Tāmaki Makaurau / Auckland Marine Sediment Contaminant Monitoring: Data report for 2021

Manukau Harbour

Hamish Allen

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Cover images:
Looking towards the Karaka / Te Hihi Estuary monitoring site, Manukau Harbour.
Looking towards the Hillsborough monitoring site and across to the Māngere coastline, Manukau Harbour.

Photographs by Hamish Allen (RIMU)

Executive summary

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

This report describes the monitoring undertaken in November 2021 for Auckland Council's Regional Sediment Contaminant Monitoring Programme (RSCMP), with all sites located in the Manukau Harbour.

The report provides:

- an overview of the RSCMP monitoring programme
- description of the sampling undertaken in 2021
- the sediment contaminant (metals) and particle size distribution (PSD) results obtained for the 2021 samples
- a summary of contaminant (metals) state and changes over time in state
- quality assurance (QA) assessments undertaken to verify the data were acceptable for the purposes of the RSCMP.

Sediments from 27 sites in the Manukau Harbour were sampled for contaminant analysis. Samples used for sediment chemistry analysis were processed and analysed for the following metals: copper (Cu), lead (Pb), zinc (Zn), arsenic (As), and mercury (Hg). Total recoverable metals, on the <500 µm fraction, were analysed. One composite sample from each site was also analysed for particle size distribution (PSD).

The quality assurance data analysis indicated that the total recoverable metals' data were of adequate quality, with the Certified Reference Material (CRM) and Bulk Reference Sediment (BRS) data being generally acceptable. Despite some CRM and BRS samples giving a small number of results that rated as a 'fail' or 'note' on some QA acceptance criteria (mainly in relation to temporal stability), indicating that some values were slightly outside the 'pass' guidelines, overall, the metals and particle size distribution data obtained in 2021 are considered suitable for use in the RSCMP.

Contaminant state (metals) are compared with Australian and New Zealand Guidelines for fresh and marine water quality (ANZG) and Auckland Council Environmental Response Criteria (ERC). The results showed a spatial pattern consistent with previous monitoring, with largely low levels of contamination (ERC-green status) at the majority of sites across the Manukau Harbour. Two sites located at the head of the harbour in the Māngere Inlet (Harania and Anns Creek) showed moderate levels of zinc contamination (ERC-amber status). These sites have shown elevated levels of metals (most commonly zinc), since monitoring began in 1998 (Anns Creek), and 2005 (Harania). Encouragingly, no sites in the harbour recorded contamination levels in the ERC-red status.

In general, ERC contaminant status (for metals Cu, Pb and Zn) has remained relatively stable over time at sites in the Manukau Harbour. Changes in state did occur at Anns Creek, dropping from Zn levels in the ERC-red status to the ERC-amber status, and Waimāhia Central, dropping from Zn levels in the ERC-amber status to the ERC-green status. It is possible that the change in state at these sites is attributable to previous issues with Zn analysis during the last samplings at these sites in 2018 (Anns Creek), and 2019 (Waimāhia Central), rather than actual decreasing concentrations. Changes in state refer to a change relative to ERC threshold levels only. More sensitive trend analysis (statistical analysis of the monitoring data to obtain the magnitude and direction of change over time) can be found in Mills and Allen, 2021.

Table of contents

List of figures

List of tables

1 Introduction

1.1 Programme overview

Chemical contaminants originating from land-based activities (e.g., urban stormwater discharges) can accumulate in the sediments of estuarine and marine receiving environments. The build-up of contaminants in sediments is of concern because it can adversely affect ecological health, by reducing the abundance and/or diversity of sensitive sediment-dwelling species. This can result in degraded communities dominated by animals that are tolerant of higher contaminant levels. This has the potential to affect both the immediate area, 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 monitoring, contributes information about land use impacts on the health of aquatic receiving environments, and the effectiveness of resource management initiatives and policies in mitigating adverse effects arising from land use activities. Auckland Council's Regional Sediment Contaminant Monitoring Programme (RSCMP) conducts regular monitoring across the region's harbours and estuaries. The RSCMP has amalgamated monitoring previously undertaken in three Auckland Regional Council (ARC) sediment contaminant monitoring programmes (see Mills and Allen (2021) for further detail on programme history).

The RSCMP aims to achieve the following objectives:

1. Provide assessment of the state of near shore marine sediment contamination using relevant guidelines where applicable.
2. Maintain regionally representative coverage, with an emphasis on areas undergoing change.
3. Provide data which allows the trends in sediment quality to be assessed over time.
4. Undertake studies to increase understanding and identify new and developing marine sediment contamination issues.

Information collected in the RSCMP is available for a wide range of end users and stakeholders. Uses of the monitoring data include State of the Environment reporting, stormwater quality management, resource consenting, policy development and public education.

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

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

In addition to sampling carried out as part of the RSCMP, sediment contaminant sampling has also been carried out in conjunction with benthic ecology monitoring in a number of additional estuaries and harbours around the Auckland region. Data for these sites can be found in Hailes et al. (2010) and Allen (2021) for the Kaipara Harbour; Townsend et al. (2010) for the Whangateau Harbour; Halliday and Cummings (2012) for the Mahurangi Estuary; Hewitt and Simpson (2012) for Waiwera, Puhoi, Mangemangeroa, Waikopua, Okura, Turanga, and Ōrewa estuaries, and Lohrer et al. (2012) and Mills (2021) for the Wairoa embayment.

In 2022, a review of the RSCMP took place, focussing on site selection, sampling frequency and programme structure (Allen, 2022). This included a review of all sites in the RSCMP network, a region wide gap analysis with an emphasis on areas where no/limited monitoring takes place and urban development is either planned or already underway, and an assessment of the current sampling frequency. As a result of the review several changes have been enacted, including establishing a temporally nested monitoring approach and extending sampling frequency, along with annual sampling focussing on specific locations, allowing more complete reporting of an area each year to take place (hence the full complement of sites in the Manukau Harbour being sampled in 2021). A report of the review documenting the process and outcomes is available on request.

1.2 Sampling

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

Sampling is usually conducted in October-November each year, to align with optimal timing for benthic ecology sampling, which is conducted at the same time as the contaminant sampling. 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).

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. Cu and Zn concentrations have generally been predicted to increase in sediments receiving urban stormwater runoff, while Pb is anticipated to decrease as its use has declined over time, particularly since the mid-1990s when it was removed from petrol. Arsenic and mercury are toxic contaminants sometimes present at elevated concentrations in Auckland marine sediments. Sources and trends for As and Hg are currently unclear, so routine analysis was instituted in 2012 to obtain more information on state and trends.

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

Prior to 2015, weak acid extractable metals in the <63 µm 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. The <63 µm fraction metals' data may be of value at some sites where trends in fine sediment contamination in variable-textured sediments are a particular focus (e.g., Long Bay stream sites), or in more detailed investigations at more contaminated sites (e.g., following the Australian and New Zealand Guidelines for fresh and marine water quality (ANZG, 2018) tiered evaluation protocols).

1.3.2 Organic contaminants

Persistent organic pollutants (POPs) such as polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides (OCPs), and polychlorinated biphenyls (PCBs) have also been analysed at times in the past. These contaminants are now scheduled to be analysed much less frequently than for metals and only at selected 'at risk' sites (see Mills 2014a and 2014b). This is because the analyses are much more expensive to reliably perform than for metals, ecosystem health is expected to be less sensitive to POPs than metals at most sites, and the concentrations are not anticipated to increase much over time. No sites sampled in 2021 were analysed for organic contaminants.

1.3.3 Emerging organic contaminants and microplastics

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

Microplastics (plastic particles <5mm in size) are increasingly being reported as contaminants in sediments and surface waters globally. Sources are many and varied and can include synthetic textiles, packaging, pre-production pellets, personal care products, and as a result of degraded larger plastic waste. International research indicates that microplastics are widespread and persistent in the environment, with the potential to cause harmful ecological impacts (e.g., Gola et al., 2021). A study identifying quantity and characteristics of microplastics in sediment was undertaken at 39 coastal sites across Auckland, finding microplastic contamination at the majority of locations studied, including at 10 out of 11 sites sampled in the Manukau Harbour (Bridson et al., 2020).

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

1.3.4 Particle size distribution

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

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

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

1.4 Data and reporting

1.4.1 Data reporting

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

1.4.2 State and trend reporting

Every few years the monitoring data have been analysed to assess spatial distribution (state) and temporal trends in contamination. State and trends in metals and PAH were reported by Mills et al. (2012), covering monitoring data collected between 1998 and 2010 (inclusive). Organochlorines – organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) – and emerging contaminants were reviewed in Mills (2014a and 2014b). Trends in metals' concentrations from 2004 to 2019 have recently been published (Mills & Allen, 2021).

1.4.3 Land, Air, Water Aotearoa (LAWA)

The Land, Air, Water Aotearoa (LAWA) data portal (https://www.lawa.org.nz/) displays sediment contaminant information for sites in the Auckland region under the 'Estuary Health' topic. Data is displayed at all sites where sampling has taken place since 2010. The LAWA portal also describes estuary and individual site characteristics, and broadly outlines contaminant impact in estuaries and monitoring methodology. Results can be viewed alongside a range of different 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 operation

The data quality and operation of the RSCMP for the period 1998-2012 were reviewed by Mills and Williamson (2014). Commentary on sites, sampling approach, analysis methods, and quality assurance protocols were made, and based on the findings some of the recommendations made to improve future monitoring and investigations were implemented. General programme operation including field practices, sample processing and QA/QC, is detailed in an internal 'working' protocol. Further details of the monitoring programme design and operation are given in a number of reports, including ARC (1999 and 2004), Kelly (2007), Lundquist et al. (2010), Townsend et al. (2015), Mills (2016), and Mills and Allen (2021).

1.4.5 Additional reports

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

1.4.6 Additional data

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

1.4.7 Data archiving

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).

1.5 Sample archiving

At least 100 g of dry, <500 µm sieved sediment is retained from each sediment sample for archiving.

The purpose of the sample archive is to provide sufficient sample in case future reanalysis is required, for example for checking trends or analysis of historical samples for new contaminants that have not been routinely monitored. These samples are stored in an Auckland Council storage facility.

2 Sampling conducted in 2021

2.1 Sites

Sediments from a total of 27 RSCMP sites were sampled for chemical contaminant analysis. The sites sampled comprised the complete site list for the Manukau Harbour, including:

- five sites along the northern coastline
- four sites in the Māngere Inlet
- three sites in the Pukaki Inlet
- one site from the Waiuku River
- one site from Karaka/Te Hihi estuary
- one site from Puhinui estuary
- two sites from the Mauku/Taihiki River, and
- ten sites from the Pāhurehure Inlet.

The majority of sampling was undertaken by NIWA, except for six sites which were sampled by Auckland Council staff. Samples were taken between November 1st and November 10th, 2021.

The locations of the 27 sites monitored in 2021 are shown in Figure 2-1.

A list of sites, sampling dates, and analyses conducted at each site are given in Table 2-1.

Potential pressures associated with developing urban areas and increasing population prompted the recent establishment of four new sites along the Manukau Harbour's south-eastern shoreline. Sites Karaka/Te Hihi Estuary, Mauku/Taihiki River A, Mauku/Taihiki River B and Whangamaire were established in 2019 and sampled for the second time in 2021. The establishment of monitoring sites in marine ecosystems adjacent to urban development will allow us to gauge the effects of land use changes on sediment contaminant levels in these areas.

More detailed information on RSCMP sites, including coordinates and key physical characteristics, is available on request.

