the remaining four sites at concentrations well below guideline thresholds. Cadmium has the potential to be elevated in marine sediments of rural areas due to it being an unavoidable contaminant in widely soil-applied phosphate fertiliser, and despite the relatively low levels observed in Mahurangi, the inclusion of cadmium in the suite of analytes when future sampling is conducted in predominantly rural areas (such as the east coast estuaries and Kaipara Harbour) is recommended to ensure other areas are showing similarly low levels.

Several sites in the Mahurangi Harbour have shown results that indicate marginal benthic ecological health related to metals. This includes sites Hamilton Landing, Te Kapa Inlet and Cowans Bay (see Drylie, 2021). While these sites are all currently recording metal values that are below conservative thresholds, impact from metals cannot be ruled out, as previous field surveys in the Auckland region have observed changes to benthic community composition occurring along a contaminant gradient (for copper, lead and zinc) below TELs (Hewitt et al., 2009). This could be a result of several factors, including simultaneous effects of multiple stressors, depth-dependant responses, biological interactions between different species or differing susceptibility of species at various life stages (Hewitt et al., 2009). Continued monitoring of the site Hamilton Landing (to be sampled three yearly as part of the RSCMP) will enable ongoing assessment of metal concentrations as urban development continues in the Mahurangi catchment.

A total of eight sites sampled had undetectable levels of mercury (below the analytical laboratory default detection limit of 0.02 mg/kg, recorded as <0.02 mg/kg in state tables). This was generally in rural areas such as the Whangateau and Okura Estuaries. Several sites (eight in total) trigger the TEL for mercury, dropping to just two sites when compared with the ANZG. Mercury is not elevated in isolation at any sites and is typically found in elevated levels alongside at least one other metal. This is particularly evident in the Tāmaki Estuary, where mercury sits alongside high zinc concentrations (and occasionally also elevated copper levels). In isolation, levels of mercury currently pose only a low level of risk to benthic fauna at most sites sampled in 2022, however, even at slightly elevated concentrations (when combined with other stressors in the environment such as other elevated metals and/or high mud content) are likely to be contributing to cumulative effects, and the overall picture of sediment quality (and therefore ecological health) in some areas of Tāmaki Makaurau.

No sites sampled in 2022 triggered the ANZG guideline for arsenic, and levels appear in line with what would be expected to occur naturally. As mentioned previously in this report, the application of conservative guidelines such as the TEL/PEL for the metalloid arsenic is not recommended for the RSCMP. This is because guideline values sit below what would be expected to occur as background concentrations in Auckland marine sediments.

Sampling in 2022 included the Long Bay beach and stream sites. Sampling at these locations was established in 1998, to track the effects of urban developments within the catchment on sediment quality in marine receiving environments, including the Okura/Long Bay Marine Reserve, and in the lower reaches of the Awaruku and Vaughan streams. Earlier analysis of monitoring results up until 2013 found that there were no apparent adverse effects from the streams on contaminant or fine sediment accumulation on the beach (Mills, 2016b). The high energy, open coastal setting presumably prevents any accumulation from occurring. However, the stream sites themselves showed higher concentrations, particularly at the Awaruku Stream site, where the metals copper and zinc were regularly elevated above ERC thresholds (see State History Table 3-4). In 2022, copper state at Awaruku Stream dropped from ERC amber to ERC green for the first time since monitoring began. No other metals were close to conservative threshold levels at Awaruku Stream. Further monitoring will determine if the change in state observed in 2022 remains, and it is recommended that after the next sampling round (three yearly; in 2025), a more detailed assessment of results and future monitoring options at these four sites take place.

The ERC state at sites sampled in 2022 have remained relatively stable over the monitoring period (see Table 3-4), with the majority of sites remaining within the ERC – green status. Improvements have been observed at sites Lucas Upper (where levels changed from ERC amber to ERC green for copper), and at site Awaruku Stream (discussed above). Site Lucas Upper has hovered around the ERC amber-green threshold value since monitoring began in 1998 (ranging between 26.2 mg/kg in 2001 and 15.5 mg/kg in 2016). The 2022 value of 17.0 mg/kg is just below the ERC threshold of 19 mg/kg. Further monitoring will determine if this change remains or if the fluctuations above and below the threshold level continue.

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5 Appendix A: Monitoring site details

Regional Sediment Contaminant Monitoring Programme sites sampled in 2022, associated marine monitoring programme, sampling location (coordinates in NZTM 2000 – New Zealand Transverse Mercator), sampling date, sampling organisation and analyses conducted. Colours distinguish general site location.

							<500 µm fraction			
Site	Location	Programme	NZTM X	NZTM Y	Sampling Date	Sampled by	Total Cu Pb Zn As Hg	Cd	Benthic Ecology	Particle Size
Whangateau Estuary 1	Whangateau Estuary	East Coast Estuaries	1759055	5975558	10/10/2022	NIWA	✓		✓	✓
Whangateau Estuary 2	Whangateau Estuary	East Coast Estuaries	1758828	5976033	10/10/2022	NIWA	✓		✓	✓
Whangateau Estuary 3	Whangateau Estuary	East Coast Estuaries	1758233	5976732	10/10/2022	NIWA	✓		✓	✓
Whangateau Estuary 4	Whangateau Estuary	East Coast Estuaries	1758491	5977966	10/10/2022	NIWA	✓		✓	✓
Whangateau Estuary 5	Whangateau Estuary	East Coast Estuaries	1757249	5978797	10/10/2022	NIWA	✓		✓	✓
Whangateau Estuary 6	Whangateau Estuary	East Coast Estuaries	1759657	5980043	10/10/2022	NIWA	✓		✓	✓
Whangateau Estuary 7	Whangateau Estuary	East Coast Estuaries	1758136	5979478	10/10/2022	NIWA	✓		✓	✓
Hamilton Landing	Mahurangi Harbour	RSCMP/Harbour Ecology	1753798	5966447	6/10/2022	NIWA	✓	✓	✓	✓
Cowans Bay	Mahurangi Harbour	Harbour Ecology	1753455	5964797	6/10/2022	NIWA	✓	✓	✓	✓
Dyers Creek	Mahurangi Harbour	Harbour Ecology	1753105	5963750	6/10/2022	NIWA	✓	✓	✓	✓
Jamiesons Bay	Mahurangi Harbour	Harbour Ecology	1753677	5959771	6/10/2022	NIWA	✓	✓	✓	✓
Mid Harbour	Mahurangi Harbour	Harbour Ecology	1754969	5964505	6/10/2022	NIWA	✓	✓	✓	✓
Te Kapa Inlet	Mahurangi Harbour	Harbour Ecology	1755354	5961578	6/10/2022	NIWA	✓	✓	✓	✓
Weiti	Weiti River	RSCMP	1752400	5946536	7/11/2022	AC	✓		✓	✓
Okura Estuary 3	Okura Estuary	East Coast Estuaries	1754577	5940595	14/10/2022	NIWA	✓		✓	✓
Okura Estuary 7	Okura Estuary	East Coast Estuaries	1753871	5940245	14/10/2022	NIWA	✓		✓	✓
Okura Estuary 9	Okura Estuary	East Coast Estuaries	1753490	5939953	14/10/2022	NIWA	✓		✓	✓
Awaruku Beach	Long Bay	RSCMP	1756588	5938356	7/11/2022	AC	✓			✓
Awaruku Stream	Long Bay	RSCMP	1756438	5938097	7/11/2022	AC	✓			✓
Vaughan Beach	Long Bay	RSCMP	1756329	5939101	7/11/2022	AC	✓			✓
Vaughan Stream	Long Bay	RSCMP	1755959	5939156	7/11/2022	AC	✓			✓
Brigham Creek	Upper Waitematā	UWH	1743254	5928631	15/11/2022	NIWA	✓		✓	✓
Central Main Channel	Upper Waitematā	UWH	1746577	5929280	15/11/2022	NIWA	✓		✓	✓
Hellyers Creek	Upper Waitematā	UWH	1750242	5927860	15/11/2022	NIWA	✓		✓	✓
Herald Island Waiarohia	Upper Waitematā	UWH	1747901	5927833	9/11/2022	NIWA	✓		✓	✓
Lucas Creek	Upper Waitematā	UWH	1748335	5929477	14/11/2022	NIWA	✓		✓	✓
Rangitopuni Creek	Upper Waitematā	UWH	1742996	5930079	15/11/2022	NIWA	✓		✓	✓
Hobsonville	Upper Waitematā	UWH	1749662	5926088	7/10/2022	NIWA	✓		✓	✓
Paremoremo	Upper Waitematā	RSCMP	1745881	5930603	9/11/2022	NIWA	✓		✓	✓
Lucas Upper	Upper Waitematā	RSCMP	1749681	5931407	15/11/2022	NIWA	✓		✓	✓
Benghazi	Tāmaki Estuary	RSCMP	1766790	5915325	9/11/2022	AC	✓		✓	✓
Bowden	Tāmaki Estuary	RSCMP	1765251	5912952	8/11/2022	AC	✓		✓	✓
Middlemore	Tāmaki Estuary	RSCMP	1765216	5909093	9/11/2022	AC	✓		✓	✓
Ōtāhuhu	Tāmaki Estuary	RSCMP	1765518	5911051	11/11/2022	AC	✓		✓	✓
Panmure	Tāmaki Estuary	RSCMP	1764480	5913903	6/11/2022	AC	✓		✓	✓
Roberta Reserve	Tāmaki Estuary	RSCMP	1768127	5918726	11/11/2022	AC	✓		✓	✓
Pakuranga Lower	Tāmaki Estuary	RSCMP	1766648	5911776	9/11/2022	NIWA	✓		✓	✓
Pakuranga Upper	Tāmaki Estuary	RSCMP	1767969	5911598	9/11/2022	NIWA	✓		✓	✓
Princes St	Tāmaki Estuary	RSCMP	1765853	5910588	9/11/2022	NIWA	✓		✓	✓
Te Matuku	Tāmaki Strait	RSCMP	1789785	5921484	10/11/2022	AC	✓		✓	✓

6 Appendix B: Sediment contaminant data

Metals' data for 2022 monitoring. Concentrations are in mg/kg freeze-dry weight (<500 µm fraction). QA sample data are included for Certified Reference Material (CRM = AGAL 10 and CRMB = AGAL 12) and Bulk Reference Sediments (Meola = MeOZ FD and Middlemore = Mid FD).

