# Tāmaki Makaurau / Auckland Marine Sediment Contaminant Monitoring: State report for 2023

## Central Waitematā Harbour

Hamish Allen

October 2024

Technical Report 2024/8

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Cover images
Looking towards Whakataka Bay monitoring site, Hobson Bay.
Looking across the harbour from the Island Bay monitoring site, 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 originate from a range of different activities and land uses including vehicle tyre and brake wear, industrial discharges, use of agrichemicals, and the breakdown of some building materials. When it rains, these pollutants can wash 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 results in degraded communities that are dominated by the remaining few species that are tolerant of higher contaminant levels, with flow-on effects for the natural functioning of these ecosystems. 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 report provides a summary of sediment contaminant (metals) state and changes over time in state, at 19 Central Waitematā Harbour sites sampled in 2023. Monitoring is carried out through Auckland Council's Regional Sediment Contaminant Monitoring Programme (RSCMP), which regularly gathers chemical contaminant data from the region's harbours and estuaries. This document also outlines the procedures for monitoring and analysis, as well as the quality assurance assessments conducted.

Samples used for sediment chemistry analysis were processed and analysed for the following metals: copper, lead, zinc, arsenic (a metalloid species), and mercury. At three sites in the Whau Estuary, cadmium, chromium, nickel, and silver were also tested. Total recoverable metals, on the <500µm fraction, were analysed. One composite sample from each site was also analysed for particle size distribution.

The quality assurance data analysis indicated that the metals and particle size distribution data obtained in 2023 are largely within acceptance criteria and considered suitable for use in the RSCMP.

Contaminant state is compared with sediment quality guidelines (thresholds used to assess the potential impact of sediment contamination on benthic health). These include the Australian and New Zealand Guidelines for fresh and marine water quality (ANZG), and the more conservative Auckland Council Environmental Response Criteria (ERC), and Threshold Effects Level / Probable Effects Level (TEL/PEL). See section 3.1 for more detail on the sediment quality guidelines used in the RSCMP. More detailed trend analysis, which involves statistical evaluations of monitoring data to assess the magnitude and direction of change over time, is conducted every few years in separate reports. For the most recent findings see Mills and Allen (2021).

Results from sampling undertaken in 2023 showed a wide range of sediment contamination. Just over half the sites sampled triggered conservative guidelines for one or more of the contaminants analysed (10 out of 19 sites; 53%), while slightly fewer sites triggered the higher ANZG amber thresholds (9 out of 19 sites; 47%). Overall, across all metals analysed, there are far fewer

exceedances of the ANZG thresholds compared with more conservative guidelines (32 exceedances of the ERC and/or the TEL/PEL, compared to 14 for the ANZG). Encouragingly, no sites sampled in 2023 triggered the ANZG red threshold for any metal.

The spatial pattern of contamination remains consistent with previous monitoring in the Central Waitematā. The more exposed and sandier sites on the northern shoreline recorded low levels of metals, while elevated concentrations were observed at several muddy and sheltered sites along the southern shoreline, in the Whau Estuary and (to a lesser degree) in Hobson Bay.

Zinc remains the metal that most regularly exceeds ERC guidelines. Zinc triggered the ERC red threshold at six sites, and the amber threshold at a further two sites. 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 Whau Estuary and sites along the southern shoreline to the west of the city centre.

The analysis of cadmium, chromium, nickel, and silver at sites in the Whau Estuary was undertaken to gauge the impact these contaminants may be having in a highly urbanised catchment. Results showed relatively low levels of these metals, indicating that any ecological impact would be minimal according to sediment quality guidelines.

In general, ERC contaminant status (for metals copper, lead, and zinc) has remained relatively stable over time. Where changes did occur, they were a mix of relatively small fluctuations above or below guideline thresholds, and more considerable differences, as was the case for improving copper and lead levels at site Whau Wairau and conversely, worsening copper and lead levels at site Whau Upper. These sites are located relatively close to one another in the same broad catchment and the varying differences observed demonstrate the site-specific nature of sediment contaminant accumulation, and the fine-scale dynamics that can occur within an estuary.

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# 1 Introduction

## 1.1 Overview

Tāmaki Makaurau is a largely marine region, surrounded by numerous sheltered bodies of water and stretches of exposed coastline. Healthy harbours and estuaries play important ecological roles. They help to regulate climate, support rich biodiversity, and maintain essential ecosystem functions. Their health is closely connected to the types of land use and activities that occur in surrounding catchments, affecting water quality, biodiversity, and ecological processes. Harbours and estuaries are also important for people. Many coastal areas are significant for Māori, containing sites that are of strong spiritual and cultural value, and they provide areas for food gathering and opportunities for recreation. Pollutants entering our marine environment can have both acute and cumulative impacts on ecological health in coastal ecosystems, and in some places, this can also impact people, compromising our ability to swim, collect seafood and interact with nature.

Chemical contaminants can accumulate in the sediments of estuarine and marine receiving environments. They can originate from both natural processes such as the weathering of rocks, and numerous human activities, including industrial processes and the breakdown of some building materials. These contaminants can then 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 as 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 environments, and helps us understand the effectiveness of resource management initiatives and remediation efforts aimed at reducing adverse effects.

Auckland Council's Regional Sediment Contaminant Monitoring Programme (RSCMP) conducts regular monitoring across the region's harbours and estuaries.

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 via the RSCMP complements that obtained in Auckland Council coastal water quality (Kelly and Kamke, 2023) 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. 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 additional estuaries and harbours around the region. Monitoring at these locations markedly increases the spatial coverage of our understanding of sediment contaminants across the region, particularly in more rural areas where sites in these programmes are typically located. These sites 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) and Allen (2023a) for the Whangateau Harbour; Halliday and Cummings (2012) and Allen (2023a) for the Mahurangi Harbour; Hewitt and Simpson (2012) for Waiwera, Puhoi, Mangemangeroa, Waikopua, Turanga, and Ōrewa estuaries, Allen (2023a) for Okura Estuary, and Lohrer et al. (2012) and Mills (2021) for the Wairoa embayment.

## 1.2 Sampling

The sampling protocols used in the RSCMP are outlined in detail in Mills and Allen (2021) and described briefly here. Sampling 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 (ARC, 2004). 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.

Sites are sampled either every three or six years on a rotational basis, with specific areas the focus of each sampling round. 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. 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 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. Routine analysis of these contaminants was initiated in 2012 to improve our understanding of their concentrations, sources and trends. A recent report assessed state and preliminary trends for arsenic and mercury at over 120 sites across the region (see Allen, 2023b for more detail). Concentrations of a wider suite of metals including cadmium (Cd), chromium (Cr), nickel (Ni) and silver (Ag) were analysed at three sites in the Whau Estuary. These metals are outside the typical suite of analytes and were sampled to serve as a ‘check’ for these contaminants in a highly urbanised estuary (see section 2.2 for more detail).

Prior to 2015, weak acid extractable metals in the <63µm sediment 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 on-going monitoring. Extractable metals are therefore no longer routinely analysed at RSCMP sites.

### 1.3.2 Organic contaminants

Organic contaminants such as polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides (OCPs), and polychlorinated biphenyls (PCBs) have also been analysed at times in the RSCMP. These contaminants are 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, and ecosystem health is expected to be less sensitive to organic contaminants than metals at most sites. Organic contaminant results are reported separately to the more routine metals analysis conducted each year in the RSCMP.

### 1.3.3 Emerging contaminants

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 human wastewater, landfill leachate, stormwater, and agricultural/horticultural runoff. A scoping study of sediments from Auckland estuarine locations in 2008, found concentrations to be largely similar to those reported internationally, with elevated concentrations observed around wastewater discharge and sewage overflows (Stewart et al., 2014).

Despite research efforts, effective monitoring and management of EOCs in the environment remains challenging. Chemicals are often present in complex mixtures, and there are knowledge gaps relating to the identification of the highest risk EOCs (Stewart and Tremblay, 2024). A recent MBIE-funded project ‘Managing the risk of emerging contaminants’ analysed water (using passive sampling devices) and sediment samples in the Whau Estuary. This project employed an effects-based monitoring approach, using a combination of bioassays and chemical fractionation to provide insights into the types of chemicals present in a sample based on their biological activity (see Leusch et al., 2024 for detail). Stewart and Tremblay (2024) identify this effects-based monitoring approach as a potentially useful tool for future monitoring of EOCs, providing information on mixtures of chemicals and identifying areas with elevated concentrations where further investigations may be required.

Formed under the United Nations Decade of Ocean Science (2021-2030), the Global Estuaries Monitoring Programme aims to develop standardised sampling and analysis methods for a range of emerging contaminants. Around 35 countries are taking part, with the first stage focusing on the occurrence and environmental risk of pharmaceuticals. As part of this programme, surface water samples from the Manukau Harbour were collected in late 2023. Results and reporting from this first stage are due in 2025, before stakeholders and partners decide on the next contaminants the programme will focus on.

Microplastics (plastic particles <5mm in size) are ubiquitous and persistent in the environment. Studies have found microplastic contamination to be widespread across Auckland's beaches and coastlines (Ghanadi et al., 2024; Bridson et al., 2020) and there is increasing concern around their detrimental impact to both ecological and human health (Gola et al., 2021). 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. The recently completed MBIE-funded project 'Aotearoa Impacts and Mitigations of Microplastics (AIM$^2$)' aimed to investigate the impact and threat of microplastics to New Zealand's environment. Key findings from the research include the occurrence of microplastics in some of New Zealand's remotest marine areas; the persistence of biodegradable plastic marketed as environmentally friendly; the large number of chemical contaminants associated with microplastic, the transfer of these potentially harmful plastic additives to marine life and the subsequent risks to organisms and ecosystems. See outputs from this project here: https://www.esr.cri.nz/news-publications/microplastics-in-aotearoa-new-zealand-local-sources-and-broad-impacts

Currently emerging contaminants are not part of routine RSCMP monitoring, and as such they are not discussed further 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 PSD 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) 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 State report

A state report is produced for each RSCMP monitoring round (the purpose of this report). This provides a summary of the sampling and analyses undertaken (sites, dates, analytes), an overall quality assurance (QA) and state assessment and the monitoring data (metals and PSD) in tabular form.

### 1.4.2 State and trend report

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. Organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and emerging contaminants were reviewed in Mills (2014a and 2014b). Mills and Allen (2021) includes state and trends in metals (copper, lead, and zinc) and mud concentrations for the period 2004 to 2019. Allen (2023b) assessed state and preliminary trends for arsenic and mercury from data collected between 2012 and 2021.

### 1.4.3 Land, Air, Water Aotearoa (LAWA)

The Land, Air, Water Aotearoa (LAWA) data portal (www.lawa.org.nz) displays sediment contaminant information for sites in the Auckland region under the ‘Estuary Health’ topic. The 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 and quality control (QC) procedures, are 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).

Several programme reviews have been conducted over the monitoring period of the RSCMP. Most recently, a review in 2022 focussed 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 where urban development is either planned or already underway, and an assessment of the current sampling frequency. As a result of the review several changes were enacted. These included establishing a temporally nested monitoring approach, extending sampling frequency, and annual sampling focussing on specific locations to allow more complete reporting of an area each year to take place (e.g., the focus in 2023 on the Central Waitematā).

### 1.4.5 Quality control / quality assurance reports

Additional reports include quality control checks conducted by R J Hill Laboratories (Hamilton), 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 upon 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 are available in PDF or excel format upon 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 Auckland Council's environmental data portal.

# 2 Sampling conducted in 2023

## 2.1 Sites sampled

Sediments from a total of 19 sites were sampled for chemical contaminant analysis. All sampling was undertaken in the Central Waitematā Harbour in the following general areas:

- three sites in the Whau Estuary
- three sites in Hobson Bay
- one site in Henderson Creek
- four sites along the northern coastline
- eight sites along the southern coastline.

Ten sites were sampled by NIWA and nine sites were sampled by Auckland Council. Samples were taken between October 27 and November 27, 2023.

The locations of the 19 sites monitored in 2023 (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 one site (Henderson Entrance) in the Harbour Ecology programme. Sites such as Henderson Entrance 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. As sampling for sediment contaminants at these sites is typically done less frequently than at RSCMP sites, data are usually not yet sufficient for trend assessment. However, they are suitable for inclusion in ‘state’ assessment, broadening the spatial coverage of contaminant distribution information across the region.

A list of sites, coordinates, sampling dates, the sampling organisation, and analyses conducted are shown in Appendix A: Monitoring site details.