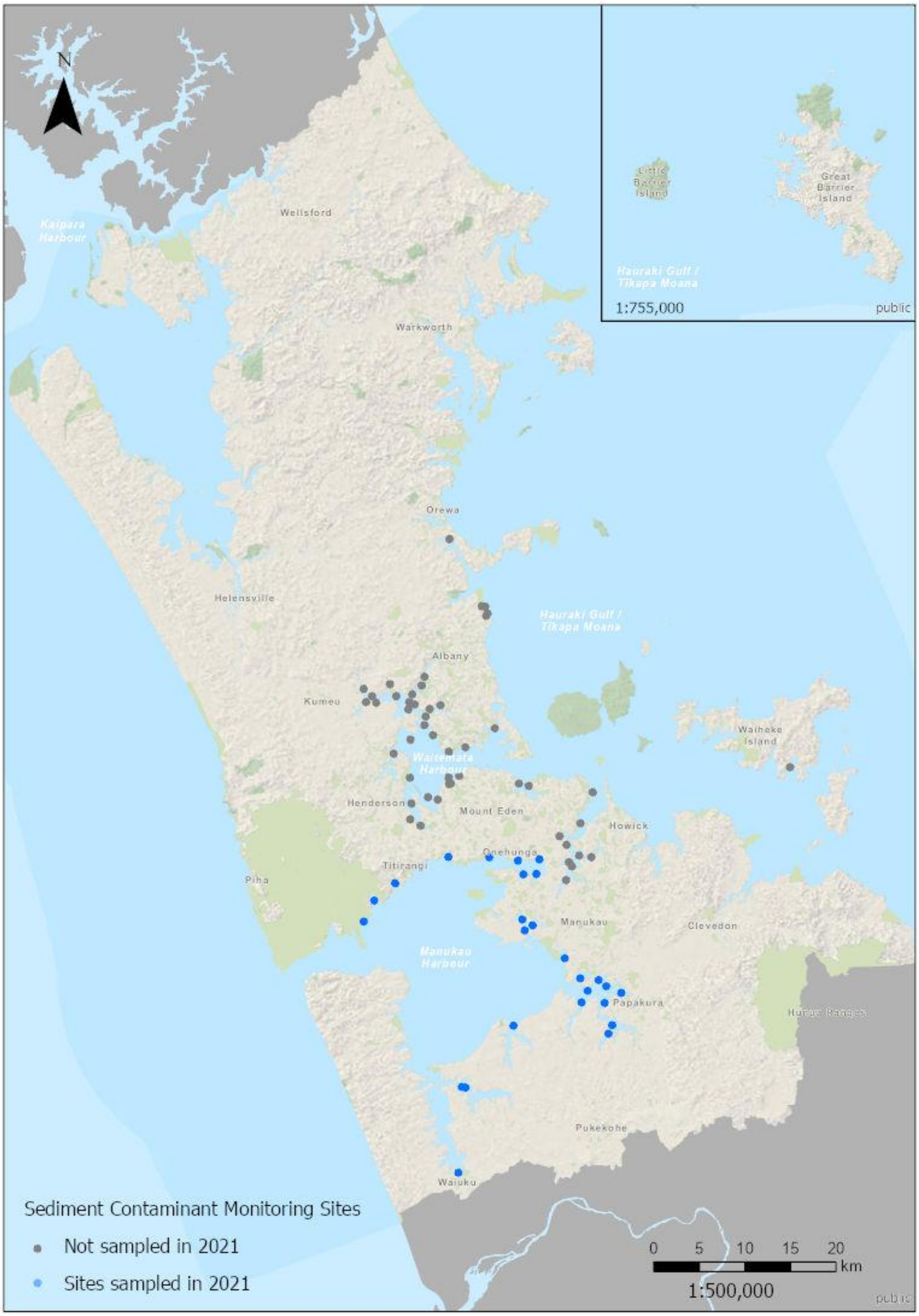

Figure 2-1. Regional Sediment Contaminant Monitoring Programme sites sampled in 2021.

Table 2-1. Regional Sediment Contaminant Monitoring Programme sites sampled and analyses conducted in 2021. Colours distinguish site location within the Manukau Harbour.

Site	Harbour	Location	Sampling Date	Sampled by	<500 µm fraction	Benthic Ecology	Particle Size
					Total Cu Pb Zn As Hg		
Anns Creek	Manukau	Māngere Inlet	2/11/2021	NIWA	✓	✓	✓
Harania	Manukau	Māngere Inlet	1/11/2021	NIWA	✓	✓	✓
Māngere Cemetery	Manukau	Māngere Inlet	2/11/2021	NIWA	✓	✓	✓
Tararata	Manukau	Māngere Inlet	1/11/2021	NIWA	✓	✓	✓
Blockhouse Bay	Manukau	Northern Coast	10/11/2021	AC	✓	✓	✓
Big Muddy	Manukau	Northern Coast	2/11/2021	NIWA	✓	✓	✓
Hillsborough	Manukau	Northern Coast	10/11/2021	AC	✓	✓	✓
Little Muddy	Manukau	Northern Coast	3/11/2021	NIWA	✓	✓	✓
Mill Bay	Manukau	Northern Coast	3/11/2021	NIWA	✓	✓	✓
Mauku/Taihiki River A	Manukau	Mauku River	4/11/2021	NIWA	✓	✓	✓
Mauku/Taihiki River B	Manukau	Mauku River	4/11/2021	NIWA	✓	✓	✓
Whangamaire	Manukau	Pāhurehure Inlet	8/11/2021	AC	✓	✓	✓
Whangapouri	Manukau	Pāhurehure Inlet	8/11/2021	AC	✓	✓	✓
Bottle Top Bay	Manukau	Pāhurehure Inlet	5/11/2021	NIWA	✓	✓	✓
Doc Island Mud	Manukau	Pāhurehure Inlet	5/11/2021	NIWA	✓	✓	✓
Drury Inner	Manukau	Pāhurehure Inlet	5/11/2021	NIWA	✓	✓	✓
Pāhurehure Middle	Manukau	Pāhurehure Inlet	1/11/2021	NIWA	✓	✓	✓
Pāhurehure Papakura	Manukau	Pāhurehure Inlet	5/11/2021	NIWA	✓	✓	✓
Pāhurehure Upper	Manukau	Pāhurehure Inlet	4/11/2021	NIWA	✓	✓	✓
Papakura Lower	Manukau	Pāhurehure Inlet	4/11/2021	NIWA	✓	✓	✓
Waimāhia Central	Manukau	Pāhurehure Inlet	5/11/2021	NIWA	✓	✓	✓
Puhinui Upper	Manukau	Puhinui	5/11/2021	NIWA	✓	✓	✓
Pukaki Airport	Manukau	Pukaki Inlet	1/11/2021	NIWA	✓	✓	✓
Pukaki Upper	Manukau	Pukaki Inlet	1/11/2021	NIWA	✓	✓	✓
Pukaki Waokauri	Manukau	Pukaki Inlet	1/11/2021	NIWA	✓	✓	✓
Karaka/ Te Hihi Estuary	Manukau	Te Hihi Inlet	9/11/2021	AC	✓	✓	✓
Waiuku	Manukau	Waiuku Inlet	9/11/2021	AC	✓	✓	✓

2.2 Sediment chemistry samples

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

A sub-sample of each of the five replicates of the sieved and freeze-dried samples (<500 µm) from each site was provided to R J Hill Laboratories (Hamilton) by NIWA for metals' analysis. Sediment samples were analysed for total recoverable metals – copper (Cu), lead (Pb), zinc (Zn), arsenic (As), and mercury (Hg) – on the <500 µm fraction (summarised in Appendix A).

Remaining freeze-dried <500 µm sieved sediment from each replicate was placed in glass jars and archived in an Auckland Council storage facility.

2.3 Particle size distribution samples

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

2.4 Benthic ecology

Benthic ecology sampling was undertaken at all sites monitored in 2021. Briefly, this involves the collection of 10 large cores (13 cm diameter, 15 cm depth) from across the site, which are then sieved over a 500 µm mesh, and specific taxa enumerated during later laboratory analysis (see Drylie (2021) for further detail). Ecology data will be analysed and reported separately to this report.

2.5 Concentration units for metals

Concentrations for metals are presented in milligrams per kilogram (mg/kg) freeze-dry weight of sediment in the <500 µm (<0.5 mm) fraction. As for the RSCMP monitoring conducted since 2013, the sediment samples provided to R J Hill Laboratories for metals' analysis were freeze-dried. No correction for residual moisture in the freeze-dried samples has been made. NIWA staff (G. Olsen, personal communication, May 2014) have indicated that their freeze-dried sediments (including fine, organic-rich sediment) typically have moisture contents of <2%, and usually <1% for sandy marine sediments. NIWA's analyses have found that the weighing errors for moisture correction are often higher than the mass difference measured between wet weight and oven-dry weight (overnight at 103°C). Therefore, moisture correction of the freeze-dried sediment results is not warranted and has not been undertaken for the 2021 sample data reported here.

3 Quality assurance

3.1 Introduction

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

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

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 five Certified Reference Material (CRM) QA samples and five 'Bulk Reference Sample' (BRS)[1] QA samples (from each of two BRS sites) with each batch of RSCMP samples. Any results that appear unusual or outside the variability range considered acceptable by the processing laboratory (NIWA, Hamilton) are checked with the analytical laboratory (RJ Hill Laboratories, Hamilton), and repeat analyses conducted if required. The results are collated, and an overall assessment provided in a 'data quality assessment' report. This report is available on request.

3. Lastly, the results from the QA assessments, in particular the CRM and BRS results, are checked against acceptance guidelines for the RSCMP programme, to ensure the variability and consistency over time are acceptable. An overall QA summary is produced (Table 3-1), 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.

[1] 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).

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.

3.2 Assessments undertaken

3.2.1 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 of 'in-house' reference sediment.
- Analysis of five 'extra' CRM samples dispersed through the analytical run. These CRM samples were added to the batch in addition to the routine laboratory in-house quality control samples.
- Analysis of the Auckland Council 'Bulk Reference Sediments' (BRS). Five replicates of each of the Meola Outer (sandy) and Middlemore (muddy) BRS in freeze-dried form were analysed.

Note on CRM: In 2020, R J Hills Laboratories advised Auckland Council that they are running short of the Hawkesbury River sediment reference material AGAL 10, and 2021 will potentially be the last RSCMP round of sampling where this CRM is available. The laboratory is transitioning to AGAL 12 (a dried powder mixture of sewage sludge and loam). Both AGAL 10 and AGAL 12 are produced and verified by the Australian National Measurement Institute. The AGAL 12 CRM does have very high levels of copper, but concentrations of other metals are in a similar range to those expected for sediments assessed in this program. R J Hills laboratories ran five replicates of AGAL 12 (called 'CRMB' in the data table) alongside the AGAL 10 CRM in 2020 and 2021 to enable comparison between the reference materials and consistency in the QA/QC process. From 2022 onwards, it is likely that AGAL 12 will be the only CRM used by R J Hills Laboratories in the RSCMP.

3.2.2 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.

3.3 Acceptance guidelines

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

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

Current acceptance guidelines include measures for:

- Potential sample contamination, as assessed from procedural blanks;
- Data accuracy, from comparison of results for the CRM with certified concentrations;
- 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[2].

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

A detailed assessment of the key features of the QA data (based on the results obtained for the CRM and BRS samples) and whether they meet the requirements of the RSCMP, as indicated by comparison with QA 'acceptance guidelines', is given in 8. An overall summary of QA assessments is presented in section 3.4 and Table 3-1.