Site name	Location	Replicate	Total Recoverable metals, mg/kg <500 µm					
			Cu	Pb	Zn	As	Hg	Cd
Whangateau Estuary 1	Whangateau Estuary	1	0.7	0.7	7.5	1.40	<0.02	
Whangateau Estuary 1	Whangateau Estuary	2	0.8	0.8	7.7	1.60	<0.02	
Whangateau Estuary 1	Whangateau Estuary	3	0.7	0.8	7.7	1.57	<0.02	
Whangateau Estuary 1	Whangateau Estuary	4	0.7	0.7	7.5	1.42	<0.02	
Whangateau Estuary 1	Whangateau Estuary	5	0.7	0.8	7.2	1.46	<0.02	
Whangateau Estuary 2	Whangateau Estuary	1	0.4	0.6	5.6	1.35	<0.02	
Whangateau Estuary 2	Whangateau Estuary	2	0.4	0.6	5.6	1.26	<0.02	
Whangateau Estuary 2	Whangateau Estuary	3	0.4	0.6	5.7	1.38	<0.02	
Whangateau Estuary 2	Whangateau Estuary	4	0.5	0.6	6.0	1.42	<0.02	
Whangateau Estuary 2	Whangateau Estuary	5	0.4	0.5	5.2	1.34	<0.02	
Whangateau Estuary 3	Whangateau Estuary	1	1.3	1.2	10.3	2.33	<0.02	
Whangateau Estuary 3	Whangateau Estuary	2	1.4	1.3	10.8	2.49	<0.02	
Whangateau Estuary 3	Whangateau Estuary	3	1.5	1.1	11.0	2.47	<0.02	
Whangateau Estuary 3	Whangateau Estuary	4	1.4	1.1	11.3	2.46	<0.02	
Whangateau Estuary 3	Whangateau Estuary	5	1.5	1.3	11.4	2.48	<0.02	
Whangateau Estuary 4	Whangateau Estuary	1	1.1	1.0	10.6	2.83	<0.02	
Whangateau Estuary 4	Whangateau Estuary	2	0.9	0.8	8.9	2.54	<0.02	
Whangateau Estuary 4	Whangateau Estuary	3	0.9	0.8	9.2	2.53	<0.02	
Whangateau Estuary 4	Whangateau Estuary	4	1.0	0.9	9.6	2.58	<0.02	
Whangateau Estuary 4	Whangateau Estuary	5	1.0	0.9	9.6	2.61	<0.02	
Whangateau Estuary 5	Whangateau Estuary	1	3.2	2.2	23.4	3.92	<0.02	
Whangateau Estuary 5	Whangateau Estuary	2	3.6	2.3	24.7	4.17	<0.02	
Whangateau Estuary 5	Whangateau Estuary	3	3.6	2.5	27.6	4.25	<0.02	
Whangateau Estuary 5	Whangateau Estuary	4	3.9	2.4	25.2	4.11	<0.02	
Whangateau Estuary 5	Whangateau Estuary	5	3.6	2.3	24.2	3.87	<0.02	
Whangateau Estuary 6	Whangateau Estuary	1	2.5	1.6	14.8	2.98	<0.02	
Whangateau Estuary 6	Whangateau Estuary	2	2.1	1.6	14.7	3.09	<0.02	
Whangateau Estuary 6	Whangateau Estuary	3	2.2	1.5	14.6	3.07	<0.02	
Whangateau Estuary 6	Whangateau Estuary	4	2.2	1.6	14.7	2.96	<0.02	
Whangateau Estuary 6	Whangateau Estuary	5	2.3	1.6	14.9	3.02	<0.02	
Whangateau Estuary 7	Whangateau Estuary	1	3.3	1.7	17.6	2.96	<0.02	
Whangateau Estuary 7	Whangateau Estuary	2	3.0	1.5	16.1	2.66	<0.02	
Whangateau Estuary 7	Whangateau Estuary	3	2.9	1.3	16.0	2.69	<0.02	
Whangateau Estuary 7	Whangateau Estuary	4	3.8	1.8	19.5	2.98	<0.02	
Whangateau Estuary 7	Whangateau Estuary	5	3.0	1.4	16.5	2.80	<0.02	
Hamilton Landing	Mahurangi Harbour	1	6.5	5.2	35.1	11.66	0.028	0.017
Hamilton Landing	Mahurangi Harbour	2	6.3	5.2	34.0	11.59	0.034	0.018
Hamilton Landing	Mahurangi Harbour	3	5.8	4.9	31.7	10.53	0.030	0.018
Hamilton Landing	Mahurangi Harbour	4	6.3	5.0	34.0	10.91	0.027	0.016
Hamilton Landing	Mahurangi Harbour	5	6.4	5.2	34.9	10.90	0.030	0.017
Cowans Bay	Mahurangi Harbour	1	3.7	3.3	28.4	9.93	0.017	0.013
Cowans Bay	Mahurangi Harbour	2	3.4	3.1	26.4	10.08	0.017	<0.010
Cowans Bay	Mahurangi Harbour	3	3.7	3.4	29.1	10.48	0.014	0.010
Cowans Bay	Mahurangi Harbour	4	3.9	3.4	29.9	10.81	0.013	<0.010
Cowans Bay	Mahurangi Harbour	5	3.7	3.2	27.3	9.98	0.012	<0.010
Dyers Creek	Mahurangi Harbour	1	2.44	1.93	17.10	4.79	0.0105	<0.010
Dyers Creek	Mahurangi Harbour	2	2.51	2.00	17.95	5.00	<0.010	<0.010
Dyers Creek	Mahurangi Harbour	3	2.32	1.92	17.77	4.71	<0.010	<0.010
Dyers Creek	Mahurangi Harbour	4	2.38	1.90	17.24	4.58	<0.010	0.010
Dyers Creek	Mahurangi Harbour	5	2.55	1.87	17.64	4.86	<0.010	<0.010

Site name	Location	Replicate	Total Recoverable metals, mg/kg <500 µm					
			Cu	Pb	Zn	As	Hg	Cd
Jamiesons Bay	Mahurangi Harbour	1	6.1	5.8	37.4	9.06	0.010	0.016
Jamiesons Bay	Mahurangi Harbour	2	5.9	5.1	36.3	7.47	0.005	0.014
Jamiesons Bay	Mahurangi Harbour	3	6.5	6.1	39.0	7.95	0.014	0.016
Jamiesons Bay	Mahurangi Harbour	4	6.0	5.3	37.0	7.67	0.010	0.016
Jamiesons Bay	Mahurangi Harbour	5	6.2	5.3	37.4	8.25	0.009	0.012
Mid Harbour	Mahurangi Harbour	1	6.1	5.8	43.4	15.87	0.024	0.018
Mid Harbour	Mahurangi Harbour	2	6.1	5.9	44.3	16.29	0.024	0.020
Mid Harbour	Mahurangi Harbour	3	5.7	5.6	41.7	15.60	0.022	0.015
Mid Harbour	Mahurangi Harbour	4	6.0	5.5	42.9	15.66	0.022	0.016
Mid Harbour	Mahurangi Harbour	5	6.6	5.9	46.5	17.68	0.028	0.014
Te Kapa Inlet	Mahurangi Harbour	1	5.6	4.1	35.6	9.65	0.015	0.017
Te Kapa Inlet	Mahurangi Harbour	2	5.9	4.2	35.8	8.69	0.017	0.018
Te Kapa Inlet	Mahurangi Harbour	3	5.6	4.1	35.6	9.91	0.014	0.017
Te Kapa Inlet	Mahurangi Harbour	4	5.8	4.2	35.4	9.79	0.014	0.018
Te Kapa Inlet	Mahurangi Harbour	5	5.5	4.0	34.6	8.34	0.014	0.016
Weiti	Weiti River	1	12.1	9.6	60.3	8.54	0.041	
Weiti	Weiti River	2	12.5	10.0	60.7	7.99	0.041	
Weiti	Weiti River	3	11.6	8.5	59.3	7.54	0.043	
Weiti	Weiti River	4	11.9	9.6	60.1	8.26	0.043	
Weiti	Weiti River	5	11.4	9.3	56.5	8.59	0.035	
Okura Estuary 3	Okura Estuary	1	2.0	3.4	19.1	4.97	<0.02	
Okura Estuary 3	Okura Estuary	2	2.3	3.3	19.9	5.42	<0.02	
Okura Estuary 3	Okura Estuary	3	2.1	3.1	18.7	5.06	<0.02	
Okura Estuary 3	Okura Estuary	4	2.1	3.1	19.3	4.94	<0.02	
Okura Estuary 3	Okura Estuary	5	2.1	3.1	18.5	5.14	<0.02	
Okura Estuary 7	Okura Estuary	1	3.0	4.2	24.8	4.98	<0.02	
Okura Estuary 7	Okura Estuary	2	3.2	4.3	25.5	5.36	<0.02	
Okura Estuary 7	Okura Estuary	3	3.6	4.4	26.6	5.73	0.023	
Okura Estuary 7	Okura Estuary	4	3.3	4.1	24.8	5.44	<0.02	
Okura Estuary 7	Okura Estuary	5	3.1	4.3	25.0	5.32	0.023	
Okura Estuary 9	Okura Estuary	1	4.9	6.0	34.6	6.71	0.031	
Okura Estuary 9	Okura Estuary	2	4.6	5.9	35.2	6.56	0.026	
Okura Estuary 9	Okura Estuary	3	4.8	6.0	36.5	6.53	0.029	
Okura Estuary 9	Okura Estuary	4	4.9	5.9	34.7	6.49	0.032	
Okura Estuary 9	Okura Estuary	5	4.2	5.3	32.8	5.90	0.026	
Awaruku Beach	Long Bay	1	1.5	3.0	21.4	11.54	0.005	
Awaruku Beach	Long Bay	2	1.7	3.3	23.2	12.71	0.006	
Awaruku Beach	Long Bay	3	1.7	3.3	23.2	12.91	0.008	
Awaruku Beach	Long Bay	4	1.6	3.2	22.4	11.80	0.009	
Awaruku Beach	Long Bay	5	1.7	3.4	22.3	12.12	0.009	
Awaruku Stream	Long Bay	1	16.3	9.2	35.7	4.47	0.050	
Awaruku Stream	Long Bay	2	16.2	9.2	25.9	3.60	0.050	
Awaruku Stream	Long Bay	3	16.2	8.9	21.8	3.59	0.050	
Awaruku Stream	Long Bay	4	17.3	11.0	36.0	4.68	0.051	
Awaruku Stream	Long Bay	5	18.2	10.3	33.9	3.67	0.047	
Vaughan Beach	Long Bay	1	1.4	2.8	21.0	11.16	0.005	
Vaughan Beach	Long Bay	2	1.5	2.8	22.9	10.55	0.004	
Vaughan Beach	Long Bay	3	1.4	2.7	21.6	10.24	0.003	
Vaughan Beach	Long Bay	4	1.4	2.7	20.6	10.39	0.003	
Vaughan Beach	Long Bay	5	1.4	2.7	20.9	11.15	0.001	
Vaughan Stream	Long Bay	1	11.4	6.4	48.5	6.70	0.030	
Vaughan Stream	Long Bay	2	10.4	5.9	46.2	6.11	0.030	
Vaughan Stream	Long Bay	3	11.7	6.1	49.2	6.50	0.035	
Vaughan Stream	Long Bay	4	12.9	6.2	50.4	6.59	0.031	
Vaughan Stream	Long Bay	5	10.9	6.0	46.6	5.94	0.034	