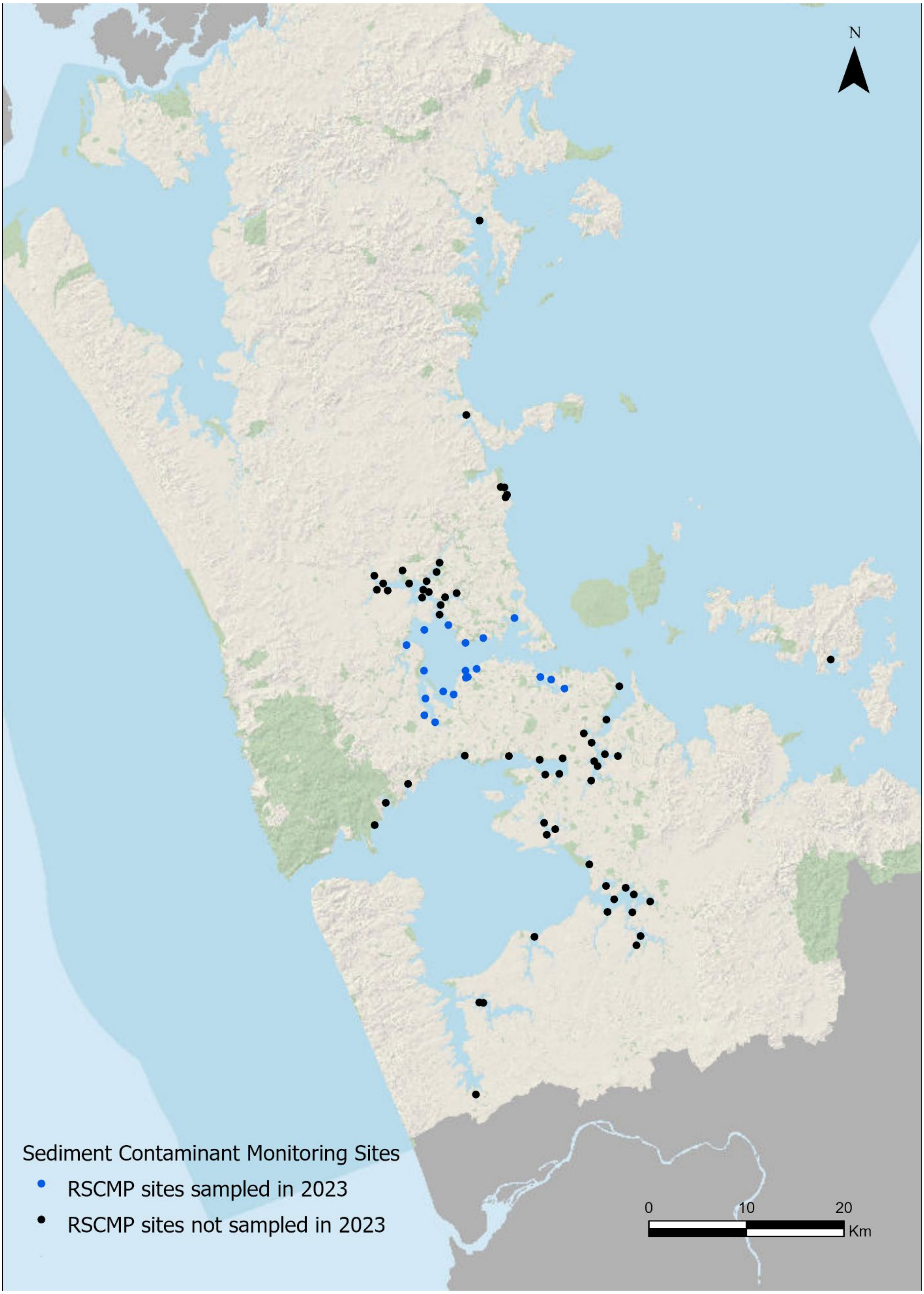

**Figure 2-1. Location of sites sampled for sediment contaminant analysis in 2023.**

## 2.2 Whau Estuary additional metal sampling

In 2023, three sites in the Whau Estuary (Whau Lower, Whau Wairau and Whau Upper) were analysed for the metals cadmium, chromium, nickel, and silver. These metals are outside the typical suite of analytes sampled in the RSCMP and were sampled at these sites to serve as a ‘check’ for these contaminants in a highly urbanised estuary.

### 2.2.1 Whau estuary catchment land use and sources of contaminants

Located in the southwest of the Waitematā Harbour, the Whau estuary is a 5.5 km long tidal creek comprising one main channel typically flanked by mud flats and mangrove forest, with several small tributaries branching off along the shoreline. The shoreline and 30.6 km$^2$ catchment of the Whau has a long history of human occupation and use. In the past, the estuary provided an important source of kai, and the surrounding land was cultivated by early Māori, before the arrival of Europeans saw the development of industrial sites such as brickworks and tanneries along the shoreline (MacKay, 2001). Following this, large areas for horticultural use were developed and remained until around the 1970’s, where a more residential and industrial setting became established (see Figure 2-2.). Today, land use in the catchment is largely dominated by residential development (58% of the catchment area), however areas of industrial (5.2%) and commercial (2.2%) land use are also present, along with open recreational and green space (12%).

**Figure 2-2. The Whau Estuary and surrounding land in 1940 (left; note the large horticultural areas), and in 2023, showing areas of varying land use, dominated by residential use (source: Auckland Council GeoMaps).**

Land use history and characteristics play a key role in the levels and types of contaminants occurring in receiving marine environments. The Whau Estuary receives specific pressures from a number of sources, and both historic and contemporary pollutants contribute to present day contaminant loads in sediment. Present day sources include wastewater overflows which can contain bacteria and faecal coliforms, along with a range of metals and industrial chemicals. Under dry weather conditions, wastewater from the Whau catchment is directed to a wastewater treatment plant for processing. However, heavy rainfall events can cause exceedance of the networks carrying capacity and result in wastewater discharge into the estuary at engineered overflow points. Additionally, there are several closed landfill sites along the shoreline of the Whau, and several more in the wider catchment. Many of the sites are now associated with recreational parks and sports fields, and the coastal sites are typically located in tidal areas and may be prone to saltwater intrusions. These landfills vary considerably in location, size, and fill type, with some sites reported as receiving a wide range of waste from industrial through to residential. Leachate[1] generated from these sites can contain contaminants. Although Auckland Council has programmes in place to manage leachate, there remains a risk of uncontrolled discharges entering water bodies, which could adversely affect aquatic life in nearby marine environments.

In addition to the various inputs from land, the physical characteristics of the estuary lend itself towards the accumulation of contaminants, as the relatively low energy environment restricts the removal and dilution of contaminants as they enter the estuary, and the predominantly muddy substrate accumulates pollutants more readily compared with coarser particles in more exposed areas.

### 2.2.2 Additional metals analysed

Cadmium, chromium, nickel, and silver are metals that can be toxic to animals if concentrations are too high. Cadmium has the potential to be elevated in marine sediments of rural areas or areas with horticultural history, because it is an unavoidable contaminant present in phosphate fertiliser. Chromium, nickel, and silver can be present in landfill leachate, industrial discharge, and untreated wastewater overflows. Analysis of this ‘extended suite’ of analytes provide a wider assessment of potential impacts from metal contaminants in an urban estuary.

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[1] Landfill leachate is caused by a process where liquid (typically rain) percolates through landfill waste, dissolving or entraining contaminants before it flows out of the waste material.

## 2.3 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 from each site was provided to R J Hill Laboratories (Hamilton) by NIWA for metal analysis. Samples were analysed for total recoverable metals – copper, lead, zinc, arsenic (a metalloid species), and mercury. Samples from three sites in the Whau Estuary were also analysed for total recoverable cadmium, chromium, nickel, and silver. 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.

## 2.4 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 until all moisture is removed and they have reached a stable weight (all PSD data is presented in Appendix C: Particle size distribution).

## 2.5 Concentration units for metals

Concentrations for metals are presented in milligrams per kilogram (mg/kg) weight of sediment in the <500µm (<0.5mm) fraction. The RSCMP 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 typically have moisture contents of <2%, and usually <1% for sandy 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. Therefore, moisture correction of the freeze-dried sediment results is not warranted and has not been undertaken for the 2023 sample data reported here.

## 2.6 Quality Assurance

For a detailed description and results of the quality assurance (QA) process see Appendix D: Quality assurance analysis.

A robust QA process is conducted to ensure that the 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 2023 monitoring data for total recoverable metals and PSD were similar in quality to those obtained in previous years. The elevated zinc levels 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 per cent annual change compared with 2022 results). Overall, the metals and mud content data from 2023 are considered acceptable for use in the RSCMP.

# 3 Contaminant state at sites sampled in 2023

## 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) for all metals, 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 chromium, mercury, cadmium, nickel, and silver. 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 2023 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 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 2023 are summarised in Table 3-1.

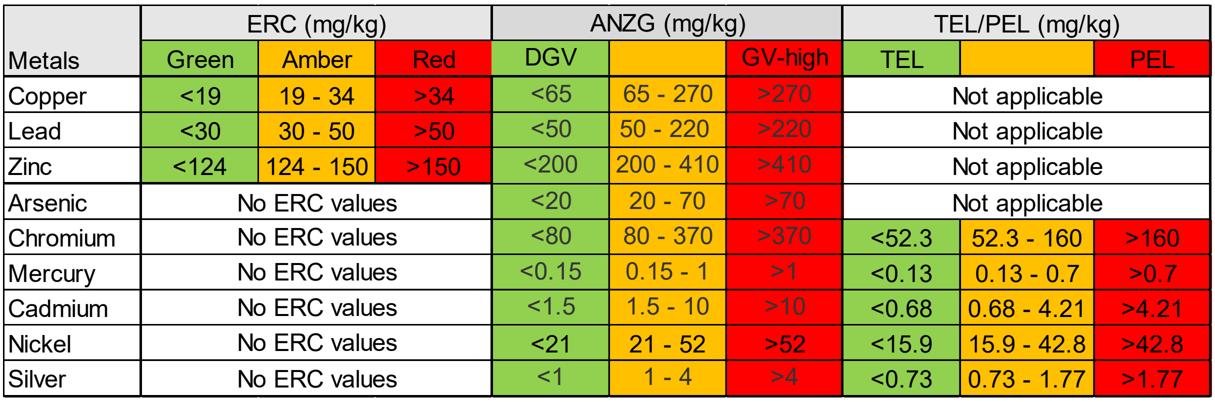
A summary of the meaning of the ERC are as follows (ARC, 2004):

- ERC Green conditions reflect a low level of impact.
- ERC Amber sites have slightly elevated concentrations where adverse effects on benthic ecology may be starting to appear.
- ERC Red sites are higher impact sites where levels are elevated and impact and degradation are likely to be occurring.

### 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 metals chromium, mercury, cadmium, nickel, and silver, for which no ERC guidelines exist. The TEL/PEL values for monitoring conducted in 2023 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.**



| Metals | ERC (mg/kg) | | | ANZG (mg/kg) | | | TEL/PEL (mg/kg) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 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 | | |
| Chromium | No ERC values | | | <80 | 80 - 370 | >370 | <52.3 | 52.3 - 160 | >160 |
| 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 |
| Nickel | No ERC values | | | <21 | 21 - 52 | >52 | <15.9 | 15.9 - 42.8 | >42.8 |
| Silver | No ERC values | | | <1 | 1 - 4 | >4 | <0.73 | 0.73 - 1.77 | >1.77 |

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, cadmium, chromium, nickel, and silver. 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. See Allen (2023b) for more detail on the interpretation of arsenic concentrations under different sediment quality guidelines.

## 3.2 State of sites sampled in 2023

### 3.2.1 Overall summary

The contaminant state of sites sampled in 2023 was assessed from median concentrations (from five replicates) of total recoverable metals in the <500µm fraction.

Levels of metal contamination varied across the monitored locations in 2023. Over half of the sites sampled (11 out of 19; 58%) were assessed in the ERC-green category (for metals copper, lead, and zinc; see Table 3-3). Sites along the harbour's northern shoreline and those in more exposed locations at the mouths of estuaries generally showed low levels of contamination. Conversely, sites in the upper reaches of sub estuaries (such as sites in the Whau Estuary and site Purewa in Hobson Bay) and at the lower reaches of creeks in relatively sheltered locations (such as sites Oakley Creek, Motions and Meola Inner) have elevated concentrations of several metals. At six sites at least one metal (most commonly zinc) is in the ERC-red category, while at four other sites at least one metal is in the ERC-amber category or above the TEL threshold. Nine sites in total trigger the less conservative ANZG guidelines for one or more metal. Lead triggers the DGV at one site, zinc at four sites and mercury at nine sites (see Table 3-2). No sites sampled in 2023 trigger the DGV for arsenic or copper, and no metals trigger the higher ANZG GV-high threshold at any site.

Figure 3-1 shows the current Environmental Response Criteria (ERC; metals copper, lead, and zinc) contaminant state for all sites sampled in the RSCMP, both in 2023 and in previous years. Figure 3-2 shows the contaminant state for the five chemicals typically analysed in the RSCMP at all sites sampled in 2023. Figure 3-2 shows state based on conservative sediment quality guidelines for each metal (i.e., the ERC for copper, lead, and zinc, the TEL/PEL for mercury, and for arsenic, the most appropriate guideline – the ANZG).

The ERC state history of sites sampled in 2023 is shown in Table 3-4. State has remained relatively stable; however, a change has been observed at four sites. Meola Inner lead levels, Whau Wairau copper and lead levels, and Henderson Lower zinc levels all decreased, changing from red to amber status, while at site Whau Upper, both copper and lead levels increased, changing from amber to red status.