3.4 Data quality assessment results for 2021 sites

Table 3-1 summarises the QA information obtained for the 2021 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 'very likely' trend probabilities for Pb and Hg) and both 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 (Middlemore). Whilst the metals which obtained 'fail' results through the QA process will require close ongoing examination, they are currently not of particular concern. This is because while trend probabilities for some metals were high (above 90%), the results are not occurring consistently, the per cent annual change remains low (within acceptance guidelines) and for analytes with successive 'very likely' probabilities, per cent annual change is decreasing.

The 2021 monitoring data for total recoverable metals and PSD were similar in quality to those obtained in previous years, although the elevated Zn issue observed in data from 2017, 2018, and 2019 appears to be resolved, and Zn trend analysis in BRS samples are continuing to show improved results. Overall, the metals and mud content data from 2021 are considered acceptable for use in the RSCMP status and trend assessment programme.

[2] 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 3-1. Summary of analytical quality assurance results for 2021 monitoring. CVs = coefficient of variation; RPDs = relative percentage difference; CLs = confidence limits; SD = standard deviation; DL = detection limit.

QA Measure	Acceptance guidelines	Pass Note Fail	Comments
Blanks	All values less than detection limits, or <10% of metal	Pass	All metals' concentrations in procedural blanks were below detection limits.
Within site variability	CVs <20%	Pass	Metals: CVs 0.79 - 7.61% for As, Cu and Zn. Pb slightly more variable (CVs between 1-10%), Hg variable with one site up to 20% threshold. Majority of Hg sites with very low concentrations near or below DLs.
Within Batch blind duplicates	RPDs <30%	Metals Pass	Metals: 4 samples analysed in duplicate by Hill labs in-house QA. RPDs ranged from 0 -13.2% for most metals except one Pb sample (17%) and one Hg sample (18.3%). Overall, good within batch agreement.
		PSD N/A	Particle size: No within batch blind duplicates analysed
Certified Reference Material	Accuracy: Results within lab control limits (+/- 3s, or 99% CLs)	Pass	Five CRM (AGAL-10) samples analysed as unknowns for total recoverable metals. Means within <10% of certified values for all metals except As (111.4%). One individual sample outside lab in-house control limits (Zn, 52.7 mg/kg) below the lower control limit of 52.8 mg/kg.
	Variability: Within-batch CV <10%	Pass	Variability <10%. CVs between 1.7-4.2% for Cu, Pb, Zn, As & Hg.
	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 -3.2% (Cu) and +1.6% (As and Hg).
	Temporal stability: No trends over time >1% of median concentration per year (and "very likely" likelihood; Sen Slope P>90%).	Note: Hg and Pb	Trends over time to Nov 2021 showed small percent annual change, between 0.09-0.41%. Pb and Hg had "very likely" trends so have been 'noted', but low percent annual change so not of major concern at this stage.
Lab In-House Reference Material (optional)	Accuracy: Results within lab control limits	Pass	19 samples of 'QC-A6' analysed as unknowns for total metals. Variability (CVs) <9% for all metals. Mean concentrations <10% of reference values for all metals (between 91.9% (As) and 104.% (Hg)). Overall, the' QC-A6' CRM results indicate good accuracy and precision for all metals.
Bulk Reference Sediments			
Total Recoverable Metals	Accuracy: Results within lab control limits (+/- 3s, or 99% CLs)	Pass	All metals' results within control limits.
	Within-year variability: CVs <10%.	Pass	Within-year variability met targets for all metals (CVs 0.4 - 8.7%). Highest variabilty seen in Meola OZ Hg (8.7%).
	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 1.08 - 7.0%).
	Temporal stability: No trends over time >2% of median concentration per year (and "very likely" likelihood; Sen Slope P>90%).	Note: As (Meola) and Zn (Midlemore)	BRS trends over time for Nov 2011 to Nov 2021 were all <2% per yer annual change. Zn improved further since 2020 but still high (98% probability and 1.61% annual change). Meola OZ As elevated annual change rate (1.51%) and "very likely" probability. Watch for trends in future.
Particle Size Distribution	Accuracy: Results within lab control limits (+/- 3s, or 99% CLs)	Pass	All mud content values within control limits
	Within-year variability: CVs <10%.	Pass	CVs <10%. CV of 0.4% for Middlemore and 7.9% for MeOZ BRS.
	Temporal stability: Means of new data within 10% of previous data means	Pass	2021 mean mud content within 4.0% of the previous data mean for Middlemore and within 3.3% of the previous data mean for Meola OZ BRS.
	Temporal stability: No trends over time >2% of median concentration per year (and "very likely" likelihood; Sen Slope P>90%).	Pass	Both sites showing "likely" decreasing trends but very low percent annual change (0.44% Meola OZ and 0.42% Middlemore).
OVERALL ASSESSMENT		Total metals Note: increasing Zn trend in Middlemore BRS. Increasing trend for As in MeOZ BRS	Metals' results for 2021 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. The high Zn results have further improved from those reported in 2019 (and to a lesser extent 2020). Continue to watch closely as data builds.
		PSD Pass	All QA targets for PSD (particle size distribution; mud content) met in 2021.

4 Contaminant state at sites sampled in 2021

4.1 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 at each site.

Contaminant concentrations are compared with sediment quality guidelines (SQG), using the Australian and New Zealand Guidelines for fresh and marine water quality (ANZG, 2018), and the Auckland Council Environmental Response Criteria (ERC; ARC, 2004).

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

The ANZG values relevant to the monitoring conducted in 2020 are summarised in Table 4-1. 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.

4.1.2 Environmental Response Criteria (ERC)

The ERC are considered to be conservative thresholds, developed and refined specifically for the Auckland region (ARC, 2004). The ERC are the guidelines predominantly used in assessment of sediment contaminant levels in the RSCMP. 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 2021 are summarised in Table 4-1.

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

- ERC Green conditions reflect a low level of impact. Further investigations are not required unless significant changes in upstream catchment land use occur.
- ERC Amber sites are showing signs of contamination, having one or more contaminants above a level at which adverse effects on benthic ecology may be expected to appear. Ecological evaluation is required to assess the actual biological impacts occurring. Management actions taken as early as possible are likely to be most effective at limiting further degradation. These sites present the best opportunity to make a difference to the future quality of the receiving environment.
- ERC Red sites are higher impact sites where significant degradation has already occurred, and remedial opportunities are often more limited. Restoration of the site may not be feasible in the short term, but actions should be taken to slow the rate of decline and limit the spread of contaminants.

Table 4-1. Environmental Response Criteria (ERC) and Australian and New Zealand Guidelines (ANZG) for metals. DGV = default guideline values, GV-high = guideline value high.

	ERC (mg/kg)			ANZG (mg/kg)		
Metals	Green	Amber	Red	DGV		GV-high
Copper	<19	19 - 34	>34	<65	65 - 270	>270
Lead	<30	30 - 50	>50	<50	50 - 220	>220
Zinc	<124	124 - 150	>150	<200	200 - 410	>410
Arsenic	No ERC values			<20	20 - 70	>70
Mercury	No ERC values			<0.15	0.15 - 1	>1

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 (50 mg/kg) is the same as the ERC-red threshold. The ANZG DGVs are all higher than the ERC green-amber threshold values. Fewer sites will therefore trigger the ANZG guideline thresholds for adverse ecological effects than the ERC.

4.2 State of sites sampled in 2021

The contaminant state of sites sampled in 2021 was assessed from median concentrations (from five replicates) of total recoverable metals in the <500 µm fraction.

Overall, there is a low level of metal contamination across the Manukau Harbour, with 25 of 27 sites (93%) assessed in the ERC-green category (see Table 4-3 and Figure 4-1). Sites that have higher contaminant levels are located at the head of the harbour in the Māngere Inlet, where elevated zinc levels result in two sites (Harania and Anns Creek) being assessed in the ERC-amber range. Note that the median Zn concentration at site Harania is on the border between ERC-green and ERC-amber thresholds (median concentration of 123.71 mg/kg, ERC-amber threshold of 124 mg/kg). In this instance, the value for Harania has been rounded up to the nearest whole number, and the site allocated ERC-amber status. Data treated in this way provides a slightly more conservative picture of contaminant levels. No sites in the Manukau Harbour fell into the ERC-red category (see Table 4-3), nor did they fall into the ANZG DGV-amber or red categories (see Table 4-2).

The ERC state at sites in the Manukau Harbour have remained relatively stable over the monitoring period (see Table 4-4), with the majority of sites remaining within the ERC-green status. The notable exception is a general improvement at sites in the Māngere Inlet, where over time, a reduction in the frequency and number of breaches above the ERC-amber and ERC-red thresholds can be observed.

A total of eight sites in the Manukau Harbour had undetectable levels of mercury (below the analytical laboratory default detection limit of 0.02 mg/kg, recorded as <0.02 mg/kg).

Concentrations of mercury at the remaining sites were also relatively low (highest median values being 0.05 mg/kg at sites Anns Creek, Harania and Waiuku). In general, RSCMP sites in the Manukau Harbour have mercury concentrations well below a level at which adverse effects on benthic ecology may be occurring.

Table 4-2. Australian and New Zealand Guidelines (ANZG) contaminant state at sites sampled in 2021. Metals' concentrations are medians of the five replicates.

Site	Location	ANZG 2018 Status	Mud Content % <63 um	Total Recoverable metals, mg/kg <500 mm				
				Cu	Pb	Zn	As	Hg
Anns Creek	Manukau Harbour		93.6	14.69	19.8	140.41	10.86	0.05
Harania	Manukau Harbour		90.4	13.35	18.12	123.71	10.7	0.05
Māngere Cemetery	Manukau Harbour		86.1	11.8	17.3	112.11	11.24	0.04
Tararata	Manukau Harbour		59.4	12.13	16.42	117.92	9.83	0.04
Blockhouse Bay	Manukau Harbour		30.6	3.93	9.87	57.2	7.29	<0.02
Big Muddy	Manukau Harbour		80.9	8.52	9.57	61.29	12.38	0.03
Hillsborough	Manukau Harbour		17.5	6.13	10.55	64.35	9.41	0.02
Little Muddy	Manukau Harbour		27.7	9.58	12.55	71.03	16.73	0.04
Mill Bay	Manukau Harbour		10.7	3.65	7.93	50.82	13.08	<0.02
Mauku/Taihiki River A	Manukau Harbour		40.2	2.86	5.49	34.02	7.69	<0.02
Mauku/Taihiki River B	Manukau Harbour		23.1	2.28	4.61	29.05	6.52	<0.02
Whangamaire	Manukau Harbour		90.5	3.24	6.22	31.28	8.24	<0.02
Whangapouri	Manukau Harbour		37.9	5.07	9.23	53.89	10.09	0.03
Bottle Top Bay	Manukau Harbour		73.0	7.62	11.68	73.64	11.79	0.04
Doc Island Mud	Manukau Harbour		30.5	3.35	6.73	49.28	8.86	0.02
Drury Inner	Manukau Harbour		44.3	5.99	9.56	65.59	10.55	0.04
Pāhurehure Middle	Manukau Harbour		31.7	3.46	7.68	49.19	12.47	<0.02
Pāhurehure Papakura	Manukau Harbour		66.2	7.51	13	85.16	11.56	0.04
Pāhurehure Upper	Manukau Harbour		83.4	7.96	12.39	88.93	13.71	0.04
Papakura Lower	Manukau Harbour		95.0	7.62	11.79	75.18	10.1	0.04
Waimāhia Central	Manukau Harbour		90.1	7.62	11.6	82.48	13.4	0.04
Puhinui Upper	Manukau Harbour		92.0	8.68	12.68	109.12	14.25	0.04
Pukaki Airport	Manukau Harbour		83.4	7.17	10.97	69.75	13.21	0.03
Pukaki Upper	Manukau Harbour		40.1	4.03	6.62	45.12	7.78	<0.02
Pukaki Waokauri	Manukau Harbour		49.6	4.67	7.87	53.55	8.73	0.02
Karaka/ Te Hihi Estuary	Manukau Harbour		39.1	2.95	5.29	34.71	8.12	<0.02
Waiuku	Manukau Harbour		77.9	8.52	14.84	90.54	14.55	0.05

Table 4-3. Environmental Response Criteria (ERC) contaminant state at sites sampled in 2021. Metals' concentrations are medians of the five replicates.

