8.3 Heavy metals in freshwater sediment

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Citation for this chapter: Tremblay, L. (2024). Heavy metals in freshwater sediment. *In:* Lohrer, D., et al. *Information Stocktakes of Fifty-Five Environmental Attributes across Air, Soil, Terrestrial, Freshwater, Estuaries and Coastal Waters Domains*. Prepared by NIWA, Manaaki Whenua Landare Research, Cawthron Institute, and Environet Limited for the Ministry for the Environment. NIWA report no. 2024216HN (project MFE24203, June 2024). [https://environment.govt.nz/publications/information-stocktakes-of-fifty-five-environmental-attributes]

Alternative attribute name: Trace metals in freshwater sediment

Preamble: Pressures from human activities, such as agriculture, effluent discharges from landfill and wastewater treatment plants (WWTPs), urbanisation, and industrial wastes increase sediment metal concentrations [1]. Metals are of growing concern in terms of water quality management, as they cannot be degraded in the environment although some metal species can be transformed into other species which may be more or less toxic [1].

State of knowledge of "Trace metals in freshwater sediment" attribute: Good / established but incomplete – general agreement, but limited data/studies

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

Trace metals are naturally present in the environment. Their distribution depends on the presence of natural sources (e.g., volcanoes or erosion) and human activities through extraction from ores [2]. The main anthropogenic activities resulting in the discharge of metals include fossil fuel combustion, industrial and agricultural processes and many metals are used in daily household activities [3]. It is important to recognise the types of metals. For instance, cadmium and mercury are heavy metals but other metals of environmental concern including zinc and copper are essential metals. It is estimated that one-third of all proteins requires a metal cofactor for normal functions [2]. However, even essential metals can be toxic and that depends on the concentration. This relates to the concept of essentiality as illustrated in Figure 1. For essential metals like copper, zinc and selenium, there is a "window of essentiality" which represents a range of concentrations that will maintain a level of health in an organism- as illustrated in Figure 1A. For non-essential metals like cadmium, when concentrations reach levels that overcome the defence capacity of an organism, then it becomes toxic (Figure 1, panel B). This is why using trace metals is the appropriate term to use as it covers all metals. The most appropriate term would be trace elements as arsenic is defined as an element or metalloid.

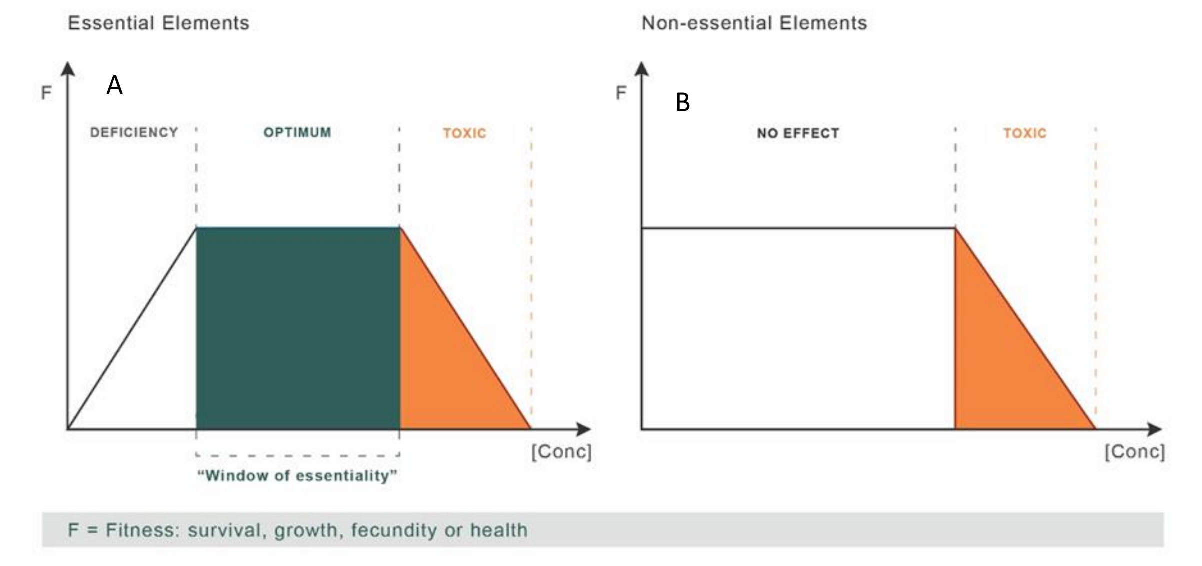

Figure 1. Conceptual diagrams illustrating the differences in concentration–response relationships with respect to organism health between A) essential metals and B) non-essential metals.

