4.5 SEDIMENT

4.5.1 Introduction

This section describes the condition of sediment in the potential footprint of the proposed New Bridgewater Bridge. The description includes a review of available information combined with a broad-scale sampling of shallow sediments to around 2.5 m below sediment-water interface to characterise their condition prior to commencement of construction works. In conjunction with hydrodynamic modelling, this information will be used to determine the risk of suspended sediment to the adjacent estuarine ecosystem and to identify appropriate controls to mitigate risk. The information will also be used by pitt&sherry to guide the appropriate handling and treatment of material removed from the water during construction.

The information obtained by analyses of sediment collected in this sampling will be relevant to the assessment of most construction activities associated with the bridge, with the exception of the extraction of deeper sediment from the interior of the hollow piles after they have been driven to/into the bedrock. The sediment from the latter will likely be tested ex-situ and will be subject of a separate sampling program i.e. is not covered in this document.

4.5.2 Sources of sediment contamination

The key point sources of contamination that may have affected sediments around the Bridgewater Bridge include the Boyer newsprint mill, the Nyrstar zinc smelter and a number of wastewater treatment plant outflows (Table 2).

In addition to these main sources, other sources from the catchment include, or have historically included, agriculture, forestry, urban runoff (stormwater), landfills, contaminated sites, tanneries, foundries and other industry, as well as atmospheric deposition (Coughanowr et al 2015). Other sources of contaminants directly into the River Derwent or its tributaries include wastes from shipping operations, port facilities and marinas, and aquaculture e.g. finfish hatcheries such as at Wayatinah (Macleod and Coughanowr 2019).

Contaminants associated with these sources include the metals: zinc, cadmium, copper, mercury, lead, magnesium, chromium, arsenic; as well as treated and untreated sewage effluent (pathogens and nutrients); by-products of wood processing such as resin acids, cellulose, tannins, lignins and phenolics; slimicides, sulphides, chlorine, chlorinated organic compounds, dyes. Other potential contaminants include petroleum hydrocarbons and antifoulants such as tributyltin (plus copper and zinc). Lead paint, blasted from the existing bridge, may have also been deposited in local sediments (Burbury 2020).

Table 2. Key sources of contaminants around Bridgewater Bridge (based on Coughanowr et al 2015).

Input source	Location	History of input	Likely contaminants	Pathways to Derwent Estuary
Nyrstar zinc Smelter	Approximately 14 km downstream of the Bridge	Plant operational 1917 – present	Metals (particularly zinc and cadmium), arsenic, fluoride, particulates, sulphur oxides/sulphate and some nutrients	Via the foreshore outfall/diffuser, groundwater, surface runoff during occasional storm events and air/dust emissions
Norske Skog paper mill	Approximately 12 km upstream of the Bridge	Plant operational 1941 – present	Organic matter, suspended solids, wood extractives (such as resin acids), hydrocarbons, nutrients, aluminium, sulphur, faecal bacteria, and air emissions associated with the coal-fired boiler	Mainly via a combined effluent stream, but also potentially via water treatment plant settling ponds, sewage treatment plant effluent, stormwater runoff, landfill leachate, groundwater and air/dust emissions
Wastewater treatment plants (WWTP)	There are 16 WWTP outfalls that discharge in the Derwent Estuary. The nearest is Green Point, which discharges in ~1m of water, ~150 m off the northern bank and ~1 km downstream of the Bridge	(information not obtained)	Faecal pathogens, metals, chlorine	Via WWTP outfall

Agricultural runoff	Throughout the catchment	(information not obtained)	Nutrients, pesticides, pathogens	Direct runoff or entering tributaries throughout the catchment
Stormwater	Throughout the catchment	(information not obtained)	Hydrocarbons, PAH, faecal pathogens, metals	Direct runoff from streets, via outfalls or tributaries

4.5.3 Previous sediment condition assessments

4.5.3.1 Sediment contaminants

Surveys upstream and downstream of the bridge were conducted in 2009 as part investigations by Department of Infrastructure, Energy and Resources (DIER; now Department of State Growth) to inform the historic investigations into the potential bridge replacement (GHD 2009). Integrated samples of the top 1 m of sediments were analysed for a broad suite of organic contaminants, metals including mercury, and acid sulphate soils. Results showed that no organic contaminants were detected in either the sediment samples, or in elutriates prepared from the sediment samples. Conversely, metals including mercury were elevated in most samples. The high-level threshold of the ANZECC sediment quality guidelines (SQG) were exceeded for arsenic, cadmium, lead, mercury and zinc, while antimony, copper, nickel and silver all exceeded the low SQG. Despite large exceedances of SQGs in sediments, elutriate tests showed that, with the exception of arsenic at one site, metals were not released in notably elevated levels from the sediments after agitation in water.

A 2011 survey by the DEP detected similar exceedances in metals in the surface 5 cm of sites in the main river channel and on the shallow macrophyte beds, where cadmium, lead, zinc and mercury were detected at levels exceeding ANZECC SQG-high values, and levels of arsenic, copper and nickel exceeded ANZECC SQG-screening levels. Information from Aquatic Science and Marine Solutions (2012).

In 2012, sediments just upriver of the crossing were analyzed for total and dilute acid-extractable metals to a depth of approximately 2 m into the estuary bed (Aquatic Science and Marine Solutions 2012). Surface sediments were also analysed for elutriates. Total concentrations for cadmium, arsenic, lead, nickel, mercury and zinc all exceeded ANZECC SQGs-low at some sites, with the latter two also exceeding high-SQG values at some sites. Exceedances were also detected in acid-extractable metals for cadmium, lead and zinc. However, elutriate test results of surface sediments indicated that metals in the sediment were generally not readily released to water.

In 2014/15, sediment sampling was conducted on surface sediments from nine locations around the Green Point WWTP outfall, over two sampling seasons (January and June; Jacobs 2016). Testing was undertaken for metals, total petroleum hydrocarbons (TPH) and nutrients. TPH ranged from less than limits of detection to 12 mg/kg. In alignment with previous studies by GHD (2009) and the DEP, metals were found to be elevated, with silver, arsenic, cadmium, copper and nickel all exceeding ANZECC ISQG-low triggers, and mercury, lead and zinc exceeding ISQG-high triggers.

A 2020 survey by pitt&sherry assessed PASS and AASS to ~5 m below the sediment surface at five sites south of the bridge, and found that, while AASS was not detected, almost all sites showed strong indication of PASS. In the same investigation, contaminant analysis of sediments was conducted at multiple sites to ~1 m depth for total and acid-extractable metals and tributyltin (TBT). Results confirmed metal contamination in surface and sub-surface sediments, with lead, mercury, zinc and arsenic concentrations exceeding high ANZECC sediment quality guideline values (high-SQGV) in near-surface sediments. High-SQGVs reflect the median of the effects range of ecotoxicity tests above which adverse effects were frequently observed.

It is noted that previous investigations have determined that there is a high degree of spatial heterogeneity in surface sediments in the vicinity of the Bridgewater Bridge (Aquatic Science and Marine Solutions 2012).

Vertical distribution of contaminants

Few studies in the vicinity of Bridgewater have rigorously assessed the vertical distribution of contaminants, however, in a 105 cm sediment core collected near the zinc refinery (the major source of metal contamination in the estuary; > 10 km downstream of Bridgewater), metal concentrations above background levels were restricted to the upper 45 cm of the core (Townsend and Seen 2012). Although deposition and transport of contamination and sediment is expected to differ around Bridgewater, it suggested that contamination would occur mostly in the upper 1 m of the sediment. Indeed, in the sampling by pitt&sherry (2020), despite multiple metals exceeding ANZECC threshold levels in the sediment of the upper 0.5 m of the cores, almost all metals were below the low threshold in sediment between 0.5 – 1 m below the sediment surface.

4.5.3.2 Acid sulfate soils

Information from the Land Information Systems Tasmania (the LIST) indicates a high modelled probability of PASS in most of the intertidal and subtidal sediments around the Bridgewater causeway (Figure 27).

Figure 27. Risk of acid sulfate sediment according to LISTmap. Dark blue = subtidal, high probability of occurrence. Light blue = intertidal, high probability of occurrence. Orange = coastal, low probability of occurrence.

Preliminary investigations around the Bridgewater causeway by GHD in 2009 identified that the sediments were not AASS, but had high potential acidity, without sufficient natural buffering capacity to neutralise the acid potentially produced by oxidisation (GHD 2009). Liming rates ranged between 27 – 73 kg / tonne.

pitt&sherry also sampled sediment opportunistically during geotechnical coring in April-June 2020 at five locations to the east of the Bridgewater causeway (pitt&sherry 2020). Sampled depths ranged from

0.3 - 0.8 m below AHD to as deep as 5.25 m into the sediment in one core. Their results also indicated an absence of AASS, but very high potential acidity, with little neutralising capacity. Liming rates were 22 - 187 kg / tonne of wet material (average 112 kg / tonne). In some cores, the percentage of oxidisable sulfur increased with depth, while in others it decreased with depth (Figure 28).

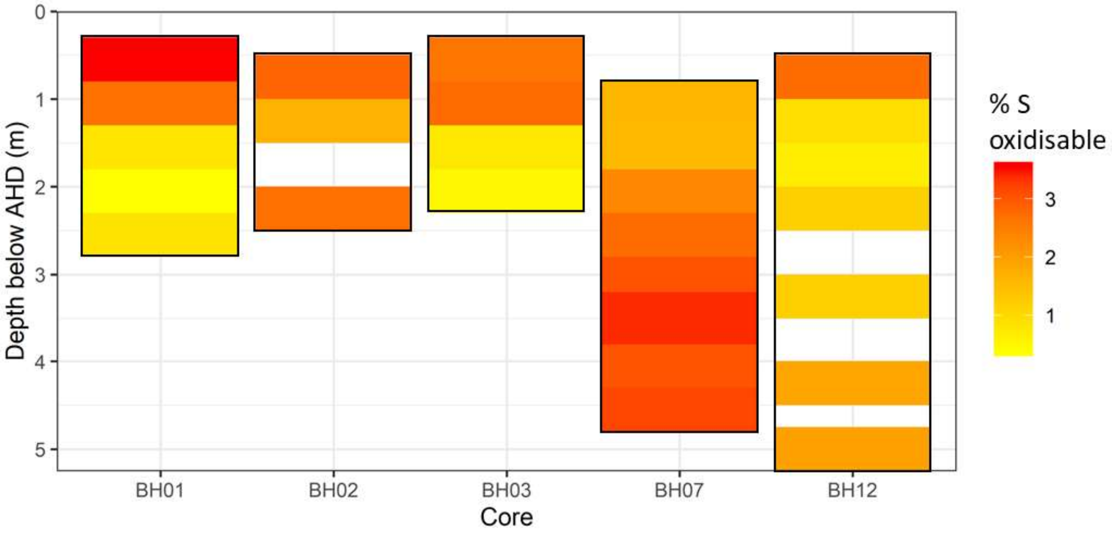

Figure 28. Results of acid sulfate sediment tests in five cores collected by pitt&sherry (pitt&sherry 2020). Data are peroxide oxidizable sulfur % S including acid neutralizing capacity. Action criteria is 0.1 % S. No colour indicates that data is not available for that section of the core.

4.5.3.3 Sediment particle size

Qualitative descriptions of the sediment by pitt&sherry (2020) were that the sediment is generally silty clay. Sediment particle size was not quantified in previous sampling by GHD (2009).

Information from the DEP suggests that sediment is predominantly fine particles higher in the estuary around Bridgewater (Coughanowr et al 2015). This is supported by field observations, such as during the deployment of logging equipment. It was observed that sediment was particularly fine and soft immediately east of the causeway and comparatively firmer 700 m further east of the causeway towards the middle of the Granton Bank. Sediment in the river channel generally consisted of coarser particles.

4.5.4 Sediment sampling

The overarching objective of the sediment sampling was to ensure sufficient coverage to provide an understanding of spatial patterns in sediment characteristics throughout the area. The approach focused heavily on the area most likely to be disturbed by the bridge designs being considered at the time. The area of potential impact is divided into different sampling domains based on water depth, expected sediment particle size and hydrodynamics (i.e. zone of scouring or deposition; Figure 29). The combination of these factors reflect that the condition of the sediment may also differ among the domains. The number of sampling locations in each zone is approximately proportional to its surface area and is intended such that the condition of each domain is sufficiently understood. This will allow in-water construction activities or treatment of extracted sediment to be adapted in the different domains where necessary. In addition to broad-scale sampling across the development footprint, a slightly higher concentration of sampling sites is required to assess the sediment within a potential dredge area. The option of dredging was however abandoned in later proposals due to its high potential for severe environmental impact.

Twenty-three sites were sampled for sediment condition (map in Figure 30; coordinates in Table 23). These were in addition to the five sites for which data was collected earlier the same year (pitt&sherry 2020; metals, tributyltin, acid sulfate soils). All proposed sites were sampled for analysis of metals, tributyltin, acid sulfate soils and sediment particle size (including sediment density). A subset of thirteen sites were additionally sampled for analysis of organo-pesticides / herbicides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, petroleum hydrocarbons and BTEX. Elutriate samples from a subset of sites were analysed for metals and nutrients, where intial concentrations exceeded sediment quality guideline values.

Figure 29. Environmental domains in the area likely to be directly affected by the development (based on the designs being considered at the time of writing), which are expected to differ in their sediment characteristics and therefore contaminant profiles. These domains were used to guide the distribution of sediment sampling. Delineation of domains is based on water depth, expected sediment particle size and hydrodynamics (i.e. zone of scouring or deposition).

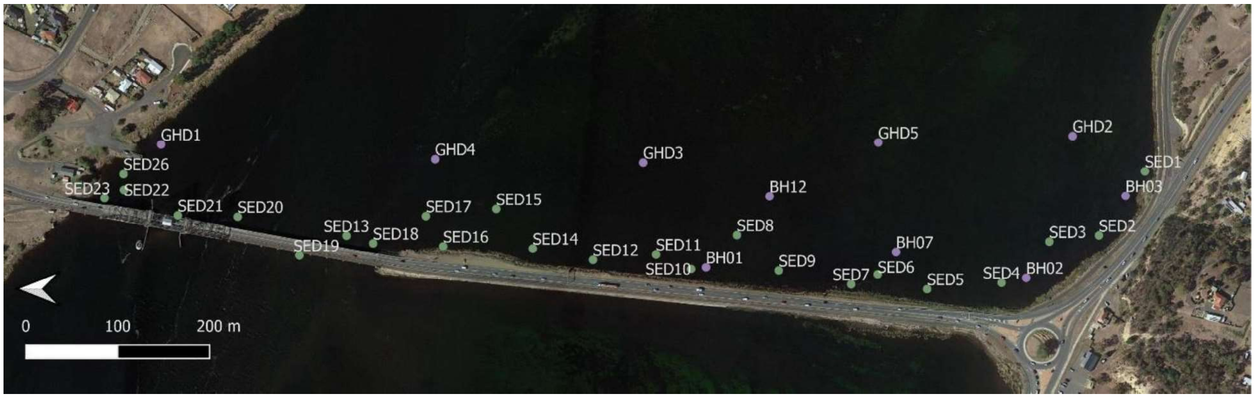

Figure 30. Map of sediment sampling sites. GHD prefix sites were sampled by GHD in 2009, BH by pitt&sherry in early 2020 and SED prefix are sites sampled by Marine Solutions in late 2020.

4.5.5 Analyses

The following parameters were analysed at all sites: acid sulfate, sediment particle size, TBT, metals, mercury and total organic carbon. PAH, TPH, PCB, pesticides/herbicides were analysed from half the sites.

Where concentrations exceeded sediment quality guideline values, the samples with the highest concentrations were processed with weak HCl and elutriate analysis. Elutriate samples also involved analysis of focal contaminants in ambient water.

An additional site was created on the northern shore of the river channel and the sample analysed for PAH (SED26) after elevated PAH was identified in this area.

TCLP-leaching was conducted for key contaminants with highest concentrations to inform land-side sediment management (not discussed in this report; see contamination report by pitt&sherry for further information).

An overview of the parameters analysed at each site and core segment are provided in Table 24. QA/QC analyses are provided in section 9.2.3.

4.5.6 Thresholds and guideline values

Total and bioavailable (1M HCl) concentrations of contaminants were compared to sediment quality guideline values (SQGV and high-SQGV; ANZG 2018, Simpson and Batley 2016). The ANZG (2018). guideline values are used in the National Assessment Guidelines for Dredging (NAGD 2009) and the DEP Guidelines for Dredging and Land Reclamation in the Derwent (DEP 2013).

Total and dissolved contaminant concentrations in elutriate samples were compared to ANZG (2018) toxicant default guideline values (DGV) for water quality. Given that the salinity of the water around Bridgewater is predominantly higher than 2 ppt, the marine DGV is used for the assessment, with the freshwater DGV also provided for reference.

Elutriate tests simulate the release of contaminants from disturbed sediment. This involves tumbling sediment through ambient water for 30 minutes at a ratio of 1:4 sediment to ambient water. An assessment of risk by comparing the results of an elutriate test to toxicant DGVs needs to consider the rate of sediment disturbance (volume per unit time), as well as the water depth and water movement at the site of the disturbance. ANZG (2018) toxicant DGVs for water are generally based on ecotoxological tests with continuous exposure over 24 - 48 hours. In the case of small-scale, short-duration disturbance such as propeller disturbance from a boat, the elutriate results provide a conservative estimate of contaminant release under most circumstances as the disturbance is brief and localised. For a large-scale, long-duration disturbance with a very high rate of sediment disturbance relative to depth and movement of water, contaminants may accumulate and reach higher concentrations than those estimated by the elutriate test.

4.5.7 Site and sample names

Site names were initially assigned moving south to north along the causeway, i.e. SED1 is the southernmost site close to Granton, while SED26 in on the north side of the river channel close to Bridgewater. Some reordering occurred during sampling such that several sites deviated from this sequence as follows (Figure 30):

- Sites SED24 and SED25 were created for the intra- and inter-laboratory comparison. Sediment representing these sites were taken as duplicates at the location of site SED22.
- Site SED26 was an additional site created, and sediment sampled at this site, after elevated PAH was identified on the northern shore of the river channel and further investigation was required. This site is slightly south (and east) of SED23.
- SED13 is just north of SED18 and just south of SED19 is in the river channel.

4.5.8 Core compression

Coring was conducted to 2.5 m into the sediment at most sites, however core compression meant that the extruded core was generally around 1.5 m. This is a well-known phenomenon and loss of material is unlikely. Several cores retained a lodged plug of hard material at the deep end of the core which acted to prevent any loss of sediment from the core during removal from the seafloor and subsequent handling. Cores with plugs were of similar length to cores without plugs when extruded suggesting minimal core loss.

Compression is assumed to be linear along the length of the core, following the relationship shown in Table 3. Core length intervals used for sampling sediment were generally 0 – 50 cm, 50 – 100 cm and

100 – 150 cm, which is equivalent to depths into the sediment of approx. 0 – 80 cm, 80 – 170 cm and 170 – 250 cm. Unless otherwise stated, the length from the top of the core is generally referred to in this document rather than the actual depth into the sediment.