Site name	Location	Replicate	Total Recoverable metals, mg/kg <500 µm					
			Cu	Pb	Zn	As	Hg	Cd
Brigham Creek	Upper Waitematā	1	23.0	26.5	128.2	13.07	0.152	
Brigham Creek	Upper Waitematā	2	20.9	23.3	110.0	10.89	0.154	
Brigham Creek	Upper Waitematā	3	22.8	24.7	117.1	11.90	0.145	
Brigham Creek	Upper Waitematā	4	21.7	24.3	109.0	12.09	0.152	
Brigham Creek	Upper Waitematā	5	23.3	25.4	117.4	12.16	0.154	
Central Main Channel	Upper Waitematā	1	13.8	26.1	118.4	15.34	0.131	
Central Main Channel	Upper Waitematā	2	13.1	25.2	116.3	14.27	0.129	
Central Main Channel	Upper Waitematā	3	11.3	22.7	104.2	12.40	0.104	
Central Main Channel	Upper Waitematā	4	12.4	24.2	111.4	13.98	0.123	
Central Main Channel	Upper Waitematā	5	14.0	25.2	116.7	14.60	0.132	
Hellyers Creek	Upper Waitematā	1	14.3	20.3	90.2	8.11	0.133	
Hellyers Creek	Upper Waitematā	2	13.1	18.2	89.6	7.18	0.115	
Hellyers Creek	Upper Waitematā	3	14.5	20.1	92.7	8.46	0.124	
Hellyers Creek	Upper Waitematā	4	13.8	19.0	91.8	8.37	0.123	
Hellyers Creek	Upper Waitematā	5	13.9	18.0	92.0	7.97	0.120	
Herald Island Waiarohia	Upper Waitematā	1	5.0	8.1	31.6	3.73	0.044	
Herald Island Waiarohia	Upper Waitematā	2	4.7	8.2	31.4	3.87	0.041	
Herald Island Waiarohia	Upper Waitematā	3	4.5	8.1	30.0	3.85	0.051	
Herald Island Waiarohia	Upper Waitematā	4	4.6	7.8	29.6	3.60	0.044	
Herald Island Waiarohia	Upper Waitematā	5	4.9	8.2	31.4	3.63	0.042	
Lucas Creek	Upper Waitematā	1	13.9	22.0	102.5	16.89	0.099	
Lucas Creek	Upper Waitematā	2	13.4	21.8	106.4	18.56	0.112	
Lucas Creek	Upper Waitematā	3	13.1	21.9	104.2	17.57	0.100	
Lucas Creek	Upper Waitematā	4	14.7	21.9	105.7	17.12	0.104	
Lucas Creek	Upper Waitematā	5	15.3	24.5	114.5	18.60	0.108	
Rangitopuni Creek	Upper Waitematā	1	25.0	24.7	115.0	10.71	0.139	
Rangitopuni Creek	Upper Waitematā	2	24.2	22.5	112.9	10.63	0.139	
Rangitopuni Creek	Upper Waitematā	3	22.9	23.3	108.1	10.22	0.132	
Rangitopuni Creek	Upper Waitematā	4	24.3	23.9	114.0	10.65	0.144	
Rangitopuni Creek	Upper Waitematā	5	25.1	23.8	116.8	11.27	0.144	
Hobsonville	Upper Waitematā	1	2.5	5.5	21.5	3.86	0.020	
Hobsonville	Upper Waitematā	2	2.4	5.5	21.8	4.45	0.029	
Hobsonville	Upper Waitematā	3	2.8	6.0	24.6	4.67	0.031	
Hobsonville	Upper Waitematā	4	3.1	6.5	25.1	4.05	0.027	
Hobsonville	Upper Waitematā	5	2.8	6.0	24.5	3.71	0.027	
Paremoremo	Upper Waitematā	1	23.4	24.6	107.4	12.74	0.156	
Paremoremo	Upper Waitematā	2	22.1	22.7	102.0	12.17	0.129	
Paremoremo	Upper Waitematā	3	20.9	21.4	95.4	11.31	0.126	
Paremoremo	Upper Waitematā	4	20.6	21.4	96.7	10.79	0.132	
Paremoremo	Upper Waitematā	5	21.9	23.2	104.1	12.16	0.139	
Lucas Upper	Upper Waitematā	1	17.0	18.4	107.8	9.38	0.105	
Lucas Upper	Upper Waitematā	2	16.7	18.7	111.5	9.70	0.113	
Lucas Upper	Upper Waitematā	3	17.3	19.5	110.8	9.65	0.104	
Lucas Upper	Upper Waitematā	4	17.0	18.6	108.5	9.81	0.108	
Lucas Upper	Upper Waitematā	5	18.0	19.0	111.3	10.74	0.114	
Benghazi	Tāmaki Estuary	1	7.0	11.5	71.2	6.37	0.049	
Benghazi	Tāmaki Estuary	2	7.4	11.8	86.2	7.15	0.060	
Benghazi	Tāmaki Estuary	3	7.5	11.8	80.6	6.53	0.060	
Benghazi	Tāmaki Estuary	4	7.7	12.7	91.6	7.55	0.061	
Benghazi	Tāmaki Estuary	5	7.4	11.4	80.5	6.80	0.048	
Bowden	Tāmaki Estuary	1	19.8	25.2	226.4	11.52	0.135	
Bowden	Tāmaki Estuary	2	19.8	25.4	237.0	11.82	0.133	
Bowden	Tāmaki Estuary	3	18.3	23.8	216.5	10.43	0.124	
Bowden	Tāmaki Estuary	4	17.1	23.2	195.9	9.91	0.127	
Bowden	Tāmaki Estuary	5	17.6	23.5	212.8	10.39	0.138	
Middlemore	Tāmaki Estuary	1	33.2	30.1	253.0	9.63	0.147	
Middlemore	Tāmaki Estuary	2	33.0	31.7	254.6	9.99	0.146	
Middlemore	Tāmaki Estuary	3	37.3	30.9	248.9	10.50	0.148	
Middlemore	Tāmaki Estuary	4	32.2	32.4	246.1	9.46	0.154	
Middlemore	Tāmaki Estuary	5	35.1	34.0	264.5	9.95	0.163	

Site name	Location	Replicate	Total Recoverable metals, mg/kg <500 µm					
			Cu	Pb	Zn	As	Hg	Cd
Ōtāhuhu	Tāmaki Estuary	1	29.3	27.6	187.1	9.41	0.149	
Ōtāhuhu	Tāmaki Estuary	2	26.9	27.3	175.5	8.77	0.161	
Ōtāhuhu	Tāmaki Estuary	3	29.3	28.6	182.1	8.90	0.146	
Ōtāhuhu	Tāmaki Estuary	4	28.5	28.9	185.1	9.28	0.174	
Ōtāhuhu	Tāmaki Estuary	5	29.5	27.2	184.8	9.52	0.138	
Panmure	Tāmaki Estuary	1	24.2	26.6	168.8	8.84	0.175	
Panmure	Tāmaki Estuary	2	24.4	26.8	171.1	8.77	0.153	
Panmure	Tāmaki Estuary	3	23.4	26.2	164.4	8.16	0.152	
Panmure	Tāmaki Estuary	4	26.7	28.1	179.3	9.21	0.160	
Panmure	Tāmaki Estuary	5	24.7	27.5	173.9	8.98	0.155	
Roberta Reserve	Tāmaki Estuary	1	4.2	7.6	45.3	9.77	0.029	
Roberta Reserve	Tāmaki Estuary	2	3.5	7.0	39.7	7.67	0.030	
Roberta Reserve	Tāmaki Estuary	3	3.7	7.0	42.3	9.66	0.026	
Roberta Reserve	Tāmaki Estuary	4	3.8	6.8	42.6	7.99	0.026	
Roberta Reserve	Tāmaki Estuary	5	3.8	7.6	42.6	8.37	0.033	
Pakuranga Lower	Tāmaki Estuary	1	17.2	20.5	166.6	8.83	0.104	
Pakuranga Lower	Tāmaki Estuary	2	17.3	19.7	163.9	9.14	0.106	
Pakuranga Lower	Tāmaki Estuary	3	16.5	19.2	158.4	8.00	0.093	
Pakuranga Lower	Tāmaki Estuary	4	17.3	19.0	153.7	8.08	0.096	
Pakuranga Lower	Tāmaki Estuary	5	15.5	18.7	152.3	8.04	0.095	
Pakuranga Upper	Tāmaki Estuary	1	28.0	27.0	231.8	9.50	0.122	
Pakuranga Upper	Tāmaki Estuary	2	26.8	26.8	230.6	9.61	0.120	
Pakuranga Upper	Tāmaki Estuary	3	24.8	24.8	215.9	8.78	0.118	
Pakuranga Upper	Tāmaki Estuary	4	27.6	26.3	242.6	9.41	0.114	
Pakuranga Upper	Tāmaki Estuary	5	29.9	28.0	242.1	9.80	0.125	
Princes St	Tāmaki Estuary	1	21.2	23.7	173.1	9.53	0.130	
Princes St	Tāmaki Estuary	2	20.6	23.8	164.6	8.98	0.156	
Princes St	Tāmaki Estuary	3	21.3	24.2	172.0	9.69	0.133	
Princes St	Tāmaki Estuary	4	20.3	23.1	162.7	9.23	0.123	
Princes St	Tāmaki Estuary	5	23.6	25.6	180.3	9.55	0.246	
Te Matuku	Tāmaki Strait	1	2.8	6.5	30.9	4.80	0.032	
Te Matuku	Tāmaki Strait	2	2.9	7.1	32.0	5.18	0.031	
Te Matuku	Tāmaki Strait	3	2.9	7.1	33.0	5.27	0.034	
Te Matuku	Tāmaki Strait	4	3.0	7.2	33.9	5.05	0.036	
Te Matuku	Tāmaki Strait	5	2.9	7.0	31.7	4.99	0.035	
MeOZ FD	Bulk Reference Sediment	1	3.13	9.20	43.36	2.91	0.0271	0.068
MeOZ FD	Bulk Reference Sediment	2	2.76	8.86	40.72	2.80	0.0275	0.062
MeOZ FD	Bulk Reference Sediment	3	2.99	9.43	42.69	2.92	0.0316	0.072
MeOZ FD	Bulk Reference Sediment	4	2.95	8.99	41.94	2.73	0.0321	0.065
MeOZ FD	Bulk Reference Sediment	5	3.07	9.67	42.47	2.93	0.0298	0.068
MID FD	Bulk Reference Sediment	1	29.2	33.2	235.0	9.03	0.153	0.145
MID FD	Bulk Reference Sediment	2	29.3	32.3	230.6	8.90	0.153	0.142
MID FD	Bulk Reference Sediment	3	29.1	32.9	235.5	9.23	0.155	0.151
MID FD	Bulk Reference Sediment	4	27.4	32.1	223.7	8.19	0.158	0.132
MID FD	Bulk Reference Sediment	5	28.3	33.3	226.6	9.03	0.162	0.142
CRM	Certified Reference Material	1	24.8	41.6	59.3	20.75	11.59	9.93
CRM	Certified Reference Material	2	21.6	38.4	51.7	18.32	10.68	8.86
CRM	Certified Reference Material	3	22.6	37.9	52.9	19.23	11.23	9.18
CRM	Certified Reference Material	4	22.1	37.6	52.5	18.81	10.92	8.98
CRM	Certified Reference Material	5	22.2	39.0	53.4	19.89	11.15	9.38
CRM	Certified Reference Material	6	24.0	41.5	55.4	19.97	11.05	9.31
CRM	Certified Reference Material	7	23.2	39.6	54.6	19.49	11.42	9.18
CRMB	Certified Reference Material	1	144.8	30.2	175.1	3.53	0.477	0.731
CRMB	Certified Reference Material	2	153.4	31.7	181.4	3.64	0.505	0.750
CRMB	Certified Reference Material	3	143.3	30.6	169.9	3.40	0.511	0.737
CRMB	Certified Reference Material	4	146.4	30.7	176.3	3.51	0.476	0.721
CRMB	Certified Reference Material	5	147.5	30.7	175.9	3.81	0.475	0.744
CRMB	Certified Reference Material	6	152.2	31.4	182.6	3.71	0.464	0.730
CRMB	Certified Reference Material	7	148.2	31.0	172.6	3.65	0.560	0.725