The toxicity of trace metals is well established and can impact both ecosystem and human health [4]. The relationship of metals to human and ecological health has been covered in the Attribute of trace metals in water. The hazards remain similar with sediment as another source of metal exposure with receptor species most at-risk being sediment dwelling organisms. Metals in sediment can enter the food chain through bioaccumulation posing a risk to exposed biota higher in the food chain and humans [5]. As sediment is the major compartment where metals accumulate, it is also the major source of exposure posing the highest risk [6], although metals in dissolved form are considered more toxic (see Trace metals in water A3 and D3) .

A2. What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

There is strong evidence globally of the adverse effects on human metabolism resulting from exposure to metal-contaminated drinking water [3]. Exposure to non-essential metals is potentially harmful as they do not have physiological roles in the metabolism of cells. In addition, the ingestion of metals via food or water can modify the metabolism of other essential elements including zinc, copper, iron and selenium [4]. Metals and metal compounds can interfere with functions of the central nervous system (CNS), the haematopoietic system, liver and kidneys [2].

Waterbodies in areas of high anthropogenic activity like urban centres or rural areas with intensive agriculture are more likely to be impacted bymetal contaminations. Urban areas have larger areas of impervious surfaces such as roofs, roads and paved areas that are sources of metals [7]. Many urban and rural streams are also the receiving environment for untreated sewage, via leakage or overflows from wastewater networks and treatment plants.

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

The status quo would result in the continuous accumulation of metals in the environment as they are not biodegradable. Worldwide, in addition to the issue of anthropogenic zinc contamination in urban areas, contamination of soils with zinc has increased in some agricultural sectors, such as dairy farming and horticulture. The most significant concern for freshwater lakes relates to the partitioning of zinc to bed sediments, where over time it may gradually build up beyond ecotoxic thresholds for macroinvertebrates and other bed-dwelling organisms, which are integral components of aquatic ecosystems [8]. Accumulation of zinc in sediments from rural lakes is now evident in the Waikato region. While 86 per cent of lakes assessed have at least twice background concentrations, three lakes presented values above the interim sediment quality guideline low value of 200 mg/kg (meaning that further investigation is required to assess the extent of risk posed by the chemical) [8]. A recent study of water quality in urban streams indicated that if urban development continues in its current form, increases in urban land cover around New Zealand can be expected to result in further declines in water quality at impacted locations [7].

There is evidence that better management of trace metal sources can reverse the trends. For instance, the global phase-out of leaded petrol use has contributed to the decline of concentrations in the ocean [9]. Also, a UK study showed that reductions in industrial activity and improved environmental controls on emissions resulted in a decline in trace metal concentrations in sediments [10].

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

A report commissioned by the PCE provided a national-level summary of the chemical contaminants including metals that Regional Councils/Unitary Authorities include in consent-based monitoring requirements and routine State of the Environment (SoE) monitoring programmes [11]. It stated that copper, zinc and lead were the most frequently listed trace metals monitored as part of consent conditions [11]. It is interesting that to date, there are no published studies have quantitatively assessed relationships of copper and zinc with intensity of urban land use, despite these metals being key contaminants in urban streams and frequently used as indicators of stormwater inputs [7].

One important aspect that is not commonly included in current monitoring frameworks is the use of biological indicators, or bioindicators. Bioindication is the use of an organism, a part of an organism, or a community of organisms, to assess the quality of its/their environment [5]. A definition of bioindicator was suggested to be an anthropogenically induced variation in biochemical, physiological, or ecological components or processes, structures, or functions (i.e., a biomarker) that can be causally-linked to biological effects [12].

Macroinvertebrate abundance can be influenced by the level of stressors as taxon richness declines across pollution gradients. Pollution sensitive taxa respond to levels of contaminants leading to alterations to benthic macroinvertebrate assemblages (e.g., [13]). Effects of trace metals on benthic communities in New Zealand streams were similar to those reported for metal-polluted streams in North America and Europe, suggesting that responses to metal contamination are predictable [14].