Table 3. Assumed correlation between length along the extruded core and actual depth into the sediment.

Length along extruded core (m)	Assumed depth into sediment (m)
0	**0**
0.3	0.5
0.5	**0.8**
0.6	1
0.9	1.5
1.0	**1.7**
1.2	2
1.5	**2.5**

4.5.9 Sediment appearance

Sediment was generally chocolate to dark brown, with broad bands (20 – 50 cm) containing a higher proportion of grey sand visible in most cores. In multiple cores, a layer of finer, darker particles with higher moisture content and organic matter continued to around 80 cm along the core, before the first layer with high sand content. A layer of dark, organic rich sediment was visible from the surface to 10-30 cm in some cores. Where bands of higher sand content were present, sediment returned to brown silt in deeper layers. Layering was highly variable between adjacent sites.

Sparse, stringy wood fibres were visible in many cores. Shells (generally bivalve), of various sizes up to 2 cm, were visible in many cores. Burrow-like structures were noted in some cores, although no live animals were observed.

4.5.10 Sediment particle size

Sediments were generally silty-sand, with mostly minor contributions of clay and gravel (Figure 31).

4.5.10.1 Spatial

No strong spatial patterns in sediment particle size were apparent across the project area.

Consistently high contributions of sand (around 75%) were evident towards the northern end of the causeway at sites SED15, SED16 and SED17 (Figure 31).

Sediments were somewhat siltier towards the southern corner of the causeway, with many samples around 50% silt.

Sediment was generally sandier in the river channel (> 80% sand), except SED13 towards the southern side of the channel, which had similar proportions of sand and silt (approximately 30%).

4.5.10.2 Depth into sediment

Few consistent vertical patterns of sediment particle size with depth into sediment were recorded (Figure 32).

Generally, deeper sediments tended to contain a higher proportion of sand.

Gravel, when encountered, was generally in higher proportions in the surface sediments.

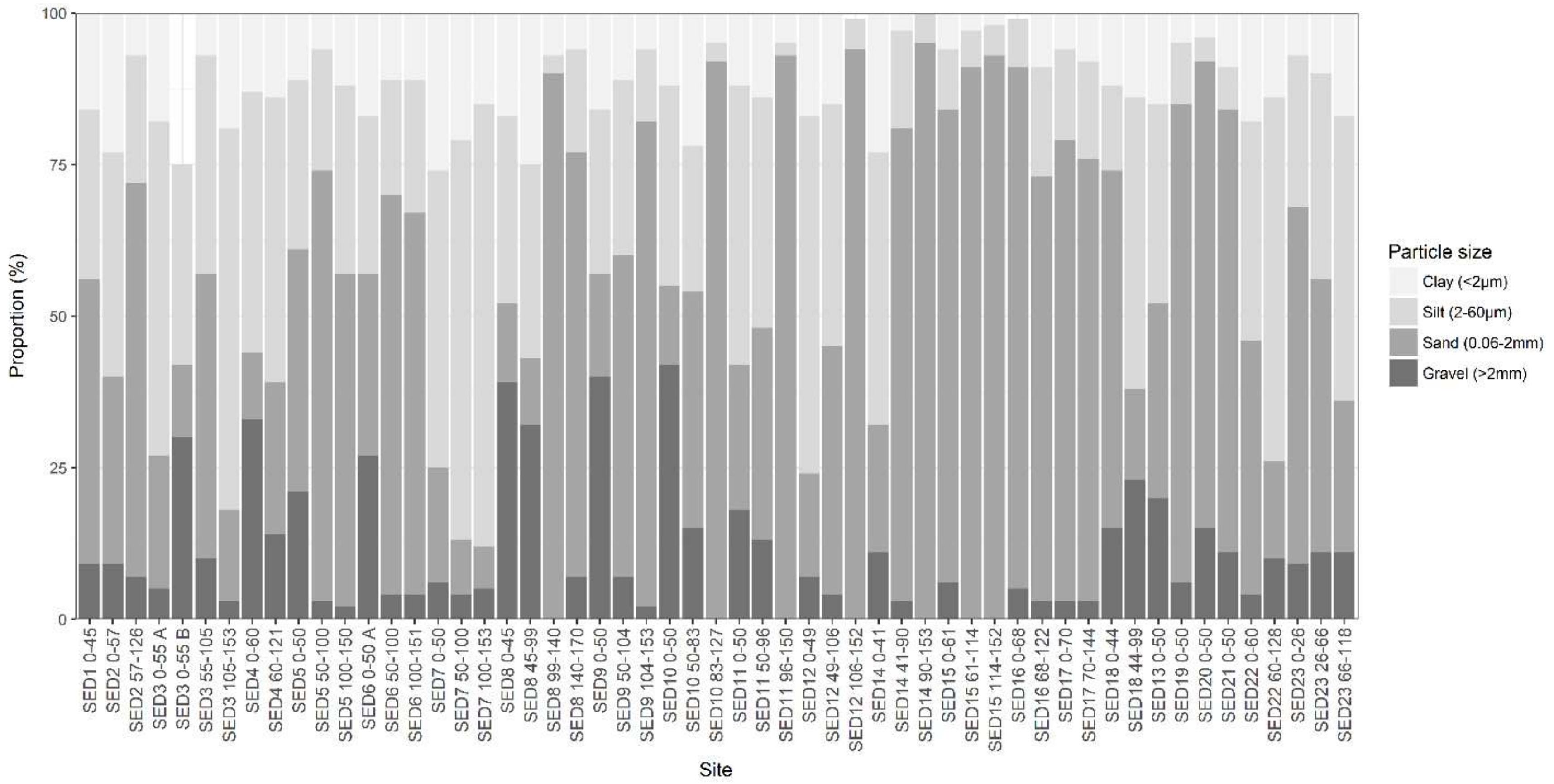

Figure 31. Sediment particle size. Sites are approximately ordered from south to north moving left to right on the graph.

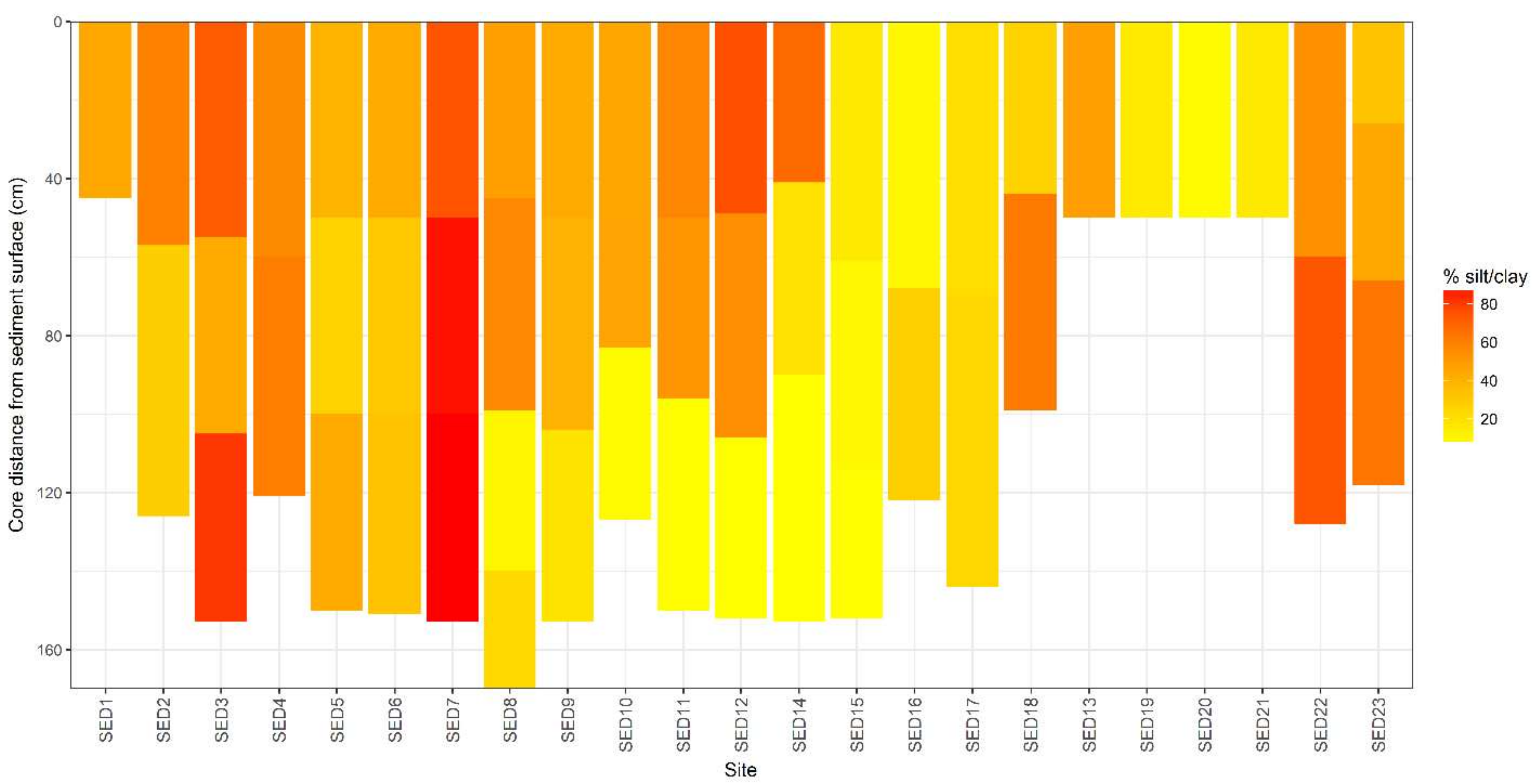

Figure 32. Vertical distribution of finer sediment fractions (< 60 µm). Sites are approximately ordered from south to north moving left to right on the graph.

4.5.11 Total organic carbon

Total organic carbon (TOC) was generally high across the sites with an average of 5.5% (Figure 33). The percent TOC was generally higher in the surface sediments and in the central-northern section of the causeway. TOC was generally lower in deeper sediments.

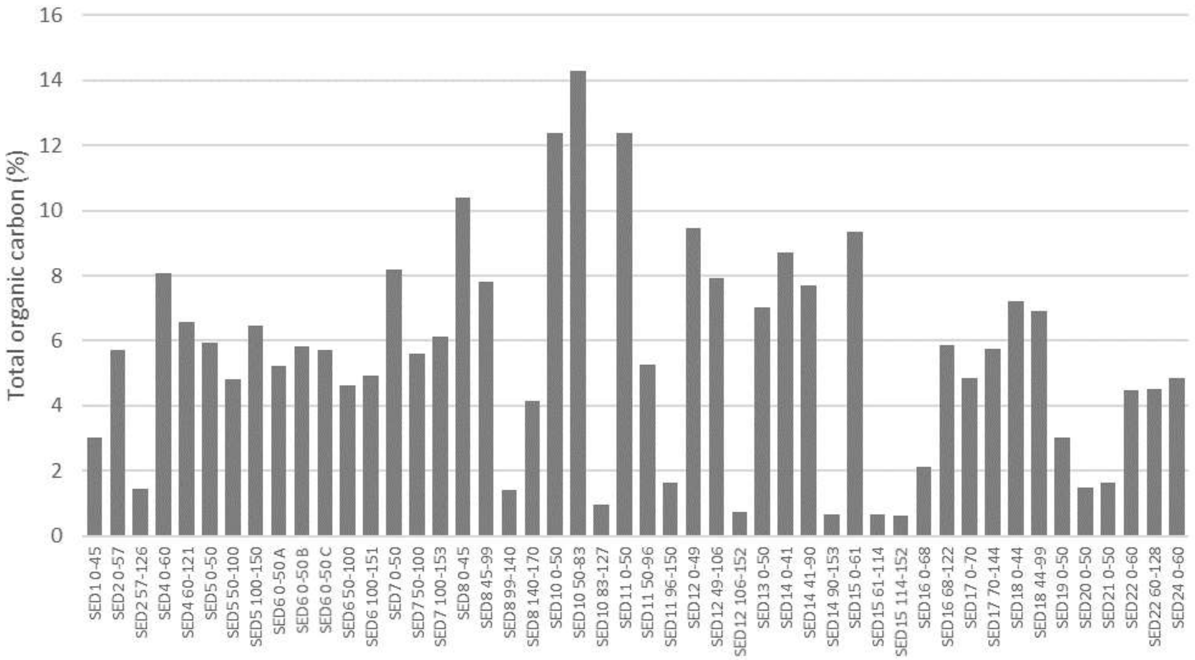

Figure 33. Variation in total organic carbon among the samples. Sites are approximately ordered from south to north moving left to right on the graph.

4.5.12 Sediment settlement rate

Sediment settlement rate was visually determined for several example sites by agitating approximately 200 mL of sediment in 800 mL of tap water. Smaller volumes at the same ratio were used for samples where less sediment was available.

In most samples, approximately 50% of the particles causing the highest visual turbidity had settled out of suspension after 15 minutes, and most of the turbidity-causing particles had settled out after 1 hour (under still conditions).

SED2 0-57 cm

Clay	25%
Silt	40%
Sand	30%
TOC	5.7%

SED2 57-126 cm

Clay	10%
Silt	20%
Sand	65%
TOC	1.4%

SED6 0-50 cm

Clay	20%
Silt	25%
Sand	30%
TOC	5.2%

SED6 50-100 cm

Clay	10%
Silt	20%
Sand	65%
TOC	4.7%

SED6 100-151 cm

Clay	10%
Silt	20%
Sand	65%
TOC	4.9%

SED12 0-106 cm

Clay	15%
Silt	50%
Sand	30%
TOC	8.5%

SED12 106-152 cm

Clay	1%
Silt	5%
Sand	94%
TOC	0.7%

Figure 34. Sediment settlement rates after agitation at the following intervals: 0 mins, 5 mins, 15 mins, 60 mins, 4 hours, 6 hours, 24 hours, 7 days. TOC = total organic carbon.

4.5.13 Odour

Most of the exposed sediment exuded a sulfurous odour, particularly from samples along the causeway and in the southern corner.

The smell was also evident while sampling. At some sites, removal of a core from the sediment was followed by a vigorous stream of bubbles from the hole for approximately 10 - 30 seconds (Figure 35), presumably hydrogen sulphide and methane.

Figure 35. Vigorous stream of bubbles emerged from the hole as the corer was removed.

4.5.14 Contaminant sampling replication

The following sections discuss the results of the sediment sampling with respect to the key contaminants. Whilst interpreting the results, it is important to remember that bioavailability and elutriate testing were conducted only on the samples with the highest total contaminant concentrations in the sediment analyses. This included most samples from the upper layer of the sediment (SEDX 0 – Y), with elutriate testing for 18 of 23 samples and bioavailability testing for 19 of 23 samples. Of the five surface sediment samples not tested in this second stage, all metals were below guideline values in the surface sediments of SED17, SED18 and SED23, while mercury and lead exceeded lower SQGV in SED16 and SED20. Testing of mercury in elutriates was conducted for SED20 0-50 (i.e. only mercury, and no other metals). Of the 31 samples from deeper sediment, three were analysed for elutriates.

Thus, the percentage of samples exceeding the relevant threshold may be higher for the second stage of testing.

4.5.15 Arsenic

4.5.15.1 Total

Over SQGV (up to 3x) in around 20% of samples, but not over high-SQGV (Figure 36).

4.5.15.2 Bioavailable (1M HCl)

Just over SQGV in 7% of the 28 tested samples with the highest total concentrations (Figure 37).

4.5.15.3 Elutriates

As(V) far over freshwater toxicant guideline value (to 10x) for all samples tested (no guideline value for marine waters) (Figure 38, 48 and 49).

A low reliability, indicative interim working level marine guideline trigger value of 4.5 µg/L for As (V) was derived using an assessment factor of 200 on the lowest no-effect concentration (200 was used because the limited data were chronic).

As(III) below limits of reporting in all samples.

4.5.15.4 Depth into sediment

Concentrations of arsenic generally decreased with depth into sediment. Key exceptions, where the concentration of arsenic was higher in the middle section of the core and above the SQGV, were at sites SED5 and SED8. Concentrations were very low in the deepest segment of these cores (Figure 41).

4.5.15.5 Spatial

High in southern corner and along causeway, and highest in centre causeway. Below SQGV in river channel and north shore of channel (Figure 42).

Exceptionally high total elutriates in SED1 0-45.

4.5.15.6 Ambient water

Below or very near to limits of reporting.

