Surface sediment quality – newly deposited sediment assessment

Assessment of surface water and sediment quality in the vicinity of power stations and coal ash repositories in Lake Macquarie, NSW

Department of Climate Change,
Energy, the Environment and Water

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

Report prepared by DCCEEW for the New South Wales Environmental Protection Authority (NSW EPA)

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Cover photo: Sediment deposition sampler before deployment. Loc Hill/DCCEEW.

Artist and designer Nikita Ridgeway from Aboriginal design agency Boss Lady Creative Designs created the People and Community symbol

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Executive summary

This report comprises an assessment of metal/metalloid contaminants within newly deposited sediment in the southern section of Lake Macquarie, NSW. Newly deposited sediment was collected at ten sites on three separate occasions, between November 2023 and May 2024, using sediment traps deployed for between four and seven weeks. All samples were analysed to determine the total recoverable metal concentrations of 11 metals of interest in Lake Macquarie. The concentrations of metals in the newly deposited sediments were compared to Australian sediment quality guideline values where available and to the total recoverable metal concentrations measured in the surface sediment (top 5 cm), reported in the *Surface sediment quality – chemical assessment* report (DCCEEW, 2024a).

In summary, this study found that:

- Most of the metals investigated in the newly deposited sediments were below their screening criteria (ANZG, 2018; Buchman, 2008), except for copper, selenium, and zinc, which exceeded the criteria at some sites. These metals also exceeded their screening criteria in the surface sediments.
- Lead exceeded its screening criterion in the surface sediments but was much lower in the newly deposited sediment, suggesting that under the environmental conditions observed during sampling, a reduction of lead in the surface sediment may occur over time.
- The newly deposited sediments had similar metal concentrations across the sites sampled despite being collected from different regions of the southern section of Lake Macquarie. When overlaid on data for the surface sediments, the newly deposited sediment appeared in the middle of the data distribution, suggesting moderate metal levels compared to the surface sediment in the southern part of the lake.
- The main differences between the newly deposited sediment samples were slightly elevated concentrations of arsenic near Myuna Bay and Bonnells Bay; mercury and zinc concentrations around the northeast region around Pulbah Island, and copper and selenium concentrations near Myuna Bay and Wyee Bay. This pattern was consistent with the hotspot regions for metal accumulation observed in the surface sediments.
- Similar to lead, the concentrations of copper and zinc observed in the newly deposited sediments were generally lower than those measured in the surface sediment for those hotspot regions, whereas the concentrations of arsenic and mercury were similar in magnitude to the surface sediments for those hotspot regions.
- The newly deposited sediments showed a marginal increase in selenium compared to the surface sediments. Selenium is potentially being adsorbed from the water column onto suspended particles and transported around the lake. While this might suggest an increase in surface sediment concentrations across the lake with time, previous research indicates that selenium concentrations within the sediment have reduced partly due to selenium volatilisation and bioturbation.

Therefore, based on the findings of the newly deposited sediment and if metal inputs into the lake do not change, metal concentrations within the sediment of the southern section of Lake Macquarie would be projected to remain stable or potentially decrease further in the future under environmental conditions experienced during the sampling period.

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Glossary of acronyms and common terms

Acronyms	
ANZG	Australian and New Zealand Governments
DCCEEW	Department of Climate Change, Energy, the Environment and Water
EPA	Environment Protection Authority
LOR	Limit of reporting
NATA	National Association of Testing Authorities
NSW	New South Wales
PCA	Principal component analysis
PVC	Polyvinyl chloride
SAQP	Sampling, Analysis and Quality Plan
S&I	Science and Insights
SQGV	Sediment quality guideline vale
TOC	Total organic carbon

Units	
cm	Centimetre
kg	Kilogram
mm	Millimetre
µm	Micrometre
mg/kg	Milligrams/kilogram

Definitions*	
Bioavailable/bioavailable fraction	Able to be taken up by an organism / a relative measure of the proportion of a chemical that an organism is exposed to through water, sediment, soil, suspended particles, organic carbon and/or food
Concentration	The quantifiable amount of a substance (e.g., in water or sediment) per unit volume or weight
Contaminants	Biological or chemical substances or entities, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function
Dilute acid-extractable metal concentration	Cold extraction using dilute acids (1M HCl for 1 h). Provides a useful estimate of the 'potentially bioavailable' metal concentration
Dissolved	Operationally defined as by what will pass through a 0.45 µm filter
Ecosystem	A community of plants, animals, bacteria and the interrelated chemical and physical environment
Porewater	The water that occupies the space between and surrounds individual sediment particles in an aquatic sediment
Screening criteria	Measurable quantity (threshold) or condition of an indicator for a specific community value below or, for some stressors, above which we consider to be a low risk of unacceptable effects occurring
Sediment	Unconsolidated mineral and organic particulate material that is deposited at the bottom of a water body
- *Newly deposited sediment*	Sediment that has settled out of the water column and collected on the surface of the lake bed or within the sediment deposition samplers used in this study
- *Surface sediment*	The top 5 cm of sediment sampled and analysed in this study
Total recoverable metal concentration	High temperature extraction (95°C for 2 h) using concentrated acids (HNO_3, HCl and H_2O_2)

* Definitions adapted from Simpson and Batley (2016)

1. Introduction

1.1 Project overview

The Science and Insights (S&I) Division of the New South Wales (NSW) Department of Climate Change, Energy, the Environment and Water (DCCEEW) was engaged by the NSW Environment Protection Authority (EPA) to undertake an independent assessment of surface water and sediment quality within the southern section of Lake Macquarie, NSW, Australia. The main purpose of this investigation was to obtain information to facilitate the EPA's contribution to the NSW Government's response to the recommendations in the NSW Parliamentary Inquiry's report into the costs of remediation of coal ash repositories (Parliament of NSW, 2021). The information gathered herein provides a present-day assessment of the contamination status of Lake Macquarie, against which future changes, impacts, and/or mitigation and remediation activities can be assessed.

The scope of works outlined in the Sampling, Analysis, and Quality Plan (SAQP) (DPE, 2023) has been developed to: (i) determine present-day concentrations of metals and metalloids (hereafter referred to as "metals" for simplicity) and nutrients to assess surface water quality; (ii) delineate the extent of metal contamination in sediments; and (iii) assess the potential risks to ecological receptors in the vicinity of the power stations, coal ash repositories, and more broadly within the southern section of Lake Macquarie. The project was divided into stages, as described in the SAQP (DPE, 2023).

The first stage involved a screening assessment of metals in surface sediments collected from 80 locations within Lake Macquarie against adopted screening criteria (ANZG, 2018; Buchman, 2008). The results of this assessment are captured in the companion report, *S*urface sediment quality – chemical assessment (hereafter referred to as the *Surface sediment quality report*; DCCEEW, 2024a). Overall, the *Surface sediment quality report* found that metals present in the surface sediment (top 5 cm) of the southern section of Lake Macquarie posed a low risk to ecosystem health. The assessment identified areas of the lake where multiple metals were present and would benefit from the investigation of additional lines of evidence to strengthen conclusions about the ecological condition. Additional lines of evidence, including toxicity testing and a benthic ecological survey, were included in the scope of works, the results of which are captured in the companion reports: Surface sediment quality – toxicity assessment (DCCEEW, 2024b) and Benthic community composition – Lake Macquarie (Dafforn et al., 2024).