There have been notable advances in the development of bioavailability models for assessing toxicity as a function of water chemistry in freshwater ecosystems. For instance, the biotic ligand model (BLM), the multiple linear regression model, and multimetal BLM have been developed for most of the common mono- and divalent metals. Species sensitivity distributions for many metals are available, making it possible for many jurisdictions to develop or update water quality criteria or guidelines [15]. Sediment bioavailability models are also emerging including models that allow for prediction of toxicity in sediments for copper and nickel [15].

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

The author is not in a position to comment but Regional Councils have selected sites where they monitor trends for the SoE. It is possible that consent holders would also have access to sites for monitoring as part of their consent conditions. Accessing sites for monitoring should use appropriate engagement practices with all stakeholders and partners.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

The analytical methods using inductively coupled plasma mass spectrometry (ICP-MS) instruments can measure elements and metals and are well established and validated. Several commercial laboratories including Hill Labs and AsureQuality can measure metals at competitive prices.

A recent investigation reported limitations that councils have identified that prevent the expansion of current monitoring programmes including the high costs for both laboratory analysis and council staff time spent doing monitoring and reporting [11]. However, it should be noted that consent holders cover agreed conditions monitoring costs.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

We are not aware of any heavy metals monitoring being regularly undertaken by iwi/hapū/rūnanga. Resourcing is difficult for iwi/hapū/rūnanga to obtain, and any monitoring by agencies is generally infrequent, inconsistent, and ad hoc, and most programmes fail to provide information on whether chemical contaminants will have impacts of concern to Māori [32]. The Waikato River Report Card and other environmental assessment frameworks being developed by/with iwi/hapū/rūnanga include “safe to eat” or “safe to swim” outcomes [33-35]. Data/indicators required to fully realise these holistic cultural assessment frameworks will require information about heavy metals in water, sediment, and/or mahinga kai species.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

Contaminants are mostly found as complex mixtures of which metals are one family of pollutants at impacted sites. The issue of multiple stressors relates to the range of sources that put pressure on the receiving environment – e.g., stormwater and wastewater contain a range of other types of contaminants. Cumulative effects, through additional new industries, climate change and other stressors, can reduce environmental resilience and increase the risk of environmental degradation or economic collapse of enterprises relying on the environment [20]. The importance of sediments as stressors will depend on site ecosystem attributes and the magnitude and preponderance of co-occurring stressors [21]. Management approaches must contend with multiple drivers in concert. The coordination of regulating agencies for urban and agricultural runoff is warranted for as metals are only one component within a range of other contaminants that can accumulate in sediment [22]. The sources of metals in urban areas of New Zealand have been well-characterised providing direction for reducing metal concentrations in stormwater through source control (e.g., reducing metal leaching from roofing materials) and at-source treatment in key locations [7].

Metals can be assimilated by, and bioaccumulate within, organisms. Riparian vegetation would be expected to assimilate metals from surface and subsurface water passing through their roots zones and from contaminated sediments deposited in riparian areas (see Riparian margin establishments and protection attribute). Furthermore, metals have been positively related to the proportion of imperviousness in upstream catchments (see B1 and Catchment permeability attribute).

Part B—Current state and allocation options

B1. What is the current state of the attribute?

The information to date indicates that trace metals are accumulating in our environment. For example zinc has been positively related to the proportion of urban land cover and imperviousness in upstream catchments [7]. The ecotoxicological effects of trace metals and their speciation under a range of environmental conditions are well understood and documented (as per references cited above). The key anthropogenic sources are well characterised to assist the management of these contaminants. The main challenge is that the management of metals requires a holistic/system approach as there are multiple factors to consider. For instance, roof material often contains zinc that can leach overtime. Some effort is required to find alternative types of material with less impacts which needs to be underpinned by appropriate policy. There are examples of recovery following policy changes, e.g., the global phase-out of leaded petrol use has contributed to the decline of concentrations in the ocean [9].

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

Finding reference sites with low levels of anthropogenic pressure is important to provide a baseline to confirm adverse impacts of metals and other stressors on receiving ecosystems. However, it is very difficult to find reference sites that experience no anthropogenic pressure.

One option to consider is to use a ranking of environmental targets in line with the ecosystems to protect. The widespread and serious degradation of urban streams has been documented and their improvement should be ranked high to achieve agreed level levels of protection but it will be challenging [7].

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

Sediment quality guideline values (SQGVs) for trace metals have been derived and updated [23]. These values are now used as default guideline values (DGVs) n the Australian and New Zealand

Guidelines for Freshwater and Marine Water Quality as Toxicant Default Guideline Values for Sediment Quality[1].