4.5.15.7 Plots

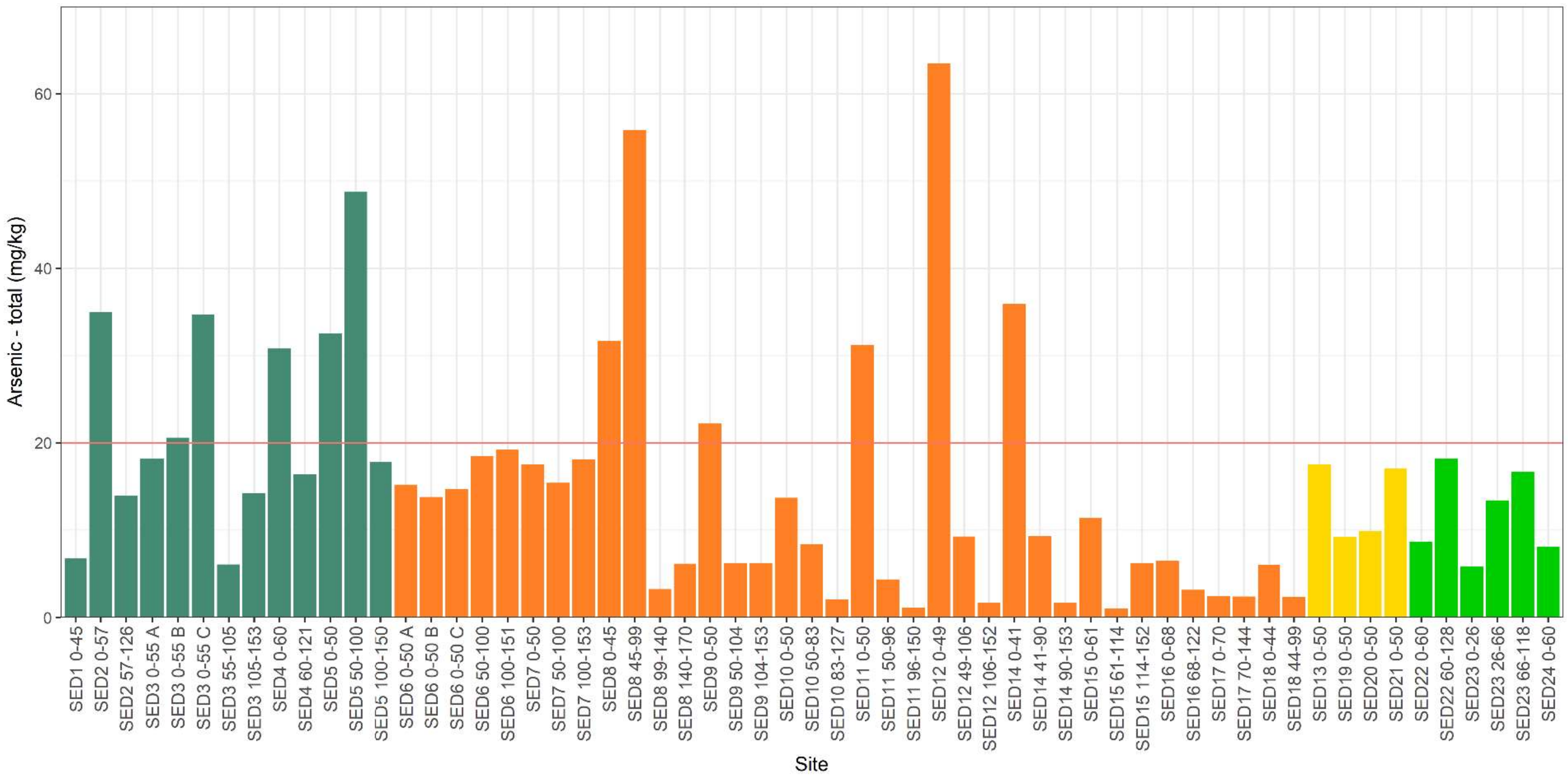

Figure 36. Concentration of total arsenic in sediment. Red line indicates the sediment quality guideline value from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

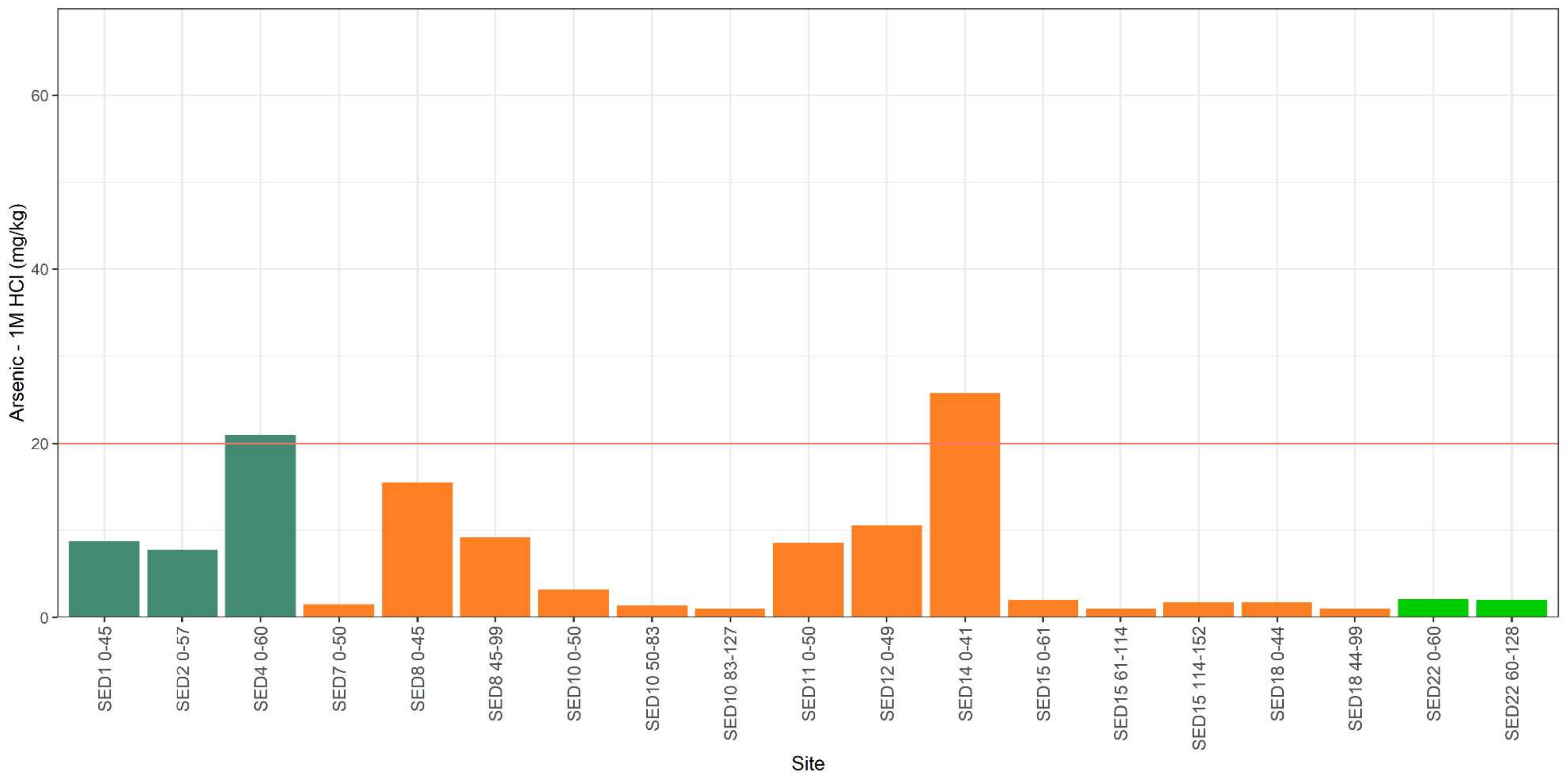

Figure 37. Concentration of bioavailable arsenic according to 1M HCl digest. Red line indicates the sediment quality guideline value from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

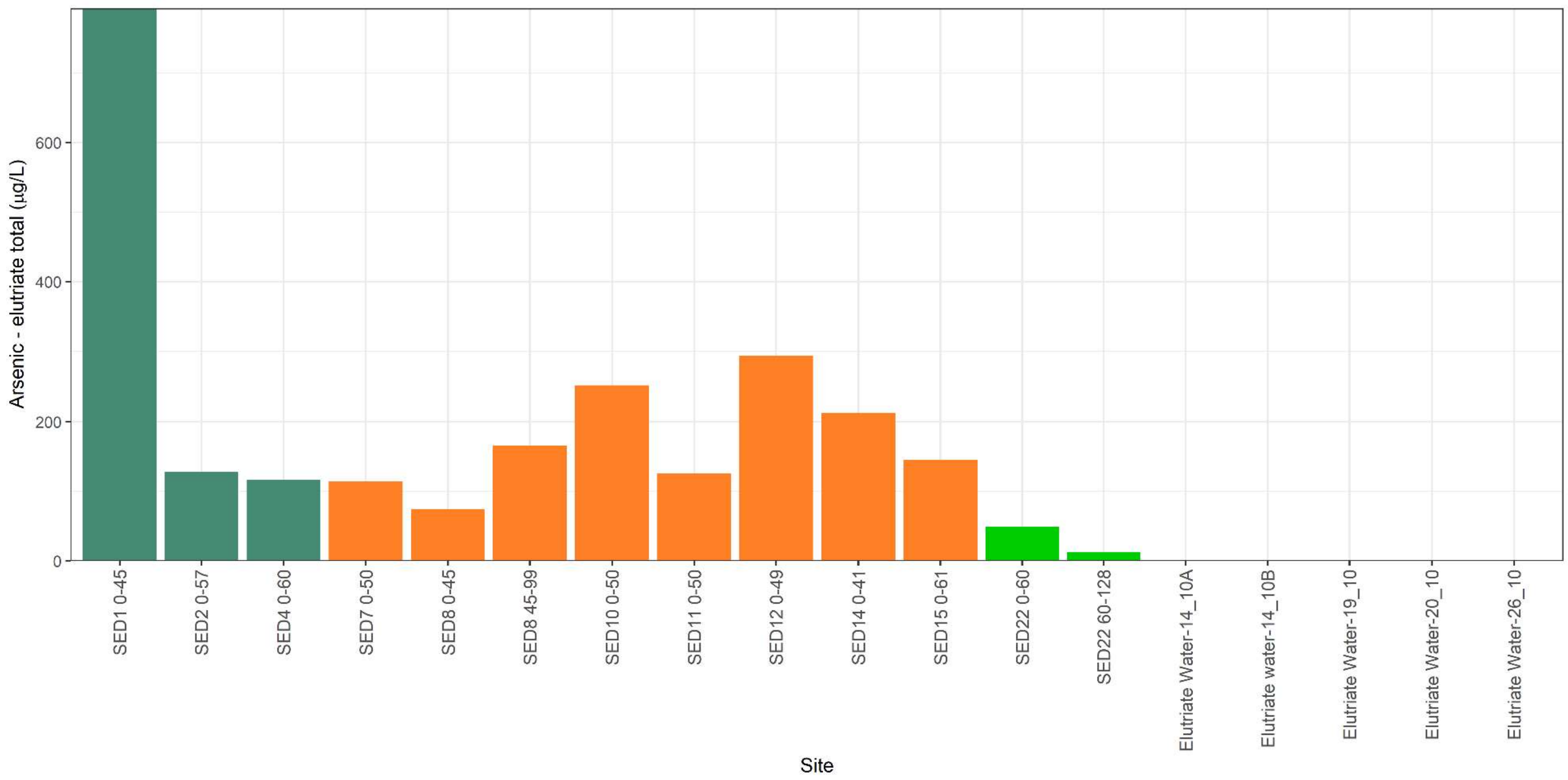

Figure 38. Concentration of total arsenic resulting from elutriate testing. No water quality guidelines are available for total arsenic, but see results for As(V). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

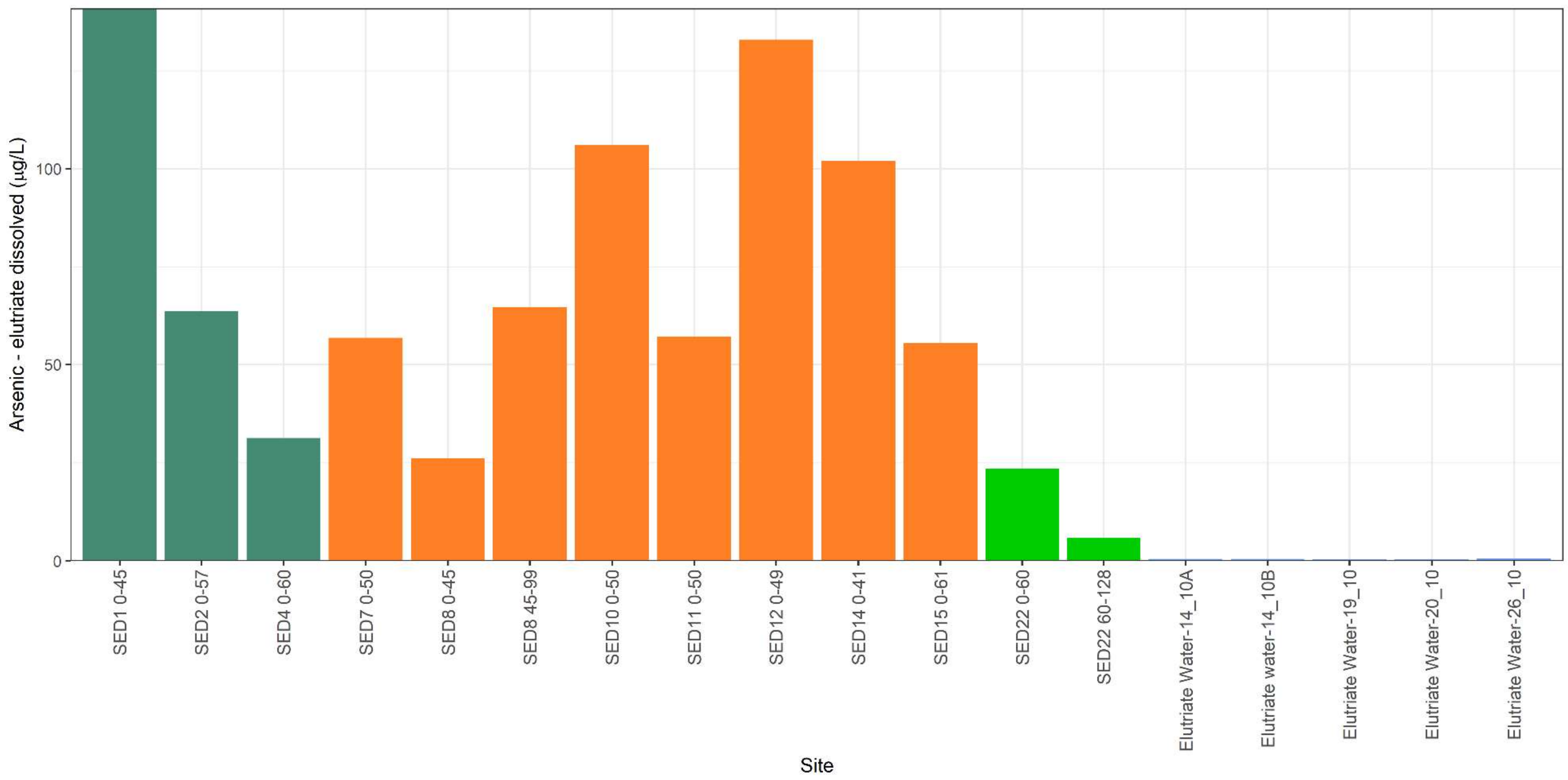

Figure 39. Concentration of dissolved arsenic resulting from elutriate testing. No water quality guidelines are available for total arsenic, but see results for As(V). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

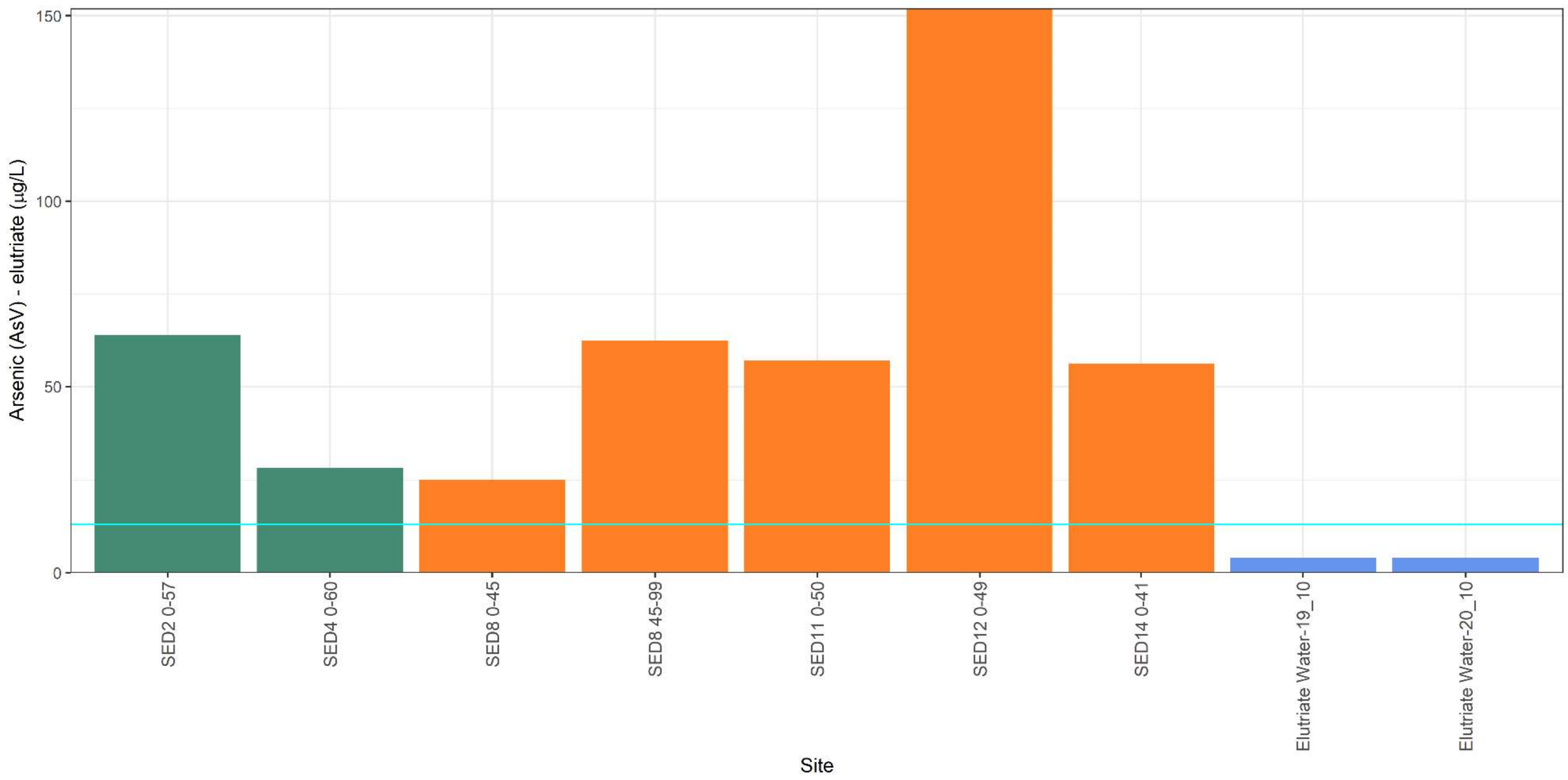

Figure 40. Concentration of arsenic (V) resulting from elutriate testing. Green line indicates the freshwater toxicant default guideline value from ANZECC & ARMCANZ (2000). Red line indicates the sediment quality guideline value from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

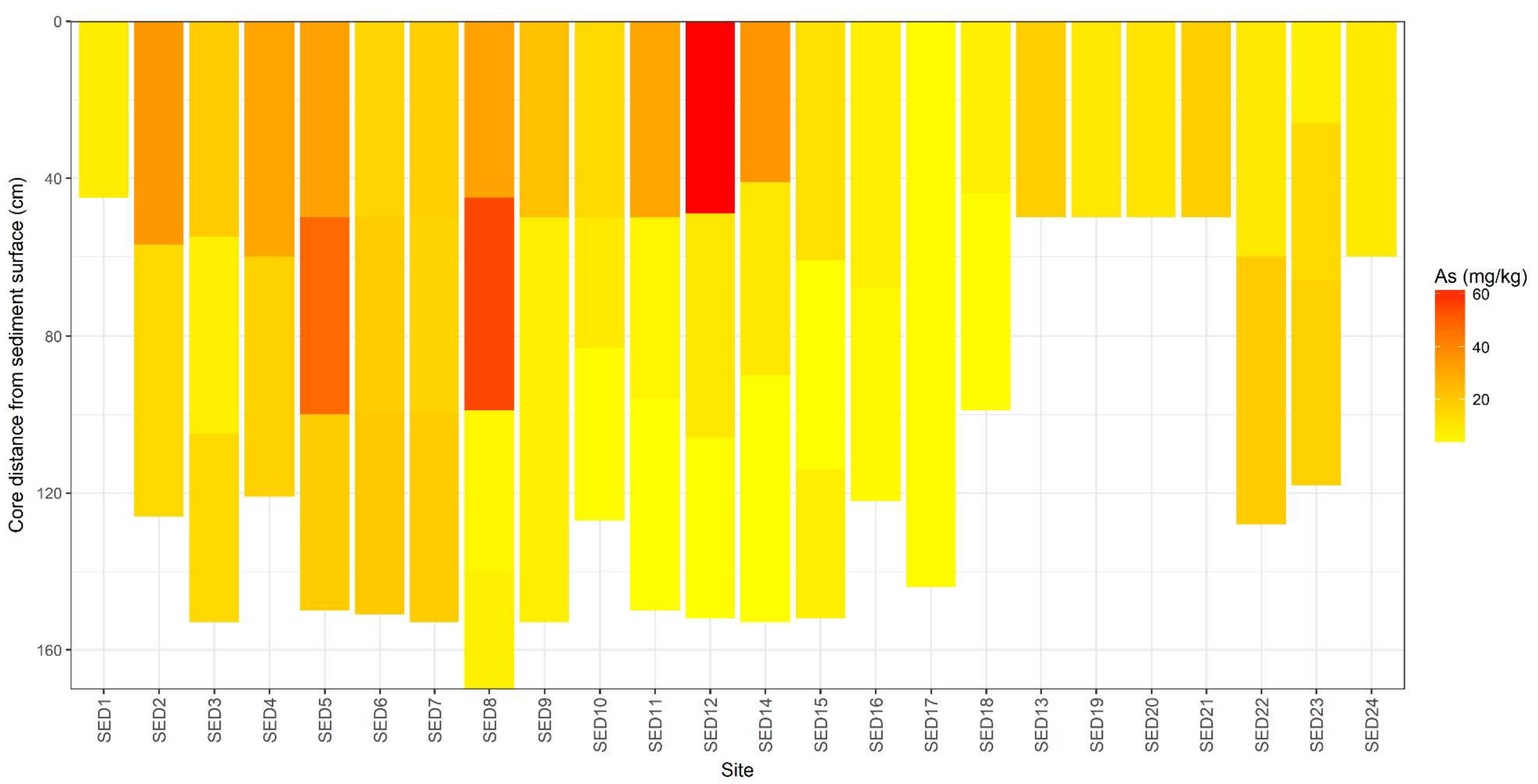

Figure 41. Vertical variation of total arsenic in sediment along cores. ANZECC SQGV is 20 mg / kg, with high SQGV of 70 mg / kg.