The *Surface sediment quality report* also compared metal concentrations in surface sediments between 2011 (Schneider et al., 2016) and 2022. Overall, the comparison broadly revealed the following: i) arsenic and cadmium concentrations were lower or remained similar in 2022 compared to 2011; ii) selenium concentrations measured in 2022 were lower than in 2011; and iii) generally, copper, lead, and zinc concentrations were lower or remained similar in most areas, except for the northeast corner of the southern lake and surrounding Pulbah Island where higher concentrations were observed in 2022 compared to 2011.

The current report has focused on determining the concentration of metals in newly deposited sediments at 10 key areas of interest in the southern section of Lake Macquarie. This investigation will facilitate a better understanding of environmental trends in metal concentrations and their potential impact on the ecosystem.

1.2 Aims and objectives

The primary aim of the surface sediment quality investigation was to determine the current concentration of metals in surface sediments within southern Lake Macquarie to assess the distribution of historical inputs and the risk they pose to ecological receptors.

The specific objective to be addressed by this assessment was to:

- Assess the present-day metal inputs to the southern lake surface sediment by determining the concentration of metals within newly deposited sediments.

1.3 Project location

The current study investigated estuarine sites located within the southern section of Lake Macquarie (Figure 1). Sites sampled in the *Surface sediment quality report* from both the northern and southern sections of the lake are used for a comparative assessment. For a detailed description of the project location, see Section 1.3 of the *Surface sediment quality report*.

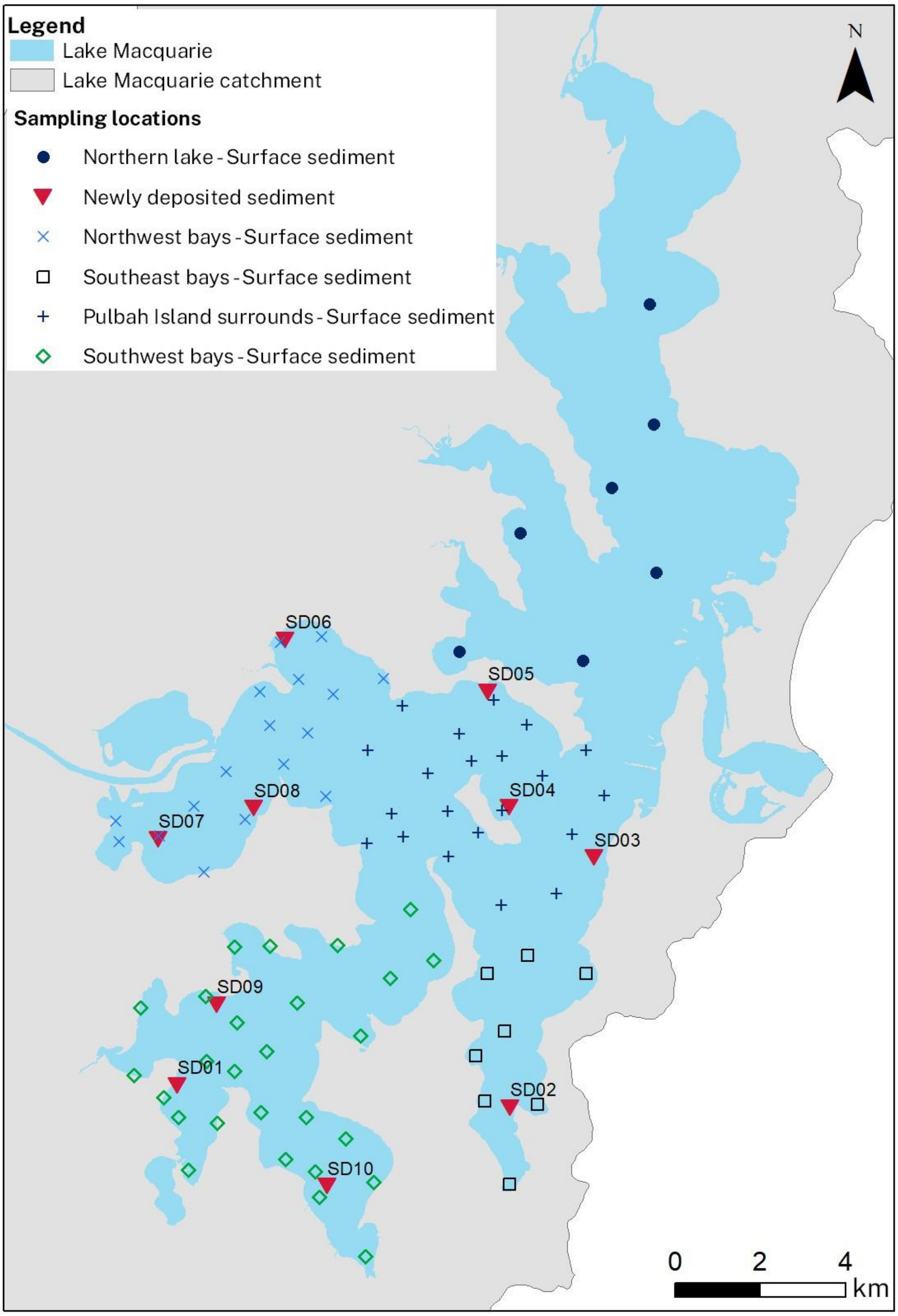

Figure 1. Newly deposited sediment sampling sites (*pink triangles,* ▽) within Lake Macquarie overlayed on the surface sediment (top 5 cm) sampling locations (●×☐+◇) from the *Surface sediment quality report* (DCCEEW, 2024a)

2. Methods

2.1 Site selection

Sediment deposition samplers were deployed at 10 locations in the southern section of Lake Macquarie on three occasions. Site selection was driven by the outcomes of data from the *Surface sediment quality report* to allow for targeted investigation of metal concentrations in newly deposited sediments. Sites were selected for the notable levels of total recoverable metals exceeding their respective screening criteria. These metals were arsenic, cadmium, copper, mercury, lead, selenium, and zinc.

Site selection also took into account water circulation patterns in the southern section of the lake, as identified by Schneider et al. (2016), and the safety of boaters. The samplers were deployed in a location that allowed sediment collection while avoiding central channels and areas with high watercraft activity to prevent damage and loss.

2.2 Sediment collection

Sampling was carried out between November 2023 and May 2024 (Table 1). The deployments and retrievals were carried out from a boat, with deployments lasting from four to seven weeks. Samplers consisted of three sediment traps attached to a central column orientated vertically 120 degrees apart radially (Figure 2). The opening of the traps was positioned vertically in the water column 50 cm from the base of the sampler to reduce the impacts of surface sediment flux and resuspension (English et al., 1997).