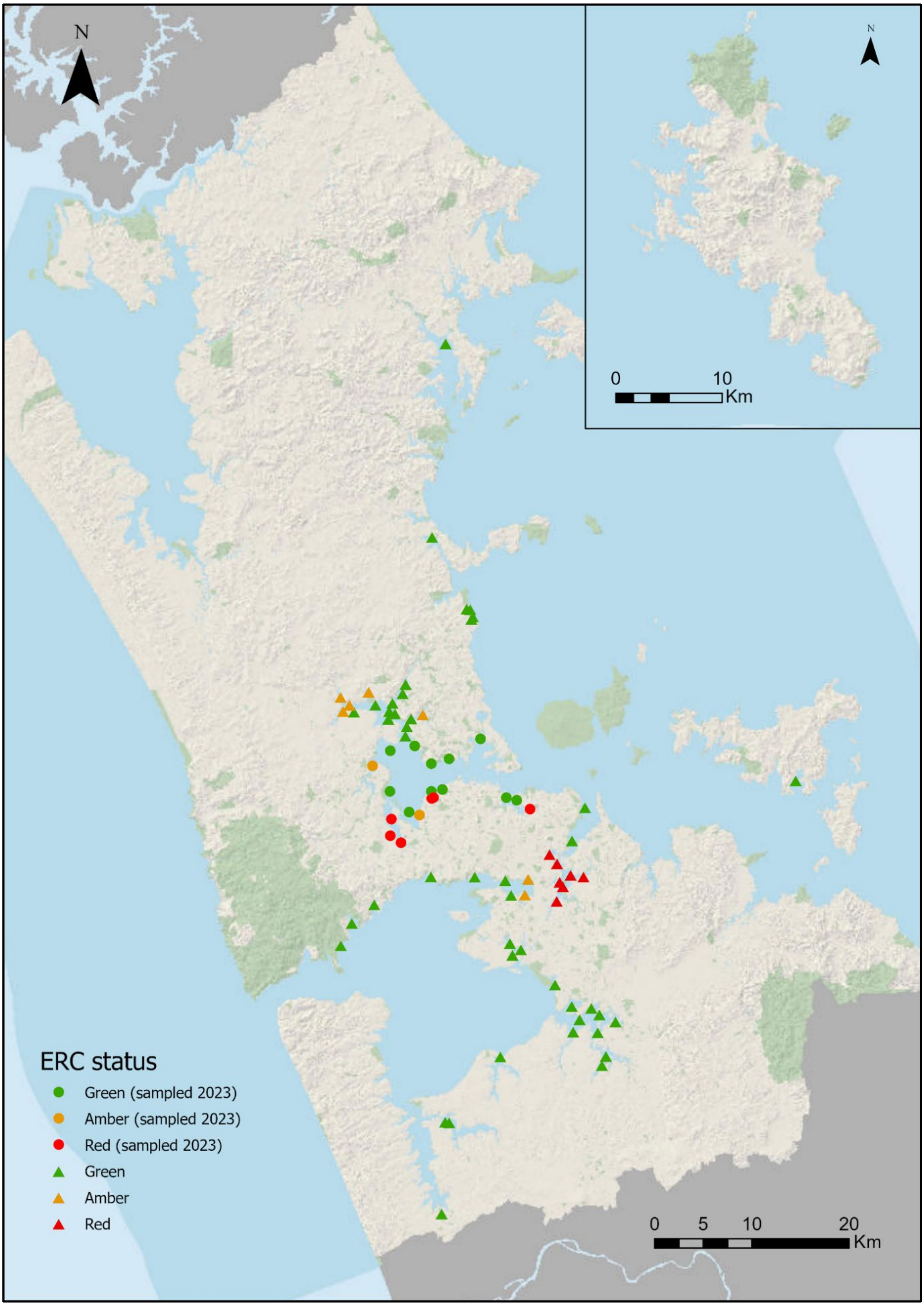


**Figure 3-1. Current Environmental Response Criteria (ERC; copper, lead, and zinc) contaminant state for all sites sampled in the Regional Sediment Contaminant Monitoring Programme. Sites sampled in 2023 are shown with a circle (●), sites sampled in previous years are shown with a triangle (▲).**

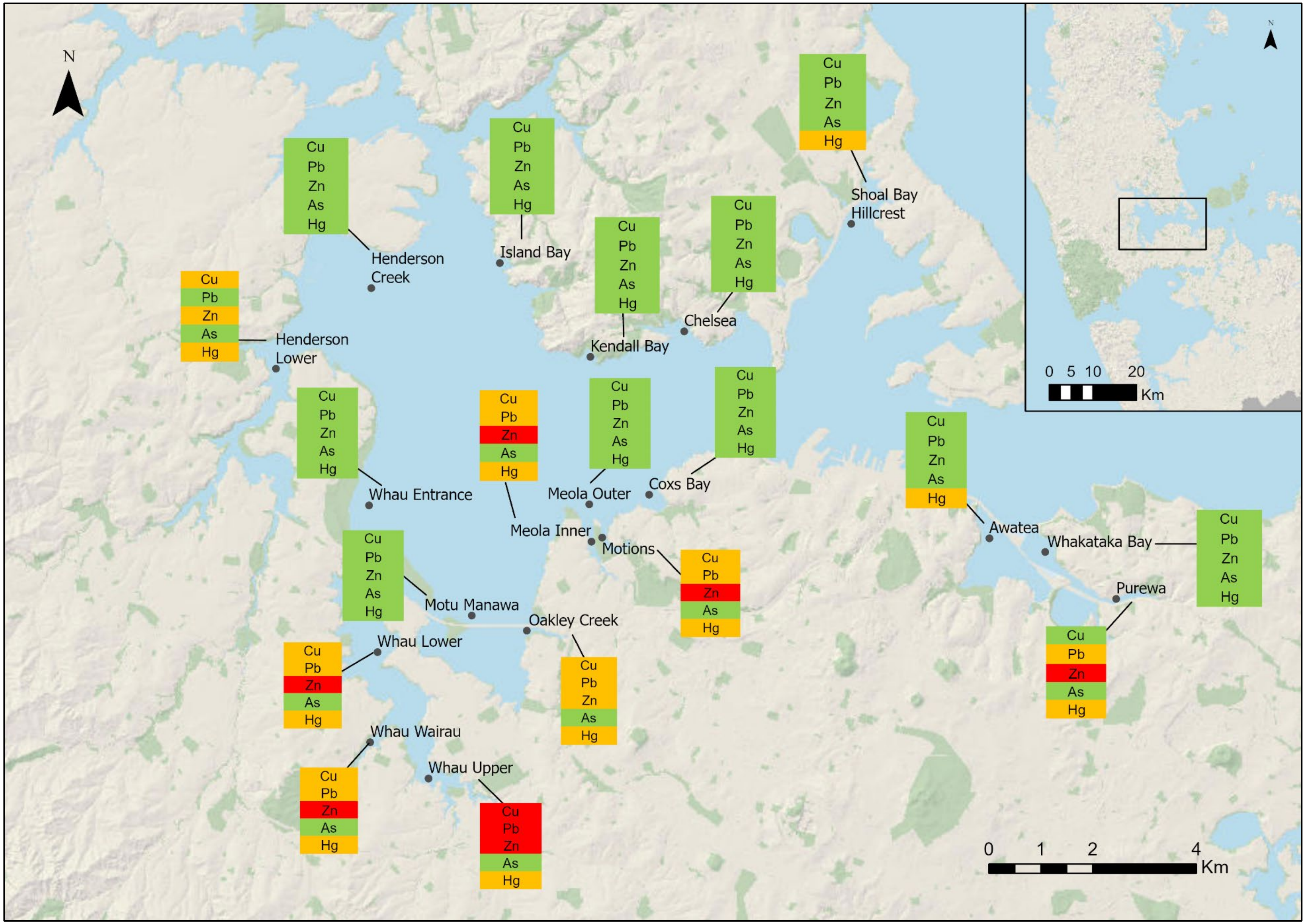


**Figure 3-2. Sites and state of metals sampled in the Regional Sediment Contaminant Monitoring Programme in 2023. Metals are copper (Cu), lead (Pb), zinc (Zn), arsenic (As), and mercury (Hg). Sediment quality guidelines used to denote potential ecological impact are the ERC for Cu, Pb and Zn, the TEL/PEL for Hg, and the ANZG for As. Inset map shows regional location.**

**Table 3-2. Australian and New Zealand Guidelines (ANZG) contaminant state at sites sampled in 2023. Metals are copper (Cu), lead (Pb), zinc (Zn), mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cd), nickel (Ni), and silver (Ag). Metals' concentrations are medians of five replicates.**

| | | | Mud Content | Total Recoverable metals, mg/kg <500 mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Location | Status ANZG | % <63 um | Cu | Pb | Zn | As | Hg | Cd | Cr | Ni | Ag |
| Awatea | Hobson Bay | 🟧 | 38.5 | 11.2 | 26.5 | 105.0 | 8.1 | 0.161 | | | | |
| Chelsea | Central Waitematā | 🟩 | 11.4 | 6.9 | 13.0 | 51.1 | 7.1 | 0.055 | | | | |
| Coxs Bay | Central Waitematā | 🟩 | 12.2 | 10.4 | 20.7 | 105.7 | 3.8 | 0.094 | | | | |
| Henderson Creek | Central Waitematā | 🟩 | 16.3 | 7.5 | 16.5 | 74.0 | 13.1 | 0.043 | | | | |
| Henderson Lower | Henderson Creek | 🟩 | 92.7 | 30.5 | 26.3 | 135.4 | 13.1 | 0.139 | | | | |
| Island Bay | Central Waitematā | 🟩 | 9.8 | 7.1 | 11.2 | 57.3 | 11.0 | 0.045 | | | | |
| Kendall Bay | Central Waitematā | 🟩 | 5.6 | 4.7 | 7.5 | 39.7 | 12.1 | 0.024 | | | | |
| Meola Inner | Meola Reef | 🟧 | 61.9 | 28.5 | 48.8 | 242.8 | 10.1 | 0.221 | | | | |
| Meola Outer | Meola Reef | 🟩 | 7.5 | 4.4 | 9.7 | 45.3 | 3.7 | 0.040 | | | | |
| Motions | Central Waitematā | 🟧 | 25.6 | 19.1 | 33.6 | 206.4 | 7.4 | 0.159 | | | | |
| Motu Manawa | Central Waitematā | 🟩 | 16.4 | 6.5 | 12.6 | 67.9 | 5.0 | 0.070 | | | | |
| Oakley Creek | Oakley Creek entrance | 🟧 | 79.1 | 24.0 | 35.6 | 139.8 | 11.5 | 0.151 | | | | |
| Purewa | Hobson Bay | 🟧 | 25.4 | 14.6 | 33.0 | 177.7 | 15.6 | 0.160 | | | | |
| Shoal Bay Hillcrest | Shoal Bay | 🟧 | 77.3 | 15.3 | 23.7 | 96.8 | 9.5 | 0.163 | | | | |
| Whakataka Bay | Hobson Bay | 🟩 | 23.2 | 6.5 | 16.1 | 85.1 | 7.1 | 0.117 | | | | |
| Whau Entrance | Whau Estuary | 🟩 | 18.2 | 4.9 | 8.3 | 41.7 | 3.3 | 0.041 | | | | |
| Whau Lower | Whau Estuary | 🟧 | 92.9 | 24.9 | 34.6 | 153.0 | 10.7 | 0.157 | 0.060 | 22.4 | 8.2 | 0.180 |
| Whau Upper | Whau Estuary | 🟧 | 75.9 | 39.4 | 53.0 | 220.8 | 13.2 | 0.167 | 0.132 | 23.2 | 8.5 | 0.221 |
| Whau Wairau | Whau Estuary | 🟧 | 80.7 | 30.4 | 35.2 | 244.3 | 13.5 | 0.178 | 0.108 | 25.0 | 9.9 | 0.222 |

**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), cadmium (Cd), chromium (Cd), nickel (Ni), and silver (Ag) at sites sampled in 2023. 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 | Cr | Ni | Ag |
| Awatea | Hobson Bay | 🟧 | 38.5 | 11.2 | 26.5 | 105.0 | 0.161 | | | | |
| Chelsea | Central Waitematā | 🟩 | 11.4 | 6.9 | 13.0 | 51.1 | 0.055 | | | | |
| Coxs Bay | Central Waitematā | 🟩 | 12.2 | 10.4 | 20.7 | 105.7 | 0.094 | | | | |
| Henderson Creek | Central Waitematā | 🟩 | 16.3 | 7.5 | 16.5 | 74.0 | 0.043 | | | | |
| Henderson Lower | Henderson Creek | 🟧 | 92.7 | 30.5 | 26.3 | 135.4 | 0.139 | | | | |
| Island Bay | Central Waitematā | 🟩 | 9.8 | 7.1 | 11.2 | 57.3 | 0.045 | | | | |
| Kendall Bay | Central Waitematā | 🟩 | 5.6 | 4.7 | 7.5 | 39.7 | 0.024 | | | | |
| Meola Inner | Meola Reef | 🟥 | 61.9 | 28.5 | 48.8 | 242.8 | 0.221 | | | | |
| Meola Outer | Meola Reef | 🟩 | 7.5 | 4.4 | 9.7 | 45.3 | 0.040 | | | | |
| Motions | Central Waitematā | 🟥 | 25.6 | 19.1 | 33.6 | 206.4 | 0.159 | | | | |
| Motu Manawa | Central Waitematā | 🟩 | 16.4 | 6.5 | 12.6 | 67.9 | 0.070 | | | | |
| Oakley Creek | Oakley Creek entrance | 🟧 | 79.1 | 24.0 | 35.6 | 139.8 | 0.151 | | | | |
| Purewa | Hobson Bay | 🟥 | 25.4 | 14.6 | 33.0 | 177.7 | 0.160 | | | | |
| Shoal Bay Hillcrest | Shoal Bay | 🟧 | 77.3 | 15.3 | 23.7 | 96.8 | 0.163 | | | | |
| Whakataka Bay | Hobson Bay | 🟩 | 23.2 | 6.5 | 16.1 | 85.1 | 0.117 | | | | |
| Whau Entrance | Whau Estuary | 🟩 | 18.2 | 4.9 | 8.3 | 41.7 | 0.041 | | | | |
| Whau Lower | Whau Estuary | 🟥 | 92.9 | 24.9 | 34.6 | 153.0 | 0.157 | 0.060 | 22.4 | 8.2 | 0.180 |
| Whau Upper | Whau Estuary | 🟥 | 75.9 | 39.4 | 53.0 | 220.8 | 0.167 | 0.132 | 23.2 | 8.5 | 0.221 |
| Whau Wairau | Whau Estuary | 🟥 | 80.7 | 30.4 | 35.2 | 244.3 | 0.178 | 0.108 | 25.0 | 9.9 | 0.222 |