Figure 42. Map of total arsenic concentrations in sediment.

Figure 43. Map of dissolved arsenic in water from elutriate analyses.

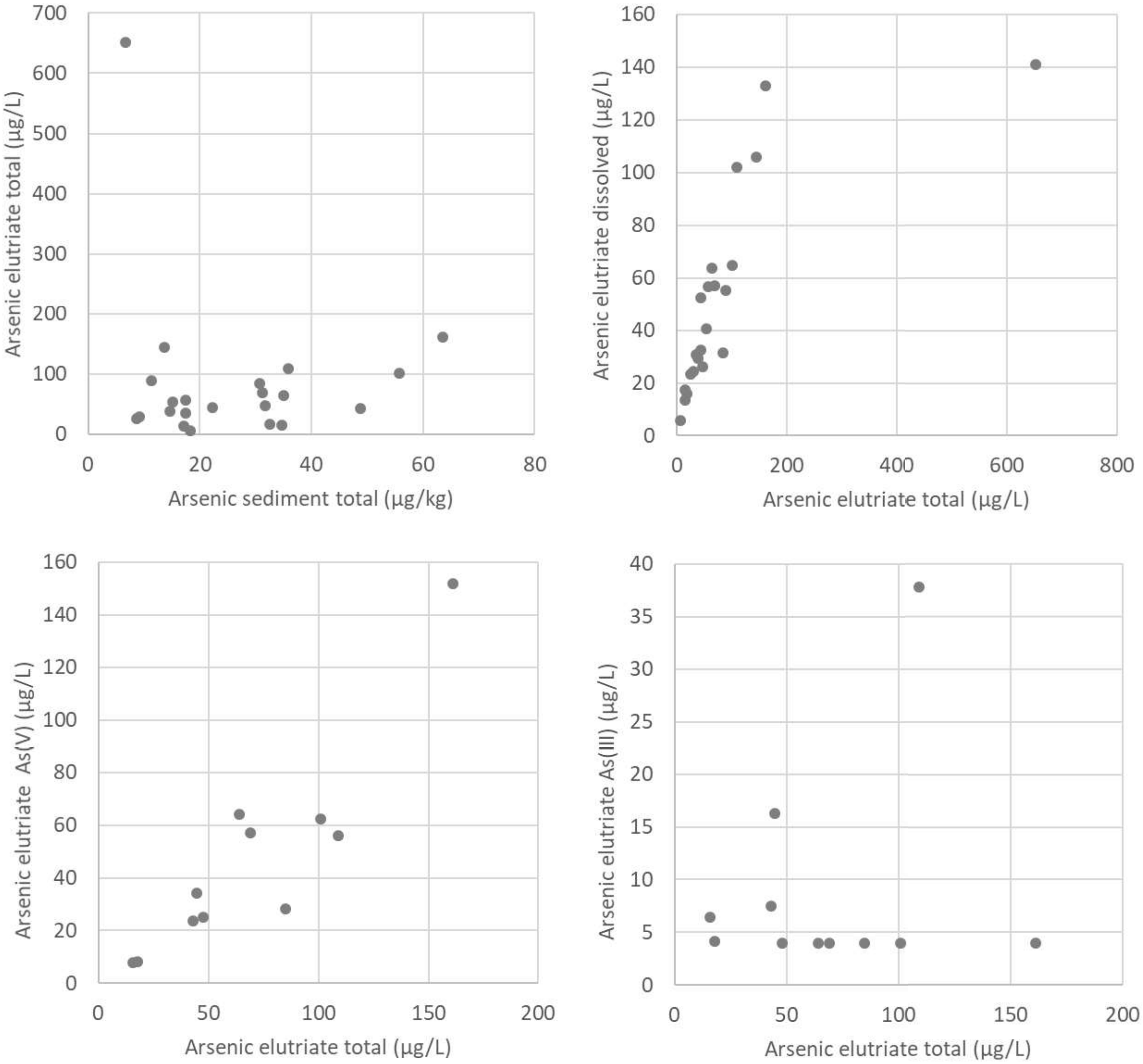

Figure 44. Relationship between different components of arsenic in sediment and elutriates. Outlier in the upper two panels is SED1 0-45.

4.5.16 Cadmium

4.5.16.1 Total

Exceeded high-SQGV in two samples (3%; to almost 2x) and over SQGV in around 27% samples (Figure 45).

4.5.16.2 Bioavailable (1M HCl)

Just over high-SQGV in around 5% of the 28 tested samples with the highest total concentrations (to 1.3x) and over SQGV in around 57% samples (Figure 46).

4.5.16.3 Elutriates

Total cadmium exceeded freshwater toxicant guideline value in around 85% of elutriate samples tested (n = 20). The concentration in one sample SED1 was exceptionally high (228x guideline value) with other samples also approaching 40x the guideline value (Figure 47 and 55).

Dissolved concentrations exceeded the freshwater toxicant guideline value in around 40% of elutriate samples, up to just below 6x the threshold.

4.5.16.4 Depth into sediment

Concentrations of cadmium decreased with depth into sediment. The exception, where the concentration of cadmium was higher in the middle section of the core and far above the SQGV, was at SED5. Cadmium was again low in the deepest segment of the core (Figure 49).

4.5.16.5 Spatial

High in southern corner and along causeway. Below SQGV in river channel and north shore of channel, except SED13 on southern edge of river channel (Figure 50).

Exceptionally high total elutriates in SED1 0-45.

4.5.16.6 Ambient water

Below limits of reporting.

4.5.16.7 Plots

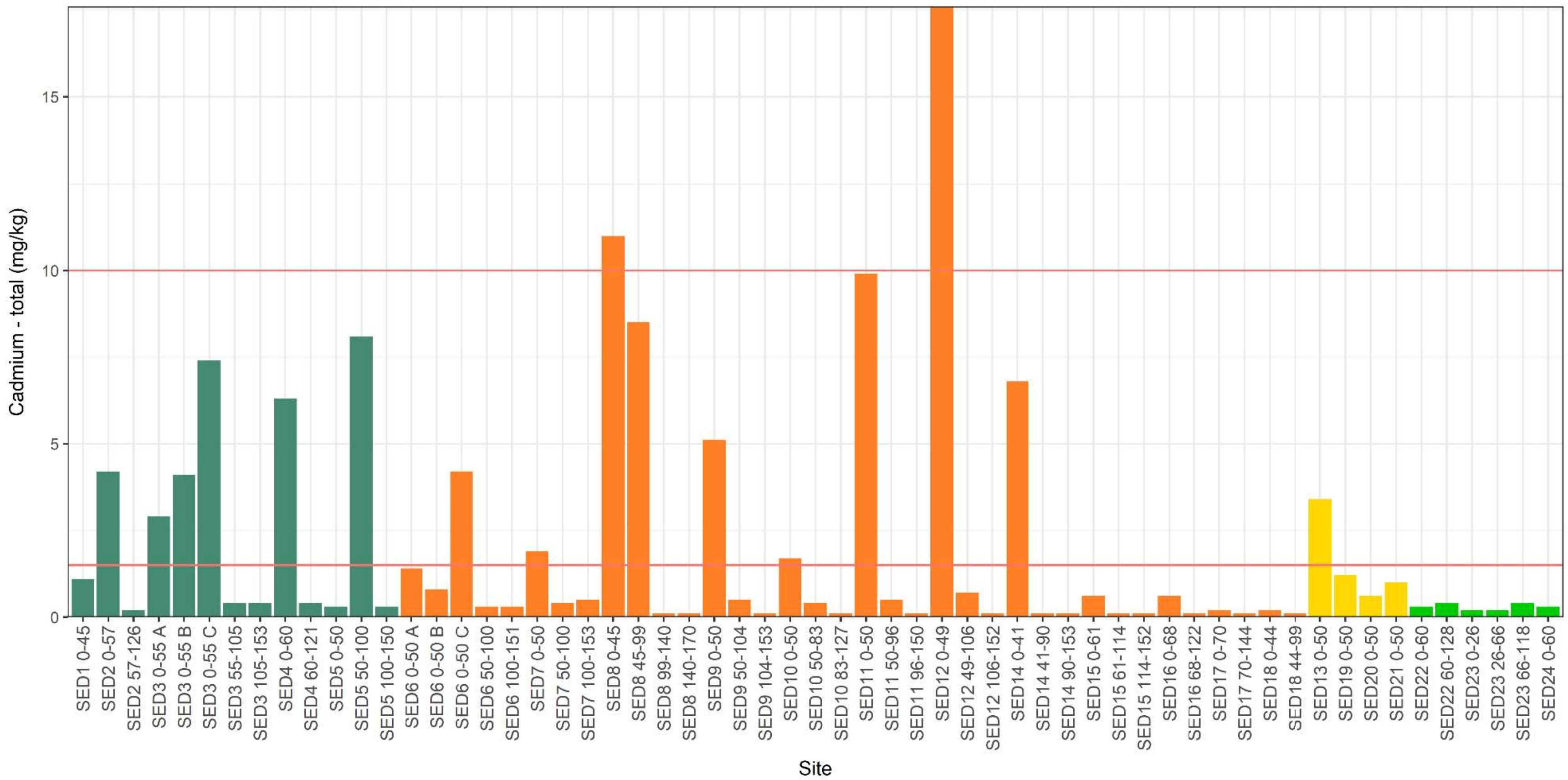

Figure 45. Concentration of total cadmium in sediment. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

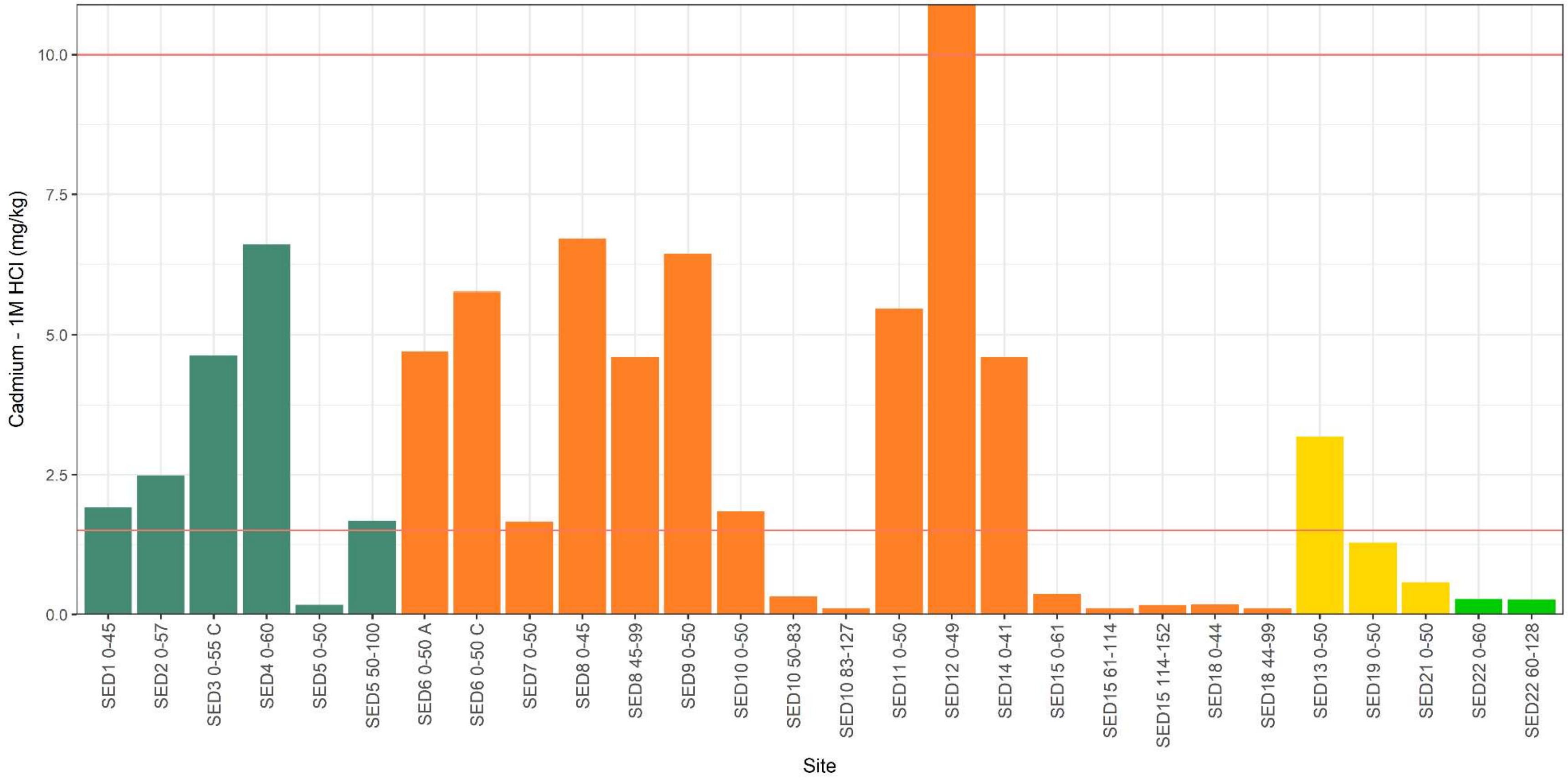

Figure 46. Concentration of bioavailable cadmium according to 1M HCl digest. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

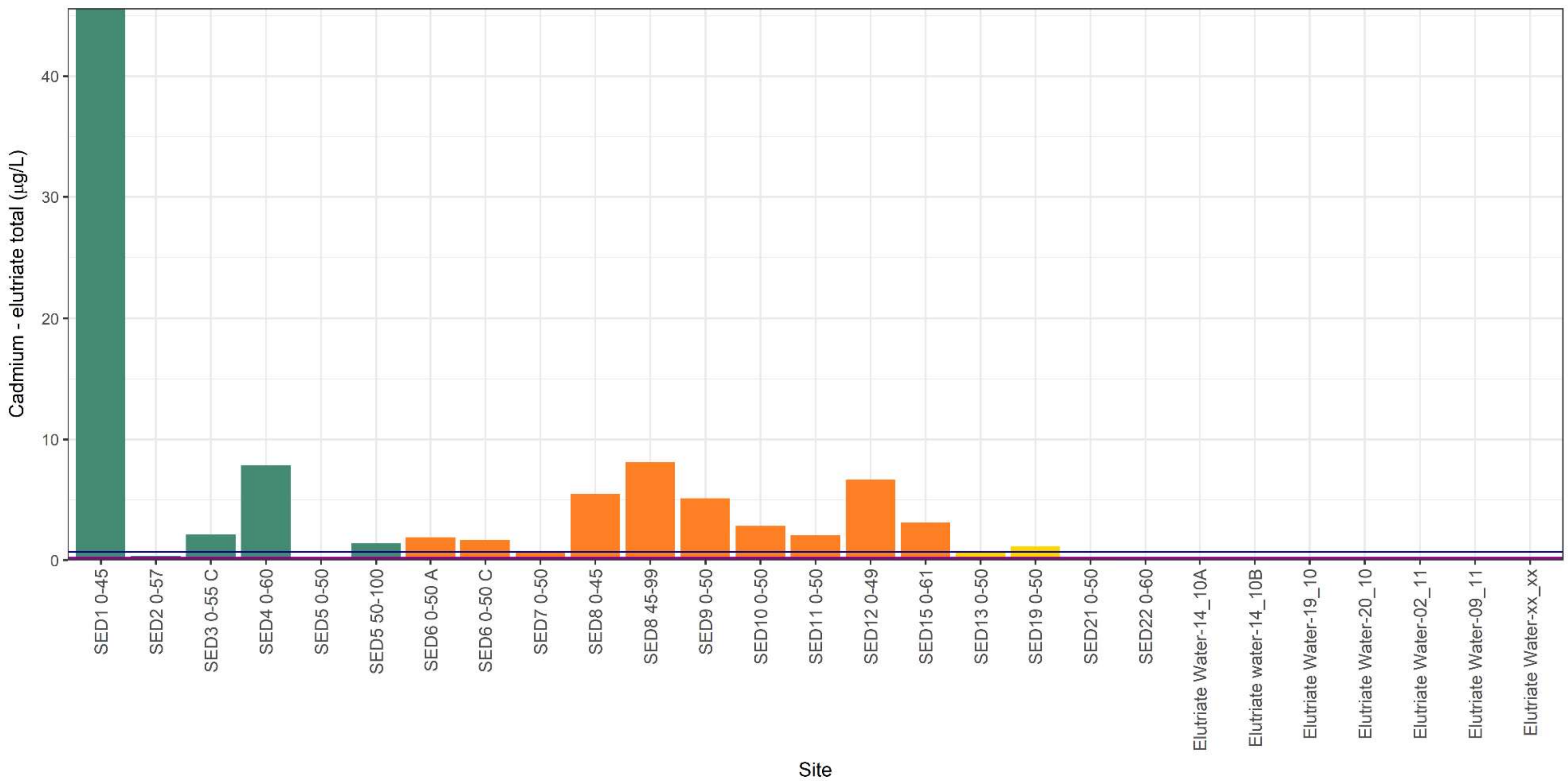

Figure 47. Concentration of total cadmium resulting from elutriate testing. DGVs for cadmium in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