Sediment traps and mounting columns were made from polyvinyl chloride (PVC) plumbing pipe primed and glued using a clear plumbing adhesive. Sediment traps were made using 90 mm PVC stormwater pipe 30 cm in length. An end cap was glued to the bottom and a screw cap fitting was glued to the top. A nylon mesh with a 1 cm aperture was secured to the opening to prevent large debris and marine life from entering the trap. The screw cap top allowed the traps to be sealed for transportation and to allow the nylon mesh to be secured in place. Sediment traps were secured and orientated to the column with cable ties and 3D-printed acrylonitrile butadiene styrene brackets, allowing for repeatable orientation and secure attachment.

The orientation and geographical position of the sampler on the lake bed was maintained with either a 15 or 20 kg mass, with the sampler column central to the mass. A 10 mm polypropylene line was secured from the sampler to a 150 or 200 mm float to aid in locating and retrieving the samplers. A 100 g 316 stainless steel mass was positioned on the rope approximately 100 cm below the surface float to reduce the risk of the line floating and creating an entanglement risk. Samplers were deployed by lowering them to the lake bed with the attached line in a controlled manner whilst the skipper held the boat in position to reduce drift from wind and current.

The sediment traps will collect depositing sediment from a range of sources, including urban runoff, industrial discharges, and natural erosion processes, as well as the resuspension of fine sediments due to wave action or boat traffic.

Samplers were retrieved by securing the float with a boat hook and raising it onto the boat by hand with the attached line. Once on board, the sediment traps were removed from their mountings one at a time. The mesh covering was removed, and the traps were sealed with a PVC screw-cap lid that had an integrated rubber seal. The sealed sediment traps were then stored upright in a plastic crate and transported at ambient temperature to the DCCEEW Environmental Forensics Laboratory

(Lidcombe, NSW). There, they were stored refrigerated at 4°C and were processed within one week of collection. Not all sediment traps were recovered after deployment (Table 1).

Table 1. Sediment deposition trap deployment dates and retrieval success

Deployment period	Samplers recovered? (Y: Yes; N: No)									
	SD01	SD02	SD03	SD04	SD05	SD06	SD07	SD08	SD09	SD10
31 October– 19 December 2023	Y	N	N	Y	Y	Y	Y	Y	Y	Y
19 February – 18 March 2024	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
20 March – 30 April 2024	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
n =	3	2	1	3	3	3	3	3	2	3

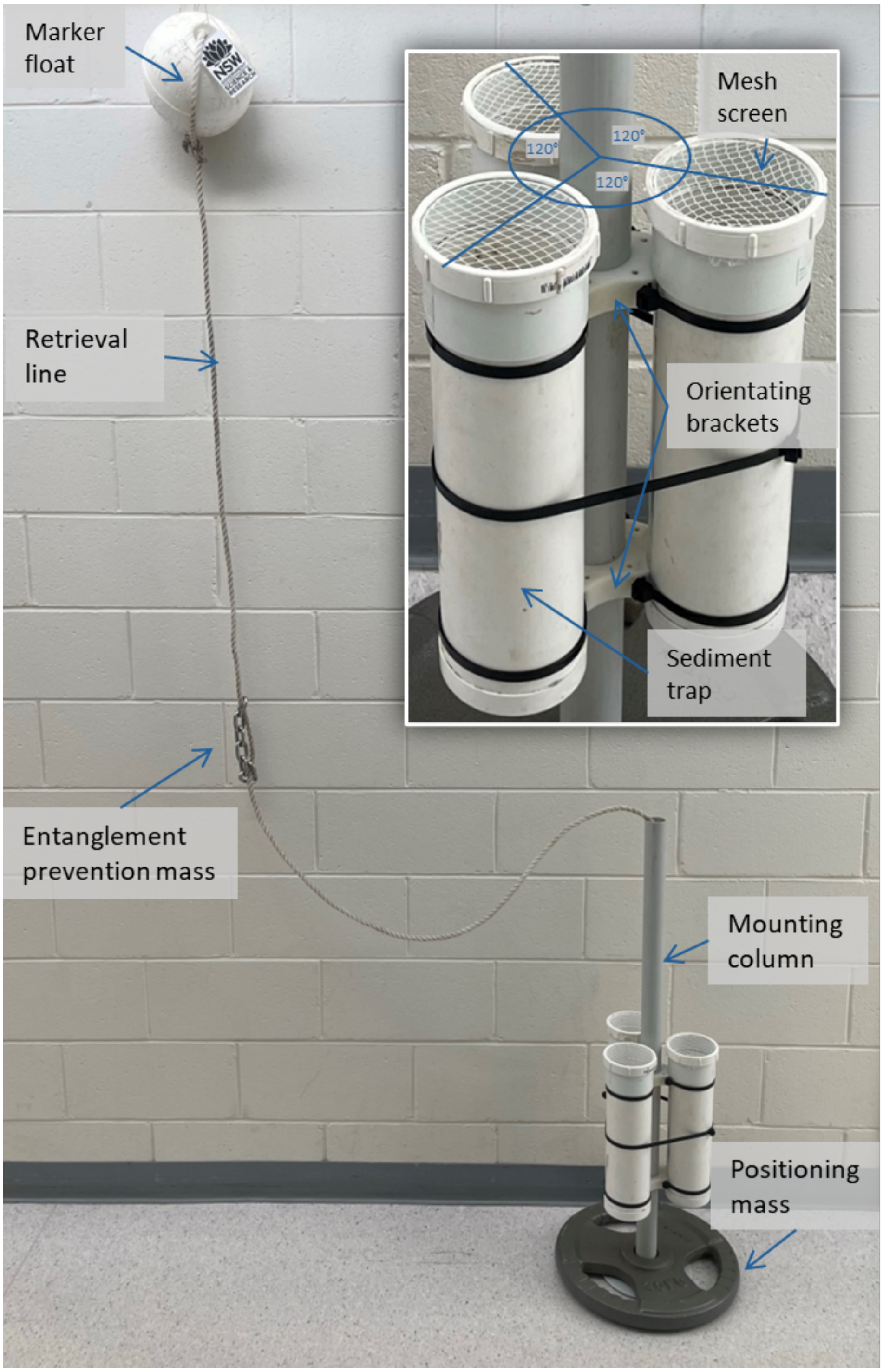

Figure 2. Schematic of the sediment deposition sampler assembly

2.3 Sediment analysis

The collected sediment was allowed to settle within the sediment traps before the overlying water was removed with a nylon hose and a peristaltic pump. Then, the sediment was press sieved and rinsed from the sediment trap using high-purity water (18 MΩ.cm, Milli-Q, Millipore, Australia) through a clean 2 mm stainless steel sieve into a clean glass dish to remove any unwanted debris. The sieved sediment was collected into new 125 ml glass sample jars with a plastic lid using a plastic spoon. The sample jars were refrigerated (4°C), and the sediment was allowed to settle for 48 hours before any remaining overlying water was removed with a nylon hose and a peristaltic pump.