**Table 3-4. History of Environmental Response Criteria (ERC) state for the metals copper (Cu), lead (Pb), and zinc (Zn) at sites sampled in 2023.**

| | | Year | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Location | 2023 | 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 |
| 🟩 Chelsea | Central Waitematā | 🟩 | | | | 🟩 | | 🟩 | | 🟩 | | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | | | | | |
| 🟩 Coxs Bay | Central Waitematā | 🟩 | | | | 🟩 | | 🟩 | | 🟩 | | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | | | | | |
| 🟩 Henderson Creek | Central Waitematā | 🟩 | | | | 🟩 | | 🟩 | | | | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | | | | | |
| 🟧 Henderson Lower | Central Waitematā | 🟧 Cu Zn | | | | 🟥 Zn | | 🟧 Cu Zn | | 🟧 Cu Zn | | | 🟧 Cu Zn | | 🟧 Cu Pb Zn | | 🟧 Cu Pb Zn | | 🟧 Cu Pb Zn | | 🟧 Cu Pb Zn | | 🟧 Cu Pb Zn | | | | |
| 🟩 Kendall Bay | Central Waitematā | 🟩 | | | | 🟩 | | 🟩 | | | | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | | | | | |
| 🟩 Meola Outer | Central Waitematā | 🟩 | | | | 🟩 | | 🟩 | | | | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | | | | | |
| 🟩 Shoal Bay Hillcrest | Shoal Bay | 🟩 | | | | 🟩 | | 🟩 | | 🟩 | | | 🟧 Pb | | 🟧 Pb | | 🟧 Cu Pb Zn | | 🟩 | | 🟧 Pb | | | | | | |
| 🟩 Whau Entrance | Whau Estuary | 🟩 | | | | 🟩 | | 🟩 | | 🟩 | | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | 🟩 | | | | |
| 🟩 Whakataka Bay | Hobson Bay | 🟩 | | | 🟩 | | 🟩 | | | | | 🟩 | | 🟩 | | 🟩 | | | | | | | | | | | |
| 🟩 Awatea | Hobson Bay | 🟩 | | | | | | | 🟩 | | | 🟩 | | 🟧 Pb | | | 🟧 Pb | | | | 🟧 Pb | | | | | | |
| 🟥 Purewa | Hobson Bay | 🟥 Zn | | | | | | 🟥 Zn | | | | | 🟥 Zn | | 🟥 Zn | | 🟧 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | | | |
| 🟩 Island Bay | Central Waitematā | 🟩 | | | | | 🟩 | | | | | 🟩 | 🟩 | | | | | 🟩 | | | | | | | | | |
| 🟥 Meola Inner | Meola Reef | 🟥 Zn | | | 🟥 Pb Zn | | 🟥 Zn | | 🟥 Pb Zn | | | 🟥 Pb Zn | | 🟥 Pb Zn | | 🟥 Pb Zn | | 🟥 Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Pb Zn | | 🟥 Pb Zn | | 🟥 Cu Pb Zn | 🟥 Cu Pb Zn |
| 🟥 Motions | Meola Reef | 🟥 Zn | | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Pb Zn | | 🟥 Pb Zn | | 🟥 Zn | 🟥 Pb Zn |
| 🟧 Oakley Creek | Oakley Creek entrance | 🟧 Cu Pb Zn | | | 🟧 Cu Pb Zn | | 🟥 Zn | | 🟧 Cu Pb Zn | | | 🟧 Cu Pb Zn | | 🟥 Zn | | 🟧 Cu Pb Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Cu Pb Zn | 🟥 Pb Zn |
| 🟩 Motu Manawa | Pollen Island | 🟩 | | | 🟩 | | 🟩 | | 🟩 | | | 🟩 | | | | 🟩 | | 🟩 | | 🟩 | | | | | | | |
| 🟥 Whau Lower | Whau Estuary | 🟥 Zn | | | 🟥 Zn | | 🟥 Zn | | 🟧 Cu Pb Zn | | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Zn | | 🟥 Pb Zn | | 🟥 Zn | | 🟥 Cu Pb Zn | 🟥 Pb Zn |
| 🟥 Whau Upper | Whau Estuary | 🟥 Cu Pb Zn | | | 🟥 Zn | | 🟥 Zn | | 🟥 Pb Zn | | | 🟥 Pb Zn | | 🟥 Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | 🟥 Cu Pb Zn |
| 🟥 Whau Wairau | Whau Estuary | 🟥 Zn | | | 🟥 Cu Pb Zn | | 🟥 Zn | | 🟥 Pb Zn | | | 🟥 Pb Zn | | 🟥 Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | | 🟥 Cu Pb Zn | 🟥 Cu Pb Zn |

## 3.3 Discussion

Results from sampling undertaken in 2023 showed a range of sediment contamination across the Central Waitematā. Spatial distribution of contamination is largely in agreement with previous monitoring in the Harbour and with the general pattern of contamination observed across the region. The highest concentrations of metals are observed at muddy, sheltered sites receiving run-off from older urban and industrial catchments, while the more exposed sites with coarser, sandier particles have considerably lower levels.

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 2023, zinc triggered the ERC red threshold at six sites, and the amber threshold at a further two sites, with a similar distribution of results observed to previous reporting. 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. Examples include the catchment surrounding the Whau Estuary and sites to the west of the city centre – Motions, Meola Inner and (to a lesser extent) Oakley Creek. The ongoing pressures associated with these land uses have cumulatively had a negative impact on sediment quality at these sites over time, with several metals triggering amber and/or red threshold levels since monitoring began (see State History Table 3-4). The much lower levels observed at sites adjacent to those heavily impacted (i.e., sites Whau Entrance and Meola Outer) are likely a reflection of these sites' locations in more exposed, less muddy, and higher energy environments, where contaminants are more readily dispersed and less likely to settle and accumulate. Similar contamination gradients are observed in other areas of Auckland (e.g., the Tāmaki Estuary), where contaminant levels decrease as you move out from the inner estuary into adjacent, generally sandy outer zones.

Three sites sampled in Hobson Bay (a tidal inlet on the southern shoreline close to the mouth of the Waitematā) showed varying contaminant levels. Site Purewa in the muddy upper reaches is by far the most impacted site in the bay, while the sites in the lower reaches (Whakataka Bay and Awatea) have relatively low levels. As described above, this is likely a result of the coarser particles and greater tidal and wave energy present in the lower reaches of the inlet.

Most sites monitored along the northern shoreline of the Central Waitematā contain sandy textured substrate. The exception is site Shoal Bay Hillcrest, located in the semi-sheltered upper reaches of a bay in the northeast of the harbour, which has fairly high mud levels (77% of the total sediment weight). These sites' relative exposure, generally sandy substrate, and smaller catchments have likely all been contributing factors to the low levels of metals currently observed.

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 1990's. Sites across the region are now generally below levels where effects on ecology would be expected. However, seven sites in the Central Waitematā triggered the ERC amber threshold (30 mg/kg) and one site (Whau Upper) the red threshold (50 mg/kg). The persistence of high levels of lead at sites in the Central Waitematā may be due to either ongoing input from land activities, or more historic input, emphasising the slow and long-term nature of contaminated sediment recovery.

Mercury triggered the ANZG DGV threshold more regularly than any other metal (nine sites in total). The slightly more conservative TEL/PEL levels for mercury are very similar to those used in the ANZG and show far less variation than they do for some other metals (e.g., ERC values compared with ANZG DGV). Only one additional site (Henderson Lower) triggered the lower TEL guideline value. Mercury is rarely elevated in isolation, except for sites Shoal Bay Hillcrest and Awatea, where mercury is the only contaminant occurring at slightly higher concentrations. Mercury is typically found in elevated levels alongside at least one other metal. This is particularly evident in the Whau Estuary, where elevated mercury concentrations sit alongside high zinc, copper, and lead levels. In isolation, levels of mercury currently pose only a moderate level of risk to benthic fauna at most sites sampled in 2023, however, even at slightly elevated concentrations are likely to be contributing to cumulative effects (when combined with other stressors in the environment such as other elevated metals and/or high mud content) and the overall picture of sediment quality and ecological health in the Central Waitematā.

No sites sampled in 2023 triggered the ANZG DGV for arsenic. Levels appear in line with what would be expected to occur naturally and are currently not of major concern at any sites in the Central Waitematā (average concentration in 2023 is 9.4 mg/kg; background concentrations are estimated to be around 12 mg/kg (see Allen (2023b) for more detail)).

All the metals included in the additional suite of analytes for sampling conducted at sites in the Whau Estuary (cadmium, chromium, nickel, and silver) showed levels well below those where an impact on ecology might be expected. This is encouraging given the various potential sources in the surrounding catchment and the elevated concentrations observed in other metals. Unless there is a specific cause for concern or a reason to expect contamination from these chemicals, the widespread inclusion of these analytes at sites in the RSCMP is not recommended. However, it may be useful to include analysis of these metals at select sites during the next sampling round in the Tāmaki Estuary (scheduled for 2025). The catchment surrounding the Tāmaki Estuary contains areas of intense industrial land use, and the inclusion of a wider suite of analytes here would serve as a useful ‘check’ to ensure (as is the case in the Whau Estuary) that none of these chemicals are present at elevated levels. The metal cadmium is also recommended for inclusion in the suite of analytes when future sampling is conducted in predominantly rural areas outside of the main RSCMP network, such as benthic ecology sites located in the east coast estuaries and Kaipara Harbour. Cadmium is present in phosphate fertiliser which can be applied to rural land. Including this metal when sampling in these locations provides assurance that the low levels observed when cadmium has been analysed in other rural catchments (e.g., the Mahurangi Harbour in 2022) are also observed in estuaries with comparable catchment land use.

In general, ERC contaminant status (for metals copper, lead, and zinc only) has remained relatively stable over time at most sites sampled in 2023 (see Table 3-4). Where changes in state did occur, they were a mix of relatively small fluctuations above or below guideline thresholds (such as a very small change in lead values at Meola Inner), and more considerable differences, as was the case for improving copper and lead levels at site Whau Wairau and conversely, worsening copper and lead levels at site Whau Upper. At these sites, the relative percent differences between 2023 and 2020 values ranged between a 22% increase in lead levels at Whau Upper, and a 41% decrease in lead levels at Whau Wairau. These sites are located relatively close to one another in the same broad catchment. The varying differences observed are indicative of the site-specific nature of sediment and contaminant accumulation and the fine scale dynamics that can occur within an estuary. The change in state at Henderson Lower, where zinc levels dropped from red to amber, is possibly attributable to previous issues with zinc analysis during the last sampling in 2019, rather than genuine decreasing concentrations. Further monitoring will confirm if these changes endure, or if status at these sites oscillates above and below threshold values.

### 2023 flood events

In early 2023, Auckland experienced two extreme weather events in relatively quick succession. In January and February, heavy and intense rain caused widespread flooding across much of the region. Severe flooding was prevalent in a number of urban suburbs surrounding the central Waitematā Harbour. Consequently, a myriad of pollutants and chemicals from industrial, residential, and commercial areas which would have otherwise remained contained, would have been expected to make their way into the marine environment. These severe weather events also led to an increase in land erosion, which can transport pollutants stored in soil into water bodies and ultimately the marine environment. It’s also possible that instances of surface sediment scouring and sediment remobilisation may occur within an estuary or river system as a result of very high flows. This process may unearth and remobilise historic contaminants sitting deeper in the profile (Crawford et al., 2022). Conversely, extreme heavy rain and flooding may disperse fine particles and dissolved contaminants, transporting them out of estuary arms into more exposed areas (Mills and Williamson, 2008). Whilst it is difficult to directly link any impact from these weather events to observations made in the RSCMP, the relatively stable results observed in 2023 when compared with the last round of sampling (three or four years previously for most sites), provides some assurance that widespread and significant increases (at least for the metals measured) did not occur.

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# 5 Appendix A: Monitoring site details

Regional Sediment Contaminant Monitoring Programme sites sampled in 2023. Table shows site name, sampling location, site coordinates in New Zealand Transverse Mercator (NZTM 2000), sampling date, sampling organisation and analyses conducted.

| Site | Location | NZTM X | NZTM Y | Sampling Date | Sampled by | <500 µm fraction | | Benthic Ecology | Particle Size |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total Cu Pb Zn As Hg | Total Cd Cr Ni Ag | | |
| Awatea | Hobson Bay | 1760037 | 5919688 | 22/11/2023 | AC | ✓ | | ✓ | ✓ |
| Chelsea | Central Waitematā | 1754158 | 5923678 | 27/11/2023 | AC | ✓ | | ✓ | ✓ |
| Coxs Bay | Central Waitematā | 1753479 | 5920531 | 31/10/2023 | NIWA | ✓ | | ✓ | ✓ |
| Henderson Creek | Central Waitematā | 1748127 | 5924512 | 27/10/2023 | AC | ✓ | | ✓ | ✓ |
| Henderson Lower | Henderson Creek | 1746287 | 5922955 | 31/10/2023 | NIWA | ✓ | | ✓ | ✓ |
| Island Bay | Central Waitematā | 1750607 | 5924995 | 24/11/2023 | AC | ✓ | | ✓ | ✓ |
| Kendall Bay | Central Waitematā | 1752352 | 5923186 | 24/11/2023 | AC | ✓ | | ✓ | ✓ |
| Meola Inner | Meola Reef | 1752369 | 5919629 | 30/10/2023 | NIWA | ✓ | | ✓ | ✓ |
| Meola Outer | Meola Reef | 1752328 | 5920342 | 30/10/2023 | NIWA | ✓ | | ✓ | ✓ |
| Motions | Central Waitematā | 1752573 | 5919704 | 30/10/2023 | NIWA | ✓ | | ✓ | ✓ |
| Motu Manawa | Central Waitematā | 1750065 | 5918198 | 7/11/2023 | NIWA | ✓ | | ✓ | ✓ |
| Oakley Creek | Oakley Creek entrance | 1751121 | 5917912 | 30/10/2023 | NIWA | ✓ | | ✓ | ✓ |
| Purewa | Hobson Bay | 1762482 | 5918521 | 24/11/2023 | AC | ✓ | | ✓ | ✓ |
| Shoal Bay Hillcrest | Shoal Bay | 1757375 | 5925746 | 31/10/2023 | NIWA | ✓ | | ✓ | ✓ |
| Whakataka Bay | Hobson Bay | 1761114 | 5919424 | 22/11/2023 | AC | ✓ | | ✓ | ✓ |
| Whau Entrance | Whau Estuary | 1748081 | 5920325 | 23/11/2023 | AC | ✓ | | ✓ | ✓ |
| Whau Lower | Whau Estuary | 1748243 | 5917496 | 7/11/2023 | NIWA | ✓ | ✓ | ✓ | ✓ |
| Whau Upper | Whau Estuary | 1749226 | 5915064 | 23/11/2023 | AC | ✓ | ✓ | ✓ | ✓ |
| Whau Wairau | Whau Estuary | 1748106 | 5915757 | 7/11/2023 | NIWA | ✓ | ✓ | ✓ | ✓ |

