NPS-FM style copper and zinc attribute framework for Otago Regional Council

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Report Prepared for

Otago Regional Council

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1 Context

Aquanet was engaged by Otago Regional Council (ORC) to provide a National Policy Statement for Freshwater Management (NPS-FM) style attribute state framework for copper (Cu) and zinc (Zn) that, if proven to be scientifically robust and defensible, could be used as part of their urban limit setting process. Rather than developing new attribute frameworks for Cu and Zn, our approach was to review existing attribute frameworks developed by other regional councils and assess their suitability for use in an urban limit setting context and for incorporation in a regional plan. Existing ORC Cu and Zn monitoring data were also assessed against the identified attribute frameworks to examine whether current state could be defined. Finally, we make recommendations for a final attribute state framework and its suitability for regional limit setting.

2 Overview of Cu and Zn stormwater sources and ecological effects

2.1 Ecological effects

Cu and Zn are both essential elements required for biological growth; however, at concentrations not much higher than those that allow for optimum growth they can be toxic to aquatic flora and fauna, particularly when dissolved in the water column. Cu and Zn can also be found bound to soil and sediment particles and accumulate in depositional areas of streams over time, in these areas they can also be toxic to benthic biota.

Fish, macroinvertebrates and periphyton can all bioaccumulate copper and zinc and toxic effects occur when the uptake rate exceeds the rates of detoxification and excretion. Toxic effects include adverse effects on survival, growth, reproduction as well as alterations of brain function, enzyme activity, blood chemistry, and metabolism.

Metal toxicity is dependent on several site dependent factors, including water temperature, pH, dissolved organic matter and hardness. Species sensitivity to contaminants also depends on the life-stage of exposure (juvenile versus adult), the ability to regulate body-burdens, as well as the duration and frequency of exposure (e.g., pulse disturbance of first flush stormwater discharges). Understanding the toxicity risk to aquatic organisms and communities is, therefore, site specific and complicated.

2.2 Sources of copper and zinc to waterways

Copper and zinc, which are both found naturally in the earth's crust, are highly valued for range of commercial, industrial, and residential uses and highly ubiquitous in the environment. Copper is used in electrical equipment such as wiring and motors and has range of uses in construction (roofing and plumbing) and industrial machinery, while zinc is used to galvanize other metals such as iron and, like copper, has a range of uses in construction, particularly roofing.

The main sources of copper to stormwater in urban environments are from roofing and cladding material and emissions from vehicle brake pads, while roof material and vehicle tryes are the main source of zinc. In a study of copper sources in Auckland residential, commercial, and industrial areas, roofing material and vehicle brake pads were collectively responsible for 33, 19, 21 % of the total copper load, respectively (Kennedy & Sutherland 2008). In the same study, roof material and vehicle tryes contributed over 58, 76 and 65% of the overall stormwater zinc load from residential, commercial, and industrial areas, respectively.

Mobilisation of copper and zinc occurs through weathering, wear and tear and corrosion processes. For example, tyre wear and tear from driving on pavement leaves small pieces of tread behind and copper and zinc can dissolve from corroded roofing and cladding material during precipitation. Mobilised metal contaminants on roofs, pavements, roads and other impervious surfaces in urban environments are transported through stormwater networks and into streams during rainfall.

3 Summary of the values effected by exposure to elevated levels of copper and zinc

Copper and zinc at elevated concentrations in the water column can be toxic to aquatic fauna and flora, which can result in:

- A reduction in the abundance of sensitive species, including some threatened native species. In a worst-case scenario this could lead to local extirpations;
- Change in community composition to more stress tolerant species; and
- A reduction in overall ecosystem health.

4 Review of Cu and Zn attributes used by other councils

No regional council has yet adopted metal-based target attribute states into their regional plan. However, Auckland Council (AC) and Greater Wellington Regional Council (GWRC) have used a 'strawman' National Objectives Framework (NOF) - styled Cu and Zn attribute developed by Gadd *et al.* (2019) in recent state of the environment reporting (Ingley 2021 and GWRC 2020). GWRC have also used a slightly modified version of the Cu and Zn strawman attribute as part of their limit setting processes and this may be adopted in their upcoming plan change. To the best of our knowledge no other Cu and Zn NOF styled attributes have been developed.