Chemical analyses were performed by an external laboratory, Envirolab Services (Chatswood, NSW). The sediment samples were analysed for total-recoverable metals (Ag, As, Cd, Cr, Cu, Ni, Pb, Sb, Se, Zn, and Hg) using an in-house National Association of Testing Authorities (NATA)-accredited method. In brief, 4-5 g of dried and crushed sediment was digested with 3 mL concentration nitric acid and 3 mL concentrated hydrochloric acid in a closed digestion tube at 90-98°C for 1.5 hours. The concentration of mercury was determined by cold vapour atomic absorption spectrometry (CV-AAS), and all other metals were determined using inductively coupled plasma mass spectrometry (ICP-MS). The analyses were performed in compliance with ISO/IEC 17025 – Testing (i.e., the results met NATA's quality assurance and quality control requirements for reporting). Duplicates and spike recoveries were included in the analysis at a rate of 10% of the samples and met the acceptability criteria (relative percentage difference less than 20% and spike recoveries within 70-130%, respectively).

2.4 Comparative analysis of newly depositing sediments with surface sediments

The total recoverable metal concentrations of the newly deposited sediment were compared to the sediment quality guideline values (SQGV) and SQGV-high values for metals (ANZG, 2018). No SQGV was available for selenium, so the apparent effect threshold provided by Buchman (2008) was adopted as the screening criterion. The rationale for the screening criteria is provided in Section 2.4 of the *Surface sediment quality report*.

The total recoverable metal concentrations of the newly deposited sediment were compared with the total recoverable metal concentrations of the surface sediment (top 5 cm) reported in the *Surface sediment quality report*. The purpose was to assess the potential impact of recent sediment inputs on metal concentrations within the lake. Descriptive statistics were determined to summarise the surface sediment data for the southern section of Lake Macquarie only (n=74 sites) from the *Surface sediment quality report* and included the minimum, maximum, the 50th (median), and 95th percentiles for interpreting the spread of the data. The 50th (or 95th) percentile in the dataset has a value greater than or equal to 50% (or 95%) of the data.

Principal component analysis (PCA) was used to explore if there were trends or relationships in the concentrations of total recoverable metals of newly depositing sediments with those found in the surface sediments of samples collected in the northern and southern sections of Lake Macquarie in 2022.

3. Results and discussion

3.1 Newly deposited sediment chemistry

The total recoverable metal concentrations of the newly deposited sediments collected within southern Lake Macquarie are presented in Table 2 alongside their respective screening criteria and key descriptive statistics from the *Surface sediment quality report*. A total of 11 metals were investigated. The results of their screening assessment are summarized below:

- Eight of these metals (Ag, As, Cd, Cr, Hg, Ni, Pb, and Sb) had total recoverable metal concentrations below their respective screening criteria at all sites (ANZG, 2018).
    - Of these metals, six (Ag, Cd, Cr, Ni, Pb, and Sb) also had total recoverable metal concentrations below the 95th percentile concentration measured in the surface sediments from the southern section of the lake (n=73 sites) from the *Surface sediment quality report*, indicating the concentration of these metals in the newly deposited sediment were similar to those measured in the surface sediment.
    - None of these metals, except for lead exceeded their respective screening criteria in the surface sediments collected within the southern section of Lake Macquarie either.
    - Lead, arsenic and mercury are discussed in more detail below.
- Three metals (Cu, Se, and Zn) exceeded their respective screening criteria at one or more sites and are discussed in more detail below.

Lead

Lead previously exceeded the SQGV in the surface sediments within the northeast region of the southern section of the lake, around Pulbah Island (Figure 3). The results of the newly deposited sediment closest to this region (e.g., SD03, SD04, and SD05), however, indicate that there is less lead accumulated on the newly deposited sediment.

Arsenic

Arsenic was marginally greater than the 95th percentile concentration measured in the surface sediments collected from the southern section of the lake (17 mg/kg) at only a single site, SD06 (18 mg/kg), located in Myuna Bay. The concentration was similar to those found at surface sediment sampling sites nearby (Figure 4). Previously, a hotspot of arsenic in the surface sediment had been observed near Cams Wharf on the eastern arm of the southern section of the lake, but no elevated arsenic concentrations were seen in the newly deposited sediment collected closest to this region (e.g., SD02 and SD03) (Figure 4).

Mercury

Mercury was marginally greater than the 95th percentile concentration measured in the surface sediments collected from the southern section of the lake (0.093 mg/kg) at two sites (SD03: 0.099 mg/kg; SD04: 0.10 mg/kg) located in the northeast of the southern section of the lake. The elevated concentrations coincided with where a hotspot for mercury was observed in the surface sediments (Figure 5).

Copper

Copper exceeded the SQGV (65 mg/kg) in newly depositing sediment at a single site, SD09 (69 mg/kg), located between Bird Cage Point and Bluff Point (just north of Wyee Bay) (Figure 6). This coincides with the previously identified hotspot for copper accumulation in the surface sediment north of Wyee Bay. A second hotspot for copper was also previously observed between Myuna Bay and Wangi Wangi Point. The results of the newly deposited sediment for this region (SD04, SD05, and SD06), however, indicated that there is less copper accumulated on the newly deposited sediment than on the surface sediments from this region. All copper concentrations for the newly deposited sediment samples were less than the 95th percentile of copper concentrations for the surface sediment sites. Five of the 10 sites (SD01, SD03, SD05, SD06, and SD09) were between the 50th and 95th and coincided with the identified hotspots in the surface sediments.

Selenium

Selenium was equal to the screening criterion (1 mg/kg) at three of the sediment deposition sites (SD01, SD05, and SD09) and exceeded at a single site, SD06 (1.09 mg/kg) (Figure 7). Compared to the surface sediment (top 5 cm), six of the newly deposited sediment samples had selenium concentrations equal to the 95th percentile concentration measured in the surface sediments collected from the southern section of the lake, three equal to the maximum concentration and a single sample greater than the maximum. The selenium concentrations of the newly deposited sediments were, however, all within a narrow concentration range of 0.9 to 1.1 mg/kg, which was only marginally greater than the concentration range observed within the surface sediments of 0.4 to 1.0 mg/kg. Total and dissolved selenium concentrations in the surface water across the Lake were low, with both having a 95th percentile concentration of <0.002 mg/L (n=228; 19 sites x 12 sampling points). These findings are supported by Maher et al. (2022), which suggests that selenium in the water column is rapidly adsorbed to suspended particles and that transport by particles is occurring within the southern section of Lake Macquarie. Their study also found that selenium concentrations within the sediment have reduced overtime partly due to selenium volatilisation and bioturbation, which is consistent with the findings of the *Surface sediment quality report*, which also found a marked reduction in selenium concentrations of the surface sediment between 2011 and 2022.