7 Appendix C: Particle size distribution

Sediment particle size distribution (PSD) data obtained from a single composite surface (0-2cm) sample per site in 2022. Samples were analysed by NIWA (Hamilton) by wet sieving/pipette analysis. The data are per cent of the total sediment (by weight) in each fraction. Colours distinguish general site location.

Site	Location	Organic Content	Gravel >2mm	Coarse Sand 500-2000um	Medium Sand 250-500um	Fine Sand 62.5-250um	Very Fine Sand 63-124um	Total Sand	Silt 3.9-62.5um	Clay 0-3.9um	Mud (Silt + Clay)
Whangateau Estuary 1	Whangateau Estuary	0.61	0.19	0.11	8.36	80.45	9.02	97.94	NA	NA	1.87
Whangateau Estuary 2	Whangateau Estuary	0.38	0.25	0.21	19.06	78.17	1.99	99.43	NA	NA	0.33
Whangateau Estuary 3	Whangateau Estuary	1.23	0.34	0.56	17.29	68.48	8.35	94.67	NA	NA	4.99
Whangateau Estuary 4	Whangateau Estuary	0.72	0.06	1.46	22.16	69.55	5.07	98.24	NA	NA	1.71
Whangateau Estuary 5	Whangateau Estuary	1.43	0.07	0.38	3.60	48.53	34.38	86.89	NA	NA	13.04
Whangateau Estuary 6	Whangateau Estuary	1.17	0.50	1.76	25.43	51.62	13.31	92.12	NA	NA	7.38
Whangateau Estuary 7	Whangateau Estuary	1.43	0.00	0.51	13.38	57.60	19.32	90.81	NA	NA	9.19
Hamilton Landing	Mahurangi Harbour	3.43	0.00	0.08	0.60	7.31	45.99	53.98	39.74	6.27	46.02
Cowans Bay	Mahurangi Harbour	2.07	0.00	0.04	1.01	23.88	49.32	74.25	19.90	5.85	25.75
Dyers Creek	Mahurangi Harbour	1.14	0.42	0.21	2.88	57.97	31.12	92.17	4.07	3.33	7.41
Jamiesons Bay	Mahurangi Harbour	1.36	6.53	10.68	15.49	33.37	29.14	88.68	3.00	1.80	4.80
Mid Harbour	Mahurangi Harbour	1.61	1.00	0.28	4.21	37.10	46.28	87.87	5.57	5.57	11.13
Te Kapa Inlet	Mahurangi Harbour	1.99	0.41	0.24	1.48	41.32	34.91	77.96	14.66	6.98	21.64
Weiti	Weiti River	3.32	0.11	0.79	10.40	37.83	28.26	77.29	11.43	11.18	22.61
Okura Estuary 3	Okura Estuary	1.37	5.71	2.08	2.99	57.66	26.50	89.23	NA	NA	5.06
Okura Estuary 7	Okura Estuary	1.48	0.34	1.43	3.05	45.52	38.07	88.08	NA	NA	11.58
Okura Estuary 9	Okura Estuary	1.97	0.00	0.23	1.07	12.16	62.81	76.26	NA	NA	23.74
Awaruku Beach	Long Bay	0.86	2.35	5.82	7.06	67.65	16.99	97.52	0.04	0.09	0.13
Awaruku Stream	Long Bay	5.38	3.04	2.46	2.88	8.24	13.50	27.07	66.08	3.80	69.88
Vaughan Beach	Long Bay	0.64	0.00	0.07	5.20	86.23	8.48	99.98	0.00	0.02	0.02
Vaughan Stream	Long Bay	6.38	4.51	2.54	6.39	23.44	17.05	49.41	37.67	8.41	46.08
Brigham Creek	Upper Waitematā	8.31	0.00	0.15	0.80	2.50	3.33	6.63	85.12	8.11	93.23
Central Main Channel	Upper Waitematā	4.34	0.00	0.30	0.86	13.11	51.44	65.41	30.39	3.91	34.30
Hellyers Creek	Upper Waitematā	3.91	0.00	0.23	2.44	20.92	23.03	46.39	49.10	4.29	53.38
Herald Island Waiarohia	Upper Waitematā	1.39	0.56	1.39	9.46	51.04	22.36	82.86	13.48	1.71	15.19
Lucas Creek	Upper Waitematā	4.01	1.75	4.99	14.37	22.45	18.88	55.71	34.91	2.64	37.55
Rangitopuni Creek	Upper Waitematā	8.63	0.07	0.16	0.15	0.54	2.74	3.42	82.90	13.44	96.35
Hobsonville	Upper Waitematā	1.10	0.31	4.51	31.34	52.89	7.87	96.60	1.30	1.79	3.08
Paremoremo	Upper Waitematā	9.25	0.00	0.07	0.16	1.18	4.68	6.09	84.59	9.32	93.91
Lucas Upper	Upper Waitematā	5.74	0.00	0.28	1.83	14.74	24.77	41.62	50.97	7.41	58.38
Benghazi	Tāmaki Estuary	2.13	8.85	5.47	11.75	32.93	28.00	78.15	9.52	3.48	13.00
Bowden	Tāmaki Estuary	4.94	0.19	2.85	3.23	14.64	35.64	56.37	36.79	6.65	43.44
Middlemore	Tāmaki Estuary	6.90	0.00	0.15	0.77	13.56	11.17	25.65	56.76	17.60	74.35
Ōtāhuhu	Tāmaki Estuary	7.51	0.03	0.24	0.18	0.56	4.81	5.79	83.83	10.35	94.18
Panmure	Tāmaki Estuary	6.05	0.08	0.13	0.42	2.48	12.02	15.05	77.02	7.85	84.87
Roberta Reserve	Tāmaki Estuary	1.53	1.25	3.74	14.59	48.90	24.96	92.19	3.87	2.69	6.56
Pakuranga Lower	Tāmaki Estuary	4.04	0.19	0.88	1.76	13.12	39.83	55.58	38.25	5.99	44.23
Pakuranga Upper	Tāmaki Estuary	7.83	0.00	0.21	1.54	11.40	13.17	26.33	62.04	11.63	73.67
Princes St	Tāmaki Estuary	5.14	0.00	1.04	3.43	28.30	15.44	48.21	43.51	8.29	51.79
Te Matuku	Tāmaki Strait	2.11	11.24	3.22	5.98	37.59	26.42	73.21	10.62	4.94	15.56
Middlemore BRS - MID PS16	QA Reference Material	6.90	0.00	0.14	0.50	13.95	15.15	29.74	63.19	7.07	70.26
Middlemore BRS - MID PS35	QA Reference Material	7.02	0.00	0.19	0.56	15.48	15.64	31.87	58.40	9.73	68.13
Middlemore BRS - MID PS42	QA Reference Material	6.55	0.00	0.27	0.54	15.23	14.77	30.81	60.47	8.72	69.19
Meola Outer Zone BRS - MO PS33	QA Reference Material	1.23	0.68	0.37	0.91	52.89	42.20	96.38	1.63	1.31	2.94
Meola Outer Zone BRS - MO PS56	QA Reference Material	1.06	0.86	0.30	0.94	50.01	44.95	96.19	1.31	1.64	2.94
Meola Outer Zone BRS - MO PS7	QA Reference Material	1.10	0.79	0.29	0.96	47.65	47.51	96.40	1.00	1.80	2.80

8 Appendix D: Quality assurance analysis

8.1 Introduction

Quality assurance (QA) is conducted to check that the RSCMP data are 'fit for purpose', i.e., suitable for reliably assessing state and temporal trends. The QA system has evolved over time since the programme first began in 1998. The approach currently used, including the use of Bulk Reference Sediment (BRS[2]) to track data consistency over time, has been operating since 2011. Certified Reference Material (CRM) results have been acquired each year since 2002. Details of the QA approaches used for the period 1998-2011 are given in Mills and Williamson (2014). The information from this review have been developed into a set of QA guidelines, as described in Mills (2016).