Following the release of the NPS-FM (2014) AC identified that the compulsory attributes within the NOF did not sufficiently address urban water quality issues and determined that Auckland-specific urban water quality attributes should be developed. A workshop supported by Ministry for the Environment (MfE) and attended by staff from Environment Canterbury, GWRC and AC was held in 2014. These 'strawman' attributes were developed by attendees for Cu and Zn based on the Australian and New Zealand Conservation Council (ANZECC) 2000 guidelines for marine and freshwater quality (now Australian and New Zealand Governments Guidelines for Fresh and Marine Water Quality (ANZG) 2018)[1] and the United States Environmental Protection Agency (US EPA) guidelines for water quality.

Following the workshop, additional data collection and analyses was undertaken by AC (2015-17) to inform and further develop the attribute. However, this work identified further tasks to be undertaken and a final attribute was not developed. Although the Cu and Zn attributes were not finalised, the work undertaken and the work still required to develop the attribute, as well as the draft attributes themselves were reported in a 2019 technical report prepared by Gadd *et al.* (2019).

4.1 Strawman attribute tables

Strawman attribute tables were developed for both dissolved Cu and Zn. Both the ANZECC (2000) and US EPA guidelines, from which the attribute tables are developed, toxicity thresholds are based on the dissolved fractions, which are the most bioavailable and therefore toxic to aquatic flora and fauna.

The strawman attribute uses two statistics, a median and a maximum (either the maximum or 95th percentile) to protect from both chronic and acute toxicity exposure. The median statistic is based directly on the chronic ANZECC Cu and Zn toxicity thresholds (e.g., A band = 99 % species protection trigger; see Table 1) and represents the 'average condition' aquatic organisms are subjected to over a long exposure time under settled baseflow conditions. Attribute bands A to C of the maximum statistic are also based on the ANZECC chronic toxicity thresholds, albeit applied more generously (A band = 95 % species protection trigger; see Table 1). However, the USA EPA criteria maximum concentration (CMC)[2] guidelines have been used for the C/D band threshold (bottom line).

[1] Australian and New Zealand Governments Guidelines for Fresh and Marine Water Quality

[2] The CMC is an estimate of the highest concentration of a material in surface water to which an organism can be exposed briefly without an unacceptable effect (= acute concentration)

Table 1: The species protection levels in each band of the strawman copper and zinc attribute tables

Attribute state	Median	Maximum	Implication
A	≥99% species protection level (ANZECC 2000 / ANZG 2018)	≥95% species protection level (ANZECC 2000 / ANZG 2018)	50% of the time ≥99% of species are protected from chronic toxicity 100% of the time >95% of species are protected from chronic toxicity
B	≥95% species protection level (ANZECC 2000 / ANZG 2018)	≥90% species protection level (ANZECC 2000 / ANZG 2018	50% of the time 99-95% of species are protected from chronic toxicity 100% of the time >90% of species are protected from chronic toxicity
C	≥80% species protection level (ANZECC 2000 / ANZG 2018)	≥ US EPA CMC acute toxicity threshold*	50% of the time ≥80% of species are protected from chronic toxicity 100% of the time > 95% species are protected from **acute toxicity**
D	<80% species protection level (ANZECC 2000 / ANZG 2018)	< US EPA CMC acute toxicity threshold	Less than 50% of the time 80% of species are protected from chronic toxicity Acute toxicity may occur

* NB. The US EPA CMC acute toxicity threshold is greater than the ANZECC 80% species protection threshold. Table adapted from Gadd *et al.* (2019).

In the 'strawman' attribute frameworks discretion is given regarding the statistic that can be used to represent the maximum condition; Gadd *et al.* (2019) indicate a maximum, 95th or 90th percentile could be used to protect from acute exposures. The 95th and 90th percentiles statistics exclude those rear and short-lived events, which although have high concentrations may not be having an effect because of their short duration and frequency.

Gadd *et al.* (2019) outline the maximum condition in the strawman attribute tables serves two purposes. The first is to provide a maximum allowable concentration for each attribute band (to ensure the range of in-stream concentrations is not excessively broad). The second is to assess acute conditions.

The strawman attributes for Cu and Zn are presented in Table 2 and 3 below.

Table 2: Strawman dissolved copper attribute developed by Gadd *et al.* (2019).

Value	Ecosystem health		
Freshwater Body Type	Lakes and Rivers		
Attribute	Dissolved Copper (Toxicity)		
Attribute Unit	µg DCu/L (micrograms of dissolved Copper per litre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median	Annual Maximum	
A	≤1	≤1.4	99% species protection level: No observed effect on any species tested
B	>1 and ≤1.4	>1.4 and ≤1.8	95% species protection level: Starts impacting occasionally on the 5% most sensitive species
C	>1.4 and ≤2.5	>1.8 and ≤4.3	80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)
Bottom Line	2.5	4.3	
D	>2.5	>4.3	Starts approaching acute impact level (i.e., risk of death) for sensitive species

Values for this metal are here expressed as a function of hardness (mg/L) in the water column, consistent with ANZECC (2000) and the value given here corresponds to a standard hardness of 30 mg CaCO3/L. Criteria values for other hardness may be calculated as per the equation presented in the ANZECC (2000) guidelines. The National Bottom Line for the annual maximum is based on US EPA CMC.