Zinc

Two sites exceeded the SQGV for zinc (200 mg/kg), SD04 (217 mg/kg) and SD05 (203 mg/kg), which were both located between Pulbah Island and Wangi Wangi (Figure 8). The exceedances coincided with the zinc hotspot previously identified in the northeast corner of the southern section of the lake, around Pulbah Island. The results of the newly deposited sediment for this region (SD03, SD04, and SD05), however, indicated that there is less zinc accumulated on the newly deposited sediment than on the surface sediments from this region. All newly deposited sediment sample sites were between the 50th and 95th percentile concentrations (120 and 284 mg/kg, respectively) of zinc for the surface sediment collected from the southern section of the lake.

Table 2. Total recoverable metal concentrations (mg/kg) in newly deposited sediments, November 2023 – May 2024. ANZG (2018) sediment quality guideline values (SQGVs) have been applied as screening criteria unless otherwise indicated. Values that exceed the SQGV are indicated by bold font. No values exceeded the GV-high value. Values greater than the 95th percentile concentration measured within surface sediment* are indicated by purple font.

Metal	Screening criteria		Surface sediment (top 5 cm)[a]			Newly deposited sediment (n=3[b])									
	SQGV	SQGV-High	50th percentile	95th percentile	Maximum	SD01	SD02 [c]	SD03 [d]	SD04	SD05	SD06	SD07	SD08	SD09[c]	SD10
Ag	1	4	<0.6	<0.6	<0.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
As	20	70	13	17	24	7	8	7	7	10	18	15	15	7	10
Cd	1.5	10	0.2	0.5	0.9	0.29	0.25	0.30	0.31	0.24	0.26	0.21	0.20	0.34	0.29
Cr	80	370	17	28	30	23	18	18	19	18	14	16	15	23	19
Cu	65	270	44	74	84	58	35	46	39	50	57	43	42	69	37
Hg	0.15	1	0.052	0.093	0.120	0.059	0.077	0.10	0.099	0.073	0.059	0.061	0.053	0.073	0.046
Ni	21	52	8	14	16	8	9	9	10	10	8	9	8	9	8
Pb	50	220	20	60	69	19	28	40	41	33	20	21	22	21	17
Sb	2	25	<1	<1	<1	<2	<1	<1	<1	<1	<1	<1	<1	<2	<1
Se	1[e]		0.4	0.9	1.0	1.0	0.9	0.9	0.9	1.0	**1.1**	0.9	0.9	1.0	0.9
Zn	200	410	120	284	310	147	192	190	**217**	**203**	139	146	144	165	121

[a] Descriptive statistics for surface sediment (top 5 cm) total recoverable metal concentrations collected within the southern section of Lake Macquarie (n=73), August 2022 (DCCEEW, 2024)

[b] The sediment deposition traps consisted of three individual replicates and the average reported for each deployment. The sediment deposition samplers were deployed three times, and the value reported here is the average of the three-time points (n=3) unless otherwise indicated.

[c] Not all sediment deposition samplers were retrieved (n=2)

[d] Not all sediment deposition samplers were retrieved (n=1)

[e] Buchman (2008)

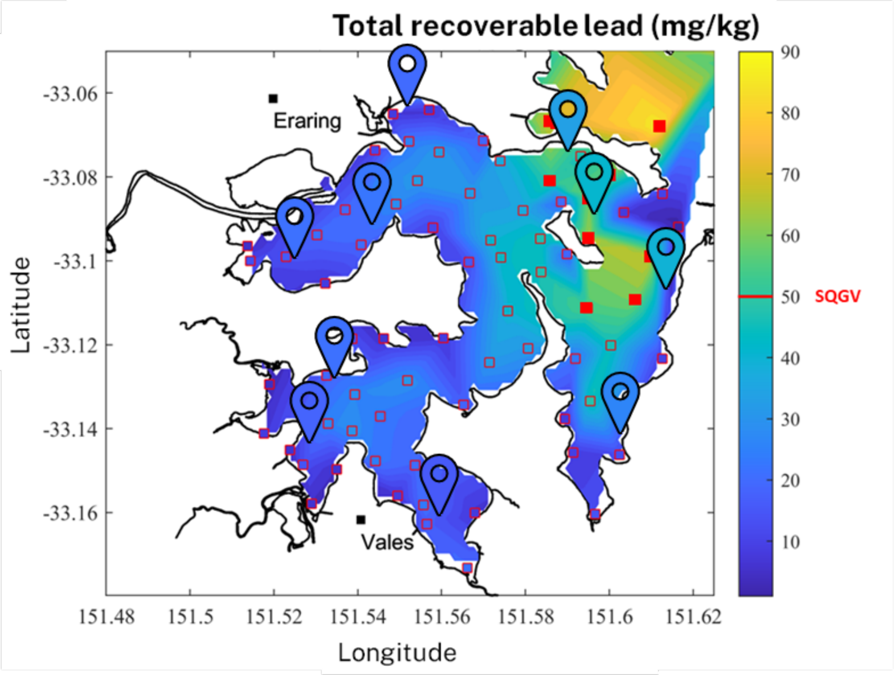

Figure 3. Total recoverable lead concentrations (TR-Pb, mg/kg) in the newly deposited sediment (*location pins*; the internal colour of the pin reflects the concentration of the metal) overlayed on the contour map of TR-Pb in the surface sediment (top 5 cm; *red squares*), southern Lake Macquarie. Sites exceeding the ANZG (2018) sediment quality guideline value (SQGV) are indicated with a solid red square.

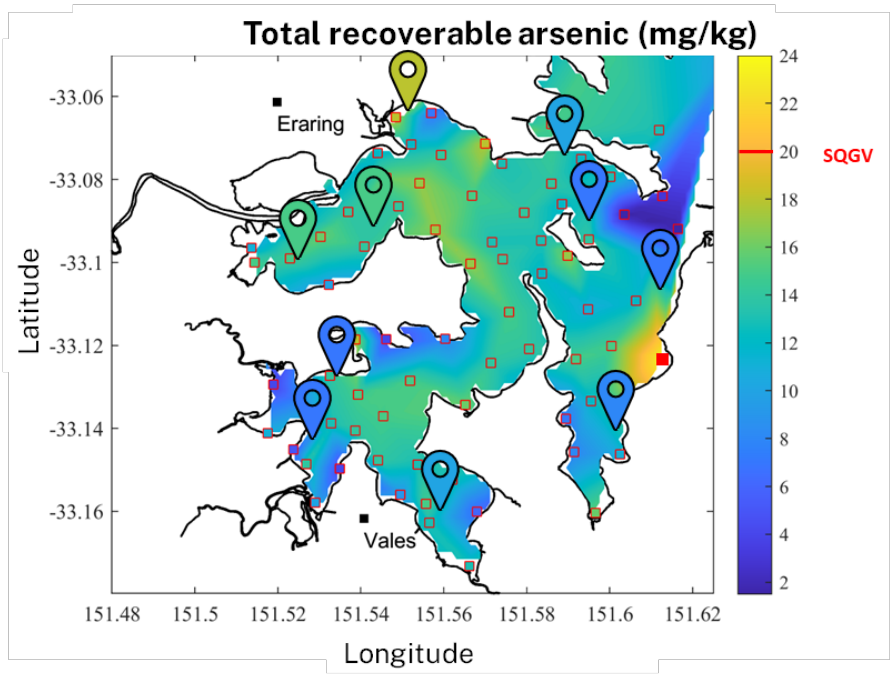

Figure 4. Total recoverable arsenic concentrations (TR-As, mg/kg) in the newly deposited sediment (*location pins*; the internal colour of the pin reflects the concentration of the metal) overlayed on the contour map of TR-As in the surface sediment (top 5 cm; *red squares*), southern Lake Macquarie. Sites exceeding the ANZG (2018) sediment quality guideline value (SQGV) are indicated with a solid red square.