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

There are threshold value guidelines available. The Australian and New Zealand Guidelines for Freshwater and Marine Water Quality Toxicant Default Guideline Values for Sediment Quality have been developed to provide threshold values for metals and other contaminants. They are set to provide a range of protection of 80, 90, 95 and 99 % relevant to the particular ecosystem of interest, e.g., from industrial areas to national park and reserve areas.

The sediment DGVs indicate the concentrations below which there is a low risk of unacceptable effects occurring, and should be used, with other lines of evidence, to protect aquatic ecosystems. In contrast, the 'upper' guideline values (GV-high), provide an indication of concentrations at which there might already have toxicity-related adverse effects. As such, the GV-high value should only be used as an indicator of potential high-level toxicity problems, not as a guideline value to ensure protection of ecosystems.

If a DGV is exceeded or even where toxicant concentrations in the sediment are trending towards the DGV, it is recommended to use a multiple lines of evidence approach as part of the weight-of-evidence process to better assess the risk to the sediment ecosystem.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

As discussed in the above sections, metals have multiple anthropogenic sources and they can continue to accumulate in various environmental compartments including sediment due to the non-degradability of metals.

Natural background levels of metals in lakes and rivers may vary widely because of differences in local geology, and the aquatic organisms that live there tend to be genetically adapted to the local levels of metals. This adaptation is described as the "metalloregion concept" [22]. This is particularly relevant to New Zealand where levels of some metals in the environment is associated with our unique soil and volcanic activity. For instance, in the central North Island, arsenic is released from geothermal systems into the Waikato River [24]. The receiving ecosystems will have adapted to higher background levels, although in the case of the Waikato River system this has been extensively modified via the creation of hydrolakes for electricity generation which is likely to have altered the biotic assemblages that now reside in those waterbodies.

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

A high standard of water quality is an outcome sought by iwi/hapū/rūnanga. There is tikanga and mātauranga Māori relevant to informing bands, allocation options, minimally disturbed conditions

[1] https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants

and/or unacceptable degradation residing in treaty settlements, catchment/species restoration strategies, cultural impact assessments, environment court submissions, iwi environmental management plans, reports, etc.

For example, as result of the Waikato-Tainui Deed of Settlement, Te Ture Whaimana o te Awa o Waikato (the Vision & Strategy) is the primary direction setting document for the Waikato River and activities within its catchment affecting the river. In order to realise Te Ture Whaimana, 13 objectives and 12 strategies guide the restoration of the health and wellbeing of the Waikato River, including: “The restoration of water quality within the Waikato River so that it is safe for people to swim in and take food from over its entire length”. The pilot Waikato River Report Card [33], funded by the Waikato River Authority (WRA) and guided by a Waikato River Iwi Advisory Group, scored ‘arsenic in water’ between A-D using the ANZECC guidelines.

There are one-off-studies where iwi/hapū/rūnanga are influencing research initiatives exploring the state and impacts of environmental contaminants (including heavy metals) on the outcomes they are seeking (e.g., mauri is protected, kai is safe to eat, water is safe to swim) (e.g., [36-38]).

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

It is important to address the increasing trends of metal accumulation and develop solutions to revert the increasing trends using better management frameworks for the sources. The National State of Environment reporting for MfE highlights the level of environmental degradation in both freshwater and marine domains [26,27]. Metals are one of the multiple stressors that have been identified with sources including stormwater, municipal treated wastewater and agricultural discharges.

The toxicity and ecotoxicity of individual metals are well characterised and understood. Predicting or assessing the environmental impacts of an individual chemical is a challenge in a field situation as contaminants are often found in complex mixtures. For instance, exposure to low levels of multiple chemicals in mixtures can cause toxicity at concentrations where exposure to an individual chemical might cause no effect based on their DGVs. This is because multiple physiological processes may be affected by chemicals having different mechanisms of toxicity. This is a strong argument for the need for a systems approach to the management of aquatic systems.

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

C2-(ii). Central government driven and C2-(v). Internationally driven

The Australian and New Zealand Guidelines for Freshwater and Marine Water Quality Toxicant Default Guidelines for Sediment Quality are designed to trigger further site-specific risk assessment based on a weight of evidence approach. In a recent survey on the type and range of chemical contaminants that councils monitor, the emphasis was on the type of chemicals, but the implications of exceedance of DGVs was not assessed [11]. The author is not aware of any follow up studies in New Zealand responding to a DGV exceedance.