Site	Location	Status Cu Pb Zn only	Mud Content % <63 um	Total Recoverable metals, mg/kg <500 mm				
				Cu	Pb	Zn	As	Hg
Anns Creek	Manukau Harbour	Zn	93.6	14.69	19.8	140.41	10.86	0.05
Harania	Manukau Harbour	Zn	90.4	13.35	18.12	123.71	10.7	0.05
Māngere Cemetery	Manukau Harbour		86.1	11.8	17.3	112.11	11.24	0.04
Tararata	Manukau Harbour		59.4	12.13	16.42	117.92	9.83	0.04
Blockhouse Bay	Manukau Harbour		30.6	3.93	9.87	57.2	7.29	<0.02
Big Muddy	Manukau Harbour		80.9	8.52	9.57	61.29	12.38	0.03
Hillsborough	Manukau Harbour		17.5	6.13	10.55	64.35	9.41	0.02
Little Muddy	Manukau Harbour		27.7	9.58	12.55	71.03	16.73	0.04
Mill Bay	Manukau Harbour		10.7	3.65	7.93	50.82	13.08	<0.02
Mauku/Taihiki River A	Manukau Harbour		40.2	2.86	5.49	34.02	7.69	<0.02
Mauku/Taihiki River B	Manukau Harbour		23.1	2.28	4.61	29.05	6.52	<0.02
Whangamaire	Manukau Harbour		90.5	3.24	6.22	31.28	8.24	<0.02
Whangapouri	Manukau Harbour		37.9	5.07	9.23	53.89	10.09	0.03
Bottle Top Bay	Manukau Harbour		73.0	7.62	11.68	73.64	11.79	0.04
Doc Island Mud	Manukau Harbour		30.5	3.35	6.73	49.28	8.86	0.02
Drury Inner	Manukau Harbour		44.3	5.99	9.56	65.59	10.55	0.04
Pāhurehure Middle	Manukau Harbour		31.7	3.46	7.68	49.19	12.47	<0.02
Pāhurehure Papakura	Manukau Harbour		66.2	7.51	13	85.16	11.56	0.04
Pāhurehure Upper	Manukau Harbour		83.4	7.96	12.39	88.93	13.71	0.04
Papakura Lower	Manukau Harbour		95.0	7.62	11.79	75.18	10.1	0.04
Waimāhia Central	Manukau Harbour		90.1	7.62	11.6	82.48	13.4	0.04
Puhinui Upper	Manukau Harbour		92.0	8.68	12.68	109.12	14.25	0.04
Pukaki Airport	Manukau Harbour		83.4	7.17	10.97	69.75	13.21	0.03
Pukaki Upper	Manukau Harbour		40.1	4.03	6.62	45.12	7.78	<0.02
Pukaki Waokauri	Manukau Harbour		49.6	4.67	7.87	53.55	8.73	0.02
Karaka/ Te Hihi Estuary	Manukau Harbour		39.1	2.95	5.29	34.71	8.12	<0.02
Waiuku	Manukau Harbour		77.9	8.52	14.84	90.54	14.55	0.05

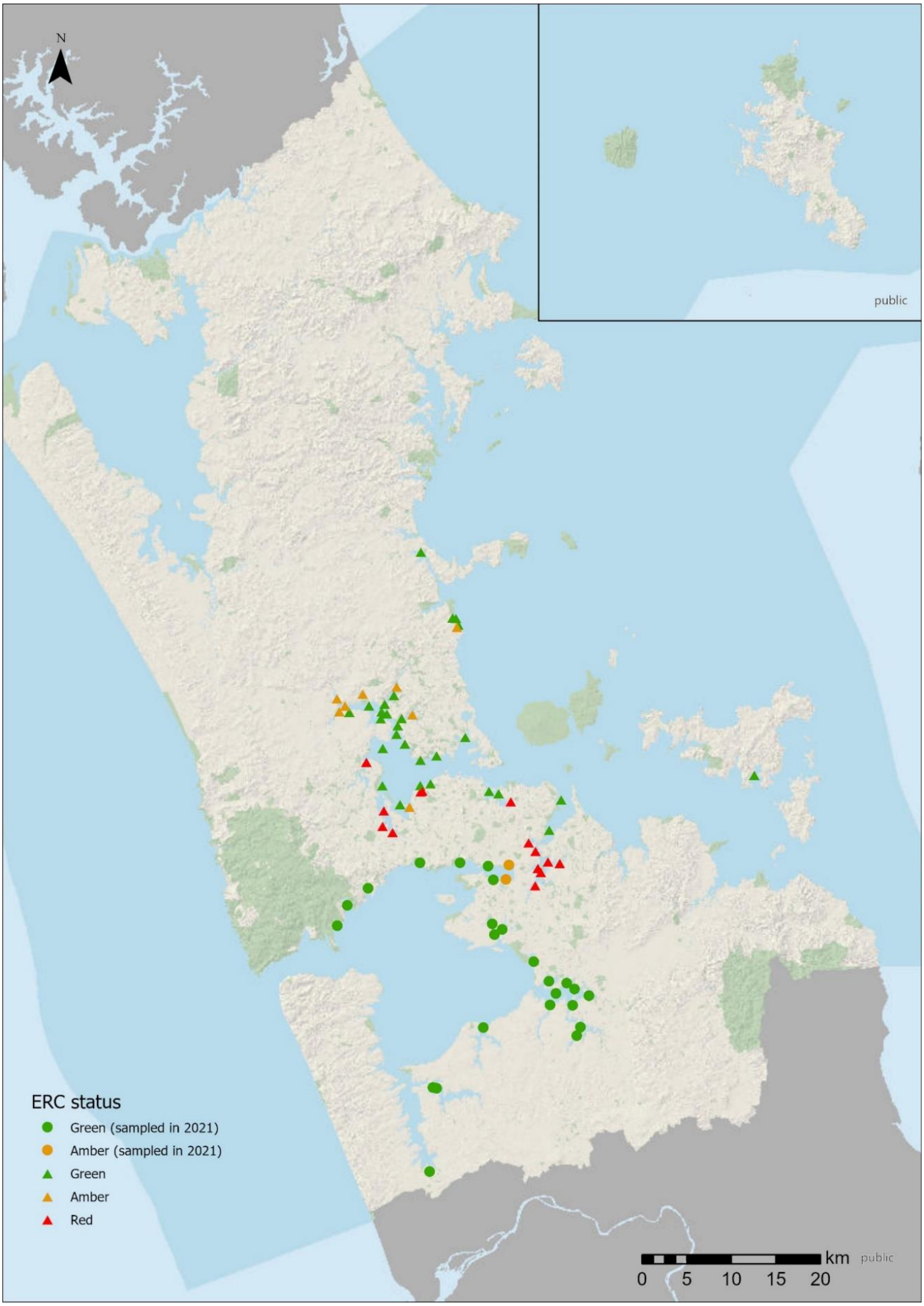

Figure 4-1. Current Environmental Response Criteria (ERC) contaminant state for all Regional Sediment Contaminant Monitoring Programme sites in 2021. Sites sampled in 2021 are shown with a circle (●), sites sampled in previous years are shown with a triangle (▲).

Table 4-4. History of Environmental Response Criteria (ERC) state for the metals copper (Cu), zinc (Zn), and lead (Pb) at sites sampled in 2021.

			Year																							
Site	Harbour	Location	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998
Anns Creek	Manukau Harbour	Māngere Inlet	Zn			Zn		Zn			Zn		Zn		Cu Zn		Cu Zn		Zn		Cu Zn		Cu Zn		Cu Zn	Cu Zn
Harania	Manukau Harbour	Māngere Inlet	Zn		Zn		Zn		Zn					Zn					Cu							
Māngere Cemetery	Manukau Harbour	Māngere Inlet											Cu Zn				Cu Zn		Cu Zn		Cu Pb Zn		Cu Zn		Cu Pb Zn	Cu Pb Zn
Tararata	Manukau Harbour	Māngere Inlet					Zn							Zn					Cu Zn							
Big Muddy	Manukau Harbour	Northern Coast																								
Blockhouse Bay	Manukau Harbour	Northern Coast																								
Little Muddy	Manukau Harbour	Northern Coast																								
Hillsborough	Manukau Harbour	Northern Coast																								
Mill Bay	Manukau Harbour	Northern Coast																								
Mauku/ Taihiki River A	Manukau Harbour	Mauku River																								
Mauku/ Taihiki River B	Manukau Harbour	Mauku River																								
Bottle Top Bay	Manukau Harbour	Pāhurehure Inlet																								
Doc Island Mud	Manukau Harbour	Pāhurehure Inlet																								
Drury Inner	Manukau Harbour	Pāhurehure Inlet																								
Pāhurehure Middle	Manukau Harbour	Pāhurehure Inlet																								
Pāhurehure Upper	Manukau Harbour	Pāhurehure Inlet																								
Papakura Lower	Manukau Harbour	Pāhurehure Inlet																								
Waimāhia Central	Manukau Harbour	Pāhurehure Inlet			Zn																					
Whangamaire	Manukau Harbour	Pāhurehure Inlet																								
Whangapouri	Manukau Harbour	Pāhurehure Inlet																								
Pāhurehure Papakura	Manukau Harbour	Pāhurehure Inlet																								
Puhinui Upper	Manukau Harbour	Puhinui																								
Pukaki Upper	Manukau Harbour	Pukaki Inlet																								
Pukaki Waokauri	Manukau Harbour	Pukaki Inlet																								
Pukaki Airport	Manukau Harbour	Pukaki Inlet																								
Karaka / Te Hihi estuary	Manukau Harbour	Te Hihi Inlet																								
Waiuku	Manukau Harbour	Waiuku Inlet																								

4.3 Discussion

Overall, a low level of contamination was found at sites sampled in 2021 within the Manukau Harbour. The spatial pattern of contaminant levels was the same as reported previously (see Auckland Council, 2021), and contaminant state has remained relatively stable over time (see Table 4-4). Contaminant levels in the Manukau were generally lower than the Waitematā Harbour, another major estuary in Tāmaki Makaurau. The large tidal movement and huge volume of regularly mixed water within the harbour has limited the impact of contaminants to the less flushed and muddier areas like the Māngere Inlet. The catchment also has a relatively small proportion of urban area (just 16% landcover), compared with almost 50% in the catchment surrounding the Waitematā.