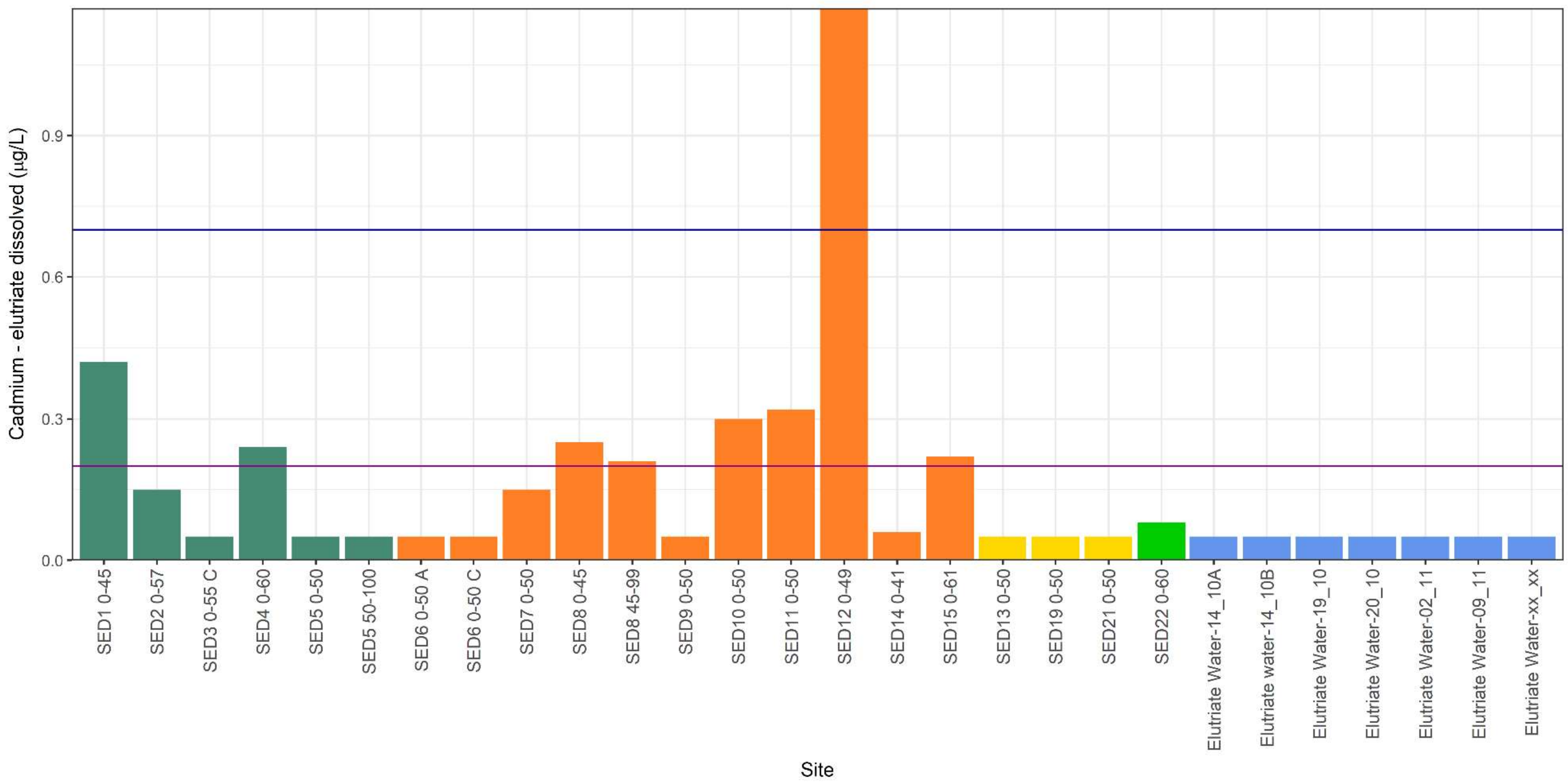

Figure 48. Concentration of dissolved cadmium resulting from elutriate testing. DGVs for cadmium in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

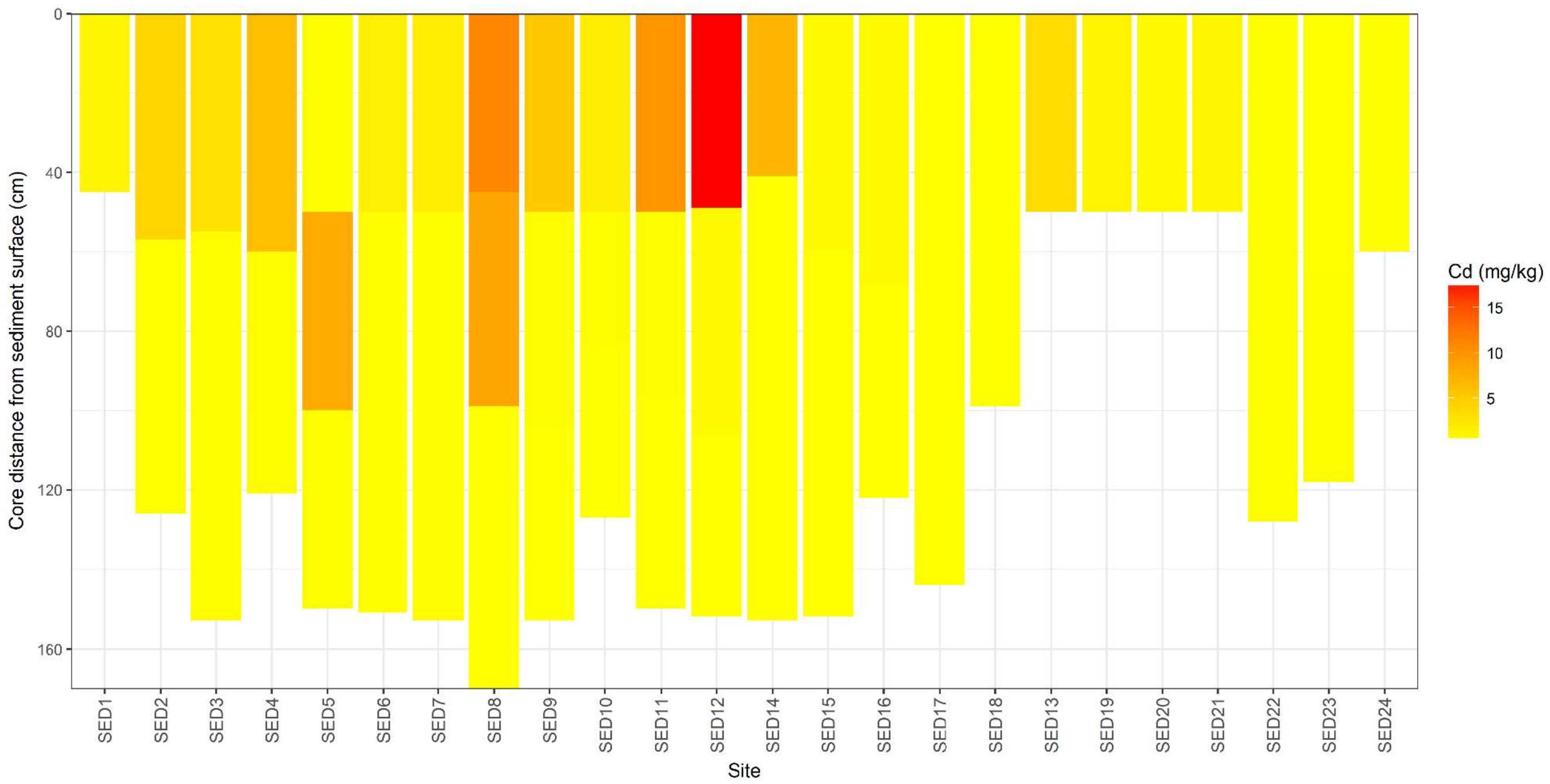

Figure 49. Vertical variation of total cadmium in sediment along cores. ANZECC SQGV is 1.5 mg / kg, with high SQGV of 10 mg / kg.

Figure 50. Map of total cadmium concentrations in sediment.

Figure 51. Map of dissolved cadmium in water from elutriate analyses.

4.5.17 Copper

4.5.17.1 Total

Exceeded SQGV in around 15% of samples (up to 2.7x). Did not exceed high-SQGV (Figure 52).

4.5.17.2 Bioavailable (1M HCl)

Below SQGV in all 28 samples tested (Figure 53).

4.5.17.3 Elutriates

Total copper exceeded freshwater toxicant guideline value in all elutriate samples tested (n = 22). The concentration of copper in one sample SED1 was exceptionally high (over 900x guideline value) with many other samples around 80x the guideline value (Figure 54 and 61).

Dissolved copper exceeded the freshwater toxicant guideline value in 85% of elutriate samples, up to almost 40x the threshold.

One outlier sample in the river channel SED22 0-60 returned a dissolved copper concentration of 54.4 µg/L, with a total concentration of 11.4 µg/L. It is not clear how it is possible that dissolved concentrations are higher than the total. ALS responded that it may have been due to heterogeneity in the sample, however given that the water samples are taken from the same elutriate preparation, this is unlikely.

4.5.17.4 Depth into sediment

Concentrations of copper were generally lower in deeper sediment. The main exception, where the concentration of copper was higher in the middle section of the core and above the SQGV, was at site SED5. Copper was again low in the deepest segment of the core (Figure 56).

4.5.17.5 Spatial

High in the southern corner and along causeway. Mostly below SQGV in channel and north shore of channel, except SED22 on the northern shore (Figure 57).

Exceptionally high concentration of total copper in elutriate of SED1 0-45.

4.5.17.6 Ambient water

Concentrations exceeded freshwater and marine guideline values in half the samples (to almost 4x; Figure 54, Figure 55).

4.5.17.7 Plots

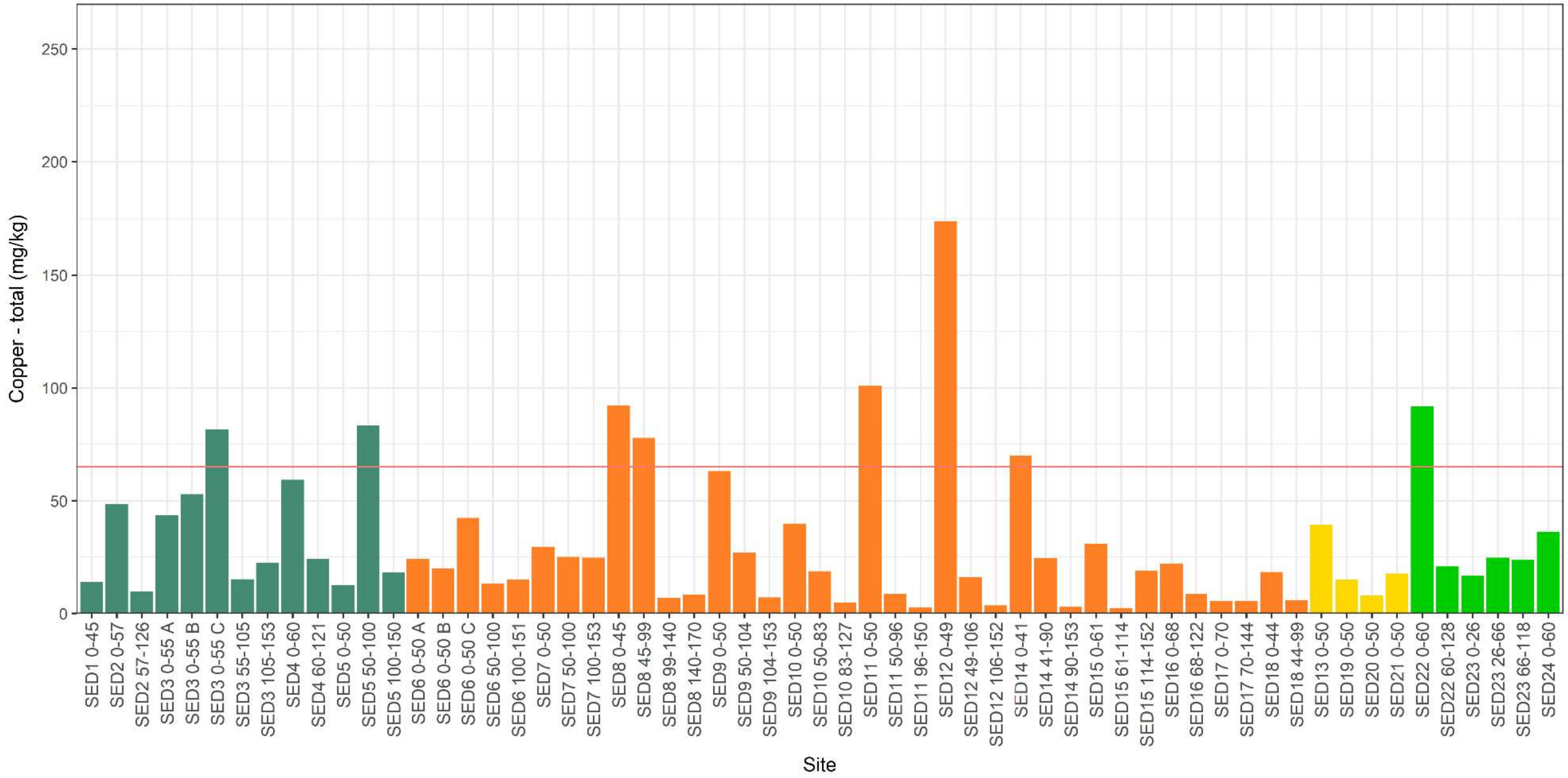

Figure 52. Concentration of total copper in sediment. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

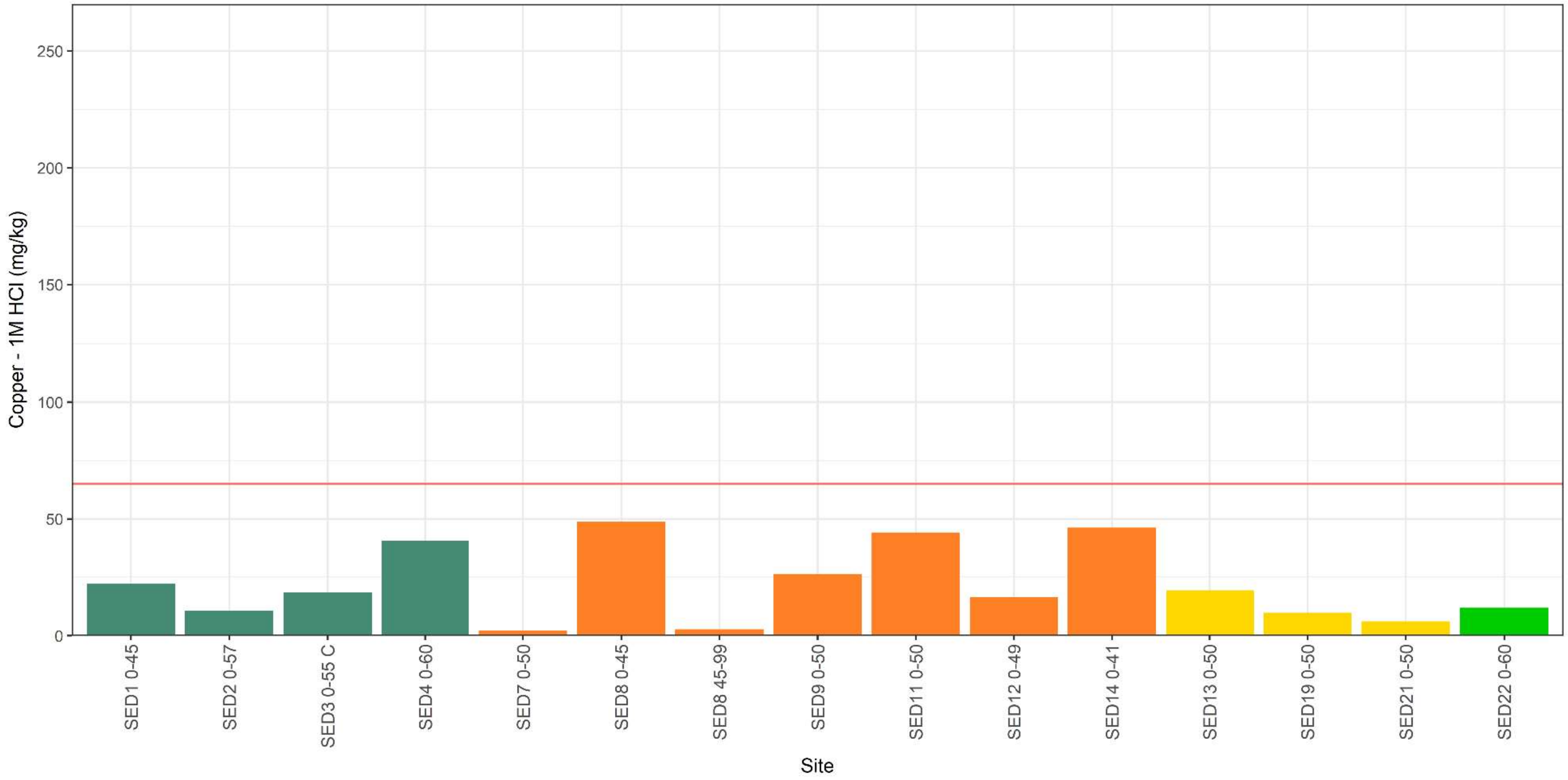

Figure 53. Concentration of bioavailable copper according to 1M HCl digest. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