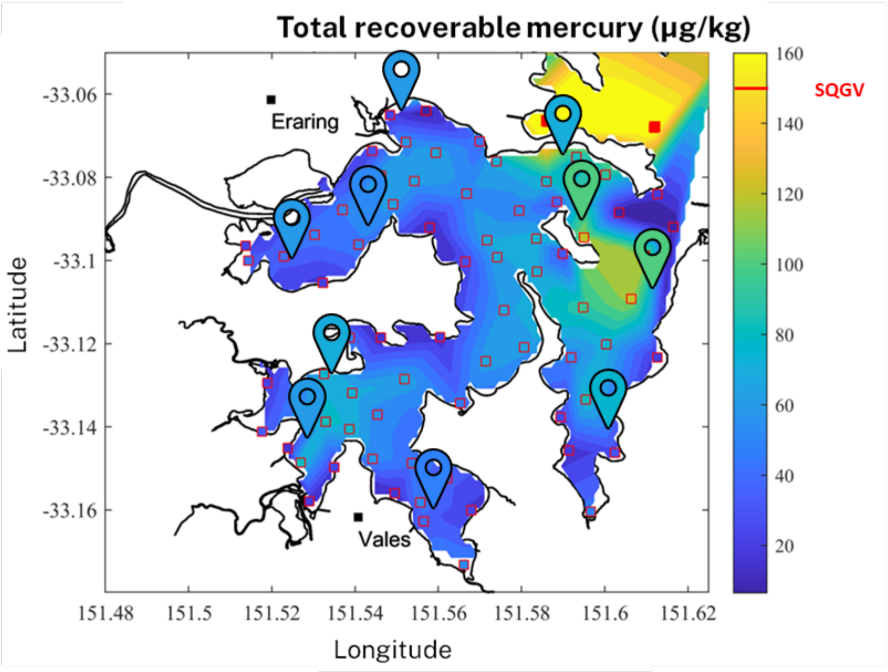

Figure 5. **Total recoverable mercury concentrations (TR-Hg, mg/kg) in the newly deposited sediment (*location pins*; the internal colour of the pin reflects the concentration of the metal) overlayed on the contour map of TR-Hg in the surface sediment (top 5 cm; *red squares*), southern Lake Macquarie. Sites exceeding the ANZG (2018) sediment quality guideline value (SQGV) are indicated with a solid red square.**

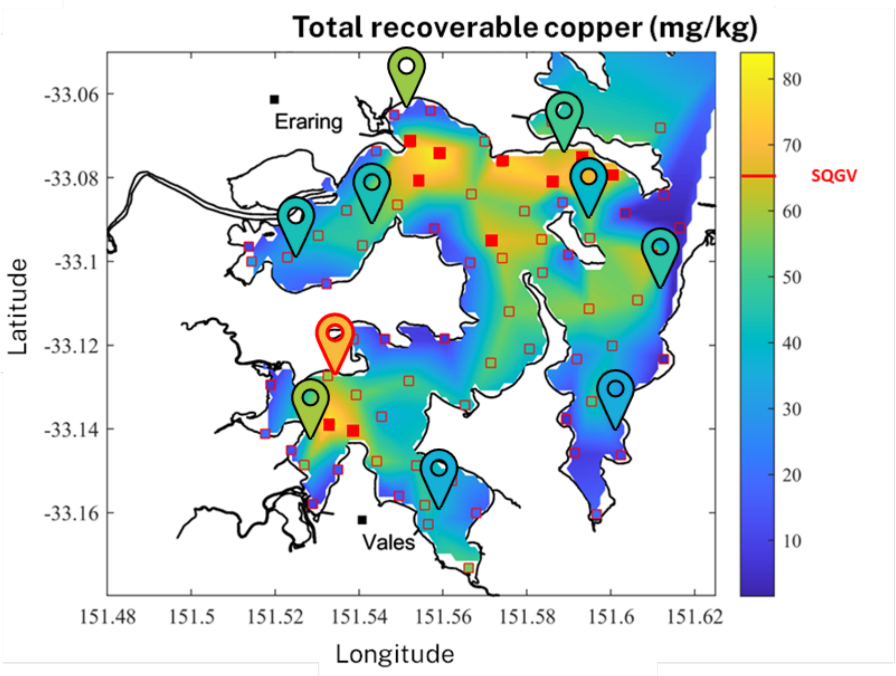

Figure 6. **Total recoverable copper concentrations (TR-Cu, mg/kg) in the newly deposited sediment (*location pins*; the internal colour of the pin reflects the concentration of the metal, a red outline indicates the concentration exceeded the ANZG (2018) sediment quality guideline value (SQGV)) overlayed on the contour map of TR-Cu in the surface sediment (top 5 cm; *red squares*), southern Lake Macquarie. Sites exceeding the ANZG (2018) sediment quality guideline value (SQGV) are indicated with a solid red square.**