Quality assurance currently used in the RSCMP follows a '3-tiered' approach as follows:

1. Quality control checks conducted by the analytical laboratory (RJ Hill Laboratories, Hamilton) to ensure that the results have met the laboratory's in-house quality standards. The laboratory is required to provide a quality assurance/control (QA/QC) report for each batch of RSCMP data. This report is available on request.
2. The sample processing laboratory (NIWA, Hamilton) undertakes an assessment of the data provided by the analytical laboratory, including their QA/QC results and the variability of the results reported for the five replicates analysed at each site. In addition, the results from QA samples added to each RSCMP sample batch are assessed. Currently, the protocol is to analyse a minimum of five CRM QA samples and five BRS QA samples (from each of two BRS sites) with each batch of RSCMP samples. Any results that appear unusual or outside the variability range considered acceptable by the processing laboratory (NIWA, Hamilton) are checked with the analytical laboratory (RJ Hill Laboratories, Hamilton), and repeat analyses conducted if required. The results are collated, and an overall assessment provided in a 'data quality assessment' report. This report is available on request.
3. Lastly, the results from the QA assessments, in particular the CRM and BRS results, are checked against acceptance guidelines for the RSCMP programme, to ensure the variability and consistency over time are acceptable. An overall QA summary is produced (Table 8-1), which highlights any aspects that may require attention in future – e.g., any data that do not meet RSCMP data quality targets and might therefore be higher or lower

[2] BRS are sediments from two sites (a sandy sediment from Meola Outer Zone, and a muddy sediment from Middlemore), which have been archived in frozen and freeze-dried forms for repeated analysis with each year's monitoring samples. Analysis of the BRS each year provides an ongoing record of within-year and between-year analytical variability and changes over time (drift or trend). Details of the BRS production and use are provided in Mills (2016).

than expected in the overall trend record or are more variable than expected from previous results.

The likelihood of the trend being greater or less than zero was assessed from the Sen Slope probability, as provided in Time Trends. Likelihood was categorised into five groups, as described by LAWA (2019):

- 'very likely' increasing or decreasing trends, where the Sen Slope probability is 90-100%. For contaminants, an increasing trend reflects a degrading or worsening state, while a decreasing trend indicates improving conditions.
- 'likely' increasing or decreasing trends (Sen Slope probability 67-90%). The lower certainty reflects the fact that while there is an indication of a trend, there is less statistical support for it.
- 'indeterminate' trends, where the Sen Slope probability is lower (<67%), reflecting insufficient evidence to confidently determine if there is an improving or degrading trend.

Because of the detailed checking of the analytical results conducted in tiers 1 and 2, it is unlikely that a significant number of 'fail' data will be encountered in tier 3. It is anticipated that some data each year may 'fail' and be flagged, but the numbers of these should decrease as a better understanding of analyte variability over time is gained, particularly from ongoing BRS analyses.

At present the QA approach is rather involved. This is currently considered necessary because trends in contaminant concentrations at RSCMP sites measured to date have been relatively small, and assessment of their reliability has been hampered by a lack of long-term QA information for verifying year-to-year data consistency over the trend monitoring period. As more QA data are acquired, guidelines/criteria can be more robustly defined, and it is hoped that in future years the QA approach can be refined and, where possible, simplified.

8.2 Assessments undertaken

8.2.1 Metals

For metals' analysis, quality assurance (QA) comprised the following:

- Laboratory quality control samples – analysis of procedural blanks, blind duplicate samples, Certified Reference Material (CRM; AGAL-10) and 'in-house' reference sediment.
- Analysis of seven 'extra' CRM samples dispersed through the analytical run. These CRM samples were added to the batch in addition to the routine laboratory in-house quality control samples.
- Analysis of the Auckland Council 'Bulk Reference Sediments' (BRS). Five replicates of each of the Meola Outer (sandy) and Middlemore (muddy) BRS in freeze-dried form were analysed.

Note on CRM: In 2020, R J Hills Laboratories advised Auckland Council that they are running short of the Hawkesbury River sediment reference material AGAL 10, and 2022 will potentially be the last RSCMP round of sampling where this CRM is available. The laboratory is transitioning to AGAL 12 (a dried powder mixture of sewage sludge and loam). Both AGAL 10 and AGAL 12 are produced and verified by the Australian National Measurement Institute. The AGAL 12 CRM does have very high levels of copper, but concentrations of other metals are in a similar range to those expected for sediments assessed in this program. R J Hills laboratories have run between five and seven replicates of AGAL 12 (called 'CRMB' in the sediment contaminant data table) alongside the AGAL 10 CRM since 2020 to enable comparison between the reference materials and consistency in the QA/QC process. At some stage in the next few years, AGAL 12 will be the only CRM available for use in the RSCMP.

8.2.2 Particle size distribution

For particle size distribution (PSD), quality assurance was conducted by analysing three replicates of each of the BRS sediments (Meola Outer and Middlemore). BRS used for PSD analysis are stored in frozen form, as drying (probably including freeze drying) is likely to affect the aggregation of particles within the sediments. The frozen BRS samples are thawed and homogenised before PSD analysis, exactly as for the RSCMP field samples.

8.3 Acceptance guidelines

The quality assurance data are assessed for acceptability using a set of 'acceptance guidelines'. If the QA results meet the guidelines, the analytical results are likely to be 'fit for purpose' for the RSCMP, particularly for monitoring temporal trends which require low variability. Considerable emphasis is placed on intercepting clearly outlying results (and verifying or correcting these), evaluating the year-to-year consistency of the results, and identifying any incorrectly high or low results that may affect trend assessment.

The acceptance guidelines are based on a combination of analytical performance characteristics as measured in the RSCMP to date, and trend measurement thresholds currently considered relevant for the RSCMP (Mills, 2016).

Current acceptance guidelines include measures for:

- Potential sample contamination, as assessed from procedural blanks;
- Data accuracy, from comparison of results with certified concentrations (i.e., CRM);
- Year-to-year data consistency, and within-year variability, as assessed principally from analysis of CRM and BRS samples. Within-site replicate results are also used to check within-year variability;
- Agreement between results from within the analytical sample batch, as assessed from blind duplicate analyses.

Each quality assurance measure is categorised as a '**pass**', '**note**' or '**fail**', depending on how the data compare with the guidelines. If the data meet the guidelines, they 'pass', if they are clearly outside then they 'fail', and if some values are slightly outside the 'pass' guidelines (or there are other considerations to be noted), they are flagged as 'note'.

Data that are classified as either a 'note' or 'fail' in the QA process are not omitted from reporting. Rather, the main purpose of this classification is to highlight data which are outside of the acceptance criteria (the 'fails') so that they can be checked and (if necessary) corrected. Results in the 'note' category may require further follow up checks in future – for example when trend assessments are done, are the values measured in some years slightly higher or lower than usual, and hence is the trend being affected by these values.

If the QA results for an analyte show continued 'note' or 'fail' grades in successive monitoring rounds, further work will be required to find out why and to take corrective action. Reanalysis of archived samples may be required[3].

These acceptance guidelines are still in development and are not yet strict quantitative criteria – some professional judgement may be required (e.g., comparing variability with historical results from the same site) when assessing whether the data are acceptable or not.

8.4 Data quality assessment results for 2022 sites

Table 8-1 summarises the QA information obtained for the 2022 RSCMP sampling round analyses, highlighting whether or not the data quality acceptance guidelines were met.

The quality assurance data indicate that the total recoverable metals data were generally of good quality. The CRM data gave results that were acceptable but rated overall as a '**note**', due to a 'very likely' trend probability for Hg. However, the percent annual change was below the 1% acceptance criteria (as was the case for the other metals showing 'likely' trends – Pb, Zn and As. The BRS samples gave results that were acceptable but also prompted a '**note**' rating with respect to temporal stability. These were for a 'very likely' trend probability for As and Pb (Meola) and Zn (Middlemore). Whilst the metals which obtained 'fail' results through the QA process will require close ongoing examination, they are currently not of particular concern. This is because while trend probabilities for some metals were high (above 90%), the results are not occurring consistently, the per cent annual change remains low (within acceptance guidelines) and for analytes with successive 'very likely' probabilities in both 2021 and 2022 (currently this is occurring for As at Meola and Zn at Middlemore), per cent annual change is decreasing.

All PSD data were well within control limits and overall show good results for both within year variability and temporal stability.

Following the summary table, sections 8.5 and 8.6 will provide more detail and present concentration values from CRM and BRS analysis.

[3] This approach has been used for extractable metals, which showed unexpectedly high concentrations in 2003-2007 at some sites. Further testing involving archived samples and BRS samples resulted in this analysis being dropped from routine RSCMP monitoring from 2015 onwards. It has also been used to test increasing trends in zinc observed in BRS samples in 2017, 2018 and 2019. This resulted in further testing of archived samples and adjustments of analytical methods to rectify the issue.

Table 8-1. Summary of analytical quality assurance results for 2022 monitoring. CVs = coefficient of variation; RPDs = relative percentage difference; CLs = confidence limits; SD = standard deviation.