Sites Harania and Anns Creek are the only sites showing elevated metal concentrations (ERC-amber category) in 2021. Both sites are located in Māngere Inlet, a location which has shown elevated levels of metals (most commonly zinc) since monitoring began in 1998. The catchment surrounding the Māngere Inlet is intensively developed and has a long history of commercial and industrial use. The pressures associated with these land uses have cumulatively had a negative impact on sediment quality in the inlet, as is seen in other areas of Tāmaki Makaurau with a similar history of catchment land use, such as the Whau Estuary, Henderson Creek, and the Tāmaki Estuary. The sheltered upper sub-estuaries, tidal creeks and inlets of harbours tend to accumulate fine sediment and can have a high proportion of mud, and in turn are more likely to trap and accumulate contaminants compared to sandy, open sites exposed to higher wave and tidal energy.

Sensitive trend analysis (statistical analysis of the monitoring data to obtain the magnitude and direction of change over time) reported in Mills and Allen (2021) indicate that metal concentrations at sites in the Māngere Inlet are showing some signs of improvement (particularly for copper and lead), possibly as a result of improved site and stormwater management associated with modernising industry in the catchment.

Three sites recorded changes in state between sampling events. Māngere Inlet sites Tararata and Anns Creek, and Waimāhia Central in the Pāhurehure Inlet, dropped from Zn levels in the ERC-red status to the ERC-amber status (Anns Creek between 2019 and 2021), and ERC-amber to ERC-green status (Tararata since 2017 and Waimāhia Central since 2019). It is possible that the change in state observed at these sites is attributable to issues with Zn analysis during the last sampling events at these sites, resulting in slightly higher concentrations in the years 2017-2019, rather than actual decreasing concentrations over this time.

While current levels of metal contamination at RSCMP sites remain relatively low, the harbour is undoubtedly impacted by catchment land use, the effects of which can be seen in other marine monitoring programmes. Coastal water quality in the harbour is poorer than elsewhere in the region, impacted by elevated nutrient concentrations (Ingley, 2021). Similar to contaminant results, benthic ecology monitoring results show that the main part of the harbour with open sandflats is generally in good condition, while sheltered tidal creeks are generally less healthy, muddier, and in a degraded state (Drylie, 2021). A synthesis report of state of the environment monitoring in the Manukau Harbour and its catchment (Auckland Council, 2021) outlines how historic and current activities continue to affect many aspects of the health of the harbour, with industrial, stormwater and wastewater discharge, fine sediment input and invasive species having detrimental effects, and how in the face of this, the harbour remains able to maintain many ecosystem services, support a myriad of living things, and is responsive to improvements in how we manage the land around it and the water that feeds into it.

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6 Appendix A: Sediment contaminant data

Metals' data for November 2021 monitoring. Concentrations in mg/kg freeze-dry weight (<500 µm fraction). QA sample data are included for Certified Reference Material (CRM = AGAL 10 and CRMB = AGAL 12) and Bulk Reference Sediments (Meola = MeOZ FD and Middlemore = Mid FD).

Site	Marine Reporting Area	Replicate	Total Recoverable metals, mg/kg <500 µm				
			Cu	Pb	Zn	As	Hg
Anns Creek	Manukau Harbour	1	14.2	19.8	140.4	10.77	0.060
Anns Creek	Manukau Harbour	2	14.2	20.4	139.6	10.86	0.054
Anns Creek	Manukau Harbour	3	14.8	20.1	142.2	11.20	0.047
Anns Creek	Manukau Harbour	4	14.7	19.7	143.1	11.06	0.049
Anns Creek	Manukau Harbour	5	15.2	19.7	140.1	10.81	0.057
Big Muddy	Manukau Harbour	1	8.6	9.6	61.3	12.38	0.031
Big Muddy	Manukau Harbour	2	8.5	9.7	61.4	12.78	0.033
Big Muddy	Manukau Harbour	3	8.8	9.6	62.3	12.80	0.032
Big Muddy	Manukau Harbour	4	8.2	9.2	60.0	12.26	0.037
Big Muddy	Manukau Harbour	5	8.3	9.5	60.4	12.21	0.036
Blockhouse Bay	Manukau Harbour	1	3.7	9.9	55.9	6.86	<0.02
Blockhouse Bay	Manukau Harbour	2	4.2	10.5	60.3	8.32	<0.02
Blockhouse Bay	Manukau Harbour	3	4.1	10.2	56.3	7.29	<0.02
Blockhouse Bay	Manukau Harbour	4	3.5	8.8	57.2	7.41	<0.02
Blockhouse Bay	Manukau Harbour	5	3.9	9.7	58.2	7.25	<0.02
Bottle Top Bay	Manukau Harbour	1	7.53	11.61	73.64	11.72	0.038
Bottle Top Bay	Manukau Harbour	2	7.58	11.68	73.34	11.79	0.035
Bottle Top Bay	Manukau Harbour	3	7.62	11.42	73.25	11.47	0.039
Bottle Top Bay	Manukau Harbour	4	7.67	11.69	74.76	12.25	0.034
Bottle Top Bay	Manukau Harbour	5	7.86	11.88	76.01	11.99	0.041
Doc Island Mud	Manukau Harbour	1	3.24	6.57	47.75	8.40	0.0203
Doc Island Mud	Manukau Harbour	2	3.35	6.76	49.28	8.60	0.0289
Doc Island Mud	Manukau Harbour	3	3.40	6.83	49.88	8.94	0.0238
Doc Island Mud	Manukau Harbour	4	3.53	6.73	50.86	9.15	0.0227
Doc Island Mud	Manukau Harbour	5	3.28	6.48	49.11	8.86	0.0206
Drury Inner	Manukau Harbour	1	5.99	9.56	65.59	10.55	0.0402
Drury Inner	Manukau Harbour	2	6.70	9.76	70.39	11.20	0.0375
Drury Inner	Manukau Harbour	3	6.33	10.00	67.43	11.23	0.0352
Drury Inner	Manukau Harbour	4	5.77	9.29	63.80	9.86	0.0383
Drury Inner	Manukau Harbour	5	5.74	9.19	63.68	10.00	0.0323
Harania	Manukau Harbour	1	13.6	18.9	126.8	9.57	0.052
Harania	Manukau Harbour	2	13.4	17.9	124.2	10.70	0.052
Harania	Manukau Harbour	3	13.2	18.3	123.7	11.23	0.048
Harania	Manukau Harbour	4	13.3	17.6	122.8	10.43	0.049
Harania	Manukau Harbour	5	13.3	18.1	123.1	10.73	0.055
Hillsborough	Manukau Harbour	1	6.3	11.7	66.8	9.57	0.022
Hillsborough	Manukau Harbour	2	5.8	10.6	63.5	9.41	0.021
Hillsborough	Manukau Harbour	3	5.8	9.1	63.8	9.82	0.024
Hillsborough	Manukau Harbour	4	6.4	11.3	64.8	8.71	0.021
Hillsborough	Manukau Harbour	5	6.1	9.8	64.3	9.04	0.022
Karaka / Te Hihi estuary	Manukau Harbour	1	3.1	5.4	34.7	8.23	<0.02
Karaka / Te Hihi estuary	Manukau Harbour	2	2.9	5.3	34.0	7.84	<0.02
Karaka / Te Hihi estuary	Manukau Harbour	3	3.0	5.3	35.1	8.12	<0.02
Karaka / Te Hihi estuary	Manukau Harbour	4	2.9	5.2	34.7	8.19	<0.02
Karaka / Te Hihi estuary	Manukau Harbour	5	2.9	5.1	34.1	7.84	<0.02

Site	Marine Reporting Area	Replicate	Total Recoverable metals, mg/kg <500 µm				
			Cu	Pb	Zn	As	Hg
Little Muddy	Manukau Harbour	1	9.0	12.0	66.6	14.81	0.033
Little Muddy	Manukau Harbour	2	9.3	12.0	68.3	15.29	0.036
Little Muddy	Manukau Harbour	3	9.6	12.8	71.0	16.81	0.035
Little Muddy	Manukau Harbour	4	9.7	12.5	72.2	16.73	0.043
Little Muddy	Manukau Harbour	5	10.4	12.7	74.3	17.62	0.038
Māngere Cemetery	Manukau Harbour	1	11.8	17.4	111.9	11.35	0.043
Māngere Cemetery	Manukau Harbour	2	11.6	16.8	110.4	10.86	0.049
Māngere Cemetery	Manukau Harbour	3	11.8	17.3	113.1	11.24	0.040
Māngere Cemetery	Manukau Harbour	4	11.9	17.5	112.1	11.13	0.041
Māngere Cemetery	Manukau Harbour	5	12.1	17.3	114.9	11.24	0.051
Mauku/ Taihiki River A	Manukau Harbour	1	2.9	5.5	34.1	7.26	<0.02
Mauku/ Taihiki River A	Manukau Harbour	2	2.9	5.2	34.0	7.69	<0.02
Mauku/ Taihiki River A	Manukau Harbour	3	2.8	5.5	33.6	7.53	<0.02
Mauku/ Taihiki River A	Manukau Harbour	4	2.8	5.2	33.9	7.72	<0.02
Mauku/ Taihiki River A	Manukau Harbour	5	3.0	5.5	35.5	8.04	<0.02
Mauku/ Taihiki River B	Manukau Harbour	1	2.3	4.6	29.0	6.52	<0.02
Mauku/ Taihiki River B	Manukau Harbour	2	2.2	4.6	28.4	7.60	<0.02
Mauku/ Taihiki River B	Manukau Harbour	3	2.4	4.8	30.2	6.52	<0.02
Mauku/ Taihiki River B	Manukau Harbour	4	2.3	4.6	29.4	6.37	<0.02
Mauku/ Taihiki River B	Manukau Harbour	5	2.2	4.6	28.9	6.48	<0.02
Mill Bay	Manukau Harbour	1	3.6	7.9	50.0	13.93	<0.02
Mill Bay	Manukau Harbour	2	3.6	8.5	52.7	12.92	<0.02
Mill Bay	Manukau Harbour	3	3.8	7.5	49.3	13.99	<0.02
Mill Bay	Manukau Harbour	4	3.7	7.9	50.8	13.08	<0.02
Mill Bay	Manukau Harbour	5	3.7	8.5	55.2	11.96	<0.02
Pāhurehure Middle	Manukau Harbour	1	3.2	7.4	45.1	11.11	<0.02
Pāhurehure Middle	Manukau Harbour	2	3.8	7.8	50.8	12.60	<0.02
Pāhurehure Middle	Manukau Harbour	3	3.6	7.8	49.2	11.79	0.021
Pāhurehure Middle	Manukau Harbour	4	3.4	7.5	47.6	12.47	<0.02
Pāhurehure Middle	Manukau Harbour	5	3.5	7.7	49.5	12.94	<0.02
Pāhurehure Papakura	Manukau Harbour	1	7.5	13.0	85.2	11.81	0.045
Pāhurehure Papakura	Manukau Harbour	2	7.2	12.6	81.4	11.13	0.041
Pāhurehure Papakura	Manukau Harbour	3	7.7	13.0	87.2	11.56	0.044
Pāhurehure Papakura	Manukau Harbour	4	7.7	13.2	84.9	11.92	0.037
Pāhurehure Papakura	Manukau Harbour	5	6.8	12.2	88.7	10.71	0.041
Pāhurehure Upper	Manukau Harbour	1	8.0	12.8	89.8	13.84	0.042
Pāhurehure Upper	Manukau Harbour	2	7.7	12.1	86.0	13.28	0.040
Pāhurehure Upper	Manukau Harbour	3	7.3	11.8	83.9	13.11	0.040
Pāhurehure Upper	Manukau Harbour	4	8.0	12.4	88.9	13.71	0.044
Pāhurehure Upper	Manukau Harbour	5	8.0	12.6	89.7	14.12	0.039
Papakura Lower	Manukau Harbour	1	7.4	11.5	72.6	9.63	0.037
Papakura Lower	Manukau Harbour	2	7.9	11.9	77.3	10.10	0.037
Papakura Lower	Manukau Harbour	3	7.5	12.0	74.2	10.18	0.036
Papakura Lower	Manukau Harbour	4	7.6	11.6	75.2	10.15	0.042
Papakura Lower	Manukau Harbour	5	7.6	11.8	76.1	10.10	0.040
Puhinui Upper	Manukau Harbour	1	9.3	13.1	115.3	14.81	0.039
Puhinui Upper	Manukau Harbour	2	8.7	12.9	108.6	14.19	0.037
Puhinui Upper	Manukau Harbour	3	8.9	12.7	110.9	14.53	0.034
Puhinui Upper	Manukau Harbour	4	8.7	12.4	109.1	14.25	0.033
Puhinui Upper	Manukau Harbour	5	8.7	12.5	108.6	13.86	0.035
Pukaki Airport	Manukau Harbour	1	6.8	10.6	67.2	12.64	0.034
Pukaki Airport	Manukau Harbour	2	7.2	11.0	70.7	13.23	0.030
Pukaki Airport	Manukau Harbour	3	7.2	10.9	69.8	13.21	0.028
Pukaki Airport	Manukau Harbour	4	7.0	11.0	69.0	13.34	0.026
Pukaki Airport	Manukau Harbour	5	7.2	11.0	70.1	13.12	0.031