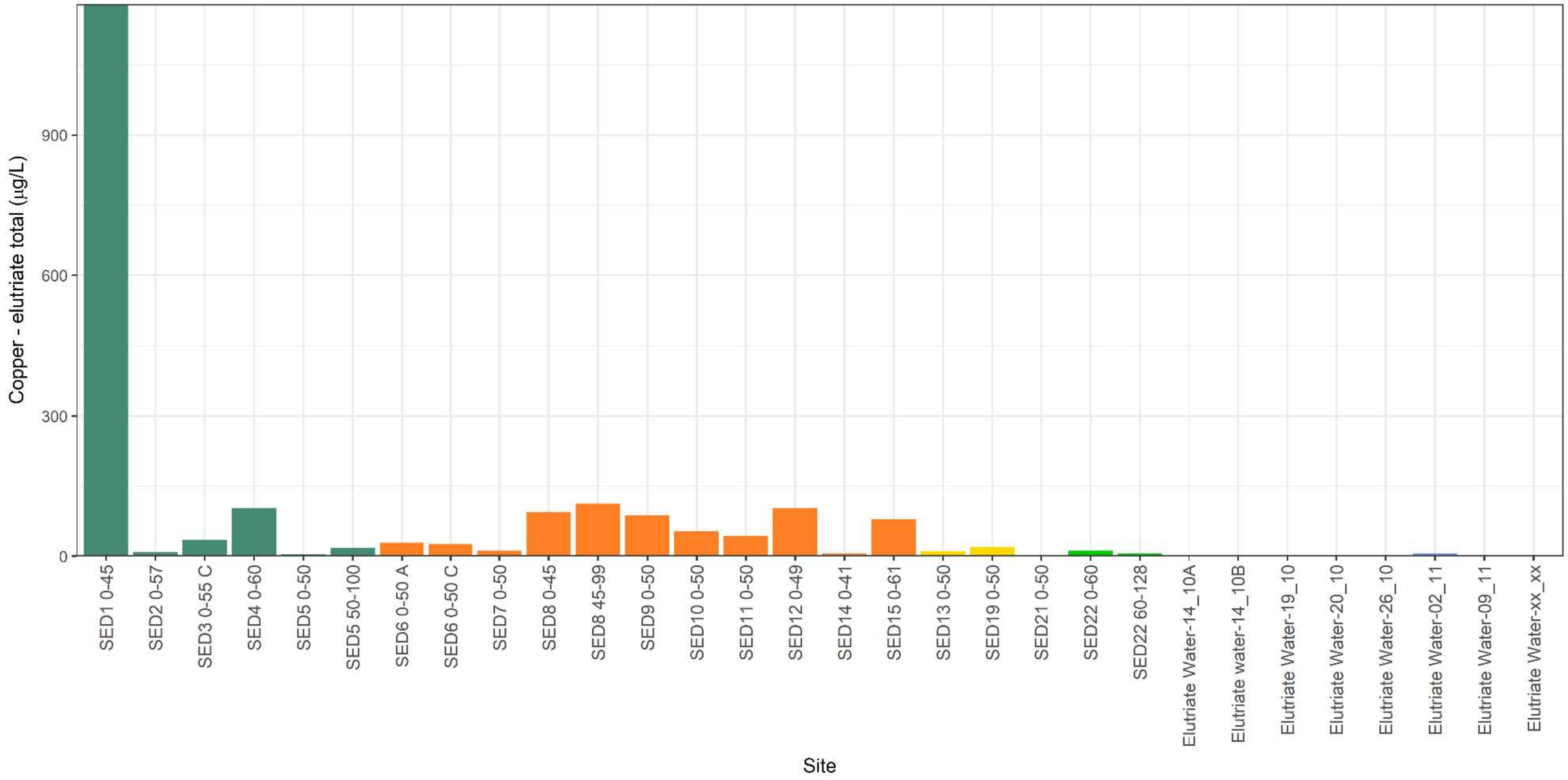

Figure 54. Concentration of total copper resulting from elutriate testing. DGVs for copper in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

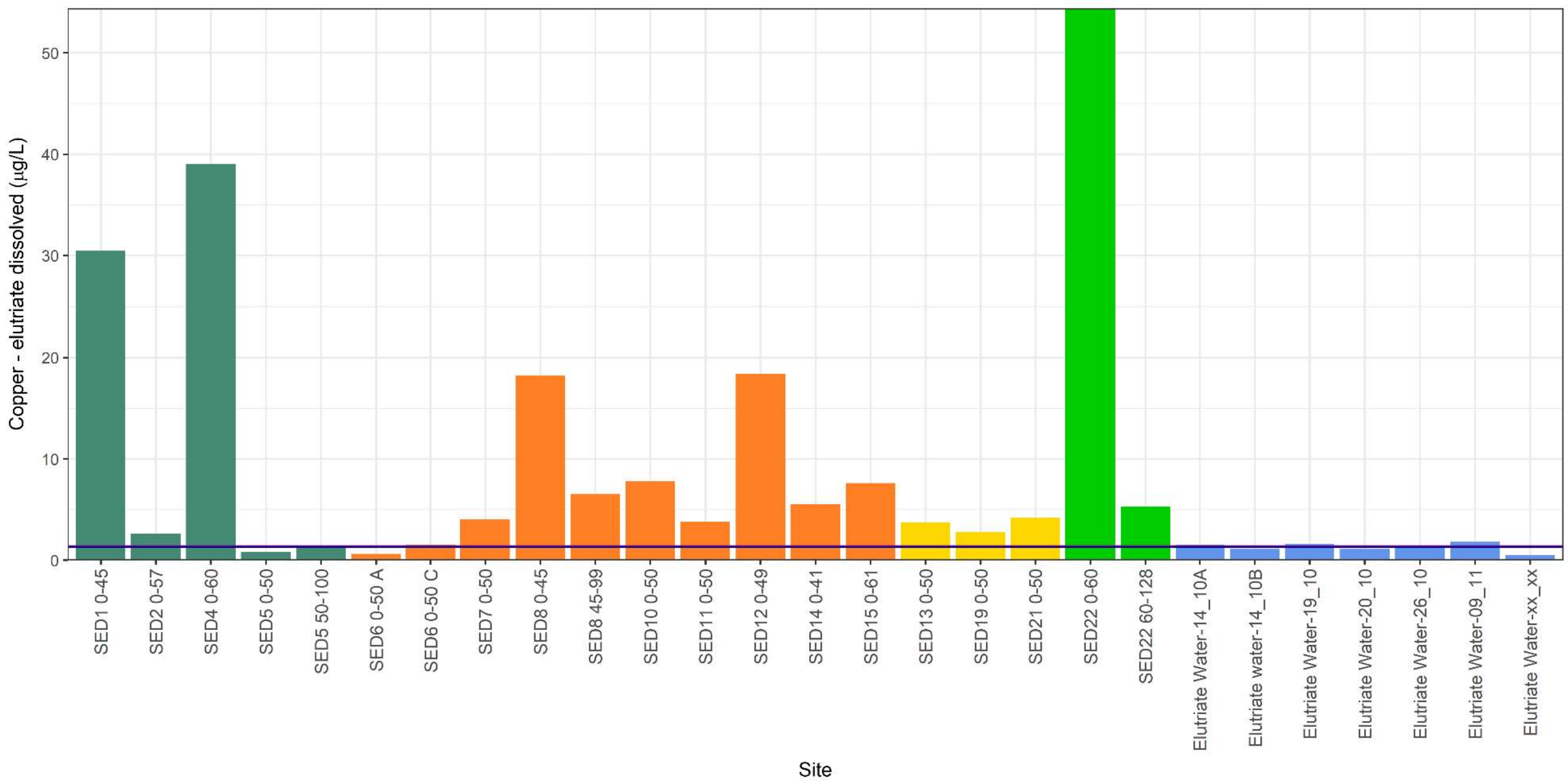

Figure 55. Concentration of dissolved copper resulting from elutriate testing. DGVs for copper in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

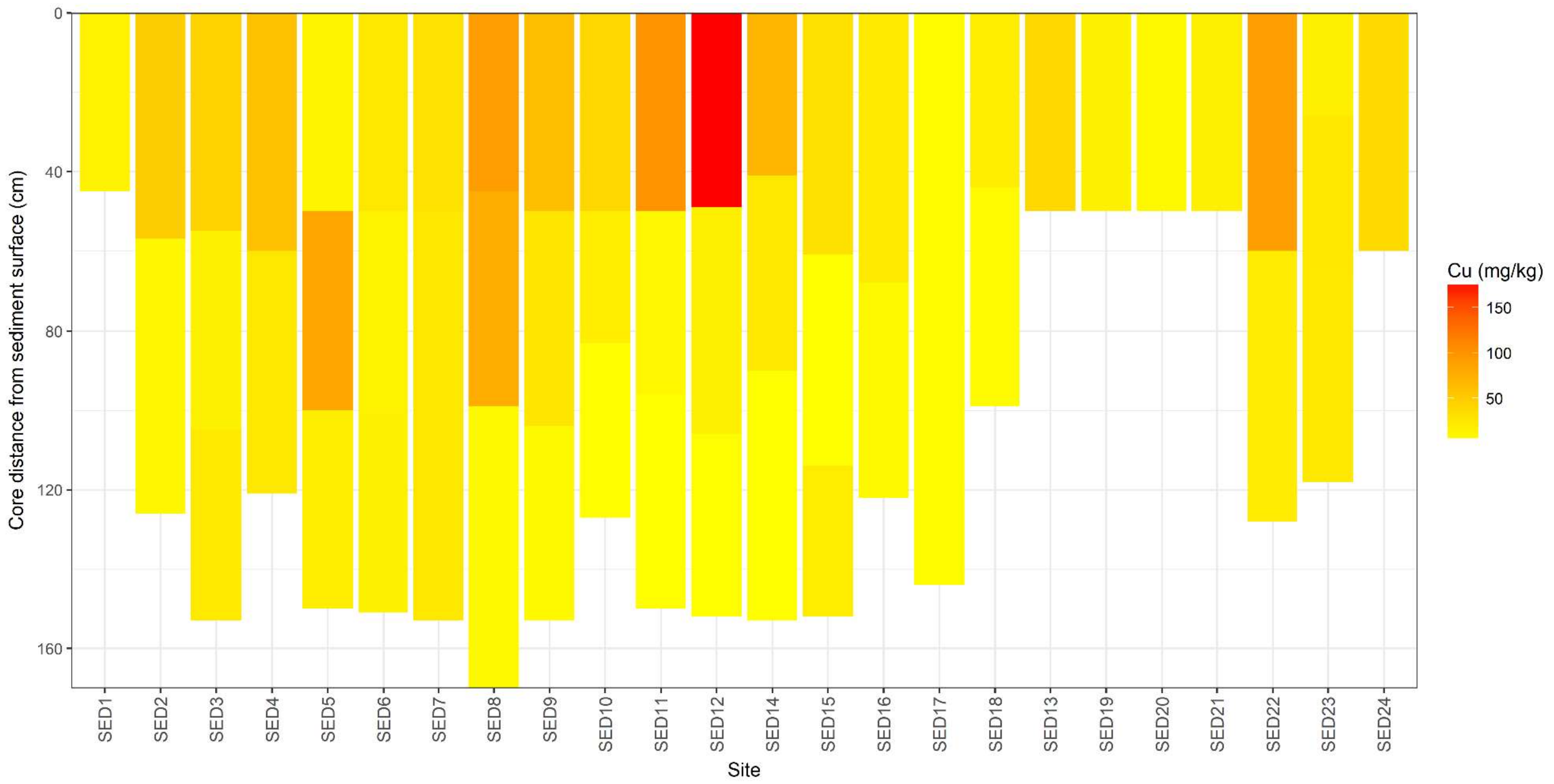

Figure 56. Vertical variation of total copper in sediment along cores. ANZECC SQGV is 1.5 mg / kg, with high SQGV of 10 mg / kg.

Figure 57. Map of total copper concentrations in sediment.

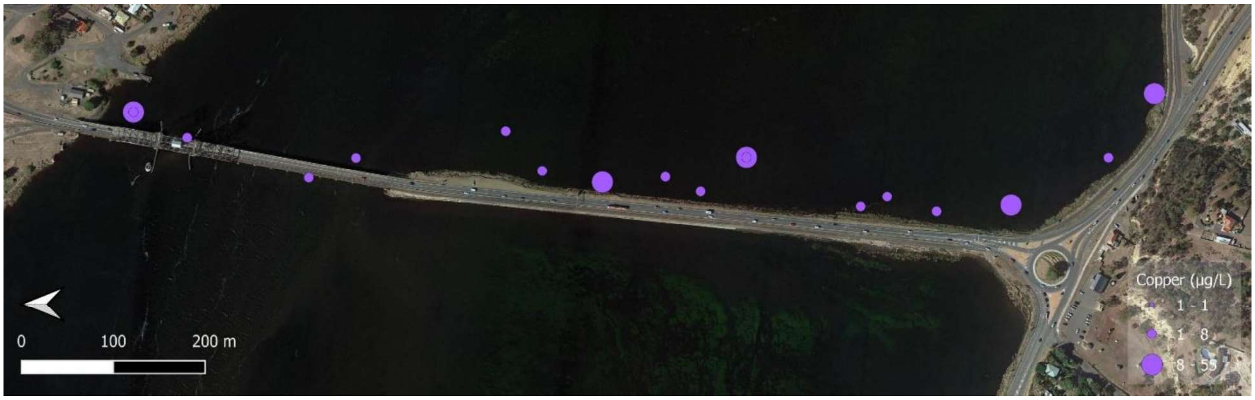

Figure 58. Map of dissolved copper in water from elutriate analyses.

4.5.18 Lead

4.5.18.1 Total

Exceeded high-SQGV in approx. 10% of samples (to 3x guideline value) and over SQGV in approx. 35% samples (Figure 59).

4.5.18.2 Bioavailable (1M HCl)

Over high-SQGV in 25% of the 28 tested samples (to 2.5x) and over SQGV in 65% samples (Figure 60).

4.5.18.3 Elutriates

Total lead exceeded freshwater toxicant guideline value in all elutriate samples tested (n = 22). The concentration of lead in one sample SED1 was exceptionally high (over 1000x guideline value) with other samples also around 100x the guideline value (Figure 61, Figure 62).

Dissolved lead exceeded the freshwater toxicant guideline value in around 30% of elutriate samples, up to 15x the threshold.

4.5.18.4 Depth into sediment

Concentrations of lead were generally lower in deeper sediment. Indeed, concentrations were below SQGV in all sub-surface sediment samples, except SED8 45-99 and SED5 50-100. Concentrations were again low in the deepest segment of these cores (Figure 63).

4.5.18.5 Spatial

Highly variable between sites. High concentrations in corner and along causeway, and highest in center causeway. Below high-SQGV in river channel and north shore of channel (Figure 64).

Exceptionally high total elutriates in SED1 0-45. Exceptionally high dissolved lead in SED12 0-49.

4.5.18.6 Ambient water

Concentrations exceeded marine guideline values one sample (1.25x) and exceeded freshwater guideline values in three samples (to 1.6x).

4.5.18.7 Plots

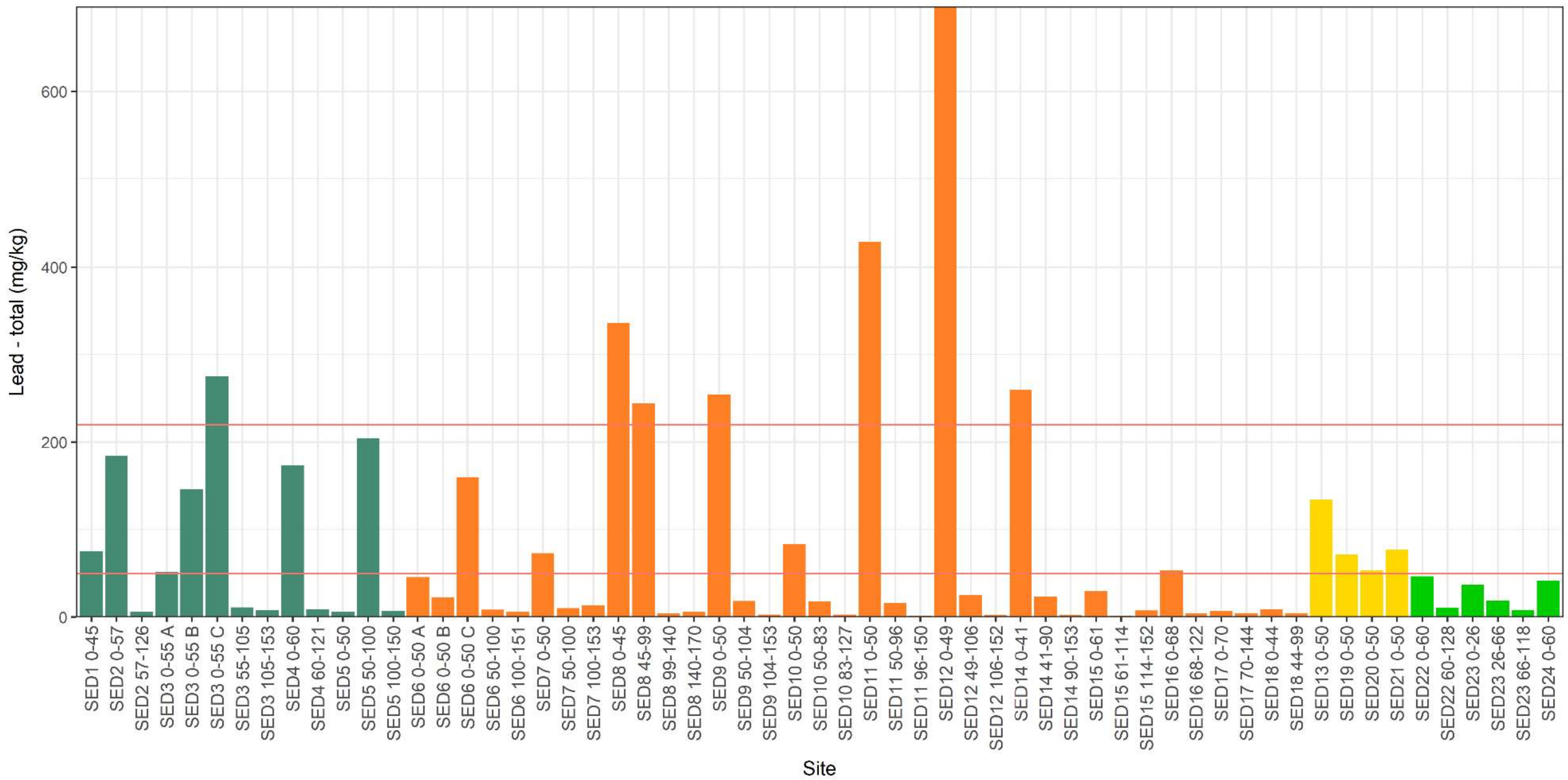

Figure 59. Concentration of total lead in sediment. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

