9.9 Heavy metals in water (or indicator spp.)

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Citation for this chapter: Tremblay, L. (2024). Heavy metals in water or indicator species. *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]

Alternate attribute name: Trace elements in water (or indicator spp.)

Preamble: Heavy metals is the commonly but wrongly used term to describe all metals. It would be more appropriate to use trace metals or even better, trace elements including arsenic, a metalloid. The term 'trace metals' will be used in this document to provide a more accurate description as it still contains the term 'metals'. Ideally 'trace elements' should be used but it can cause some level of confusion.

State of knowledge of "Trace metals in estuary/coastal water (or indicator species)" 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 [1]. 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 home activities [2].

The term heavy metals is often used to describe metals in general. However, it is not appropriate as not all metals are heavy or non-essential. 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 [1]. 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.

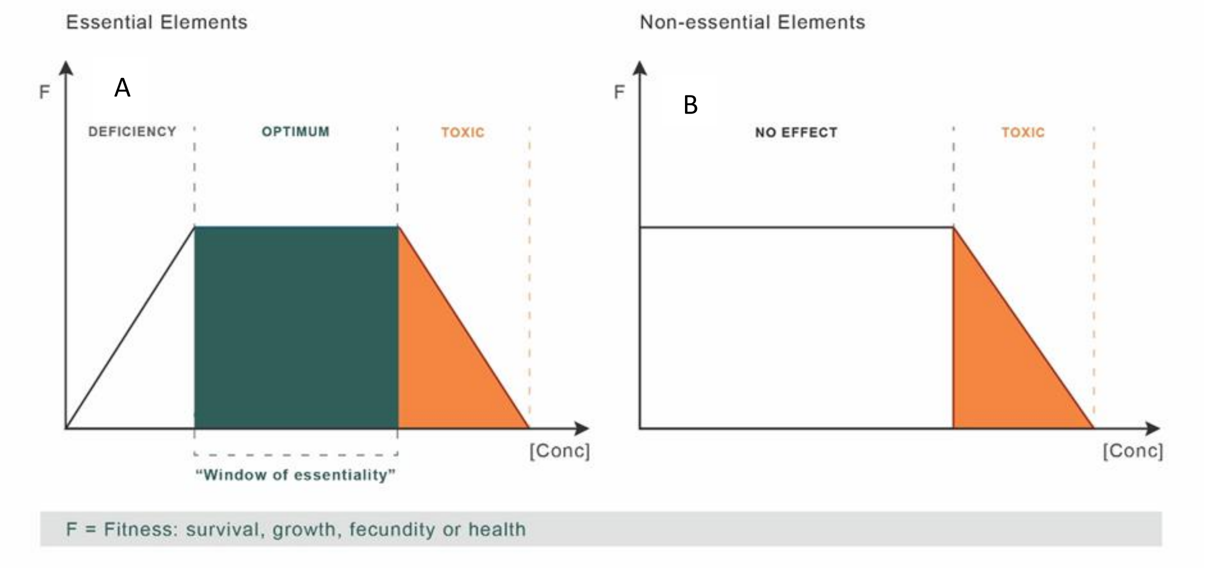

Figure 1. Conceptual diagrams illustrating the differences in concentration–response relationships with respect to organism health between A) essential metals and B) non-essential metals.

The toxicity of trace metals is well established and can impact both ecosystem and human health. Metals and metal compounds can interfere with functions of the central nervous system (CNS), the haematopoietic system, liver and kidneys [2].

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 [2]. The general mechanism of heavy metal toxicity is through the production of reactive oxygen species (ROS) leading to oxidative damage and subsequently, adverse effects on health [3]. The disruption of metal ion homeostasis leads to oxidative stress through the formation of ROS which overwhelm body antioxidant protection and subsequently induces DNA damage, lipid peroxidation, protein modification and other effects, all symptomatic of numerous diseases, including cancer, cardiovascular disease, diabetes, atherosclerosis, neurological disorders (Alzheimer's disease, Parkinson's disease), chronic inflammation and others [4]. Another important mechanism of toxicity is the bonding of redox inactive metals like cadmium, arsenic and lead to sulphydryl groups of proteins and depletion of glutathione [4]. The mechanisms of toxicity are conserved, and metals affect ecosystem health in a similar way.