Site	Marine Reporting Area	Replicate	Total Recoverable metals, mg/kg <500 µm				
			Cu	Pb	Zn	As	Hg
Pukaki Upper	Manukau Harbour	1	3.9	6.6	44.0	7.73	<0.02
Pukaki Upper	Manukau Harbour	2	4.0	6.6	44.7	7.78	<0.02
Pukaki Upper	Manukau Harbour	3	4.1	6.5	45.1	7.76	<0.02
Pukaki Upper	Manukau Harbour	4	4.2	6.9	46.1	8.27	<0.02
Pukaki Upper	Manukau Harbour	5	4.0	6.9	45.5	8.14	<0.02
Pukaki Waokauri	Manukau Harbour	1	4.5	7.5	52.2	8.46	0.022
Pukaki Waokauri	Manukau Harbour	2	4.6	7.9	52.4	8.35	<0.02
Pukaki Waokauri	Manukau Harbour	3	4.7	7.6	53.6	8.73	0.022
Pukaki Waokauri	Manukau Harbour	4	4.8	7.9	54.7	8.74	0.021
Pukaki Waokauri	Manukau Harbour	5	4.8	7.9	55.7	8.82	0.022
Tararata	Manukau Harbour	1	12.1	17.3	118.6	9.62	0.053
Tararata	Manukau Harbour	2	12.0	16.4	117.0	9.50	0.043
Tararata	Manukau Harbour	3	12.0	16.2	117.9	9.83	0.043
Tararata	Manukau Harbour	4	12.7	17.0	122.6	10.10	0.050
Tararata	Manukau Harbour	5	12.1	16.3	117.9	9.88	0.044
Waimāhia Central	Manukau Harbour	1	7.6	11.6	84.0	13.49	0.038
Waimāhia Central	Manukau Harbour	2	7.7	12.1	83.5	13.73	0.037
Waimāhia Central	Manukau Harbour	3	7.5	11.6	80.8	13.28	0.033
Waimāhia Central	Manukau Harbour	4	7.6	11.6	82.5	13.40	0.033
Waimāhia Central	Manukau Harbour	5	7.6	11.7	82.1	13.29	0.037
Waiuku	Manukau Harbour	1	8.1	14.5	86.6	14.04	0.051
Waiuku	Manukau Harbour	2	8.4	14.8	89.9	14.51	0.052
Waiuku	Manukau Harbour	3	9.1	15.5	95.5	15.42	0.054
Waiuku	Manukau Harbour	4	8.5	14.8	91.2	14.55	0.057
Waiuku	Manukau Harbour	5	8.6	15.0	90.5	15.02	0.051
Whangapouri	Manukau Harbour	1	4.91	8.63	51.70	9.66	0.0285
Whangapouri	Manukau Harbour	2	5.07	9.23	53.26	10.72	0.0325
Whangapouri	Manukau Harbour	3	5.01	8.93	53.89	10.04	0.0291
Whangapouri	Manukau Harbour	4	5.34	9.88	55.33	10.09	0.0313
Whangapouri	Manukau Harbour	5	5.39	9.39	55.00	10.30	0.0276
Whangamaire	Manukau Harbour	1	3.25	6.30	32.62	8.25	<0.02
Whangamaire	Manukau Harbour	2	3.32	6.41	32.32	8.51	0.022
Whangamaire	Manukau Harbour	3	2.95	5.92	28.96	7.77	<0.02
Whangamaire	Manukau Harbour	4	3.23	6.09	31.28	8.24	<0.02
Whangamaire	Manukau Harbour	5	3.24	6.22	30.72	8.19	<0.02
MeOZ FD	Bulk Reference Sediment	1	2.97	9.04	41.12	2.77	0.0305
MeOZ FD	Bulk Reference Sediment	2	3.11	9.12	41.71	2.77	0.0271
MeOZ FD	Bulk Reference Sediment	3	3.13	9.34	44.55	3.08	0.0267
MeOZ FD	Bulk Reference Sediment	4	3.16	9.46	45.41	2.80	0.0258
MeOZ FD	Bulk Reference Sediment	5	2.81	8.42	40.63	2.62	0.0313
MID FD	Bulk Reference Sediment	1	29.0	35.2	235.6	9.03	0.168
MID FD	Bulk Reference Sediment	2	29.8	36.7	242.2	9.56	0.189
MID FD	Bulk Reference Sediment	3	30.6	37.0	243.2	9.68	0.172
MID FD	Bulk Reference Sediment	4	30.0	36.6	243.3	9.77	0.172
MID FD	Bulk Reference Sediment	5	29.3	35.2	237.4	9.11	0.170
CRM	Certified Reference Material	1	22.7	42.1	53.9	18.96	11.45
CRM	Certified Reference Material	2	23.2	39.6	54.4	19.81	11.32
CRM	Certified Reference Material	3	21.4	39.8	52.7	18.48	10.67
CRM	Certified Reference Material	4	22.1	39.8	53.1	19.37	10.82
CRM	Certified Reference Material	5	22.0	41.8	53.2	19.21	10.73
CRMB	Certified Reference Material	1	148.8	30.9	175.5	3.60	0.459
CRMB	Certified Reference Material	2	154.8	30.9	181.7	3.67	0.466
CRMB	Certified Reference Material	3	155.2	32.3	178.4	3.66	0.555
CRMB	Certified Reference Material	4	148.2	30.7	174.8	3.60	0.507
CRMB	Certified Reference Material	5	151.1	29.7	175.9	3.55	0.540

7 Appendix B: Particle size distribution

Sediment particle size distribution (PSD) data obtained from a single composite surface (0-2 cm) sample per site in 2021. 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	Harbour	Location	Organic Content	Gravel >2mm	Coarse Sand 500-2000um	Medium Sand 250-500um	Fine Sand 62.5-250um	Very Fine Sand 63-124um	Silt 3.9-62.5um	Clay 0-3.9um	Mud (Silt + Clay)
Anns Creek	Manukau	Māngere Inlet	6.915	0.000	0.034	0.040	0.534	5.817	49.156	44.418	93.574
Harania	Manukau	Māngere Inlet	7.269	0.000	0.203	0.213	2.256	6.889	53.594	36.846	90.439
Māngere Cemetery	Manukau	Māngere Inlet	7.527	0.000	0.038	0.058	1.153	12.608	59.896	26.247	86.143
Tararata	Manukau	Māngere Inlet	4.694	0.000	0.493	2.265	27.328	10.486	42.571	16.857	59.428
Blockhouse Bay	Manukau	Northern Coast	7.994	0.552	0.000	4.584	11.382	52.882	30.116	0.484	30.600
Big Muddy	Manukau	Northern Coast	6.516	0.000	0.319	0.366	3.034	15.347	44.752	36.183	80.935
Hillsborough	Manukau	Northern Coast	3.197	18.760	27.436	14.170	11.446	10.712	11.336	6.141	17.477
Little Muddy	Manukau	Northern Coast	5.154	1.328	7.463	12.218	28.103	23.207	17.260	10.421	27.681
Mill Bay	Manukau	Northern Coast	3.372	1.151	15.100	25.610	37.422	10.055	7.196	3.465	10.661
Mauku/Taihiki River A	Manukau	Mauku River	3.748	0.581	1.282	1.162	33.241	23.533	33.291	6.909	40.200
Mauku/Taihiki River B	Manukau	Mauku River	2.915	0.145	0.586	1.167	61.949	13.099	16.137	6.916	23.053
Whangamaire	Manukau	Pāhurehure Inlet	10.250	0.000	0.294	0.572	2.873	5.762	72.225	18.274	90.499
Whangapouri	Manukau	Pāhurehure Inlet	3.907	0.227	2.169	2.299	40.213	17.171	24.514	13.406	37.921
Bottle Top Bay	Manukau	Pāhurehure Inlet	1.945	3.877	0.000	0.000	0.668	22.460	71.123	1.872	72.995
Doc Island Mud	Manukau	Pāhurehure Inlet	3.688	0.050	0.998	2.873	50.136	15.492	14.293	16.158	30.451
Drury Inner	Manukau	Pāhurehure Inlet	6.560	0.000	0.350	1.232	27.792	26.300	23.520	20.806	44.326
Pāhurehure Middle	Manukau	Pāhurehure Inlet	4.158	1.894	3.634	10.410	45.181	7.146	24.648	7.086	31.735
Pāhurehure Papakura	Manukau	Pāhurehure Inlet	6.965	0.301	2.089	2.664	15.420	13.312	34.849	31.364	66.214
Pāhurehure Upper	Manukau	Pāhurehure Inlet	7.544	0.071	0.329	0.595	6.710	8.896	64.060	19.339	83.399
Papakura Lower	Manukau	Pāhurehure Inlet	6.936	0.000	0.135	0.123	1.139	3.590	74.884	20.130	95.013
Waimāhia Central	Manukau	Pāhurehure Inlet	6.536	0.000	0.083	0.062	1.389	8.316	71.518	18.631	90.149
Puhinui Upper	Manukau	Puhinui	8.069	0.161	0.177	0.193	1.975	5.498	60.582	31.413	91.995
Pukaki Airport	Manukau	Pukaki Inlet	7.295	0.000	0.137	0.101	4.729	11.630	46.575	36.827	83.402
Pukaki Upper	Manukau	Pukaki Inlet	4.051	0.056	0.357	0.908	48.488	10.044	28.676	11.470	40.147
Pukaki Waokauri	Manukau	Pukaki Inlet	4.291	0.050	0.295	1.085	36.773	12.200	37.679	11.919	49.598
Karaka/ Te Hihi Estuary	Manukau	Te Hihi Inlet	3.032	0.054	0.255	0.378	16.810	43.376	26.954	12.173	39.127
Waiuku	Manukau	Waiuku Inlet	7.606	0.000	0.200	0.489	2.702	18.666	51.344	26.600	77.943
Meola Outer Zone BRS - MO PS18	QA Reference Material		1.858	1.493	0.358	0.937	45.604	48.540	1.151	1.918	3.069
Meola Outer Zone BRS - MO PS20	QA Reference Material		1.516	0.147	0.457	0.930	46.990	48.230	0.999	2.247	3.246
Meola Outer Zone BRS - MO PS38	QA Reference Material		1.780	2.888	0.542	0.943	50.017	42.837	1.386	1.386	2.772
Middlemore BRS - MID PS23	QA Reference Material		7.559	0.016	0.420	0.679	14.708	15.112	37.410	31.654	69.064
Middlemore BRS - MID PS8	QA Reference Material		7.529	0.000	0.366	0.615	14.374	15.077	33.178	36.389	69.568
Middlemore BRS - MID PS87	QA Reference Material		7.533	0.000	0.299	0.613	14.827	15.204	43.361	25.695	69.057

8 Appendix C: Quality assurance analysis

8.1 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.