Table 3: Strawman dissolved zinc attribute developed by Gadd *et al.* (2019).

Value	Ecosystem health		
Freshwater Body Type	Lakes and Rivers		
Attribute	Dissolved Zinc (Toxicity)		
Attribute Unit	µg DZn/L (micrograms of dissolved Zinc per litre)		
Attribute State	**Numeric Attribute State**		**Narrative Attribute State**
	Annual Median	Annual Maximum	
A	≤2.4	≤8	99% species protection level: No observed effect on any species tested
B	>2.4 and ≤8	>8 and ≤15	95% species protection level: Starts impacting occasionally on the 5% most sensitive species
C	>8 and ≤31	>15 and ≤42	80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)
Bottom Line	31	42	
D	>31	>42	Starts approaching acute impact level (i.e., risk of death) for sensitive species

Values for this metal should be expressed as a function of hardness (mg/L) in the water column. The value given here corresponds to a standard hardness for ANZECC guidelines of 30 mg CaCO3/L. Criteria values for other hardness may be calculated as per the equation presented in the ANZECC 2000 guidelines.

4.3 Strawman limitations

Gadd *et al.* (2019) identified that, although underpinned by the best available information (ANZECC and US EPA guidelines), the strawman attributes had a number of technical deficiencies and recommended several tasks be completed before the attribute frameworks were finalised, these are summarised below:

- The first recommendation was for the ANZECC (2000) guidelines used in the strawman tables to be updated with the revised ANZG (2018) guidelines. Other than the requirement to correct Cu default guideline values for water hardness being removed, the chronic guidelines did not change.

- The next recommendation was for the current US EPA Criterion Maximum Concentration (CMC) acute thresholds to be replaced with acute ANZG guidelines or NZ-specific acute thresholds if developed. New Zealand species specific thresholds have yet to be developed and wide-ranging acute toxicity testing, especially during short exposure periods, of aquatic organisms found in NZ waterways is limited.

- Cu and Zn exist in many different forms and these different forms, and their relative bioavailability and toxicity to aquatic organisms, are dependent on several abiotic factors including pH, alkalinity, dissolved organic carbon and hardness. The current ANZG guidelines do not adjust toxicity for these factors, other than a hardness correction for zinc. Gadd *et al.* (2019) recommended that an assessment should be made whether to incorporate copper and zinc speciation and bioavailability into the attribute tables using look-up tables or a Biotic Ligand Model (BLM). Developing such a tool would allow species protection thresholds to be adjusted based on local water chemistry. Canada adopted a BLM approach in their recent Federal Water Quality Guidelines for Zn and Cu (CCME 2018). The approach allows for the consideration of a diverse set of water quality factors that are known to affect Cu and Zn toxicity to aquatic organisms. AC are currently collecting a minimum of 5 years of these additional abiotic factors so that the assessment of metal toxicity for Cu and Zn can be revised (Ingley 2021).

- There is a poor understanding of metal concentrations during high flows, the length of time organisms are exposed to elevated metal concentrations during high flows and whether they are likely to cause acute toxicity. Gadd *et al* (2019) recommended that the relative importance of concentrations during higher flows be investigated further.

- The strawman attribute frameworks do not prescribe which maximum statistic (maximum or 95th percentile) should be used. Gadd *et al.* (2019) highlight that it is unclear whether the current monthly based monitoring programmes are accurately able to determine a maximum concentration and recommend that implications of using a maximum statistic vs a 95th percentile be investigated.

- The final recommendation proposed an assessment is undertaken to determine whether the final attribute frameworks could be developed to integrate Cu and Zn attributes for freshwater and coastal management.

4.4 GWRC attribute development

During GWRC's Te Awarua-o-Porirua Whaitua process it was identified that local urban streams have elevated levels of dissolved Cu and Zn, which are contributing to poor ecological health outcomes. Stormwater was identified as the major source of Cu and Zn contamination and it was considered necessary that attributes were implemented to enable better management of stormwater Cu and Zn inputs to urban streams.