C2-(iii). Iwi/hapū driven

Treaty of Waitangi settlements have resulted in waterways/lakes/wetlands being returned to Māori ownership and/or management, many of which are in a highly degraded state. Many settlements include cultural redress packages to address the protection, restoration or rehabilitation of values, uses and services (and at scales) that have not previously been a strategic priority for research, restoration and monitoring by agencies. Treaty Settlements have also been the key drivers in the provision of new innovative approaches that bring together multiple knowledge systems together to inform co-management and restoration regarding values, species, catchments, and/or at scales that have not previously been prioritised by agencies.

Iwi/hapū/rūnanga are also influencing resource consent conditions which may include contaminant/bioaccumulation assessments that include heavy metals in water, sediments and/or mahinga kai species; however, generally these reports are not accessible in the public domain.

C2-(iv). NGO, community driven

Part D—Impact analysis*.*

D1. What would be the environmental/human health impacts of not managing this attribute?

A business-as-usual scenario would lead to on-going increase of metals in sediment and have detrimental impacts on exposed ecosystems. There is no doubt that the accumulation of anthropogenic pollutants in the environment is causing harm and scientists need to work with other stakeholders to reduce pollution [28]. Metals are not degradable so any continuous discharges will accumulate in the various environmental compartments including biota. The impacts of human activities have pushed estuarine and coastal ecosystems far from their historical baseline of rich, diverse, and productive ecosystems [26]. The impacts on freshwater ecosystems are also considered to be significant. Managing the sources is a priority to ensure the protection of these valuable ecosystems and to protect water supplies from contamination. Encouragingly, there are examples of declining metal concentrations from improved environmental controls on emissions and discharges of metals and other contaminants, e.g., [10].

There are multiple challenges to reduce the discharge of metals in urban and rural environments, particularly non-point sources like stormwater. There are examples of options to reduce metals at the sources summarised in the PCE report, but they may be challenging to implement [8]. For example, an initiative to impose restrictions on the maximum amount of zinc in galvanised or zinc coated roofing materials may be opposed by those who manufacture these materials [8].

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

Freshwater, coastal and ocean ecosystems provide commercial, cultural, recreational and economic benefits as well and they support diverse habitats and species of local and global significance [20]. It is well-recognized that healthy and thriving coastal and freshwater ecosystems are essential for economic growth and food production [20]. The key impacts from the pressure that metals place on receiving environments is the potential loss in biodiversity and disruption of ecosystem functions and services through shifts in distributions of key species. The economic implications resulting from the impacts of metals would be loss of revenue for fishery and aquaculture industries in both freshwater and marine environments that are most likely to be impacted by pressure from metal contamination. Healthy and functional ecosystems and healthy fish stocks are important for the freshwater and marine fishery industries [29]. There are also other aspects to consider including natural beauty and recreational use of our freshwaters, estuaries, coastal and open ocean areas that are central to our culture and national identity and support our tourism industry. Furthermore, there are likely to be increased costs and economic impacts associated with the need for removal of trace metals from water supplies to ensure its safe use for drinking water, stock water, irrigation and other industrial and agricultural uses if this attribute were not managed.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Climate change will have multiple effects in modulating the accumulation and bioavailability of metals. Climate change increasingly affects the variation in volume and frequency of stormwater events and runoff which can increase transport of trace metals in dissolved and particulate form and resuspension and direct exposure of sediments in water bodies [1]. A key concern with the effects of climate change on the risks associated with metal contamination is that changes to temperature and pH can modulate the speciation of metals and consequently their bioavailability. The importance of metal speciation cannot be overstated as it modulates the bioavailability and toxicology of trace metals. The simplest feature of speciation is whether the metal is in the dissolved or particulate form. Originally, environmental regulations were based on total metals present in the water as assayed by hot acid digestion of the samples. However, there has been a gradual change in many jurisdictions to regulations based on the dissolved component only. This reflects the general recognition that particulate metals exhibit negligible toxicity and bioavailability to aquatic organisms relative to dissolved metals [2]. Increases in temperature have been correlated with increasing toxicity of metals to aquatic organisms [30]. As such, temperature should be accounted in risk assessment, because it may modify the effects of chemicals on the structure and functioning of aquatic communities, especially at higher levels of biological organization [31].

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