Five CRM samples (AGAL-10) were included in the analytical run as 'unknowns'. Results for these are summarised in Table 5-1 and have been assessed according to the following 'acceptance guidelines':

- Accuracy: Results are within lab control limits (+/- 3 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 8.0, Jowett Consulting Ltd).

The results summarised in Table 5-1 show that the CRM results generally met all the QA acceptance guidelines, despite two results receiving a '**fail**'. These were 'very likely' trend probabilities (>90%) for Hg and Pb, however per cent annual change for these metals was well below the 1% acceptance criteria (0.22% for Pb and 0.34% for Hg). 'Likely' increasing trends were observed for Cu, As, and Zn, again with very low (<1%) rates of annual change. These have been noted in Table 5-1. When compared with the certified value, As had a slightly high mean (111.4%) just above the 10% acceptance criteria. All results are within upper and lower limits (± 3 SD) of the certified reference value. 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 Table 5-1. The trend plots are shown in Figure 5-1 and depict very weak increasing trends for Cu, Zn, and As, and slightly stronger increasing trends for Pb and Hg.

Table 5-1. Quality assurance results for five Certified Reference Material (CRM; AGAL 10) samples analysed as unknowns in the 2021 sediment sample batch.

Sample I.D. and Quality Assurance Measures	QA Acceptance Pass Note Fail	Total Recoverable Metals (<500 µm)				
		Cu	Pb	Zn	As	Hg
CRM - Agal 10 - 1	Pass	22.7	42.1	53.9	19.0	11.5
CRM - Agal 10 - 2	Pass	23.2	39.6	54.4	19.8	11.3
CRM - Agal 10 - 3	Pass	21.4	39.8	52.7	18.5	10.7
CRM - Agal 10 - 4	Pass	22.1	39.8	53.1	19.4	10.8
CRM - Agal 10 - 5	Pass	22.0	41.8	53.2	19.2	10.7
New mean	n/a	22.3	40.6	53.5	19.2	11.0
Variability in new mean (CV, %)	Pass	3.1	3.0	1.3	2.6	3.3
Mean of all previous CRM data	n/a	23.01	40.28	54.22	18.86	10.83
Difference between new and previous data means (RPD, %)	Pass	-3.2	0.8	-1.4	1.6	1.6
New mean, as % of certified value	Note (As)	96.1	100.5	93.8	111.4	94.8
Trends (% annual change, Sen Slope)	Pass	0.09	0.22	0.21	0.41	0.34
Trends (probabilities, Sen Slope p values)	Fail Pb & Hg	0.7	0.92	0.83	0.78	0.91
Trends (likelihood based on Sen Slope p values)	Fail Pb & Hg	likely	very likely	likely	likely	very likely
Certified Reference Value (mg/kg)	n/a	23.2	40.4	57.0	17.2	11.6
Lab in-house lower limit (mg/kg; mean - 3s)	n/a	19.6	32.5	46.1	16.2	10.0
Lab in-house upper limit (mg/kg; mean + 3s)	n/a	26.4	48.4	62.7	23.1	13.6
Overall assessment	Note	Pass	Note	Pass	Pass	Note
Comments	Small (<1%/year) but very likely trend for Pb and Hg, small (1%/year) likely trends for Cu, Zn and As	Note small likely increasing trend <1%/year	Note small very likely increasing trend, <1%/year	Note small likely increasing trend <1%/year	Note small likely increasing trend <1%/year	Note small very likely increasing trend <1%/year

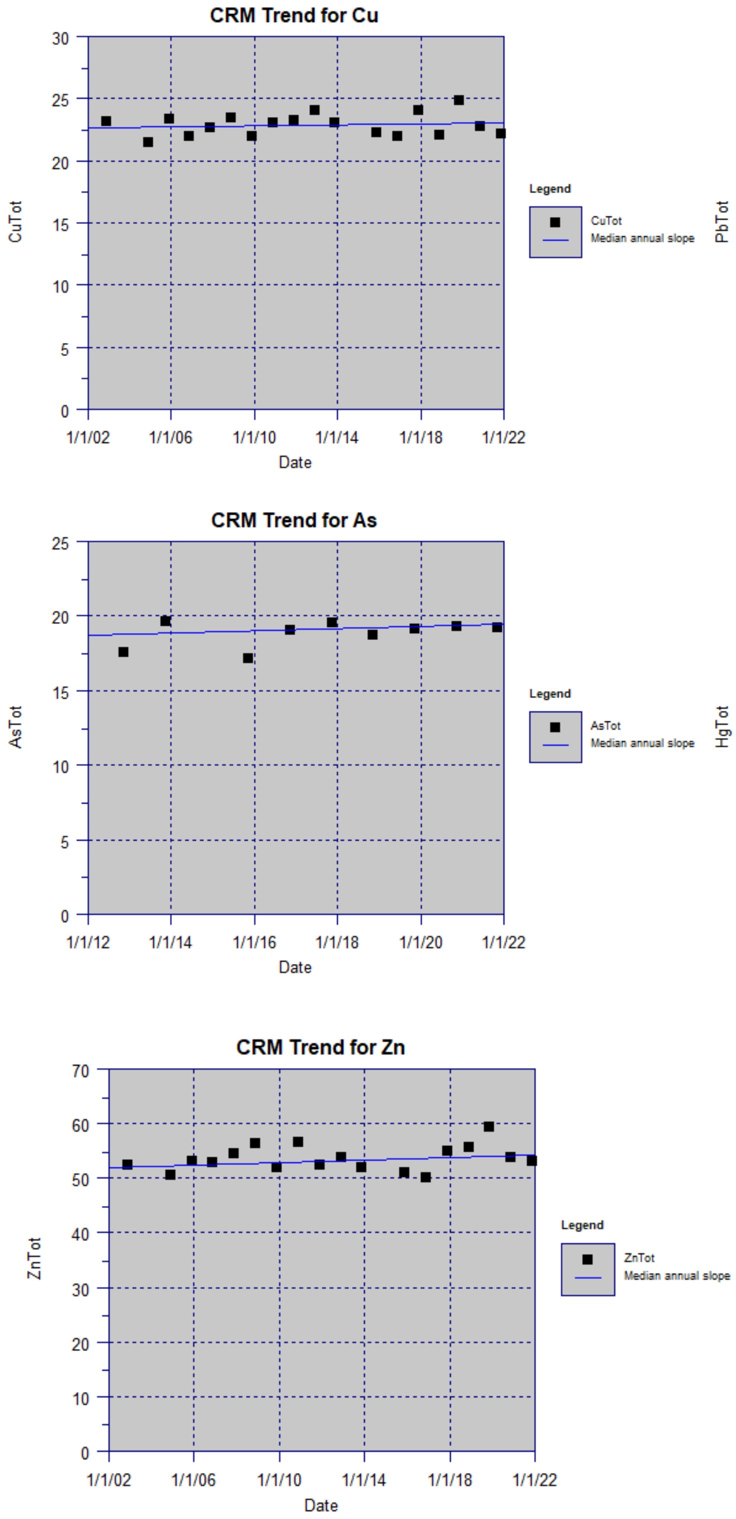

Figure 5-1. Certified Reference Material (CRM) results for total recoverable metals in CRM AGAL-10 samples analysed with RSCMP samples taken from 2002 to 2021. The plots show annual medians. The line is a linear regression.

8.2 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 8.2.1 and 8.2.2.

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 (section 8.1), 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; 10 so far, from 2011 to 2021. 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 data acceptance guidelines used for the 2021 data are therefore:

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

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

8.2.1 Meola Outer Zone BRS

The total recoverable metals' results from the 2021 sample batch for the sandy Meola Outer Zone BRS are summarised in Table 5-2. Median values of BRS data acquired with RSCMP monitoring from November 2011 to 2021 are shown in Figure 5-2.

The metals' results for the Meola Outer Zone BRS obtained in 2021 are a '**note**', having failed one acceptance criteria (a 'very likely' increasing trends for arsenic). Percent annual change for As also received a 'note', with a value above 1% (1.51%). In addition, several 'notes' were made for 'likely' trends occurring for Mud, Cu, Pb, Zn, and Hg, however the percent annual change for these are all low (<1%).

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 (RDP <6%).

The results for the Meola BRS obtained in 2021 were generally consistent with previous years and are acceptable for use in the RSCMP.

Table 5-2. Quality assurance results for Bulk Reference Sediment (BRS) samples from Meola Outer Zone analysed with the 2021 RSCMP sample batch.

Sample ID and QA measures	QA Guidelines	Mud Content	Total Recoverable Metals (mg/kg, <500 µm)				
	Pass Note Fail	% <63 µm	Cu	Pb	Zn	As	Hg
Meola OZ BRS 1	Pass	3.07	2.97	9.04	41.12	2.77	0.0305
Meola OZ BRS 2	Pass	3.25	3.11	9.12	41.71	2.77	0.0271
Meola OZ BRS 3	Pass	2.77	3.13	9.34	44.55	3.08	0.0267
Meola OZ BRS 4	Pass		3.16	9.46	45.41	2.80	0.0258
Meola OZ BRS 5	Pass		2.81	8.42	40.63	2.62	0.0313
New mean	Pass	3.03	3.03	9.08	42.68	2.81	0.028
Variability in new data (CV, %)	Pass	7.9	4.8	4.4	5.0	6.0	8.7
Difference between new and previous data means (RPD, %)	Pass	3.31	2.10	1.08	4.66	4.66	-5.82
Trends (% annual change, Sen Slope)	Note As	-0.44	0.35	0.51	0.74	1.51	-0.55
Trends (probabilities, Sen Slope p values)	Fail As. Note others.	0.85	0.71	0.87	0.82	0.91	0.79
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	2.93	2.97	8.98	40.74	2.68	0.03
Lower control limit (mean - 3s)	n/a	2.63	2.58	7.66	32.88	1.93	-0.06
Upper control limit (mean + 3s)	n/a	3.23	3.36	10.3	48.6	3.43	0.12
Overall assessment	Note	Pass	Pass	Pass	Pass	Note	Pass
Comments	Overall good results and generally meet acceptance criteria. Note: watch As for trends.	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