Areas of high anthropogenic activity like urban centres are more susceptible to the impacts of metals. Urban areas have larger areas of impervious surfaces such as roofs, roads and paved areas that are sources of metals [5]. Stream water quality changes in urban areas as development both increases the generation of contaminants and changes the transport and processing of contaminants. Many urban streams and coastal zones are also the receiving environment for untreated sewage, via leakage or overflows from wastewater networks and treatment plants.

Increasing population pressure and urbanization of the coastal zones have resulted in a variety of chronic impacts operating on coastal and estuarine ecosystems. Land-based activities affect the runoff of pollutants and nutrients into coastal waters affecting global biodiversity and ultimately the provision of ecosystem services [6-8]. Local studies in the Auckland coastal zone and the Tauranga Harbour showed ecological health decline, based on community structure composition changes along a pollution gradient, occurring at metal levels below guideline threshold values [9,10]. These are good examples that coastal ecosystems are often exposed to multiple stressors and robust management frameworks are required to consider the presence of multiple physical and chemical stressors.

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. Another poorly managed key source is the of run-off from stormwater, which can contain complex mixtures of industrial chemicals, pharmaceuticals, metals and nutrients. Metals are transported into waterways via stormwater from roads (zinc from tyre wear, copper from brake pad wear); roofs (zinc from galvanised roofing); and other impervious surfaces (including paved areas around industrial sites) [11]. 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 [5]. Current chemical stressors combined with the significant impacts of legacy metals remain a concern for water quality, e.g., like in the Sydney Harbour [12]. The analysis of a range of parameters including dissolved zinc indicates that if urban development continues in its current trend, increases in urban land cover around New Zealand can be expected to result in further declines in water quality and a reduced likelihood that water quality objectives will be achieved at impacted locations [5].

There is evidence that better management of trace metal sources can reverse the trends. Better waste management like depositing treated wastewaters offshore and the introduction of more articulate environmental protection laws, regulations and enforcement can lead to improved water quality [12]. For instance, the global phase-out of leaded petrol use has contributed to the decline of concentrations in the ocean [13].

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?

Some metals are monitored as part of the State of Environment (SoE) reporting. Councils are conducting routine analyses for the occurrence and trends of metals for coasts, rivers and groundwaters as part of SoE monitoring and to meet consent condition requirements [14]. The SoE monitoring by regional councils focuses on a set of metals as reported in the recent Parliamentary Commissioner for the Environment (PCE) report on regulating the environmental fate of chemicals [15]. Monitoring of metal residues in relation to determining compliance with consent conditions is also often conducted for landfill leachate, wastewater and stormwater discharges [14].

The Australia and New Zealand Guidelines for fresh and marine water quality are the key tools to help planners, regulators and researchers to manage the quality of our water in New Zealand[1]. They provide default guideline values (DGVs) for all metals. These DGVs are jointly developed by the Australian and New Zealand governments.

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

Regional Councils have selected sites where they monitor trends in trace metals for State of Environment reporting. Consent holders would also have access to sites for monitoring as part of their consent conditions.

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 Laboratories and AsureQuality can measure metals at competitive prices.

A Jacobs investigation reported limitations that councils have identified that preventing the expansion of current monitoring programmes including the high costs for both laboratory analysis and council staff time spent doing monitoring and reporting [14]. 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 in water 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]. Some of the 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. See also [16-19].

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

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[1] https://www.waterquality.gov.au/anz-guidelines

contaminants. Cumulative effects, through additional new marine industries, climate change and other stressors, can reduce environmental resilience and increase the risk of environmental or economic collapse [12]. The importance of sediments as stressors will depend on site ecosystem attributes and the magnitude and preponderance of co-occurring stressors [20]. Therefore, management of coastal waters must contend with multiple drivers in concert as the coordination of regulating agencies for urban and agricultural runoff is warranted as metals are only one component within a range of other contaminants that can accumulate in sediment [8].

Part B—Current state and allocation options

B1. What is the current state of the attribute?

The ecotoxicological effects of 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. This needs to be underpinned by appropriate policy. For instance, the global phase-out of leaded petrol use has contributed to the decline of concentrations in the ocean [13].