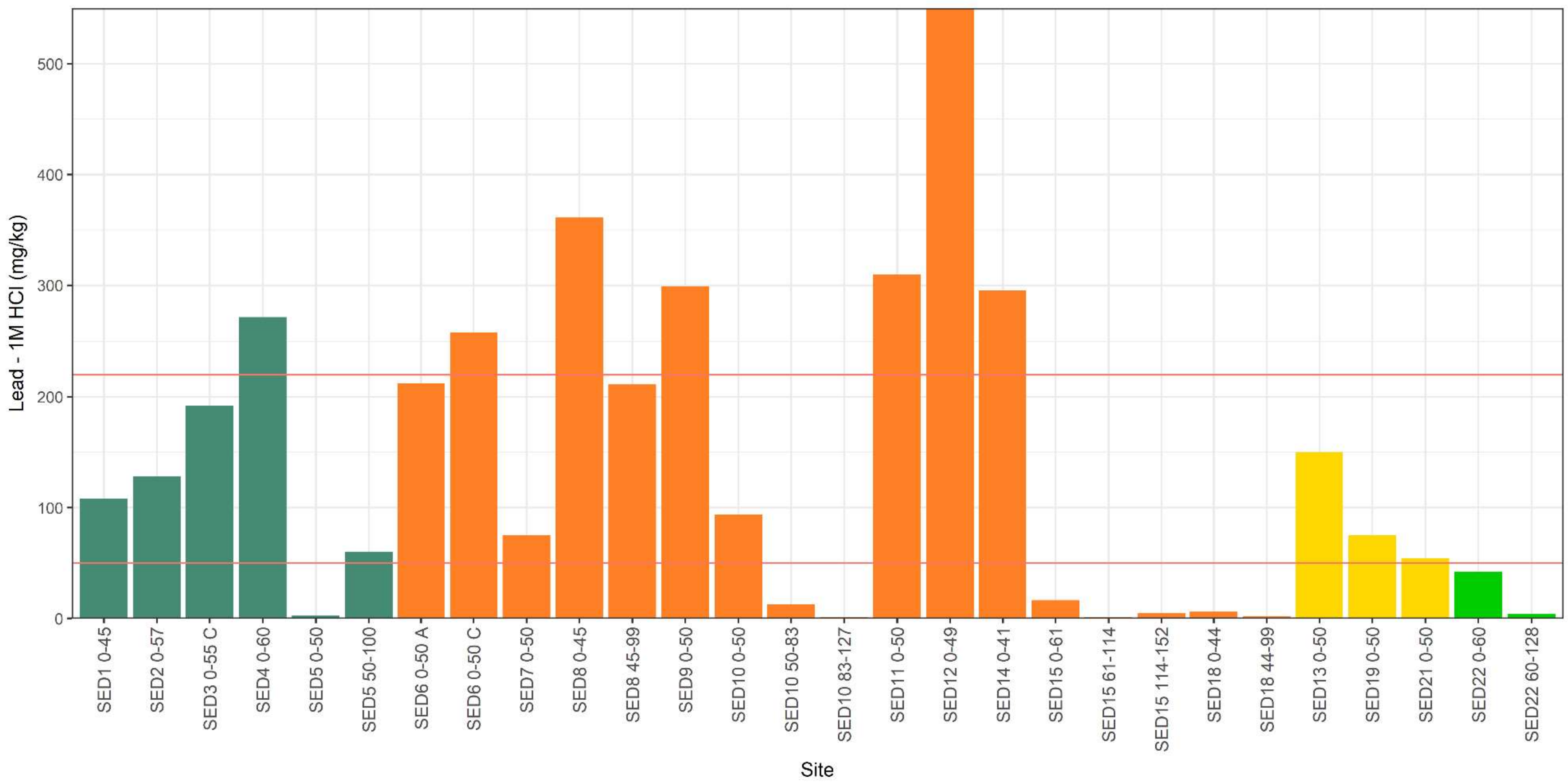

Figure 60. Concentration of bioavailable lead according to 1M HCl digest. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

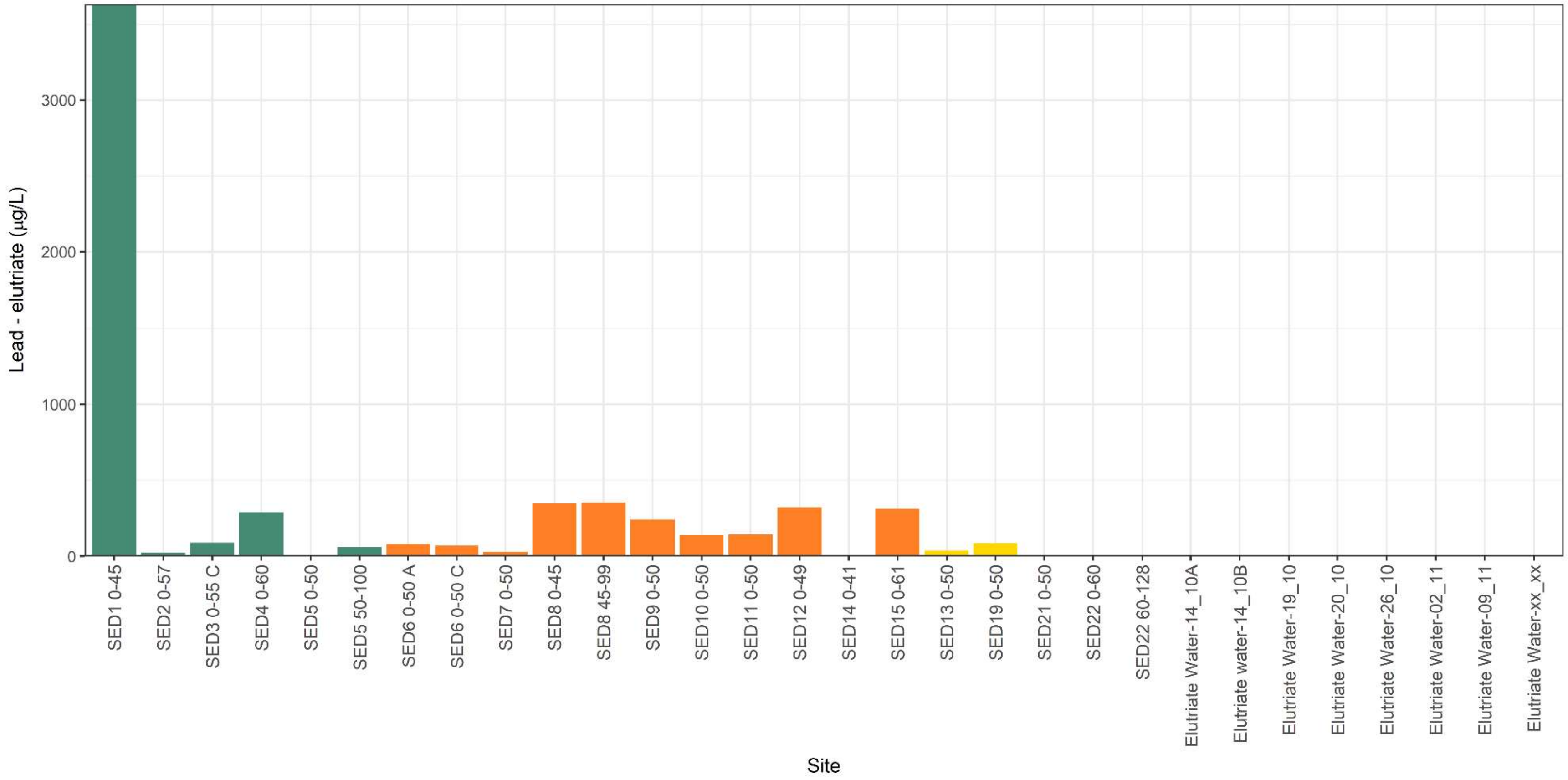

Figure 61. Concentration of total lead resulting from elutriate testing. DGVs for lead in fresh and marine water are low relative to the data and are therefore not visble. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

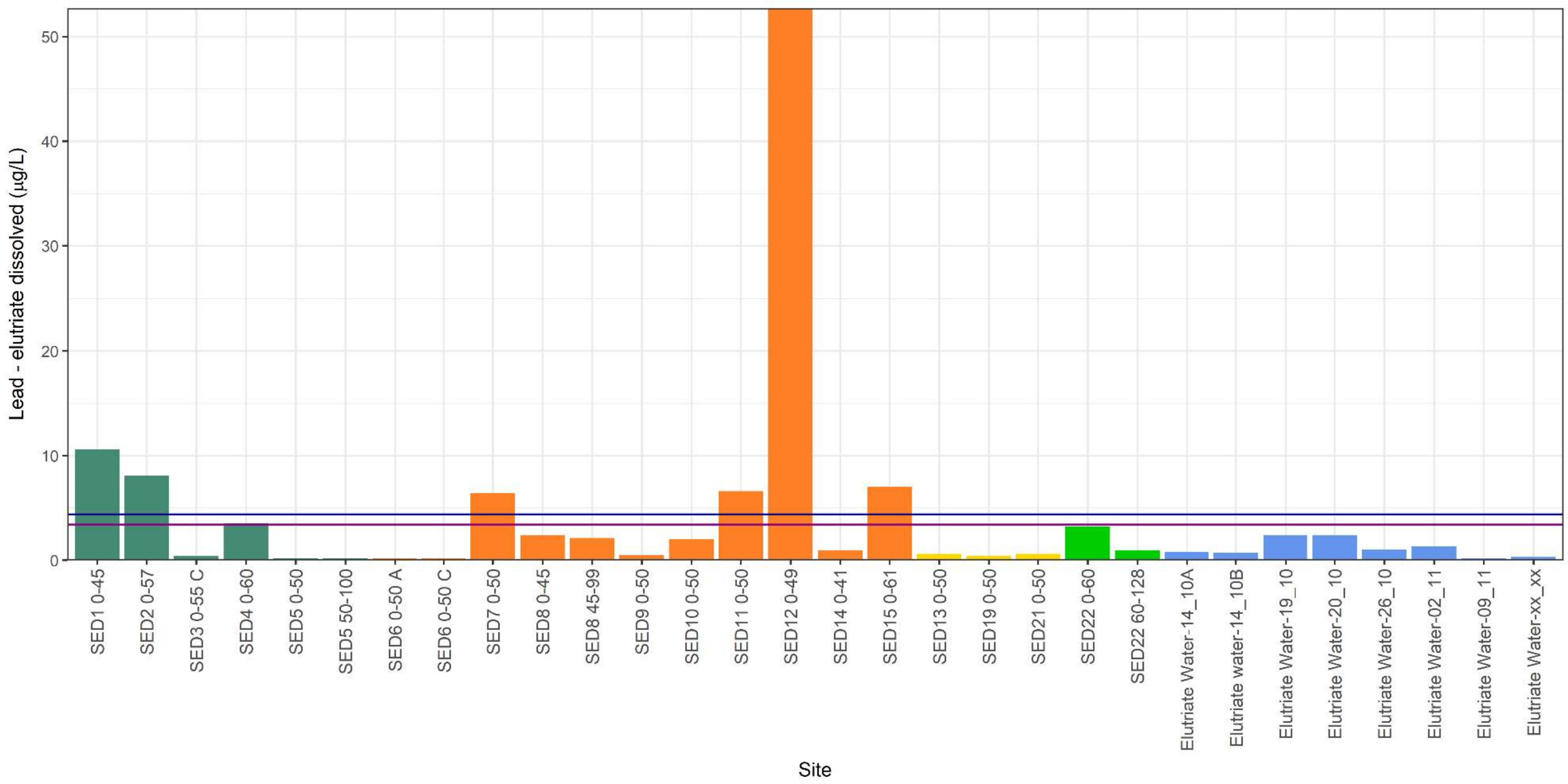

Figure 62. Concentration of dissolved lead resulting from elutriate testing. DGVs for lead in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

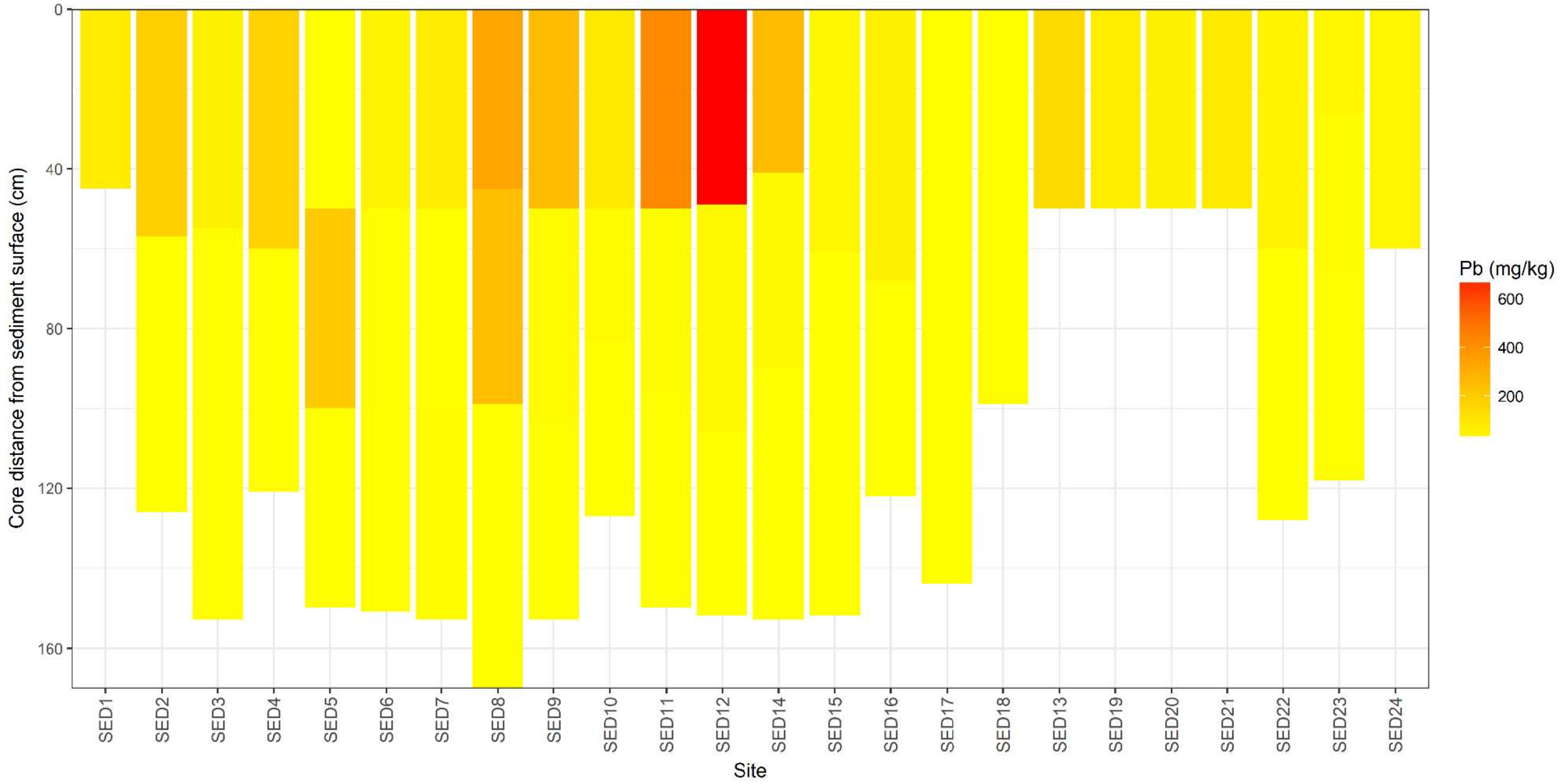

Figure 63. Vertical variation of total lead in sediment along cores. ANZECC SQGV is 1.5 mg / kg, with high SQGV of 10 mg / kg.

Figure 64. Map of total lead concentrations in sediment.

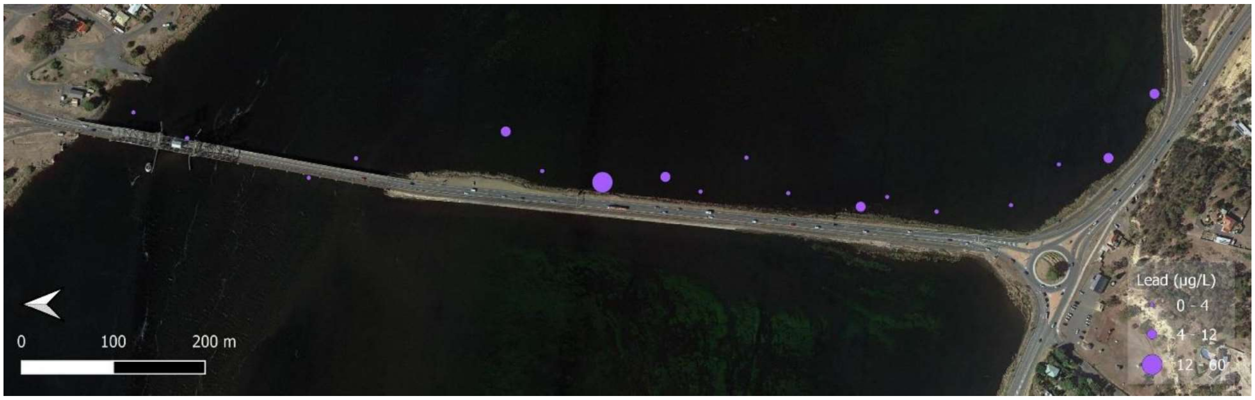

Figure 65. Map of dissolved lead in water from elutriate analyses.

4.5.19 Mercury

4.5.19.1 Total

Exceeded high-SQGV in 20% samples (up to 8x) and over SQGV in around 50% samples (Figure 66).

4.5.19.2 Bioavailable (1M HCl)

Below SQGV in all tested samples (Figure 67).

4.5.19.3 Elutriates

Total mercury exceeded freshwater toxicant guideline value in around 65% of elutriate samples tested (n = 22). The concentration of mercury in one sample SED1 was exceptionally high (370x guideline value) with other samples also approaching 65x the guideline value (Figure 68).

Dissolved mercury was below limits of reporting in most samples but exceeded the freshwater toxicant guideline value in almost 20% of elutriate samples and the marine guideline in 5% samples (Figure 69). The highest exceedance was from sample SED12 0-49 at 11x and 7x the freshwater and marine thresholds respectively. Dissolved concentrations in other samples were below guideline values.

4.5.19.4 Depth into sediment

Concentration of mercury was generally lower in deeper sediment. Key exceptions, where the concentration of mercury was higher in the middle section of the core and above the SQGV, were at sites SED5 and SED8. Most other sub-surface samples (i.e. below 0.5 m core length) were below or near to SQGV (Figure 70).

4.5.19.5 Spatial

High in corner and along causeway. All below SQGV on the north shore of the river channel (Figure 71).

Exceptionally high total concentration in elutriate of SED1 0-45, and exceptionally high dissolved concentration in elutriate of SED12 0-49.

4.5.19.6 Ambient water

All samples below limits of reporting.