# 6 Appendix B: Sediment contaminant data

Metals' data for 2023 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).

| | | | Total Recoverable metals, mg/kg <500 µm | | | | |
|---|---|---|---|---|---|---|---|
| Site name | Location | Replicate | Cu | Pb | Zn | As | Hg |
| Awatea | Hobson Bay | 1 | 10.8 | 26.5 | 104.4 | 7.73 | 0.150 |
| Awatea | Hobson Bay | 2 | 11.2 | 26.1 | 105.3 | 8.25 | 0.161 |
| Awatea | Hobson Bay | 3 | 11.2 | 27.3 | 105.0 | 8.49 | 0.165 |
| Awatea | Hobson Bay | 4 | 11.3 | 26.4 | 104.4 | 7.55 | 0.146 |
| Awatea | Hobson Bay | 5 | 10.8 | 26.5 | 105.1 | 8.12 | 0.167 |
| Chelsea | Central Waitematā | 1 | 6.4 | 13.0 | 49.3 | 6.85 | 0.046 |
| Chelsea | Central Waitematā | 2 | 6.8 | 12.4 | 49.9 | 6.67 | 0.049 |
| Chelsea | Central Waitematā | 3 | 7.2 | 13.1 | 51.1 | 7.07 | 0.062 |
| Chelsea | Central Waitematā | 4 | 7.0 | 13.1 | 51.7 | 7.27 | 0.058 |
| Chelsea | Central Waitematā | 5 | 6.9 | 12.9 | 53.3 | 7.54 | 0.055 |
| Coxs Bay | Central Waitematā | 1 | 9.9 | 19.7 | 103.9 | 3.70 | 0.088 |
| Coxs Bay | Central Waitematā | 2 | 10.4 | 21.6 | 101.5 | 3.76 | 0.102 |
| Coxs Bay | Central Waitematā | 3 | 9.9 | 20.7 | 113.7 | 4.05 | 0.095 |
| Coxs Bay | Central Waitematā | 4 | 10.9 | 20.0 | 105.7 | 4.01 | 0.091 |
| Coxs Bay | Central Waitematā | 5 | 11.0 | 21.0 | 114.6 | 3.84 | 0.094 |
| Henderson Creek | Central Waitematā | 1 | 7.6 | 16.8 | 75.1 | 13.43 | 0.040 |
| Henderson Creek | Central Waitematā | 2 | 7.3 | 15.8 | 69.8 | 12.32 | 0.044 |
| Henderson Creek | Central Waitematā | 3 | 7.5 | 16.7 | 74.0 | 13.15 | 0.048 |
| Henderson Creek | Central Waitematā | 4 | 7.6 | 16.5 | 74.5 | 13.14 | 0.043 |
| Henderson Creek | Central Waitematā | 5 | 7.4 | 16.0 | 71.8 | 12.71 | 0.041 |
| Henderson Lower | Henderson Creek | 1 | 30.0 | 26.9 | 134.8 | 12.65 | 0.135 |
| Henderson Lower | Henderson Creek | 2 | 30.4 | 26.3 | 136.2 | 13.24 | 0.139 |
| Henderson Lower | Henderson Creek | 3 | 30.5 | 26.8 | 134.5 | 12.49 | 0.124 |
| Henderson Lower | Henderson Creek | 4 | 30.6 | 26.0 | 137.2 | 13.24 | 0.144 |
| Henderson Lower | Henderson Creek | 5 | 31.0 | 25.8 | 135.4 | 13.06 | 0.142 |
| Island Bay | Central Waitematā | 1 | 7.2 | 10.7 | 56.5 | 10.42 | 0.049 |
| Island Bay | Central Waitematā | 2 | 6.6 | 11.2 | 60.6 | 11.50 | 0.040 |
| Island Bay | Central Waitematā | 3 | 7.1 | 11.2 | 58.5 | 11.54 | 0.045 |
| Island Bay | Central Waitematā | 4 | 7.2 | 11.3 | 55.1 | 10.42 | 0.043 |
| Island Bay | Central Waitematā | 5 | 7.0 | 11.4 | 57.3 | 10.98 | 0.045 |
| Kendall Bay | Central Waitematā | 1 | 4.4 | 7.0 | 35.4 | 10.80 | 0.027 |
| Kendall Bay | Central Waitematā | 2 | 4.7 | 7.5 | 39.7 | 12.07 | 0.023 |
| Kendall Bay | Central Waitematā | 3 | 4.9 | 8.0 | 41.1 | 12.52 | 0.029 |
| Kendall Bay | Central Waitematā | 4 | 4.6 | 7.2 | 36.2 | 11.90 | 0.024 |
| Kendall Bay | Central Waitematā | 5 | 5.0 | 7.7 | 42.4 | 12.12 | 0.024 |
| Meola Inner | Meola Reef | 1 | 28.3 | 48.5 | 242.8 | 9.99 | 0.221 |
| Meola Inner | Meola Reef | 2 | 29.5 | 48.8 | 260.2 | 10.11 | 0.231 |
| Meola Inner | Meola Reef | 3 | 28.5 | 49.5 | 243.6 | 9.72 | 0.214 |
| Meola Inner | Meola Reef | 4 | 28.1 | 46.2 | 239.1 | 10.49 | 0.218 |
| Meola Inner | Meola Reef | 5 | 30.0 | 51.0 | 242.5 | 10.65 | 0.247 |
| Meola Outer | Meola Reef | 1 | 4.2 | 9.4 | 42.3 | 3.21 | 0.040 |
| Meola Outer | Meola Reef | 2 | 4.4 | 9.7 | 45.7 | 3.89 | 0.039 |
| Meola Outer | Meola Reef | 3 | 4.6 | 10.1 | 45.3 | 3.69 | 0.041 |
| Meola Outer | Meola Reef | 4 | 4.3 | 9.7 | 43.2 | 3.58 | 0.041 |
| Meola Outer | Meola Reef | 5 | 4.7 | 10.1 | 47.6 | 3.92 | 0.039 |
| Motions | Central Waitematā | 1 | 19.7 | 33.6 | 215.2 | 7.83 | 0.159 |
| Motions | Central Waitematā | 2 | 18.1 | 32.5 | 197.4 | 7.06 | 0.139 |
| Motions | Central Waitematā | 3 | 18.3 | 31.8 | 204.7 | 7.41 | 0.146 |
| Motions | Central Waitematā | 4 | 20.8 | 36.2 | 227.7 | 7.95 | 0.177 |
| Motions | Central Waitematā | 5 | 19.1 | 33.9 | 206.4 | 7.32 | 0.175 |

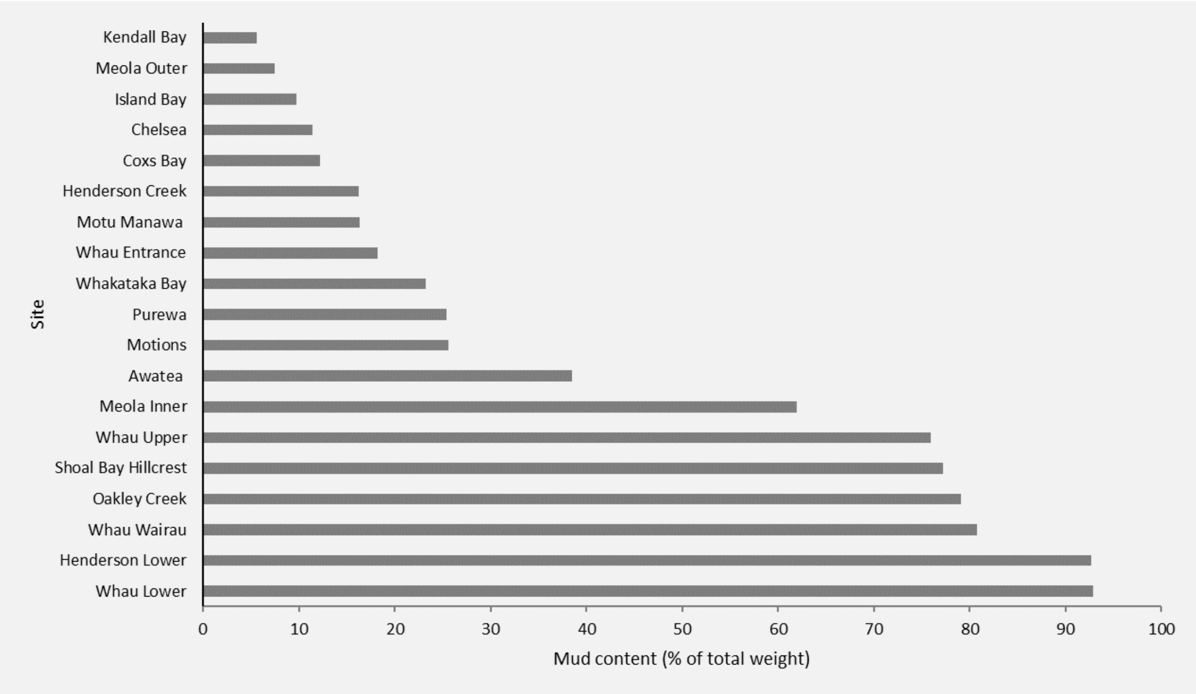
Metals’ data for 2023 monitoring cont.