QA Measure	Acceptance guidelines	Pass Note Fail	Comments
Blanks	All values less than detection limits, or <10% of metal concentrations	Pass	Metals' concentrations in procedural blanks were below detection limits for all metals.
Within site variability	CVs <20%	Note	CVs 1.70 - 13.23 % for Cu, Pb and As. Zn slightly more variable (CVs between 0.85 -20.88%; one sites above 20%), Hg variable with five sites exceeding 20% threshold. Majority of these sites have Hg with very low concentrations near detection limits.
Within Batch blind duplicates	RPDs <30%	Metals Pass	Metals: 4 samples analysed in duplicate by Hill labs in-house QA. RPDs ranged from 0.0 -13.7%. The highest RDPs of 10.1% and 13.7 were for Hg and As. Overall, good within batch agreement.
Between Batch blind duplicates	RPDs <30%	N/A	No between batch duplicate samples analysed.
Certified Reference Material	Accuracy: Results within upper and lower control limits (+/- 1sd, or 99% CLs). Note: reduced this year to 1s.d from the previous 3 s.d limit.	Pass	Seven CRM (AGAL-10) samples analysed as unknowns for total recoverable metals. Means within <10% of certified values for all metals except As (113.3%). Four individual samples outside lab in-house control limits. Pb 37.6 mg/kg just below the lower control limit of 37.7 mg/kg, As 20.8 mg/kg above the upper limit of 20.2 mg/kg, and Zn 51.7 mg/kg and 52.5 mg/kg below the 52.8 mg/kg lower limit.
	Variability: Within-batch CV <10%	Pass	Variability <10%. CVs between 2.7 - 4.9% for all metals.
	Temporal stability: Means of new data within 10% of previous data means	Pass	Good temporal stability. Difference in means (RPDs) between new and previous means were between -0.3% (Cu) and +3.3% (As).
	Temporal stability: No trends over time >1% of median concentration per year (and "very likely" likelihood; Sen Slope P>90%).	Note Hg with "very likely " trend probability	Trends over time to Nov 2022 were small: between 0.06-0.59% per year. Pb, Zn and As had 'likely' trends, while Hg had 'very likely' so has been 'noted', but per cent annual change<1% (0.47%) so not of major concern at this stage.
Lab In-House Reference Material	Accuracy: Results within lab control limits	Pass	42 samples of 'QC-A6' were included through the analytical run. Variability (CVs) <7.1% for all metals. Mean concentrations <10% of reference values for all metals (between 95.6% (Cd) and 103.1% (Zn)). Overall, the' QC-A6' CRM results indicate good accuracy and precision for most metals. Lead results are more variable this year (two exceedances of lab in house control limits), although the average value is close to the certified value.
Bulk Reference Sediments:			
Total Recoverable Metals	Accuracy: Results within lab control limits (+/- 3s, or 99% CLs)	Pass	All metals' results within control limits.
	Within-year variability: CVs <10%.	Pass	Within-year variability met targets for all metals (CVs 1.6 - 7.8%). Highest variability seen in Hg at Meola OZ.
	Temporal stability: Means of new data within 10% of previous data means	Pass	Results for all metals within 10% of the previous data means (RDP between -8.5 - 6.1%).
	Temporal stability: No trends over time >2% of median concentration per year (and 'very likely' likelihood; Sen Slope P>90%).	Note Watch increasing trend for As and Pb (Meola), and Zn (Midlemore).	BRS trends over time for Nov 2011 to Nov 2022 were all <2% per yer annual change. Zn continues to improve since 2020 but still high (95% probability and 1.27% annual change at Middlemore). 'Very likely' increasing trends for As and Pb (Meola) and Zn (Middlemore). As showing slight improvement on 2021 results. Watch closely for trends in future.
Particle Size Distribution	Accuracy: Results within control limits (+/- 3sd, or 99% CLs)	Pass	All mud content values within control limits.
	Within-year variability: CVs <10%.	Pass	CVs <10%. CV of 1.5% for Middlemore and 2.8% for MeOZ.
	Temporal stability: Means of new data within 10% of previous data means	Pass	2022 mean mud content within 4.0% of the previous data mean for Middlemore and within 1.19% of the previous data mean for Meola OZ.
	Temporal stability: No trends over time >2% of median concentration per year (and 'very likely' likelihood; Sen Slope P>90%).	Pass	Overall good temporal stability results. Middlemore showing 'indeterminate' trend and Meola OZ 'likely' decreasing trend but very low percent annual change (0.35%).
OVERALL ASSESSMENT		Total metals Note: increasing Zn trend in Middlemore BRS. Increasing trend for As and Pb in MeOZ BRS.	Metals' results for 2022 sampling are acceptable for use in the RSCMP. The most notable exceptions are in BRS analysis with 'very likely' trend probability and percent annual change above 1% for As (Meola) and Zn (Middlemore). However, these results are within acceptance criteria and both are showing slight improvements on 2021 results. The high Zn continues to improve from those reported in 2019. Continue to watch closely as data builds.
		PSD Pass	All QA targets for particle size distribution met in 2022.

8.5 Certified Reference Material

Two types of reference materials were used by RJ Hill Laboratories as a quality control check for metal analysis:

- Certified Reference Material (CRM) 'AGAL-10', Hawkesbury River Sediment, prepared by the Australian Government Analytical Laboratories. This reference material has been used in the RSCMP and preceding monitoring programmes since 2002 to check data accuracy and consistency over time; and
- an 'in-house' laboratory reference material, 'QC-A6', a sediment sample prepared by Hill Laboratories for use in their QA/QC programme. The results from these QA/QC analyses are provided in NIWA's assessment report. This report is available on request.

The reference material analyses involve extraction/digestion and ICP-MS analysis only, and do not include the homogenising/sub-sampling/sieving/drying steps undertaken for analysis of field samples. Variability may be higher when sediment processing steps such as sieving and drying are included.

Seven CRM samples (AGAL-10) were included in the analytical run as 'unknowns'. Results for these have been assessed according to the following 'acceptance guidelines':

- Accuracy: Results are within control limits (+/- 1 Standard Deviations (SD), or 99% confidence limits)
- Variability: within-batch Coefficient Variation (CV) <10%
- Temporal stability:
  - Means of new data are within 10% of previous data means; and
  - trends over time are <1% of the median concentration per year (Sen slope) and with less than a 'very likely' trend probability (Sen Slope P<0.90, as per LAWA likelihood categorisation (LAWA, 2019)). Trends were analysed by the Mann Kendall trend test, on median data using Time Trends software (Version 6.3, Jowett Consulting Ltd).

The results summarised in Table 8-2 show that the CRM results generally met all the QA acceptance guidelines, despite one '**fail**', due to a 'very likely' trend probability (>90%) for Hg, however per cent annual change was below the 1% acceptance criteria (0.47%). 'Likely' increasing trends were observed for Pb, Zn and As, again with very low (<1%) rates of annual change. When compared with the certified value, As had a slightly high mean (113.3%) just above the 10% acceptance criteria. All results are within upper and lower limits (± 1 SD) of the certified reference value. This has been reduced from the previous limit (± 3 SD) as a more conservative and rigorous acceptance criteria. Overall, the CRM results recorded a '**note**', and are deemed to be satisfactory (and generally consistent with previous years' results).

The CRM trend results obtained for total recoverable Cu, Pb, Zn, As, and Hg since 2002 are shown in Figure 8-1, and depict very weak increasing trends for Cu, Zn, Pb, and As, and a slightly stronger increasing trend for Hg.

Table 8-2. Quality assurance results for seven Certified Reference Material (CRM; AGAL10) samples analysed as unknowns in the 2022 sediment sample batch.

	QA Acceptance	Total Recoverable Metals (<500 mm)					
Sample i.d. and quality assurance measures	Pass Note Fail	Cu	Pb	Zn	As	Hg	Cd
CRM - Agal 10 - 1	Pass	24.8	41.6	59.3	20.75	11.59	9.93
CRM - Agal 10 - 2	Pass	21.6	38.4	51.7	18.32	10.68	8.86
CRM - Agal 10 - 3	Pass	22.6	37.9	52.9	19.23	11.23	9.18
CRM - Agal 10 - 4	Pass	22.1	37.6	52.5	18.81	10.92	8.98
CRM - Agal 10 - 5	Pass	22.2	39.0	53.4	19.89	11.15	9.38
CRM - Agal 10 - 6	Pass	24.0	41.5	55.4	19.97	11.05	9.31
CRM - Agal 10 - 7	Pass	23.2	39.6	54.6	19.49	11.42	9.18
New mean	n/a	22.9	39.4	54.3	19.5	11.1	9.3
Variability in new mean (CV, %)	Pass	4.9	4.1	4.7	4.1	2.7	3.7
Mean of all previous CRM data	n/a	22.99	40.29	54.2	18.87	10.83	n/a
Difference between new and previous data means (RPD, %)	Pass	-0.3	-2.2	0.1	3.3	2.9	
New mean, as % of certified value	Pass	98.8	97.5	95.2	113.3	96.1	99.6
Trends (% annual change, Sen Slope)	Pass	0.06	0.11	0.15	0.59	0.47	n/a
Trends (probabilities, Sen Slope p values)	Note Pb, Zn and As,	0.64	0.83	0.83	0.87	0.96	n/a
Trends (likelihood based on Sen Slope p values)	Fail Hg very likely trend	indeterminate	likely	likely	likely	very likely	n/a
Certified Reference Value (mg/kg)	n/a	23.2	40.4	57.0	17.2	11.6	9.3
Lab in-house lower limit (mg/kg; mean - 1 s.d)	n/a	21.3	37.7	52.8	14.2	10.5	8.7
Lab in-house upper limit (mg/kg; mean + 1 s.d)	n/a	25.1	43.1	61.2	20.2	12.7	10.0
Overall assessment	Note	Pass	Pass	Pass	Note	Note	Pass
Comments	Small (<1%/year) but likely trends for Pb, Zn and As. Small (<1%/year) very likely trend for Hg. As new mean just above 10% threshold.Four values greater than 1 sd from reference value.	Indeterminate trends and very low per cent annual change	Note small likely increasing trend <1%/year	Note small likely increasing trend <1%/year	Note small likely increasing trend <1%/year and new mean >10%	Note small very likely increasing trend <1%/year	Low variability in new mean. Trend analysis not available.