GWRC adopted the 'strawman' attributes tables developed in the 2014 workshop and reported in Gadd *et al.*, (2019) verbatim, but used slightly more reader friendly narrative descriptions. GWRC chose to use 95th percentile for their maximum statistic as it was believed a maximum was too strict. The 95th percentile was also chosen to protect from potential sampling and laboratory errors. AC also adopted the 95th percentile in their 2010-2019 river water quality state and trends report, however no reason was given to why the 95th percentile was preferred (Ingley 2021). GWRC are now working towards including the attribute tables in their Natural Resources Plan as part of their upcoming plan change.

As part of this work, GWRC had Dr Gadd review the Canadian Council of Ministers for the Environment (CCME) recently released zinc acute guidelines (CCME 2018). The CCME acute guidelines are derived in a similar way to the ANZG

(2018) chronic guidelines, which means that it is possible to derive acute toxicity thresholds for all levels of species protection possible. Thus, GWRC were interested if the CCME zinc guidelines could be used in place of the US EPA acute criteria for the 'bottom-line' threshold as well as for the other band thresholds, which currently use ANZECC (2000) chronic thresholds. Unlike the dataset used to derive the US EPA acute criteria, the CCME short-exposure toxicity dataset included plants and algae. The data set also included eight species indigenous to New Zealand (five water fleas and three hydra species) as well as 12 species found in New Zealand but are not native (these were mostly species belonging to the Salmonidae family) (Gadd 2021).

Gadd (2021) derived acute threshold for the 99, 95, 90 and 80% species protection levels following a methodological approach outlined in ANZG (2018). While the derivation of short exposure acute toxicity attribute thresholds for all levels of species protection is more technically defensible and sensible than the use of a mixture of chronic and acute toxicity (bottom line only) thresholds, it does have large implications for the current Zn strawman attribute. As Gadd (2021) outlines, whilst use of the acute thresholds is relevant to the short-term exposures, they do not imply protection. Adopting the acute thresholds in place of the existing acute thresholds (in the second column) resulted in considerably more permissive thresholds (Gadd 2021). This was in large part due to the current attribute framework using a median statistic rather than a 95th percentile for the chronic attribute threshold (first column of the attribute table). As a result, Gadd (2021) ultimately recommended GWRC retain the current attribute table thresholds values and narratives, rather than adjusting the chronic toxicity median statistic. Gadd (2021) had initially recommended changing the C/D attribute from the US EPA CMC to the CCME acute toxicity guideline because of its more complete and Newer Zealand relevant dataset; however, both thresholds were identical. Thus, providing additional confidence in the acute threshold used for the Zn bottom-line.

4.5 Attribute defensibility

The Cu and Zn strawman attributes are based on the ANZECC (2000) / ANZG (2018) and US EPA (CMC guidelines, which have been derived from empirical toxicological studies[3]. The chronic freshwater ANZECC guidelines for dissolved copper were derived from 130 data points covering 21 different species from four different taxonomic groups and was assessed to have highly reliable 95% species protection trigger value. Similarly, dissolved zinc guidelines were derived from 85 data points covering 20 different species from 6 taxonomic groups and the 95% species protection trigger value was assessed to be highly reliable (Warne 2000). The US EPA CMC copper and zinc acute thresholds were also both derived from substantial datasets (e.g., the copper CMC thresholds were obtained from 350 test representing 27 different genera) (USEPA 2007 & 1995). Thus, there is a strong technical underpinning to the attribute frameworks.

It is our opinion, however, that the attribute frameworks are not yet sufficiently robust and defensible to be used to set target attribute states in a regional plan in their current state, for the following reasons:

- The maximum statistic (2nd column of the attribute tables), other than the bottom-line (C/D threshold), are not at all linked to the protection aquatic organisms from short term exposure during rainfall events and as a result are far too restrictive;
- The monitoring frequency required to assess acute toxicity risk needs assessing, it is unclear whether monthly monitoring aimed at assessing long-term exposure risk is appropriate to protect from acute toxicity;
- In the ANZG (2018) it is recommended that action is triggered if the 95th percentile (not the median) of the test distribution exceeds the trigger value because of potential of ecological harm from even one exceedance. Thus, the statistic used for assessing chronic toxicity from long-term exposure requires further justification; and
- The recommended tasks outline by Gadd *et al.* (2019) have not all been undertaken / implemented (see section 4.3).

[3] The Zinc acute guideline is also supported by the Canadian Council of Ministers for the Environment guidelines

5 Assessment whether Cu and Zn current state can be defined from ORC monitoring data

The current strawman attributes frameworks provide little guidance regarding data requirements. There is no minimum monitoring frequency requirement from which annual medians and maximums should be generated, nor is there any guidance regarding the time-period from which annual median and maximums should be derived. Similarly, no guidance is provided in GWRC Te Awarua-o-Porirua attributes.