| Site name | Location | Replicate | Total Recoverable metals, mg/kg <500 µm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cu | Pb | Zn | As | Hg | Cd | Cr | Ni | Ag |
| Motu Manawa | Central Waitematā | 1 | 6.5 | 12.8 | 67.9 | 4.97 | 0.071 | | | | |
| Motu Manawa | Central Waitematā | 2 | 6.2 | 12.3 | 66.9 | 4.55 | 0.068 | | | | |
| Motu Manawa | Central Waitematā | 3 | 6.4 | 12.4 | 67.8 | 4.62 | 0.064 | | | | |
| Motu Manawa | Central Waitematā | 4 | 6.7 | 12.6 | 70.1 | 5.28 | 0.070 | | | | |
| Motu Manawa | Central Waitematā | 5 | 6.9 | 12.8 | 70.2 | 5.23 | 0.074 | | | | |
| Oakley Creek | Oakley Creek entrance | 1 | 24.0 | 36.0 | 139.6 | 11.38 | 0.149 | | | | |
| Oakley Creek | Oakley Creek entrance | 2 | 23.8 | 35.0 | 140.1 | 11.49 | 0.161 | | | | |
| Oakley Creek | Oakley Creek entrance | 3 | 24.5 | 35.6 | 145.0 | 11.56 | 0.152 | | | | |
| Oakley Creek | Oakley Creek entrance | 4 | 24.0 | 36.0 | 138.3 | 11.29 | 0.151 | | | | |
| Oakley Creek | Oakley Creek entrance | 5 | 24.1 | 34.9 | 139.8 | 12.15 | 0.148 | | | | |
| Purewa | Hobson Bay | 1 | 14.5 | 32.9 | 177.7 | 14.78 | 0.160 | | | | |
| Purewa | Hobson Bay | 2 | 14.6 | 33.0 | 177.7 | 15.60 | 0.157 | | | | |
| Purewa | Hobson Bay | 3 | 14.2 | 31.9 | 172.0 | 14.72 | 0.156 | | | | |
| Purewa | Hobson Bay | 4 | 15.8 | 35.2 | 194.2 | 16.54 | 0.168 | | | | |
| Purewa | Hobson Bay | 5 | 15.4 | 33.3 | 183.3 | 15.60 | 0.171 | | | | |
| Shoal Bay Hillcrest | Shoal Bay | 1 | 14.8 | 23.9 | 94.1 | 8.85 | 0.163 | | | | |
| Shoal Bay Hillcrest | Shoal Bay | 2 | 15.3 | 23.0 | 96.8 | 9.79 | 0.163 | | | | |
| Shoal Bay Hillcrest | Shoal Bay | 3 | 15.6 | 23.7 | 97.3 | 9.46 | 0.168 | | | | |
| Shoal Bay Hillcrest | Shoal Bay | 4 | 14.5 | 22.8 | 93.4 | 9.01 | 0.158 | | | | |
| Shoal Bay Hillcrest | Shoal Bay | 5 | 15.7 | 23.7 | 98.3 | 9.87 | 0.156 | | | | |
| Whakataka Bay | Hobson Bay | 1 | 6.3 | 16.1 | 83.2 | 7.11 | 0.123 | | | | |
| Whakataka Bay | Hobson Bay | 2 | 6.5 | 16.1 | 85.2 | 7.05 | 0.128 | | | | |
| Whakataka Bay | Hobson Bay | 3 | 6.8 | 17.0 | 87.7 | 7.68 | 0.110 | | | | |
| Whakataka Bay | Hobson Bay | 4 | 6.4 | 15.9 | 82.7 | 6.93 | 0.110 | | | | |
| Whakataka Bay | Hobson Bay | 5 | 6.6 | 15.4 | 85.1 | 6.95 | 0.117 | | | | |
| Whau Entrance | Whau Estuary | 1 | 4.9 | 8.5 | 40.0 | 3.31 | 0.040 | | | | |
| Whau Entrance | Whau Estuary | 2 | 5.1 | 8.3 | 41.7 | 3.66 | 0.041 | | | | |
| Whau Entrance | Whau Estuary | 3 | 4.6 | 8.1 | 39.6 | 3.17 | 0.040 | | | | |
| Whau Entrance | Whau Estuary | 4 | 5.2 | 8.8 | 42.7 | 3.52 | 0.045 | | | | |
| Whau Entrance | Whau Estuary | 5 | 4.9 | 8.2 | 41.7 | 3.33 | 0.043 | | | | |
| Whau Lower | Whau Estuary | 1 | 24.1 | 34.0 | 151.3 | 10.59 | 0.161 | 0.059 | 22.1 | 7.99 | 0.175 |
| Whau Lower | Whau Estuary | 2 | 24.9 | 34.6 | 156.3 | 10.70 | 0.157 | 0.060 | 24.2 | 8.60 | 0.184 |
| Whau Lower | Whau Estuary | 3 | 25.1 | 34.8 | 153.0 | 10.91 | 0.154 | 0.055 | 22.4 | 8.15 | 0.180 |
| Whau Lower | Whau Estuary | 4 | 24.3 | 34.0 | 152.6 | 10.11 | 0.157 | 0.062 | 21.5 | 8.02 | 0.177 |
| Whau Lower | Whau Estuary | 5 | 25.6 | 35.0 | 158.0 | 10.98 | 0.154 | 0.066 | 23.4 | 8.68 | 0.185 |
| Whau Upper | Whau Estuary | 1 | 39.4 | 51.4 | 220.8 | 13.50 | 0.166 | 0.135 | 23.4 | 8.89 | 0.224 |
| Whau Upper | Whau Estuary | 2 | 39.1 | 51.4 | 217.2 | 13.16 | 0.167 | 0.131 | 23.2 | 8.65 | 0.221 |
| Whau Upper | Whau Estuary | 3 | 40.0 | 53.9 | 221.3 | 13.50 | 0.174 | 0.136 | 25.0 | 8.35 | 0.223 |
| Whau Upper | Whau Estuary | 4 | 39.0 | 53.0 | 217.7 | 13.07 | 0.157 | 0.127 | 21.5 | 8.51 | 0.211 |
| Whau Upper | Whau Estuary | 5 | 40.5 | 54.3 | 226.7 | 13.18 | 0.173 | 0.132 | 21.9 | 8.54 | 0.221 |
| Whau Wairau | Whau Estuary | 1 | 29.6 | 34.6 | 239.8 | 13.54 | 0.170 | 0.108 | 24.4 | 10.3 | 0.221 |
| Whau Wairau | Whau Estuary | 2 | 30.4 | 35.0 | 244.3 | 13.52 | 0.179 | 0.110 | 25.2 | 9.8 | 0.259 |
| Whau Wairau | Whau Estuary | 3 | 30.6 | 35.6 | 249.0 | 13.82 | 0.170 | 0.106 | 25.0 | 10.0 | 0.226 |
| Whau Wairau | Whau Estuary | 4 | 31.1 | 35.4 | 251.8 | 13.21 | 0.178 | 0.116 | 24.3 | 9.9 | 0.218 |
| Whau Wairau | Whau Estuary | 5 | 29.9 | 35.2 | 241.0 | 13.83 | 0.180 | 0.106 | 26.7 | 9.3 | 0.222 |
| MeOZ FD | Bulk Reference Sediment | 1 | 2.87 | 8.73 | 41.70 | 2.73 | 0.0349 | 0.061 | 4.4 | 1.80 | 0.036 |
| MeOZ FD | Bulk Reference Sediment | 2 | 3.01 | 8.98 | 41.22 | 2.59 | 0.0327 | 0.062 | 4.1 | 1.65 | 0.036 |
| MeOZ FD | Bulk Reference Sediment | 3 | 2.99 | 9.51 | 39.91 | 2.60 | 0.0317 | 0.062 | 3.8 | 1.56 | 0.036 |
| MeOZ FD | Bulk Reference Sediment | 4 | 3.01 | 9.17 | 42.08 | 2.85 | 0.0307 | 0.059 | 4.1 | 1.75 | 0.038 |
| MeOZ FD | Bulk Reference Sediment | 5 | 3.25 | 8.80 | 43.00 | 2.80 | 0.0326 | 0.071 | 4.6 | 1.90 | 0.040 |
| MID FD | Bulk Reference Sediment | 1 | 29.6 | 34.6 | 239.8 | 8.75 | 0.170 | 0.161 | 28.2 | 11.2 | 0.231 |
| MID FD | Bulk Reference Sediment | 2 | 30.4 | 35.0 | 244.3 | 8.85 | 0.179 | 0.154 | 28.4 | 11.9 | 0.235 |
| MID FD | Bulk Reference Sediment | 3 | 30.6 | 35.6 | 249.0 | 9.34 | 0.170 | 0.153 | 29.2 | 11.1 | 0.250 |
| MID FD | Bulk Reference Sediment | 4 | 31.1 | 35.4 | 251.8 | 9.44 | 0.178 | 0.161 | 29.5 | 11.0 | 0.239 |
| MID FD | Bulk Reference Sediment | 5 | 29.9 | 35.2 | 241.0 | 8.63 | 0.180 | 0.149 | 26.2 | 10.7 | 0.229 |
| CRM | Certified Reference Material | 1 | 26.1 | 39.9 | 54.4 | 18.08 | 11.16 | 9.38 | 39.2 | 11.0 | 0.062 |
| CRM | Certified Reference Material | 2 | 22.9 | 39.9 | 53.4 | 18.13 | 11.26 | 9.44 | 45.4 | 11.4 | 0.073 |
| CRM | Certified Reference Material | 3 | 23.1 | 39.6 | 55.3 | 19.54 | 11.47 | 9.51 | 52.6 | 11.1 | 0.061 |
| CRM | Certified Reference Material | 4 | 23.0 | 40.7 | 54.9 | 19.11 | 11.41 | 9.35 | 58.8 | 10.5 | 0.060 |
| CRM | Certified Reference Material | 5 | 24.1 | 40.7 | 56.2 | 18.50 | 11.38 | 9.32 | 48.9 | 11.5 | 0.066 |
| CRM | Certified Reference Material | 6 | 22.8 | 38.8 | 53.1 | 18.63 | 10.94 | 9.10 | 45.8 | 11.3 | 0.058 |
| CRM | Certified Reference Material | 7 | 23.4 | 41.3 | 54.5 | 18.63 | 11.59 | 9.25 | 43.5 | 11.0 | 0.059 |
| CRMB | Certified Reference Material | 1 | 144.1 | 30.4 | 173.4 | 3.21 | 0.444 | 0.730 | 30.3 | 14.7 | 6.165 |
| CRMB | Certified Reference Material | 2 | 147.9 | 31.3 | 178.4 | 3.34 | 0.509 | 0.733 | 31.1 | 15.5 | 6.213 |
| CRMB | Certified Reference Material | 3 | 152.1 | 30.6 | 179.6 | 3.62 | 0.466 | 0.725 | 31.2 | 14.4 | 6.059 |
| CRMB | Certified Reference Material | 4 | 153.1 | 31.6 | 184.2 | 3.75 | 0.491 | 0.750 | 32.4 | 14.1 | 6.276 |
| CRMB | Certified Reference Material | 5 | 147.4 | 30.9 | 174.8 | 3.46 | 0.459 | 0.752 | 29.8 | 15.0 | 6.215 |
| CRMB | Certified Reference Material | 6 | 151.9 | 30.6 | 177.5 | 3.60 | 0.434 | 0.742 | 31.1 | 15.6 | 6.149 |
| CRMB | Certified Reference Material | 7 | 146.8 | 30.8 | 175.7 | 3.50 | 0.584 | 0.736 | 29.3 | 14.8 | 6.170 |

# 7 Appendix C: Particle size distribution data

Sediment particle size distribution (PSD) data obtained from a single composite surface (<2cm) sample per site in 2023. 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.

| 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Awatea | Hobson Bay | 1.95 | 0.00 | 0.15 | 0.55 | 14.48 | 46.27 | 61.46 | 32.65 | 5.89 | 38.54 |
| Chelsea | Central Waitematā | 1.30 | 0.08 | 0.58 | 16.36 | 29.84 | 41.71 | 88.49 | 8.65 | 2.79 | 11.43 |
| Coxs Bay | Central Waitematā | 1.39 | 2.14 | 5.55 | 8.91 | 39.69 | 31.54 | 85.69 | 8.26 | 3.91 | 12.17 |
| Henderson Creek | Central Waitematā | 1.89 | 1.32 | 4.01 | 15.15 | 45.19 | 18.04 | 82.39 | 11.11 | 5.18 | 16.29 |
| Henderson Lower | Henderson Creek | 6.02 | 0.00 | 0.15 | 0.26 | 1.21 | 5.71 | 7.32 | 66.89 | 25.79 | 92.68 |
| Island Bay | Central Waitematā | 1.46 | 1.62 | 7.51 | 27.29 | 38.46 | 15.36 | 88.63 | 4.37 | 5.38 | 9.75 |
| Kendall Bay | Central Waitematā | 0.98 | 0.54 | 1.22 | 28.10 | 33.73 | 30.84 | 93.88 | 1.97 | 3.61 | 5.58 |
| Meola Inner | Meola Reef | 4.89 | 0.07 | 0.53 | 2.27 | 14.03 | 21.17 | 38.00 | 34.06 | 27.87 | 61.93 |
| Meola Outer | Meola Reef | 1.12 | 0.13 | 0.71 | 3.74 | 42.24 | 45.73 | 92.42 | 3.95 | 3.51 | 7.45 |
| Motions | Central Waitematā | 2.48 | 0.28 | 2.29 | 9.30 | 36.68 | 25.89 | 74.15 | 15.92 | 9.65 | 25.57 |
| Motu Manawa | Central Waitematā | 1.74 | 5.17 | 1.20 | 1.46 | 9.36 | 66.44 | 78.46 | 10.36 | 6.01 | 16.37 |
| Oakley Creek | Oakley Creek entrance | 5.16 | 0.00 | 0.49 | 1.36 | 6.98 | 12.09 | 20.93 | 62.77 | 16.30 | 79.07 |
| Purewa | Hobson Bay | 3.32 | 0.33 | 3.74 | 7.85 | 24.62 | 38.04 | 74.24 | 15.52 | 9.91 | 25.43 |
| Shoal Bay Hillcrest | Shoal Bay | 3.58 | 0.00 | 0.22 | 0.89 | 4.81 | 16.81 | 22.73 | 66.50 | 10.77 | 77.27 |
| Whakataka Bay | Hobson Bay | 1.54 | 0.16 | 0.58 | 2.47 | 33.12 | 40.43 | 76.60 | 15.41 | 7.83 | 23.24 |
| Whau Entrance | Whau Estuary | 1.46 | 0.00 | 0.10 | 0.83 | 27.23 | 53.66 | 81.81 | 14.09 | 4.09 | 18.19 |
| Whau Lower | Whau Estuary | 5.08 | 0.00 | 0.08 | 0.07 | 0.55 | 6.44 | 7.14 | 74.71 | 18.15 | 92.86 |
| Whau Upper | Whau Estuary | 6.15 | 0.00 | 1.01 | 5.03 | 10.07 | 7.96 | 24.07 | 51.84 | 24.09 | 75.93 |
| Whau Wairau | Whau Estuary | 6.36 | 0.00 | 0.24 | 0.92 | 6.45 | 11.66 | 19.26 | 60.06 | 20.68 | 80.74 |
| Middlemore BRS - MID PS72 | QA Reference Material | 4.79 | 0.00 | 0.09 | 0.49 | 14.41 | 15.08 | 30.07 | 58.02 | 11.90 | 69.93 |
| Middlemore BRS - MID PS74 | QA Reference Material | 4.70 | 0.00 | 0.14 | 0.51 | 15.17 | 16.48 | 32.30 | 46.63 | 21.06 | 67.70 |
| Middlemore BRS - MID PS9 | QA Reference Material | 4.78 | 0.00 | 0.09 | 0.56 | 15.94 | 16.15 | 32.74 | 44.01 | 23.25 | 67.26 |
| Meola Outer Zone BRS - MO PS25 | QA Reference Material | 0.66 | 1.91 | 0.31 | 0.96 | 44.23 | 49.75 | 95.25 | 0.85 | 1.99 | 2.85 |
| Meola Outer Zone BRS - MO PS50 | QA Reference Material | 0.67 | 0.33 | 0.30 | 0.96 | 46.24 | 49.20 | 96.70 | 0.99 | 1.98 | 2.97 |
| Meola Outer Zone BRS - MO PS60 | QA Reference Material | 0.65 | 0.74 | 0.40 | 1.23 | 42.39 | 52.30 | 96.32 | 1.21 | 1.73 | 2.94 |



Mud content (sediment <63µm; the sum of silt and clay particles) data obtained from a single composite surface (<2cm) sample per site in 2023. Mud content is presented as per cent of the total sediment weight.

# 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 which require low variability. The QA data are assessed for acceptability using a set of ‘acceptance guidelines’. 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 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, 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).

QA 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 are checked with the analytical laboratory, 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.

Requests can be made via Auckland Council’s environmental data portal.

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[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 on-going 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).

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

The likelihood of trends in the reference material being greater than or less than zero was assessed from the Sen Slope probability, as provided in 'Time Trends' software (Version 11.0). Note that for contaminants, an increasing trend reflects a degrading or worsening state, while a decreasing trend indicates improving conditions. 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%.
- '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 on-going 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.

Requests can be made via Auckland Council's environmental data portal.

## 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 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. 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 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 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 2023 sites

Table 8-1 summarises the QA information obtained for the 2023 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 per cent annual change was below the 1% acceptance criteria (as was the case for the other metals showing ‘likely’ trends – Cu, 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 (Meola) and Zn and Cu (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 were high (above 90%), the results are generally not occurring consistently, the per cent annual change remains low (within acceptance guidelines) and for analytes with successive ‘very likely’ probabilities in both 2022 and 2023 (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 below, sections 8.5 and 8.6 will provide more detail and present concentration values from CRM and BRS analysis.