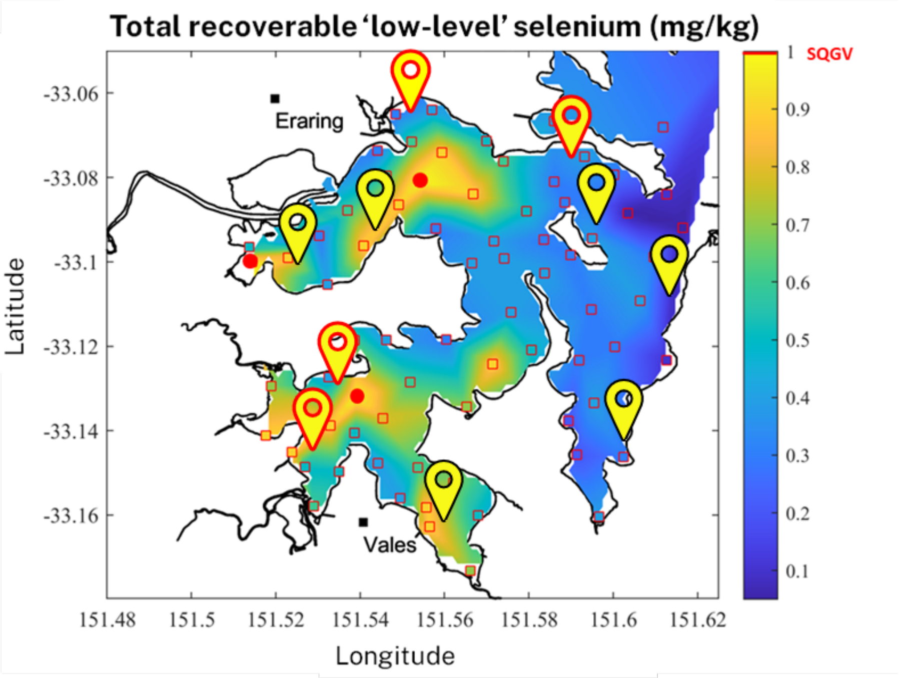

Figure 7. Total recoverable selenium concentrations (TR-Se, mg/kg) in the newly deposited sediment (*location pins*; the internal colour of the pin reflects the concentration of the metal, a red outline indicates the concentration was equal to or exceeded the ANZG (2018) sediment quality guideline value (SQGV)) overlayed on the contour map of TR-Se in the surface sediment (top 5 cm; *red squares and circles*), southern Lake Macquarie. Sites equal to the ANZG (2018) sediment quality guideline value (SQGV) are indicated with a solid red circle.

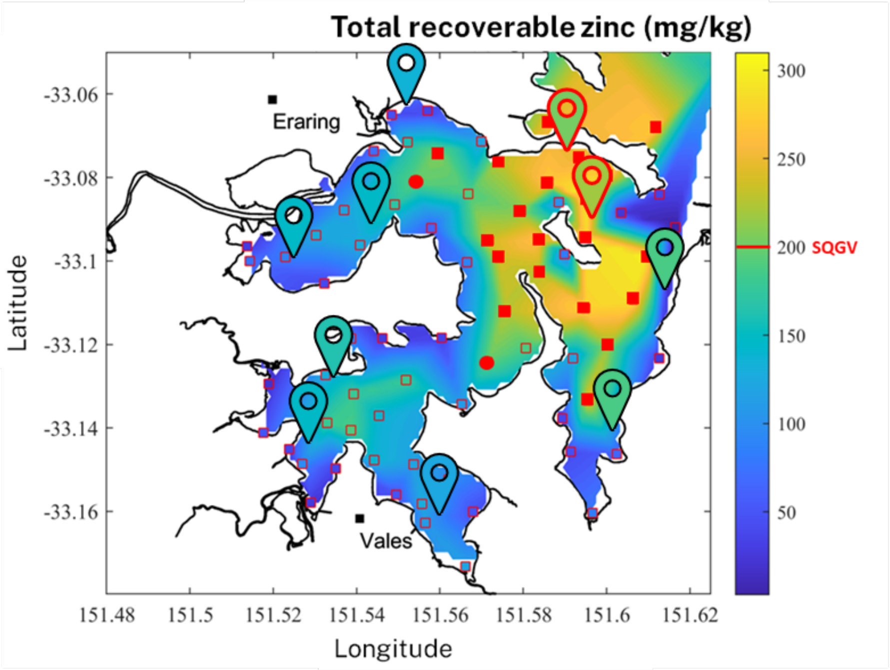

Figure 8. Total recoverable zinc concentrations (TR-Zn, mg/kg) in the newly deposited sediment (*location pins*; the internal colour of the pin reflects the concentration of the metal, a red outline indicates the concentration exceeded the ANZG (2018) sediment quality guideline value (SQGV)) overlayed on the contour map of TR-Zn in the surface sediment (top 5 cm; *red squares and circles*), southern Lake Macquarie. Sites equal to or exceeding the SQGV are indicated with a solid circle or red square, respectively.

3.2 Comparison of newly deposited sediment and surface sediment total recoverable metal concentrations

PCA was used to analyse and illustrate the variance of total recoverable metal concentrations for newly depositing sediments and surface sediments collected from both the northern and southern sections of Lake Macquarie (Figure 9). The first PCA axis explained 49.3% of the variation, with the three strongest influencing factors driving separation being increasing zinc, chromium, and nickel. The second PCA axis explained a further 19.9% of the variation, with the three strongest factors driving separation being increasing selenium and decreasing mercury and lead. The PCA showed distinct patterns or groupings among the different sediment samples. The newly deposited sediments clustered closely together, indicating very similar metal concentrations within the newly deposited sediments despite being collected from different regions of the lake. The surface sediments, collected from the southern section of the lake, also clustered together and spanned the region that encompassed the newly depositing sediments. The surface sediments collected from the northern section of the lake were more dispersed and formed a separate grouping in the direction of higher concentrations of the metals: lead, mercury, zinc, and cadmium. Overall, the newly deposited sediments were more similar to the surface sediments collected within the southern section of the lake. Particle transport from the northern to the southern section of Lake Macquarie does not appear to be a significant factor influencing metal concentrations in the newly deposited sediments.

The similarity between the newly deposited sediment and the surface sediments collected from the southern section of the lake only was explored further in Figure 10. Surface sediments from different regions of the lake, represented by different-coloured crosses, show no distinct groupings in metal concentration by region, suggesting variability in metal concentrations across the lake. The contour plots provided in the *Surface sediment quality report* and a subset reproduced in Figures Figure 3-Figure 8 showed that generally, metals accumulation was lower around the lake foreshore where sediments were coarser grained and had less organic carbon content, and greater in the deeper channels where the sediments were finer grained and had a greater organic carbon content. Cadmium and selenium correlated strongly together, suggesting that they are related contaminants from the same source and vary independently from the other metals. In contrast, the other elements (As, Cr, Cu, Hg, Ni, Zn, and Pb) also correlated strongly together. The newly deposited sediment formed a closely clustered group, again indicating their overall similarity to each other. The newly deposited sediments most closely resembled sediments collected within the northwest and southwest bays. Their cluster overlaid in the centre of the sample distribution, indicating moderate metal concentrations compared to those found in the surface sediment across the southern section of the lake.