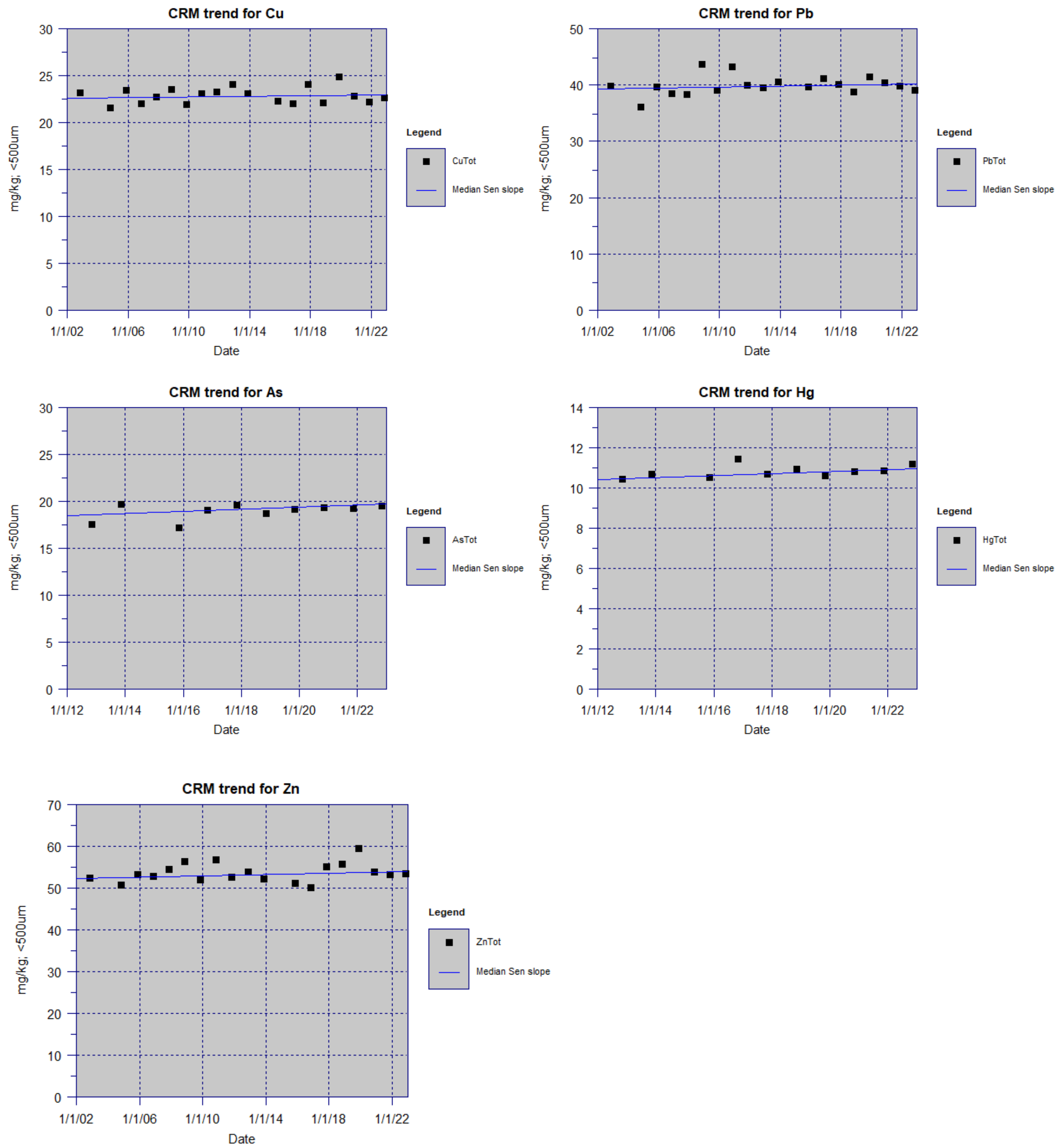

Figure 8-1. Certified Reference Material (CRM) results for total recoverable metals in CRM AGAL-10 samples analysed with RSCMP samples taken from 2002 to 2022. The plots show annual medians. The line is a linear regression.

8.6 Bulk Reference Sediments

Five samples (stored in freeze-dried form) from each of the sandy Meola Outer Zone and muddy Middlemore BRS sites were analysed for metals. The results for the metal analyses are summarised in sections 8.6.1 and 8.6.2.

Three replicates of each of the BRS sediments (stored in frozen form) were analysed for particle size distribution (PSD).

The BRS results for metals have been assessed according to the same 'acceptance guidelines' as those used for the CRM, with the exception of the temporal stability trend measure, for which a trend acceptance guideline of ±2% per year (rather than the ±1% per year for the CRM) has been used. This broader guideline range for an acceptable trend for the BRS reflects the small number of samples analysed to date; 11 so far from 2011 to 2022. In future, with a larger BRS trend dataset, and a better understanding of temporal variability in the BRS results, tighter trend guidelines may be able to be justified. The BRS also currently has a slightly more lenient upper and lower control limit (3 SD compared with 1 SD used for the CRM). As with the trend acceptance guidelines, it is envisioned that these limits may be able to be tightened as the data set grows.

The BRS data acceptance guidelines used for the 2022 data are therefore:

- Accuracy: results are within lab control limits (+/- 3 standard deviations, or 99% confidence limits)
- Variability: within-batch coefficient variation <10%
- Temporal stability:
  - means of new data are within 10% of previous data means; and
  - trends over time are <2% of the median concentration per year (Sen slope) and with less than a 'highly likely' trend probability (Sen Slope P<0.90, as per LAWA likelihood categorisation (LAWA, 2019)). Trends were analysed by the Mann Kendall trend test, on median data using 'Time Trends' software (Version 8.0, Jowett Consulting Ltd).

BRS samples for chemistry analysis were initially prepared in both freeze dried and frozen forms. RSCMP samples may be analysed in either of these forms – field monitoring samples are generally frozen while they await chemistry analysis, but archived samples are stored in freeze dried form. Both frozen and freeze dried BRS were analysed with RSCMP monitoring rounds from November 2011 to June 2015, and the results compared in annual RSCMP reports (see Mills (2016a) for the last time they were compared). For total recoverable metals, the results from both freeze dried and frozen BRS were essentially the same. For RSCMP monitoring from November 2015 onwards, only analysis of the freeze dried BRS for total recoverable metals is considered necessary. Frozen samples are still used for PSD analysis, as drying (probably including freeze drying) is likely to affect the aggregation of particles within the sediments. The frozen BRS samples are thawed and homogenised before PSD analysis, exactly as for the RSCMP field samples.

8.6.1 Meola Outer Zone BRS

The total recoverable metals' results from the 2022 sample batch for the sandy Meola Outer Zone BRS are summarised in Table 8-3. Median values of BRS data acquired with RSCMP monitoring from November 2011 to 2022 are shown in Figure 8-2.

The metals' results for the Meola Outer Zone BRS obtained in 2022 are a '**note**', having failed two acceptance criteria (a 'very likely' increasing trends for As and Pb). Percent annual change for As also received a 'note', with a value above 1% (1.38%). In addition, several 'notes' were made for 'likely' (probability 67-90%) trends occurring for Mud, Cu, Zn, and Hg, however the percent annual change for these are all low (<1%). The Meola Outer Zone BRS trend plots obtained for total recoverable metals Cu, Pb, Zn, As, and Hg and mud content since 2011 are shown in Figure 8-2 and depict slightly increasing trends for Pb, Zn and Cu, a stronger increasing trend for As, and weak decreasing trends for Hg and mud content.

All results are within upper and lower limits (± 3 SD) of the certified reference value. Variability in the data was low (CVs <10%), as was the difference between the new means and the previous data means (RPD <6.1%).

The results for the Meola Outer Zone BRS obtained in 2022 were generally consistent with previous years.

Table 8-3. Quality assurance results for Bulk Reference Sediment (BRS) samples from Meola Outer Zone analysed with the 2022 RSCMP sample batch.

Sample ID and QA measures	QA Guidelines Pass Note Fail	Mud Content % <63 mm	Total Recoverable Metals (mg/kg, <500 mm) Cu	Pb	Zn	As	Hg
Meola OZ BRS 1	Pass	2.9	3.1	9.2	43.4	2.9	0.027
Meola OZ BRS 2	Pass	2.9	2.8	8.9	40.7	2.8	0.027
Meola OZ BRS 3	Pass	2.8	3.0	9.4	42.7	2.9	0.032
Meola OZ BRS 4	Pass		3.0	9.0	41.9	2.7	0.032
Meola OZ BRS 5	Pass		3.1	9.7	42.5	2.9	0.030
New mean	Pass	2.90	2.98	9.23	42.24	2.86	0.030
Variability in new data (CV, %)	Pass	2.8	4.8	3.5	2.3	3.1	7.8
Difference between new and previous data means (RPD, %	Pass	-1.19	0.00	2.42	3.36	6.10	-1.38
Trends (% annual change, Sen Slope)	Note As	-0.35	0.33	0.50	0.73	1.38	-0.56
Trends (probabilities, Sen Slope p values)	Fail As & Pb. Note others.	0.82	0.69	0.92	0.87	0.96	0.80
Trends (likelihood based on Sen Slope p values)	Fail As & Pb. Note others.	likely	likely	very likely	likely	very likely	likely
Overall mean of previous data	n/a	2.93	2.98	9.01	40.84	2.69	0.03
Lower control limit (mean - 3sd)	n/a	2.63	2.62	7.84	33.79	2.03	-0.06
Upper control limit (mean + 3sd)	n/a	3.23	3.34	10.18	47.89	3.35	0.12
Overall assessment	**Note**	**Pass**	**Pass**	**Note**	**Pass**	**Note**	**Pass**
Comments	Overall good results and generally meet acceptance criteria. Note: watch As for trends. % annual change slightly lower than 2021.	Likely decreasing trend, <1% per year.	Likely increasing trend, <1% per year.	Very likely increasing trend but <1% per year	Likely increasing trend, <1% per year	Very likely increasing trend but <2% per year	Likely decreasing trend, < 1% per year