The recommended number of samples for nitrate and ammoniacal nitrogen toxicity attributes is at least 30 samples over 3 years. Moreover, the WHO recommends that percentiles (e.g., 95) based sample statistics should be calculated using the Hazen method rather than the default method in Microsoft Excel (World Health Organization, 2003). The ORC Cu and Zn monthly monitoring datas*et al*igns with these monitoring requirements.

Cu and Zn strawman attribute states have been derived for each of ORCs five monitoring sites in Table 3 and 4, respectively, for the three-year period between January 2019 and December 2021.

Table 4: Otago Region copper attribute states.

Site	Annual Median	Annual Maximum		Overall attribute State
		Maximum	95th	
Oamaru Creek at SH1 (FH846)	A	C	A	C/A
Horn Creek at Queenstown Bay FH825	A	C	C	C
Bullock Creek at Dunmore St Footbridge (FG697)	A	A	A	A
Lindsay's Creek at North Road Bridge (EM136)	A	C	C	C
Leith at Dundas Street Bridge (EU664)	A	D	C	D/C

Table 5: Otago Region zinc attribute states.

Site	Median	Maximum		Overall attribute State
		Maximum	95th	
Oamaru Creek at SH1 (FH846)	A	A	A	A
Horn Creek at Queenstown Bay FH825	A	C	C	C
Bullock Creek at Dunmore St Footbridge (FG697)	A	B	A	B/A
Lindsay's Creek at North Road Bridge (EM136)	A	C	C	C
Leith at Dundas Street Bridge (EU664)	A	C	C	C

5.1 Summary of results

The results show that all five monitored sites are in the A attribute table for both the Cu and Zn median toxicity statistic, respectively. Meaning that for 50% of the time, which represents the average stream condition, ≥99% of species are protected from chronic toxicity. The maximum statistic, represented by both the maxima and 95th percentile, show several sites have C attribute state concentrations for both Cu and Zn. At C state concentrations for the maximum Cu and Zn statistic > 95% of species are protected from acute toxicity. However, C state concentrations also indicate that for at least 5% of the time >20% of species may be exposed to concentration that have been associated with chronic toxicity[4]. The Leith at Dundas Street Bridge monitoring site had a concentration consistent with the D attribute state for Cu when a maximum rather than a 95 percentile was used for the maximum statistic, indicating acute toxicity of >5% of species.

Overall, three sites (Horn Creek at Queenstown Bay, Lindsay's Creek at North Road Bridge and Leith at Dundas Street Bridge) were in the C state and two sites were in the A state (Oamaru Creek at SH1 and Bullock Creek at Dunmore St Footbridge) for Cu and Zn, respectively, when the 95th percentile was used for the maximum statistic.

[4] The acute toxicity threshold at the C/D attribute threshold for both Cu (4.3 µg/L) and Zn (42 µg/L) are greater than the 80% ANZECC (2000) / ANZG (2018) chronic Cu and Zn toxicity thresholds, respectively.

6 Conclusions and recommendations

It is our opinion that the Cu and ZN attribute frameworks in their current state should not be used to set limits until the tasks recommended by Gadd (2019) and the limitations identified in section 4.5 have been addressed / finalised. There is no current policy directive for Cu and Zn attributes to be adopted by regional councils; thus, it is our view that ORC do not need to be early adopters of Cu and Zn NOF styled attributes that have not been finalised or tested through a Schedule 1 or Freshwater Planning process.

The Cu and Zn strawman attributes were developed following the release of the NPS-FM 2014, which did not include an urban based attribute to manage stormwater contaminants and their potential effects on aquatic organisms (i.e., macroinvertebrates and fish). It is, therefore, not surprising that AC held a workshop with the aim to develop an urban-based attribute to manage stormwater in urban streams in 2014. In the 2020 NPS-FM, several changes were made to the NPS-FM including the introduction of a number of additional attributes (i.e., macroinvertebrates and fish) and action plans as a policy instrument (tool) for achieving target attribute states. We recommend that action plans for macroinvertebrates and / or fish (end point indicators of ecosystem health) are used to identify if Cu and Zn are contributing to poor ecosystem health outcomes and to manage Cu and Zn stormwater inputs to urban streams if they are found to be contributing to poor outcomes.

Until which point Cu and Zn attribute thresholds are finalised and / or included in the national objective's framework, we recommend any Cu and Zn monitoring should be benchmarked against the current ANZG (2018) chronic guidelines and USA EPA CMC threshold for acute toxicity risk.

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