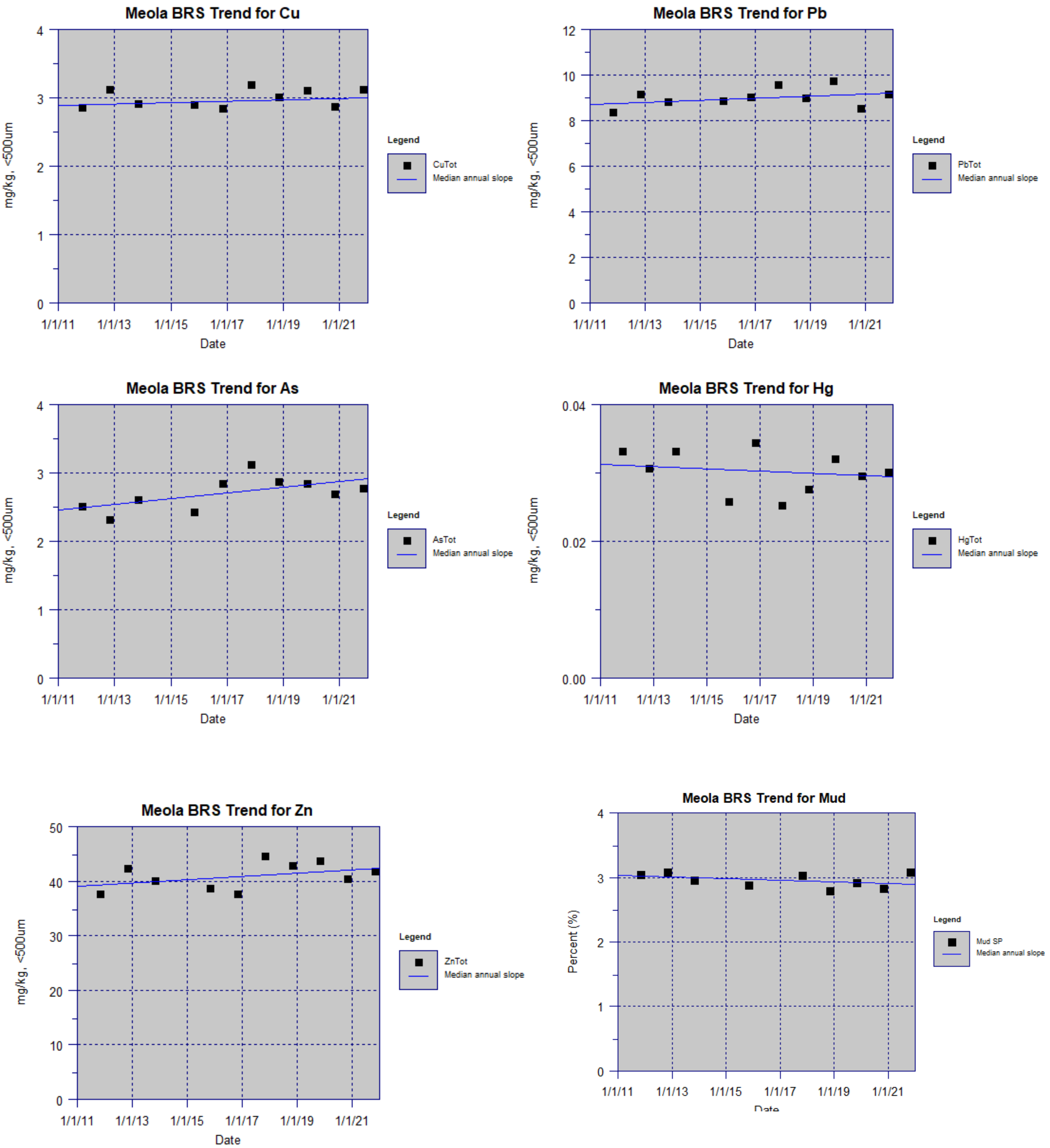

Figure 5-2. Plots of median data for Meola Outer Zone BRS metals and mud samples, November 2011 to November 2021. Metals are in mg/kg <500µm fraction, mud is silt + clay <63µm fraction.

8.2.2 Middlemore BRS

The total recoverable metals' results from the 2021 sample batch for the muddy Middlemore BRS samples are summarised in Table 5-3. Median values from data acquired with RSCMP monitoring from November 2011 to 2021 are shown in Figure 5-3. The results for the Middlemore BRS obtained in 2021 were generally consistent with previous years and mostly met acceptance guidelines.

Acceptance guideline 'fails' were observed due to a 'very likely' trend observed in zinc, however the per cent annual change was below the 2% criteria (1.61%). In addition, several 'notes' were made for potential data issues to watch for in the future. These included 'likely' trends observed for Mud, Cu, Pb, and Hg. As passed all acceptance criteria, with a trend probability of 'indeterminate' (64%). Mud and metals (Cu, Pb and Hg) showed <1% per year annual change, and as such, these 'likely' trends are not considered to be of major concern at this stage. All results are within upper and lower limits (± 3 SD) of the certified reference value.

The overall assessment for the Middlemore BRS is a '**note**', based on the 'very likely' trend observed for zinc. The continual reduction in the rate of increase observed in Zn trends in 2021 compared to that of 2020 (down from 1.83% annual change to 1.61% annual change) is encouraging. It is anticipated that the trend probability and per cent annual change for zinc will continue to decrease following the improvements made in analytical methods in 2019. Ongoing analyses will confirm if this is in fact occurring.

Table 5-3. Quality assurance results for Bulk Reference Sediment (BRS) samples from Middlemore analysed with the 2021 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	69.06	29.0	35.2	235.6	9.03	0.168
Middlemore BRS 2	Pass	69.57	29.8	36.7	242.2	9.56	0.189
Middlemore BRS 3	Pass	69.06	30.6	37.0	243.2	9.68	0.172
Middlemore BRS 4	Pass		30.0	36.6	243.3	9.77	0.172
Middlemore BRS 5	Pass		29.3	35.2	237.4	9.11	0.170
New mean	Pass	69.2	29.7	36.1	240.4	9.43	0.174
Variability in new data (CV, %)	Pass	0.4	2.1	2.5	1.5	3.6	4.8
Difference between new and previous data means (RPD, %)	Pass	4.0	1.5	2.9	3.2	7.0	2.5
Trends (% annual change, Sen Slope)	Note Zn	-0.42	0.46	0.78	1.61	0.56	-0.36
Trends (probabilities, Sen Slope p values)	Fail Zn. Note Mud, Cu, Pb and Hg.	0.87	0.87	0.89	0.98	0.64	0.78
Trends (likelihood based on Sen Slope p values)	Fail Zn. Note Mud, Cu, Pb and Hg.	likely	likely	likely	very likely	indeterminate	likely
Overall mean of previous data	n/a	66.5	29.3	35.12	232.79	8.79	0.17
Lower control limit (mean - 3s)	n/a	59.42	23.78	29.12	176.45	7.05	0.14
Upper control limit (mean + 3s)	n/a	73.58	34.82	41.12	289.13	10.53	0.2
Overall assessment	Note	Pass	Pass	Pass	Note	Pass	Pass
Comments	Increasing trend <2% per year for Zn. Improving since 2020, continue to watch. Watch trends for Pb, approaching very likely and >1%.	Likely decreasing trend, <1% per year.	Likely increasing trend, <1% per year.	Likely increasing trend, <1% per year.	Very likely increasing trend < 2% per year. Results continuing to improve from	Indeterminate trend and <1% per year	Likely decreasing trend, < 1% per year

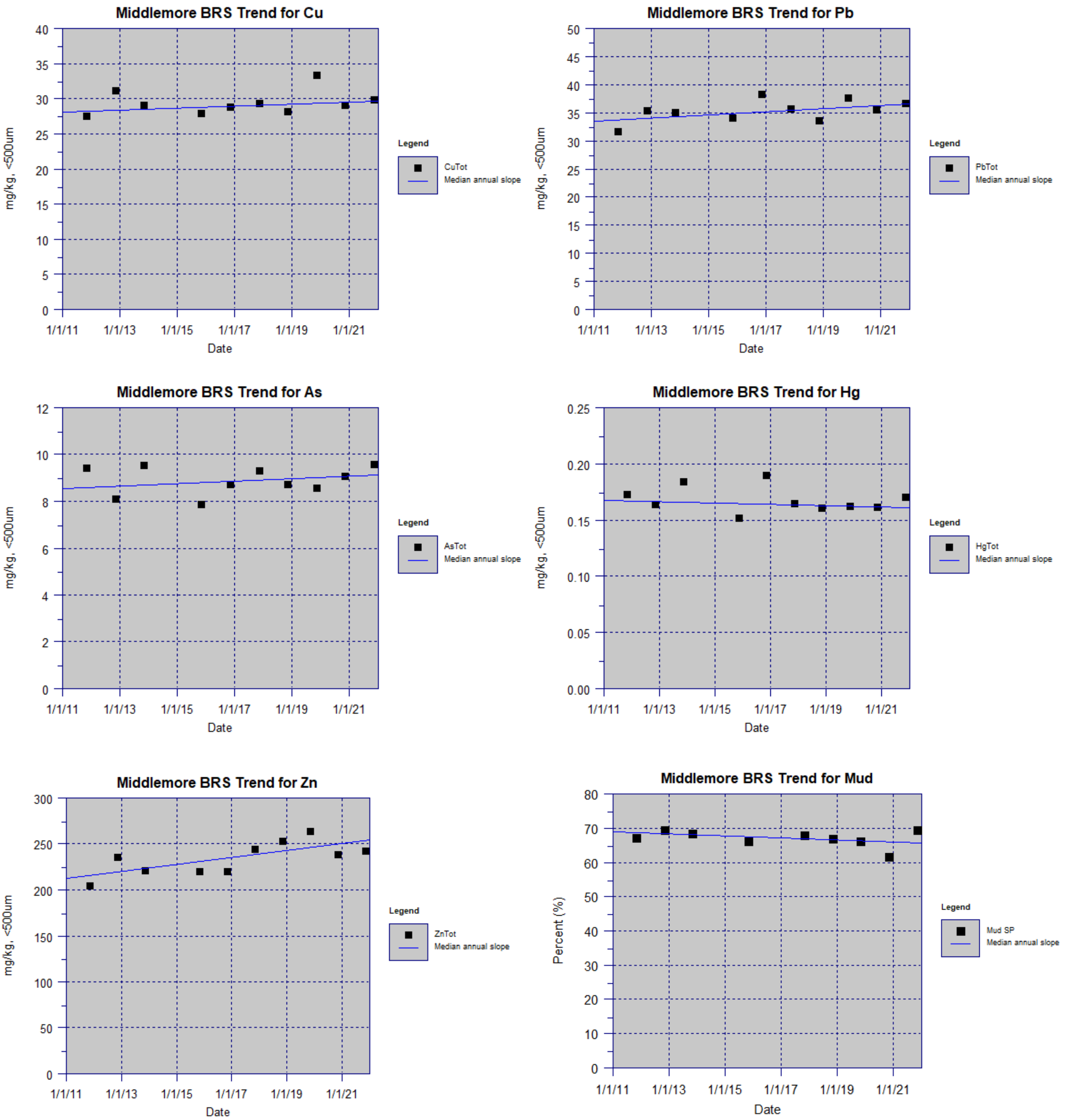

Figure 5-3. Plots of median data for Middlemore BRS metals and mud samples, November 2011 to November 2021. Metals are in mg/kg <500µm fraction, mud is silt + clay <63µm fraction.

8.3 Within-batch data variability from blind duplicates

No blind duplicate samples were submitted with the 2021 sample batch as this is no longer considered to be a necessary component of the QA programme – the BRS, CRM, and replicates from the field samples, provide adequate measures of within-batch variability. However, several samples were analysed as blind within-batch duplicates for some or all of the total recoverable metals by R J Hill Laboratories as part of their in-house QA/QC regime. Results are given in the Hill lab's QC report and are summarised in the NIWA data assessment report (reports available on request), and in the summary Table 3-1 of this report.

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