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[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 2023 monitoring. CVs = coefficient of variation; RPDs = relative percentage difference; CLs = confidence limit; SD = standard deviation.**

| QA Measure | Acceptance guidelines | Pass Note Fail | Comments |
|---|---|---|---|
| **Blanks** | All values less than detection limits, or <10% of metal concentrations | Pass | Concentrations in procedural blanks were below detection limits for all analytes. |
| **Within site variability** | CVs <20% | Pass | Overall variability within sites is very good for all analytes. No sites exceed 20% and only two sites exceed 10% (both for Hg). |
| **Within Batch blind duplicates** | RPDs <30% | Pass | Three samples analysed in duplicate by Hill labs in-house QA. RPDs ranged from 0.1 - 11.2% with no exceedances of the 15% threshold. The highest RDP was for copper. Overall, good within batch agreement. |
| **Certified Reference Material** | Accuracy: Results within lab control limits (+/- 3s, or 99% CLs) | Pass | Seven CRM (AGAL-10) samples analysed as unknowns for total recoverable metals. Means <10% of certified values for metals As, Cu, Pb, Hg, Zn and Cd. One individual sample was outside lab in-house control limits - Cu 26.1 mg/kg just above the upper control limit of 25.1 mg/kg. Low recoveries reported for chromium and nickel may be due to differences in digestion methodologies for the extraction of metals. |
|  | Variability: Within-batch CV <10% | Pass | Variability <10%. CVs between 1.4 - 4.9% for all metals (excluding Cr and Ni). |
|  | 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 -1.3% (As) and +4.1% (Hg). |
|  | Temporal stability: No trends over time >1% of median concentration per year (and "very likely" likelihood; Sen Slope P>90%). | Note<br>Hg with "very likely" trend probability | Trends over time to Nov 2023 were small: between 0.06-0.51% per year. Cu, Pb, Zn and As had "likely" trends, while Hg had "very likely" so has been 'noted', but low per cent annual change (0.51%) so not of major concern at this stage. |
| **Lab In-House Reference Material (optional)** | Accuracy: Results within lab control limits | Pass | 16 samples of 'QC-A6' were included through the analytical run. Variability (CVs) <11.7% for all metals. Mean concentrations <10% of reference values for all metals except As (87.6%). Overall, the QC-A6 CRM results indicate good accuracy and precision for Cu, Pb, Zn, Hg, Cd and Ni in the November 2023 sample analytical batch. As values were slightly lower compared to previous years. |
| **Bulk Reference Sediments:** |  |  |  |
| Total Recoverable Metals | Accuracy: Results within lab control limits (+/- 3sd) | Pass | All metals' results within control limits. |
|  | Within-year variability: CVs <10%. | Pass | Within-year variability met targets for all metals (CVs 1.1 - 4.7%). 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 -0.25 - 8.06%). |
|  | Temporal stability: No trends over time >2% of median concentration per year (and "very likely" likelihood; Sen Slope P>90%). | Note - Overall good results and generally meet acceptance criteria.<br>Watch increasing trend for As (Meola), and Zn and Cu (Middlemore). | BRS trends over time for Nov 2011 to Nov 2023 were all <2% per year annual change. Zn continues to improve since 2020 but still high (97% probability and 1.13% annual change at Middlemore). "Very likely' increasing trends for As (Meola) and Zn and Cu (Middlemore). As showing slight improvement on 2022 results. Watch closely for trends in future. Cu <1% per year annual change so not of concern at this stage but watch closely. |
| Particle Size Distribution (PSD) | Accuracy: Results within lab control limits (+/- 3sd) | Pass | All mud content values within control limits |
|  | Within-year variability: CVs <10%. | Pass | CVs <10%. CV of 2.1% for Middlemore and 2.2% for Meola. |
|  | Temporal stability: Means of new data within 10% of previous data means | Pass | 2023 mean mud content within 2.0% of the previous data mean for Middlemore and within 1.07% of the previous data mean for Meola. |
|  | 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 (0.26%). |
| **OVERALL ASSESSMENT** |  | **Total metals**<br>**Note: increasing Zn and Cu trend in Middlemore BRS. Increasing trend for As in MeOZ BRS.** | Metals' results for 2023 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 2022 results. The high Zn continues to improve from those reported in 2020. Continue to watch closely as data builds. |
|  |  | **PSD**<br>**Pass** | All QA targets for particle size distribution met in 2023. |

## 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 upon 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 11.0).

Note: The additional metal cadmium has been included in the CRM results table, however chromium, nickel and silver have not. Low recoveries were observed when compared with CRM for these metals. Hill Laboratories advised that low recoveries reported for chromium and nickel are due to differences in acid digestion methodologies and they consistently report low concentrations for these metals. When compared with lab inhouse reference values, chromium (Cr), nickel (Ni), and silver (Ag) showed good accuracy and precision with the average results for Cr and Ni 96% and 95% respectively. No certified values were reported for Ag in the certificate of analyses and therefore it is not shown here.

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 (0.51%). ‘Likely’ increasing trends were observed for Cu, Pb, Zn and As, again with very low (<1%) rates of annual change. When compared with the certified value, no metals had a mean outside the 10% acceptance criteria (values between 95.7% - 108.5%). All results are within upper and lower limits (± 1 SD) of the certified reference value except for one Cu value (26.1 mg/kg, slightly above the limit of 25.1 mg/kg). 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 2023 sediment sample batch.**

| | QA Acceptance | Total Recoverable Metals (<500 µm) | | | | | |
|---|---|---|---|---|---|---|---|
| Sample i.d. and quality assurance measures | Pass Note Fail | Cu | Pb | Zn | As | Hg | Cd |
| CRM - Agal 10 - 1 | Pass | 26.1 | 39.9 | 54.4 | 18.1 | 11.2 | 9.4 |
| CRM - Agal 10 - 2 | Pass | 22.9 | 39.9 | 53.4 | 18.1 | 11.3 | 9.4 |
| CRM - Agal 10 - 3 | Pass | 23.1 | 39.6 | 55.3 | 19.5 | 11.5 | 9.5 |
| CRM - Agal 10 - 4 | Pass | 23.0 | 40.7 | 54.9 | 19.1 | 11.4 | 9.4 |
| CRM - Agal 10 - 5 | Pass | 24.1 | 40.7 | 56.2 | 18.5 | 11.4 | 9.3 |
| CRM - Agal 10 - 6 | Pass | 22.8 | 38.8 | 53.1 | 18.6 | 10.9 | 9.1 |
| CRM - Agal 10 - 7 | Pass | 23.4 | 41.3 | 54.5 | 18.6 | 11.6 | 9.2 |
| New mean | n/a | 23.6 | 40.1 | 54.5 | 18.7 | 11.3 | 9.3 |
| Variability in new mean (CV, %) | Pass | 4.9 | 2.1 | 2.0 | 2.8 | 1.9 | 1.4 |
| Mean of all previous CRM data | n/a | 22.98 | 40.25 | 54.2 | 18.91 | 10.856 | 9.26 |
| Difference between new and previous data means (RPD, %) | Pass | 2.8 | -0.3 | 0.6 | -1.3 | 4.1 | 0.8 |
| New mean, as % of certified value | Pass | 101.9 | 99.3 | 95.7 | 108.5 | 97.5 | 100.4 |
| Trends (% annual change, Sen Slope) | Pass | 0.06 | 0.1 | 0.17 | 0.3 | 0.51 | Na |
| Trends (probabilities, Sen Slope p values) | Note Cu, Pb, Zn, As. Fail Hg | 0.7 | 0.85 | 0.88 | 0.7 | 0.99 | Na |
| Trends (likelihood based on Sen Slope p values) | Note Cu, Pb, Zn, As. Fail Hg | likely | likely | likely | likely | very likely | Na |
| 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** | **Pass** | **Note** | **Pass** |
| Comments | Small (<1%/year) but likely trends for Cu, Pb, Zn and As. Small (<1%/year) very likely trend for Hg. All new means close to previous values (RDP % < 4.1). One value (Cu) slightly greater than 1 sd from upper reference limit. | Note small likely increasing trend <1%/year | Note small likely increasing trend <1%/year | Note small likely increasing trend <1%/year | Note small likely increasing trend <1%/year | Note very likely increasing trend <1%/year | Low variability in new mean. Trend analysis not available. |

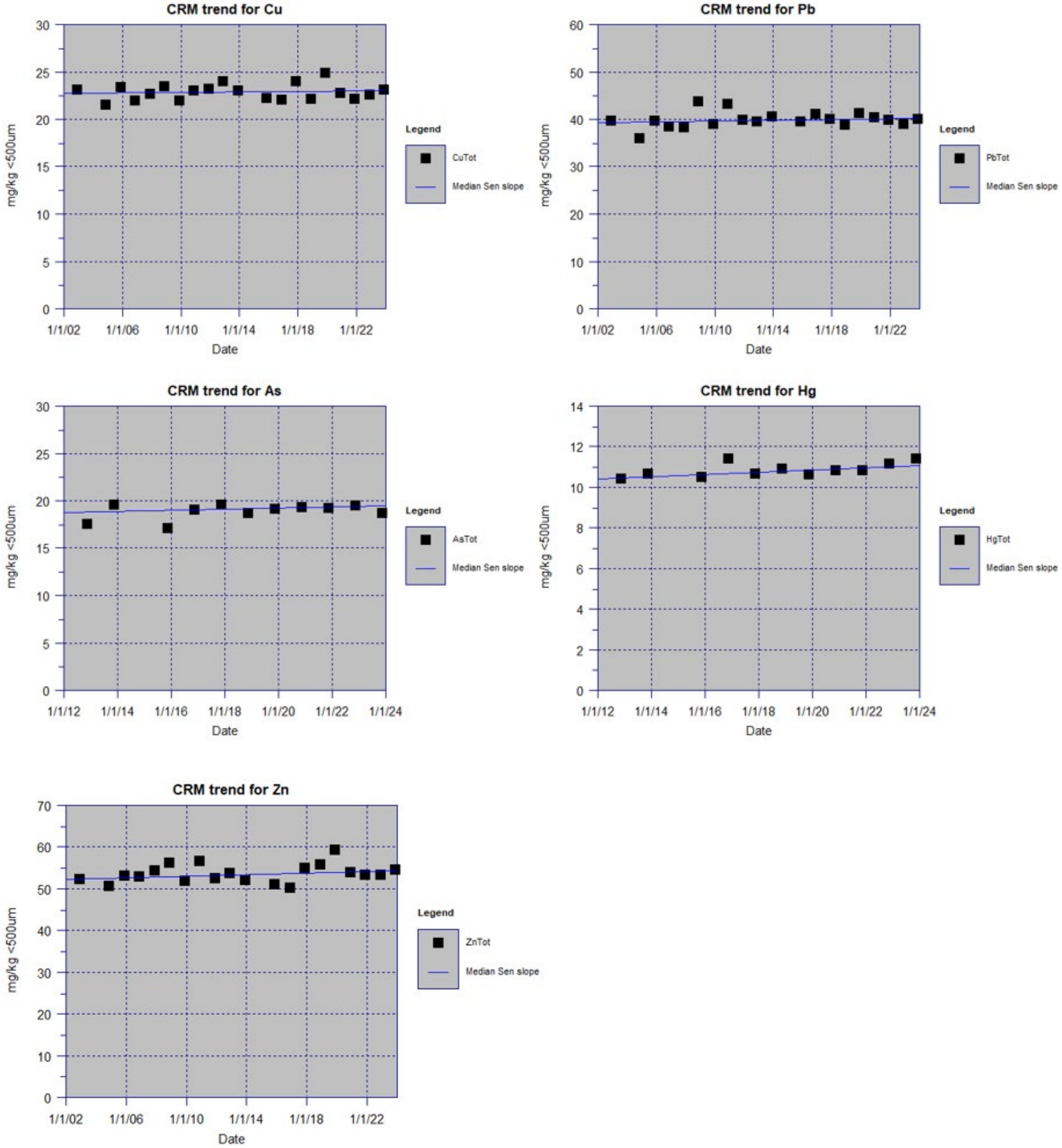


**Figure 8-1. Certified Reference Material (CRM) results for total recoverable metals in CRM AGAL-10 samples analysed with RSCMP samples taken from 2002 to 2023. The plots show annual medians. The line is a linear regression.**

## 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; 12 so far from 2011 to 2023. 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 2023 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 11.0).

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 freeze dried. 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 because drying, including freeze-drying, may alter particle aggregation in sediments. The frozen BRS samples are thawed and homogenised prior to PSD analysis, following the same procedure as the RSCMP field samples.

### 8.6.1 Meola Outer Zone BRS

The total recoverable metals' results from the 2023 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 2023 are shown in Figure 8-2.

The metals' results for the Meola Outer Zone BRS in 2023 are a '**note**', having failed one acceptance criteria (a 'very likely' increasing trends for As). Percent annual change for As also received a 'note', with a value above 1% (1.14%). This result has improved slightly from 2022, dropping in both per cent annual change (from 1.38%), and trend probability (from 96% to 93%), however will need to be watched closely in future. In addition, several 'notes' were made for 'likely' (probability 67-90%) trends occurring for Mud, Cu, Pb, Zn, and Hg, however the per cent annual change for these are all low (<1%). The Meola Outer Zone BRS trend plots obtained for total recoverable metals Cu, Pb, Zn, As, Hg, and mud content since 2011 depict slightly increasing trends for Pb, Zn and Cu, a stronger increasing trend for As, and weak decreasing trends for Hg and mud content (see Figure 8-2).

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 <8.06%).