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 and nearly impossible to find reference sites that experience no anthropogenic pressure.

The hazards of metals and their mechanisms of toxicity have been extensively characterised using model test species under controlled laboratory conditions. The data generated is used to derive the default guideline values (DGVs) which provide threshold values over which adverse impacts are expected. A metal concentration above a DGV should trigger further investigations to fully assess the impacts of the metal on the receiving ecosystem. This is where having good baseline values of what a healthy ecosystem looks like is important. There are options to compensate for the lack of proper reference sites by monitoring across a gradient of stressors.

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)

There are well established default guideline values (DGVs) for several metals that have recently been reviewed by the Australian and New Zealand Guidelines for Fresh and Marine Water Quality [1]. These threshold values cover a range of protection levels of 80, 90, 95 and 99 % relevant to the particular ecosystem of interest, e.g., from industrial areas to national park and reserve areas.

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[1] www.waterquality.gov.au/anz-guidelines

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

Yes, there are threshold value guidelines available. The ANZG DGVs have been developed to provide threshold values for metals and other contaminants. They are set to provide a range of protection as per point B3.

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 surface water, groundwater, and coastal waters 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” [8]. 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 [21]. The receiving ecosystems will have adapted to higher background levels.

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.

It has been recognised that indigenous peoples, knowledge frameworks, and values are critical in orienting international efforts for the management of chemicals and waste that are more sustainable and equitable for all [22]. A high standard of environmental quality is an outcome sought by iwi/hapū/rūnanga. There is tikanga and mātauranga Māori relevant to informing bands, allocation options, minimally disturbed conditions and/or unacceptable degradation residing in treaty settlements, catchment/species restoration strategies, cultural impact assessments, environment court submissions, iwi environmental management plans, reports, etc.

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]).

See also [16-19].

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?

The SoE reporting for MfE highlights the level of environmental degradation in both freshwater and marine domains [23,24]. Metals are one of the multiple stressors that have been identified with sources including stormwater, municipal treated wastewater and agricultural discharges. For instance, cadmium, chromium, copper, nickel, lead, platinum and zinc are on the list of selected stormwater priority pollutants [25].

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

The Australia New Zealand guidelines for fresh & marine water quality trigger values are designed to lead to further specific site risk assessment. In a recent survey on the type and range of chemical contaminants councils do, the emphasis was on the type of chemicals, but the implications of exceedance of DGVs was not assessed [14]. I am not aware of any follow up studies in New Zealand in response to a DGV exceedance.

C2-(iii). Iwi/hapū driven and C2-(iv). NGO, community driven

We are not aware of interventions/mechanisms being used by NGOs or iwi/hapū/rūnanga to directly affect this attribute.

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 devastating 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 [26]. Metals are not degradable so any continuous discharges will accumulate into the various environmental compartments and biota. The impacts of human activities have pushed estuarine and coastal ecosystems far from their historical baseline of rich, diverse, and productive ecosystems [27]. Managing the sources is a priority to ensure the protection of these valuable ecosystems. However, there are examples of declining metal concentrations from improved environmental controls on emissions and discharges of metals and other contaminants, e.g., [28].

There are multiple challenges to reduce the discharge of metals in urban environments, particularly non-point sources like stormwater. There are examples of options to reduce metals at the sources summarised in the PCE report. For instance, the challenge of an initiative to impose restrictions on the maximum amount of zinc in galvanised or zinc coated roofing materials [15].

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)

Coastal and ocean ecosystems provide commercial, cultural, recreational and economic benefits as well as support diverse habitats and species of local and global significance [12]. It is well-recognized that healthy and thriving coastal and freshwater ecosystems are essential for economic growth and food production [12]. 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. Fishery and aquaculture industries are most likely to be impacted by pressure from metal contamination. Healthy and functional ecosystems and healthy fish stocks are important for the fisheries industry [23]. There are other aspects to consider including natural beauty of our estuaries, coastal and open ocean areas that are central to our culture and national identity.

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 resuspension and direct exposure of sediments in water bodies [29]. The 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 or basically, 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 [1]. Increases in temperature were 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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