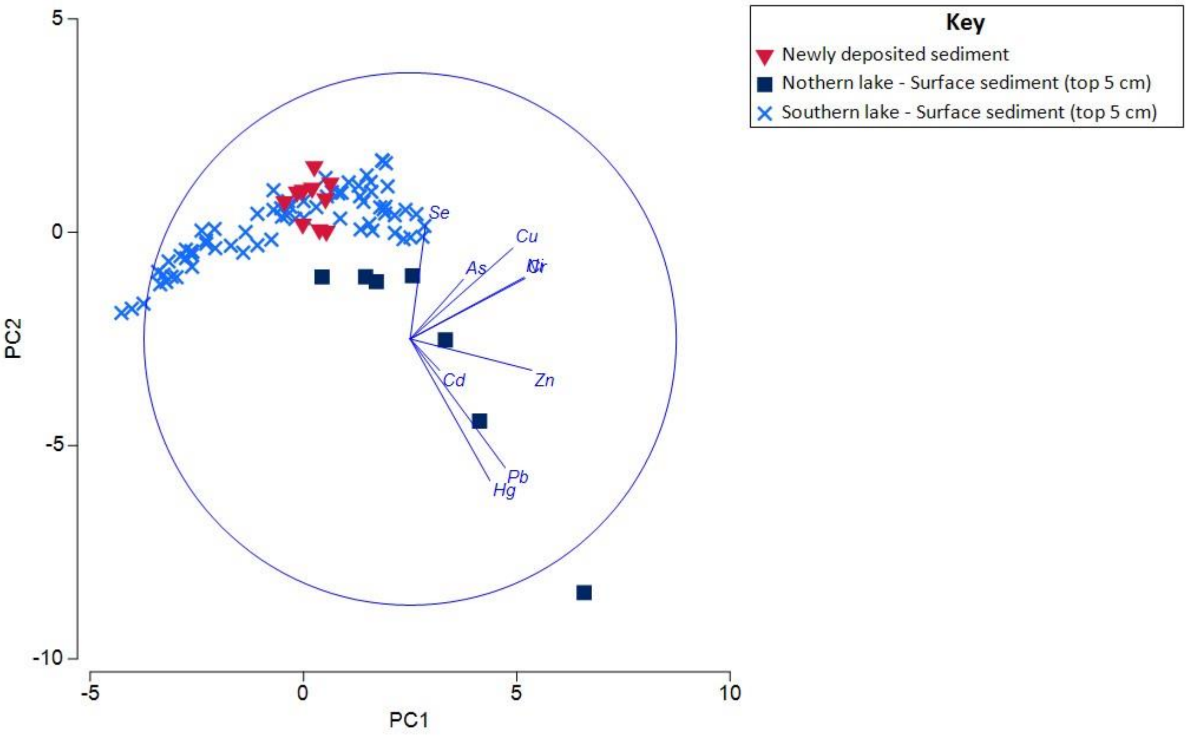

Figure 9. Principal components analysis of total recoverable metal concentrations of newly deposited sediments collected from Lake Macquarie (2023 to 2024), and surface sediments (top 5 cm) collected from the northern and southern sections of Lake Macquarie (2022; data from DCCEEW (2024a))

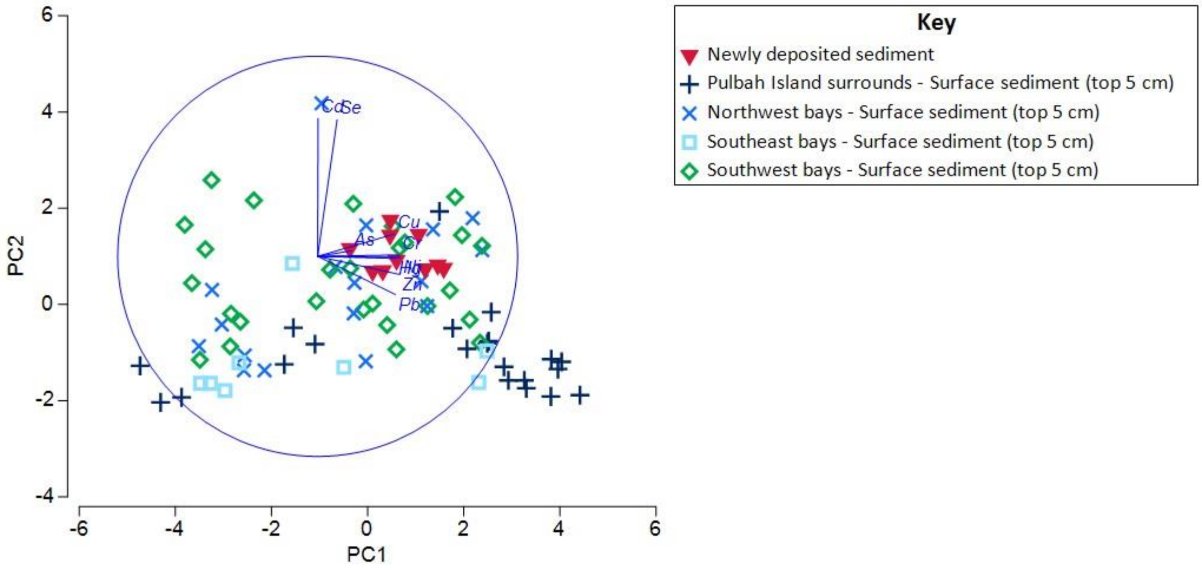

Figure 10. Principal components analysis of total recoverable metal concentrations of newly deposited sediments collected from Lake Macquarie (2023 to 2024), and surface sediments (top 5 cm) collected from the southern sections of Lake Macquarie (2022; data from DCCEEW (2024a))

4. Conclusion

The current study assessed metal contaminants in newly deposited sediments collected within the southern section of Lake Macquarie. Most metals were below their screening criteria except for copper, selenium, and zinc, which exceeded screening criteria at one or more sites (ANZG, 2018; Buchman, 2008). These metals also exceeded their screening criteria in the surface sediments. Lead exceeded its screening criterion in the surface sediments (within the northeast region of the southern section of the lake, around Pulbah Island) but not the newly deposited sediments. The lead concentrations of the newly deposited sediment were much lower in this region, suggesting that under the environmental conditions observed during sampling, a reduction of lead in the surface sediment may occur over time.

The newly deposited sediments had similar metal concentrations between the sample sites despite being collected from different regions of the southern section of Lake Macquarie. When overlaid on data for the surface sediments, the newly deposited sediment appeared in the middle of the data distribution, suggesting moderate metal levels compared to the surface sediment in the southern part of the lake.

The main differences among the newly deposited sediment samples were slightly elevated concentrations of arsenic near Myuna Bay and Bonnells Bay; mercury and zinc concentrations around the northeast region around Pulbah Island; and copper and selenium concentrations in the south near Myuna Bay and Wyee Bay. This pattern was consistent with the hotspot regions for metal accumulation observed in the surface sediments. Similar to lead, the concentrations of copper and zinc observed in the newly deposited sediments were generally lower than those measured in the surface sediment for those hotspot regions. Whereas the concentrations of arsenic and mercury were similar in magnitude to the surface sediments in those hotspot regions. Only selenium in the newly deposited sediments (concentration range 0.9 to 1.1 mg/kg) exceeded the maximum concentration observed in the surface sediments (concentration range 0.4 to 1.0 mg/kg). Selenium is potentially being adsorbed from the water column onto suspended particles and transported around the lake. While this might suggest an increase in surface sediment concentrations across the lake with time, previous research indicates that selenium concentrations within the sediment have reduced partly due to selenium volatilisation and bioturbation (DCCEEW, 2024a; Maher et al., 2022).

Therefore, based on the findings of the newly deposited sediment and if metal inputs into the lake do not change, metal concentrations within the sediment of the southern section of Lake Macquarie would be projected to remain stable or potentially decrease further in the future under environmental conditions experienced during the sampling period.

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6. Acknowledgements

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