The results for the Meola Outer Zone BRS obtained in 2023 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 2023 RSCMP sample batch.**

| Sample ID and QA measures | QA Guidelines<br>Pass Note Fail | Mud Content<br>% <63 µm | Total Recoverable Metals (mg/kg, <500 µm)<br>Cu | Pb | Zn | As | Hg |
|---|---|---|---|---|---|---|---|
| Meola OZ BRS 1 | Pass | 2.85 | 2.87 | 8.73 | 41.70 | 2.73 | 0.0349 |
| Meola OZ BRS 2 | Pass | 2.97 | 3.01 | 8.98 | 41.22 | 2.59 | 0.0327 |
| Meola OZ BRS 3 | Pass | 2.94 | 2.99 | 9.51 | 39.91 | 2.60 | 0.0317 |
| Meola OZ BRS 4 | Pass | | 3.01 | 9.17 | 42.08 | 2.85 | 0.0307 |
| Meola OZ BRS 5 | Pass | | 3.25 | 8.80 | 43.00 | 2.80 | 0.0326 |
| New mean | Pass | 2.92 | 3.03 | 9.04 | 41.58 | 2.71 | 0.033 |
| Variability in new data (CV, %) | Pass | 2.2 | 4.6 | 3.5 | 2.7 | 4.3 | 4.7 |
| Difference between new and previous data means (RPD, %) | Pass | -1.07 | 1.52 | 0.42 | 1.19 | -0.25 | 8.06 |
| Trends (% annual change, Sen Slope) | Note As | -0.26 | 0.34 | 0.37 | 0.64 | 1.14 | -0.42 |
| Trends (probabilities, Sen Slope p values) | Fail As. Note others. | 0.80 | 0.74 | 0.88 | 0.83 | 0.93 | 0.78 |
| Trends (likelihood based on Sen Slope p values) | Fail As. Note others. | likely | likely | likely | likely | very likely | likely |
| Overall mean of previous data | n/a | 2.95 | 2.98 | 9 | 41.09 | 2.72 | 0.03 |
| Lower control limit (mean - 3sd) | n/a | 2.5 | 2.47 | 7.62 | 32.51 | 2 | 0.018 |
| Upper control limit (mean + 3sd) | n/a | 3.4 | 3.48 | 10.38 | 49.67 | 3.44 | 0.042 |
| Overall assessment | **Note** | **Pass** | **Pass** | **Pass** | **Pass** | **Note** | **Pass** |
| Comments | Overall good results and generally meet acceptance criteria. Watch As for trends. % annual change slightly lower than 2022. | Likely decreasing trend, <1% per year. | Likely increasing trend, <1% per year. | Likely increasing trend, <1% per year | Likely increasing trend, <1% per year | Very likely increasing trend but <2% per year | Likely decreasing trend, < 1% per year |

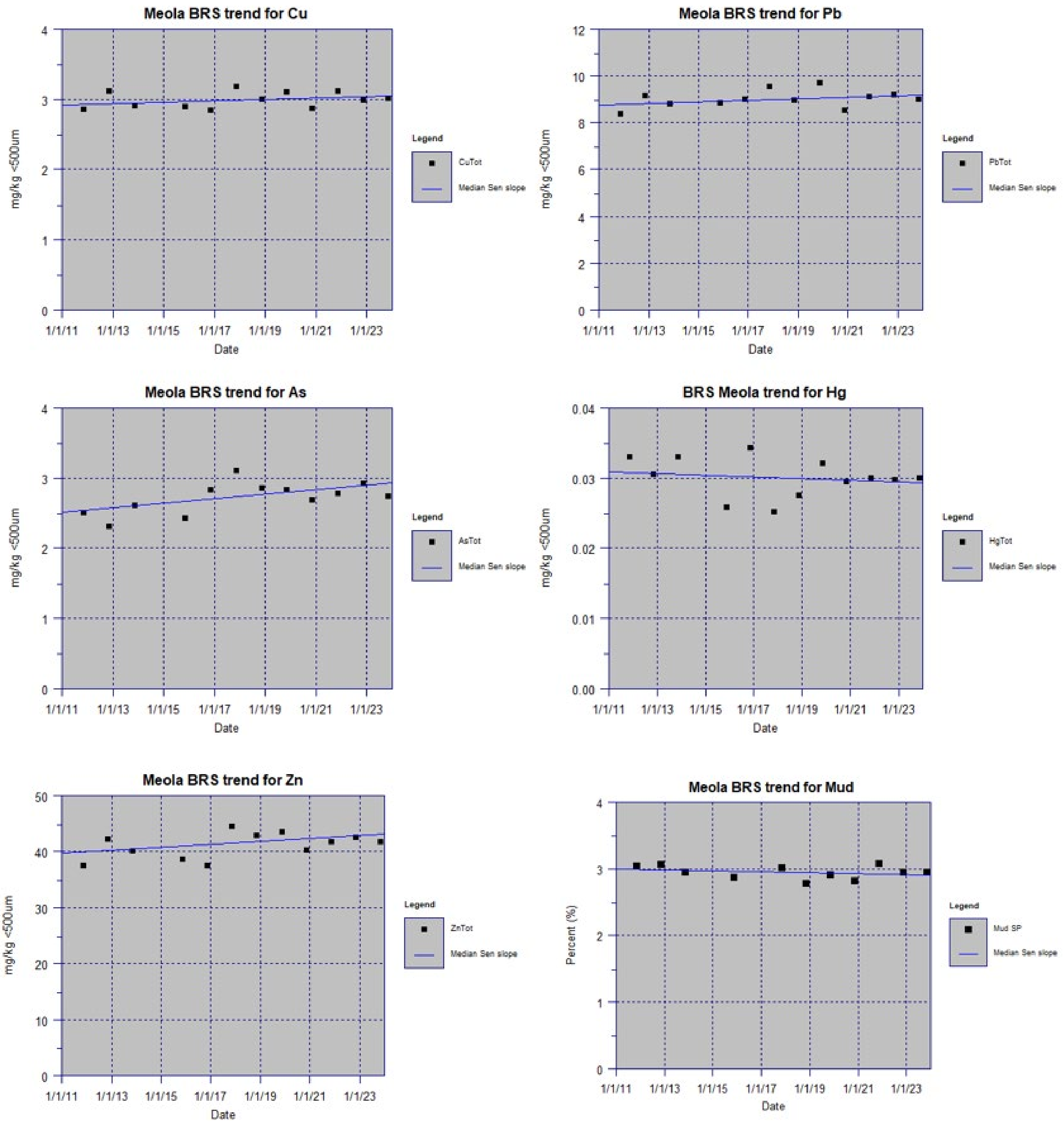


**Figure 8-2. Plots of median data for Meola Outer Zone BRS metals and mud samples, November 2011 to November 2023. Metals are in mg/kg <500µm fraction, mud is silt + clay <63µm fraction.**

### 8.6.2 Middlemore BRS

The total recoverable metals' results from the 2023 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 2023 are shown in Figure 8-3. The results for the Middlemore BRS obtained in 2023 were generally consistent with previous years and mostly met acceptance guidelines.

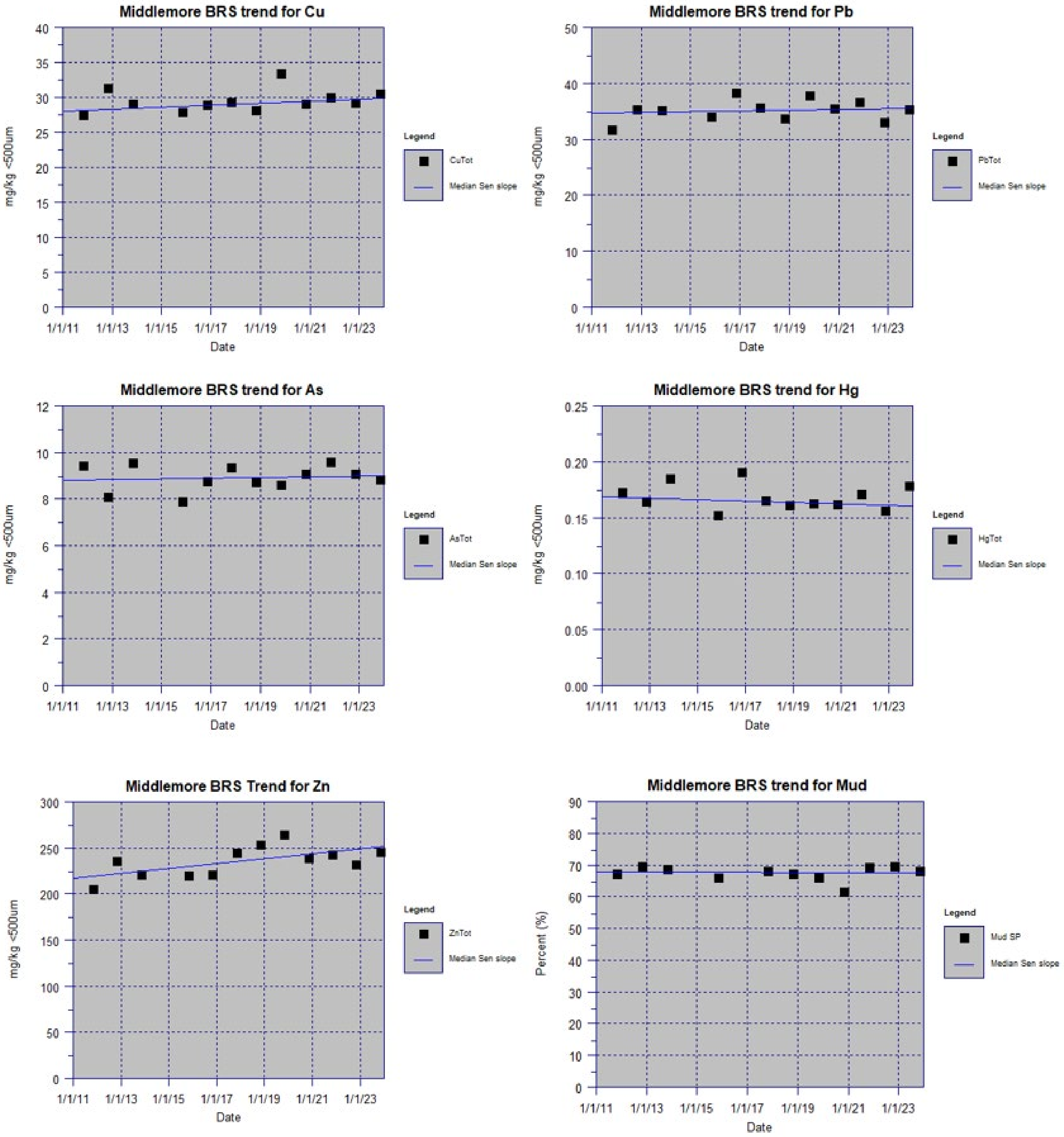
Two acceptance guideline '**fails**' were observed due to a 'very likely' increasing trend observed in Zn and Cu, however the per cent annual change was below the 2% criteria for both metals (1.13% for Zn and 0.50% for Cu). In addition, a 'note' was made for a 'likely' decreasing trend for Hg (probability 74%), however this showed a very low per cent annual change (0.36%) and is not currently of concern. 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 Zn and Cu. The continual reduction in the rate of increase observed in Zn trends in 2023 compared to that of 2022 (down from 1.27% annual change to 1.13% annual change) is encouraging. It is anticipated that the trend probability and per cent annual change for Zn will continue to decrease following the improvements made in analytical methods in 2019. Ongoing analyses will confirm if this is in fact occurring. Cu needs to be watched closely in coming years. The trend probability has moved from 'likely' (86%) to 'very likely' (0.93%), however the percent annual change remains low (0.50%).

**Table 8-4. Quality assurance results for Bulk Reference Sediment (BRS) samples from Middlemore analysed with the 2023 RSCMP sample batch.**

| | QA Guidelines | Mud Content | Total Recoverable Metals (mg/kg, <500 µm) | | | | |
|---|---|---|---|---|---|---|---|
| Sample ID and QA measures | Pass Note Fail | % <63 µm | Cu | Pb | Zn | As | Hg |
| Middlemore BRS 1 | Pass | 69.93 | 29.6 | 34.6 | 239.8 | 8.75 | 0.170 |
| Middlemore BRS 2 | Pass | 67.70 | 30.4 | 35.0 | 244.3 | 8.85 | 0.179 |
| Middlemore BRS 3 | Pass | 67.26 | 30.6 | 35.6 | 249.0 | 9.34 | 0.170 |
| Middlemore BRS 4 | Pass | | 31.1 | 35.4 | 251.8 | 9.44 | 0.178 |
| Middlemore BRS 5 | Pass | | 29.9 | 35.2 | 241.0 | 8.63 | 0.180 |
| New mean | Pass | 68.3 | 30.3 | 35.1 | 245.2 | 9.00 | 0.175 |
| Variability in new data (CV, %) | Pass | 2.1 | 2.0 | 1.1 | 2.1 | 4.1 | 2.8 |
| Difference between new and previous data means (RPD, %) | Pass | 2.0 | 3.7 | 0.5 | 4.6 | 2.8 | 5.5 |
| Trends (% annual change, Sen Slope) | Note Zn | -0.02 | 0.50 | 0.19 | 1.13 | 0.17 | -0.36 |
| Trends (probabilities, Sen Slope p values) | Fail Zn and Cu. Note Hg. | 0.58 | 0.93 | 0.66 | 0.97 | 0.58 | 0.74 |
| Trends (likelihood based on Sen Slope p values) | Fail Zn and Cu. Note Hg. | indeterminate | very likely | indeterminate | very likely | indeterminate | likely |
| Overall mean of previous data | n/a | 66.97 | 29.23 | 34.98 | 234.1 | 8.75 | 0.166 |
| Lower control limit (mean - 3sd) | n/a | 59.1 | 24.0 | 29.1 | 177.4 | 6.86 | 0.127 |
| Upper control limit (mean + 3sd) | n/a | 74.8 | 34.5 | 40.86 | 290.8 | 10.64 | 0.205 |
| Overall assessment | **Note** | **Pass** | **Note** | **Pass** | **Note** | **Pass** | **Pass** |
| Comments | Overall good results and generally meet acceptance criteria. Increasing trend <2% per year for Zn. Continual improvement since 2020, keep close watch. Watch trends for Cu, very likely direction but low % annual change. | Indeterminate trend, <1% per year. | Very likely increasing trend, <1% per year. | Indeterminate trend, <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 |



Middlemore BRS trend for Cu

Middlemore BRS trend for Pb

Middlemore BRS trend for As

Middlemore BRS trend for Hg

Middlemore BRS Trend for Zn

Middlemore BRS trend for Mud

**Figure 8-3. Plots of median data for Middlemore BRS metals and mud samples, November 2011 to November 2023. Metals are in mg/kg <500µm fraction, mud is silt + clay <63µm fraction.**

Find out more:
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