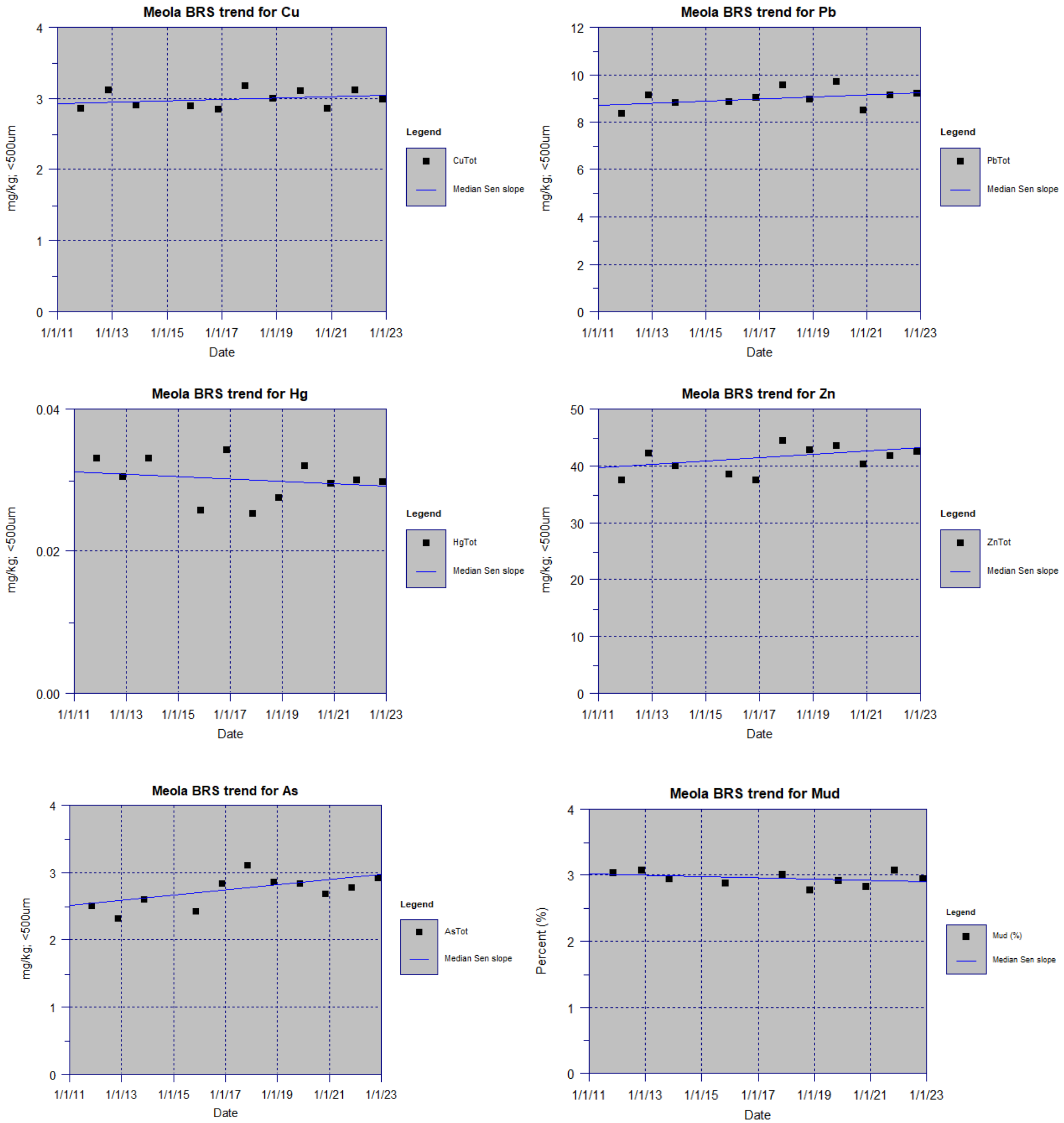

Figure 8-2. Plots of median data for Meola Outer Zone BRS metals and mud samples, November 2011 to November 2022. Metals are in mg/kg <500µm fraction, mud is silt + clay <63µm fraction.

8.6.2 Middlemore BRS

The total recoverable metals' results from the 2022 sample batch for the muddy Middlemore BRS samples are summarised in Table 8-4. Median values from data acquired with RSCMP monitoring from November 2011 to 2022 are shown in Figure 8-3. The results for the Middlemore BRS obtained in 2022 were generally consistent with previous years and mostly met acceptance guidelines.

One acceptance guideline '**fail**' was observed due to a 'very likely' increasing trend observed in zinc, however the per cent annual change was below the 2% criteria (1.27%). In addition, a '**note**' was made for 'likely' trends (probability 67-90%) for Cu (increasing) and Hg (decreasing), however these showed very low per cent annual change (Cu 0.34% and Hg 0.66%). Trends observed for Mud, Pb, and As passed acceptance criteria, with a trend probability of 'indeterminate' (probability <67%).

All results are within upper and lower limits (± 3 SD) of the certified reference value.

The overall assessment for the Middlemore BRS is a '**note**', based on the 'very likely' trend observed for zinc. The continual reduction in the rate of increase observed in Zn trends in 2022 compared to that of 2021 (down from 1.61% annual change to 1.27% annual change) is encouraging. It is anticipated that the trend probability and per cent annual change for zinc will continue to decrease following the improvements made in analytical methods in 2019. Ongoing analyses will confirm if this is in fact occurring.

Table 8-4. Quality assurance results for Bulk Reference Sediment (BRS) samples from Middlemore analysed with the 2022 RSCMP sample batch.

Sample ID and QA measures	QA Guidelines	Mud Content	Total Recoverable Metals (mg/kg, <500 mm)				
	Pass Note Fail	% <63 mm	Cu	Pb	Zn	As	Hg
Middlemore BRS 1	Pass	70.3	29.2	33.2	235.0	9.0	0.153
Middlemore BRS 2	Pass	68.1	29.3	32.3	230.6	8.9	0.153
Middlemore BRS 3	Pass	69.2	29.1	32.9	235.5	9.2	0.155
Middlemore BRS 4	Pass		27.4	32.1	223.7	8.2	0.158
Middlemore BRS 5	Pass		28.3	33.3	226.6	9.0	0.162
New mean	Pass	69.2	28.7	32.8	230.3	8.87	0.156
Variability in new data (CV, %)	Pass	1.5	2.8	1.6	2.2	4.5	2.4
Difference between new and previous data means (RPD, %	Pass	4.0	-2.4	-7.4	-1.5	0.1	-8.5
Trends (% annual change, Sen Slope)	Note Zn	-0.02	0.34	0.34	1.27	0.55	-0.66
Trends (probabilities, Sen Slope p values)	Fail Zn. Note Cu & Hg.	0.59	0.86	0.67	0.95	0.63	0.90
Trends (likelihood based on Sen Slope p values)	Fail Zn. Note Cu & Hg.	indeterminate	likely	indeterminate	very likely	indeterminate	likely
Overall mean of previous data	n/a	66.5	29.35	35.27	233.73	8.87	0.17
Lower control limit (mean - 3sd)	n/a	59.42	24.4	29.63	182.67	7.19	0.14
Upper control limit (mean + 3sd)	n/a	73.58	34.3	40.91	284.79	10.55	0.2
Overall assessment	Note	Pass	Pass	Pass	Note	Pass	Pass
Comments	Increasing trend <2% per year for Zn. Continual improvement since 2020, keep close watch. Watch trends for Cu and Hg, 'likely' increasing but low % annual change.	Indeterminate trend and <1% per year	Likely increasing trend, <1% per year.	Indeterminate trend and <1% per year	Very likely increasing trend < 2% per year. Results continuing to improve from 2020.	Indeterminate trend and <1% per year	Likely decreasing trend, < 1% per year

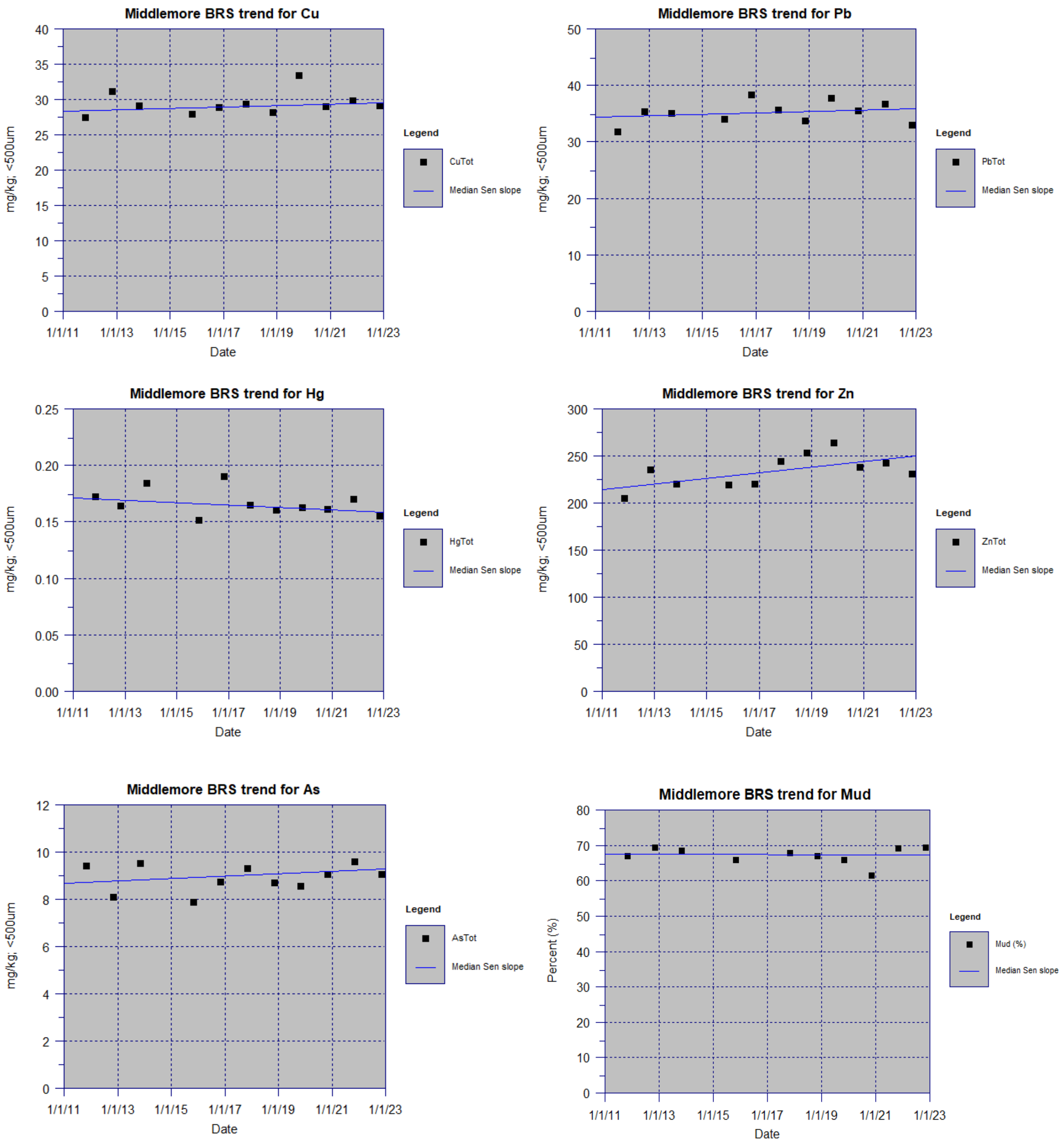

Figure 8-3. Plots of median data for Middlemore BRS metals and mud samples, November 2011 to November 2022. Metals are in mg/kg <500µm fraction, mud is silt + clay <63µm fraction.

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