4.5.19.7 Plots

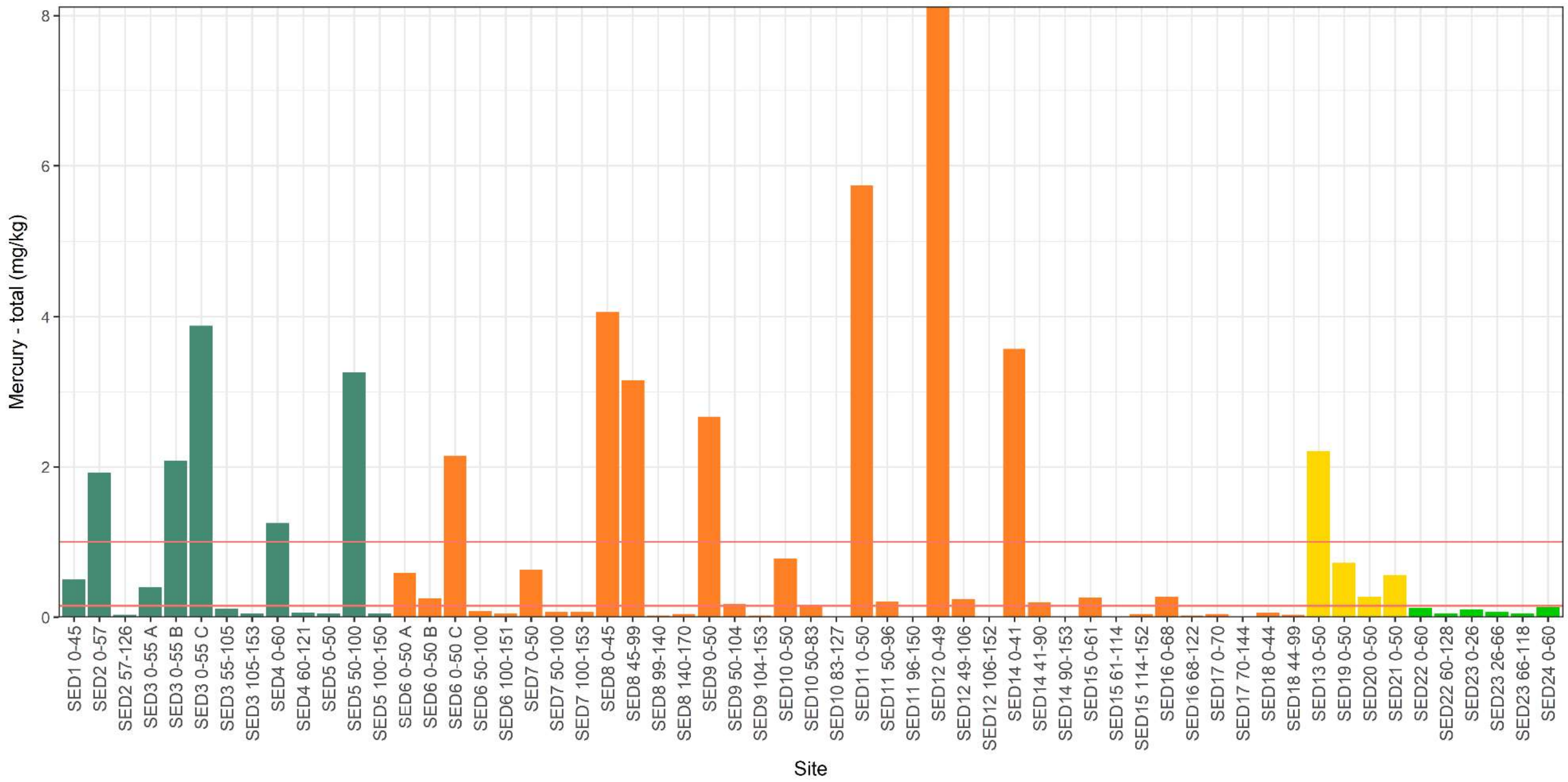

Figure 66. Concentration of total mercury in sediment. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

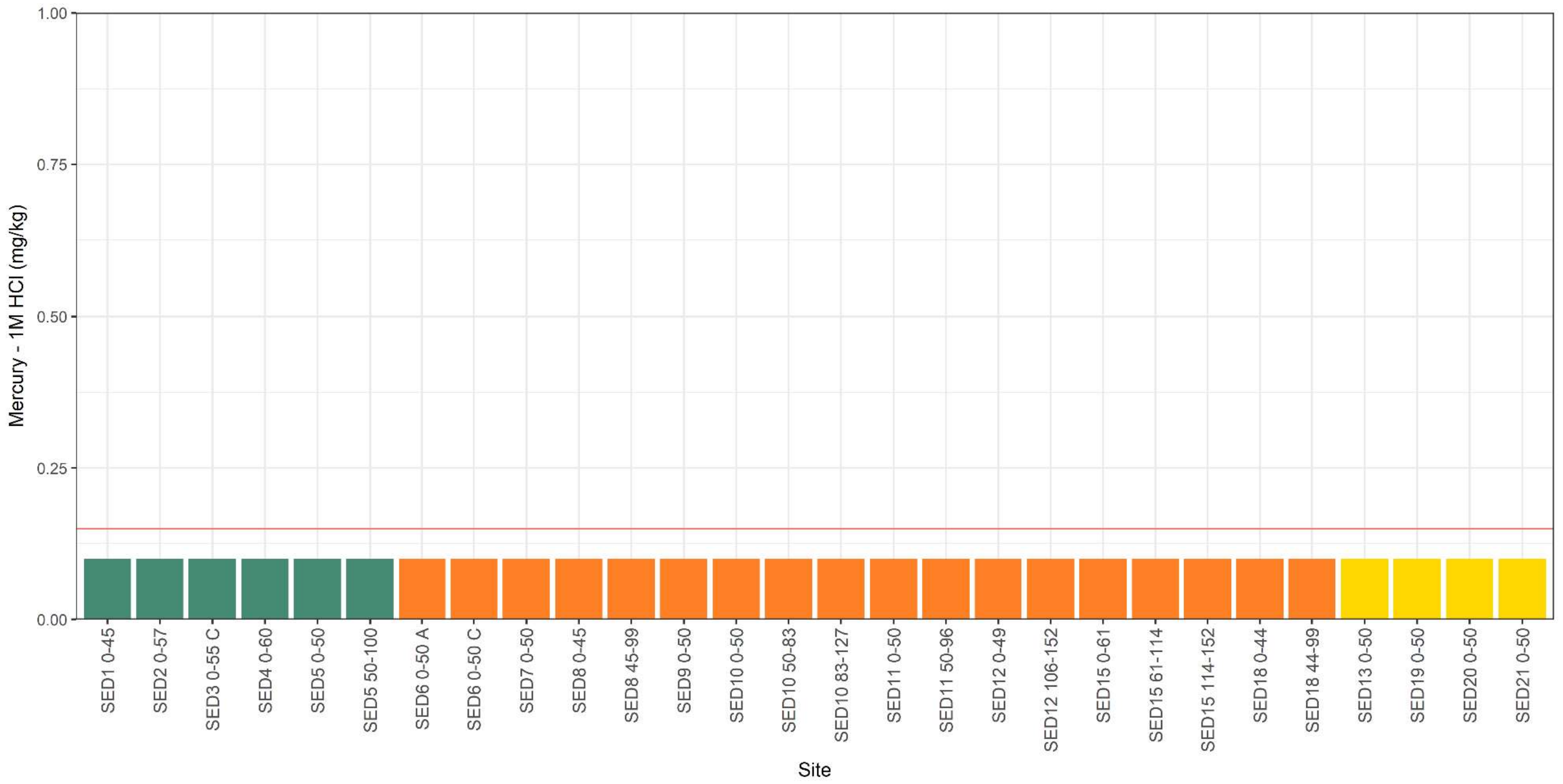

Figure 67. Concentration of bioavailable mercury according to 1M HCl digest. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

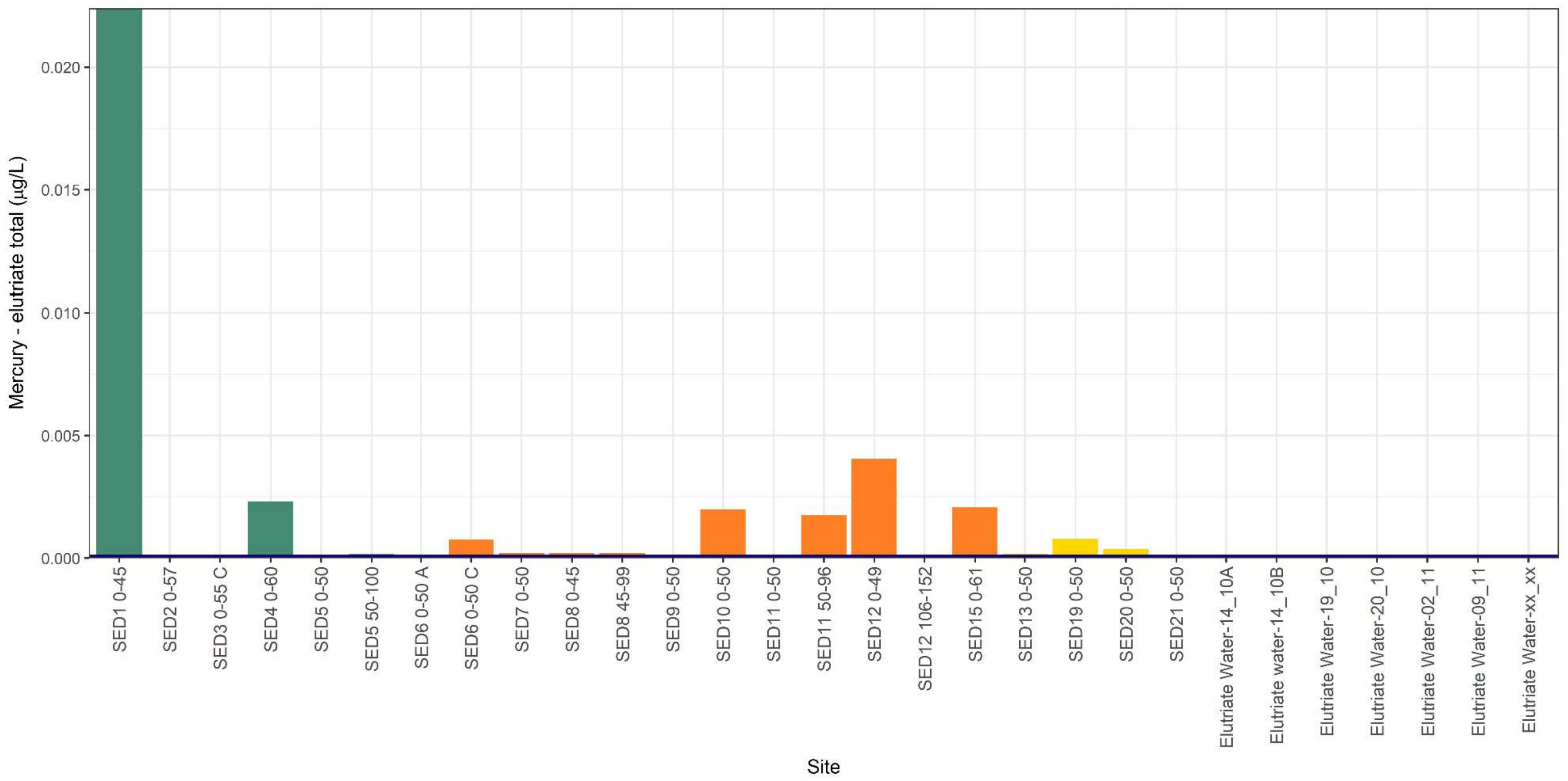

Figure 68. Concentration of total mercury resulting from elutriate testing. DGVs for mercury in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

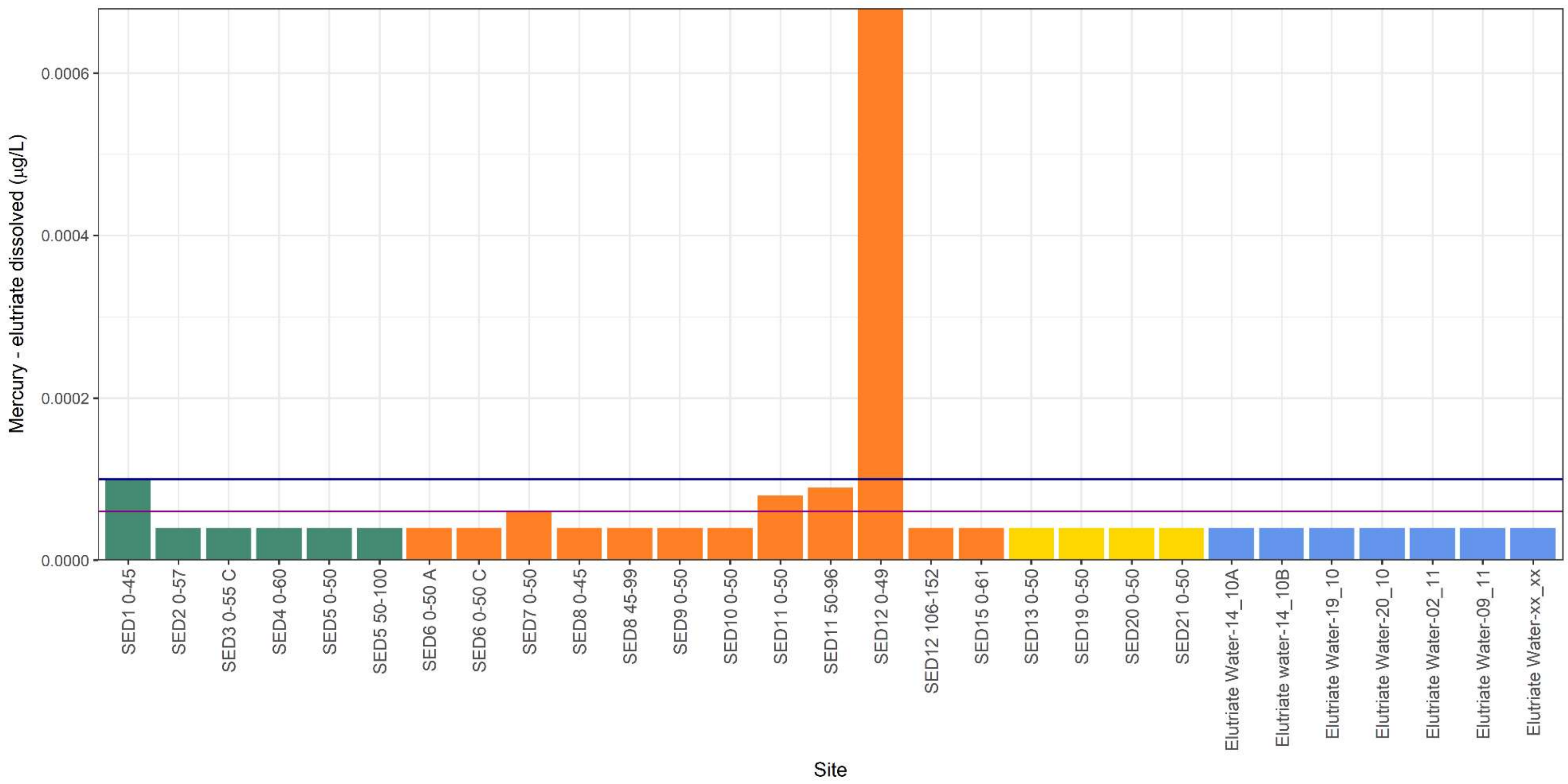

Figure 69. Concentration of dissolved mercury resulting from elutriate testing. DGVs for mercury in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

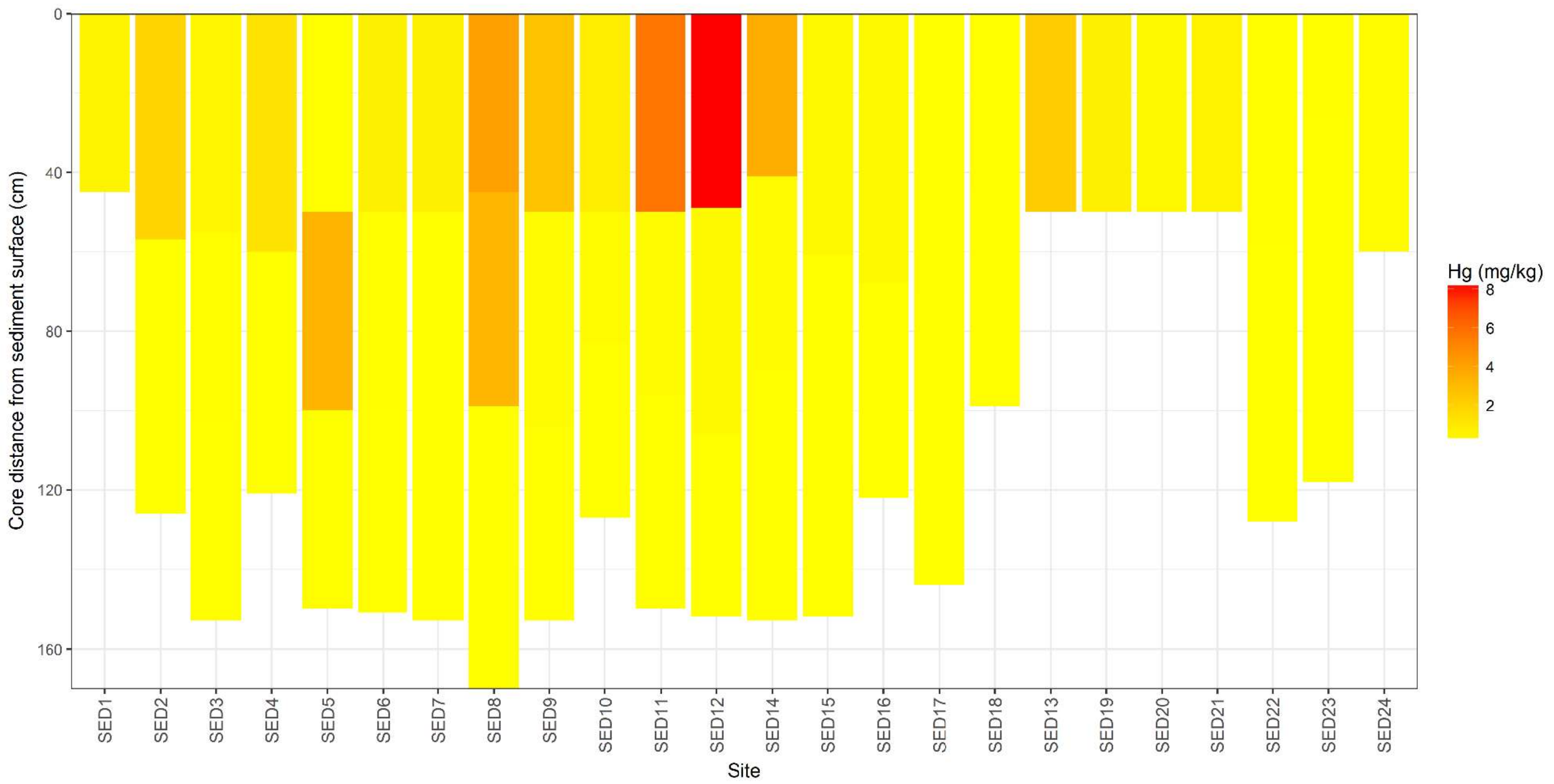

Figure 70. Vertical variation of total mercury in sediment along cores. ANZECC SQGV is 1.5 mg / kg, with high SQGV of 10 mg / kg.

Figure 71. Map of total mercury concentrations in sediment.

Figure 72. Map of dissolved mercury in water from elutriate analyses.

4.5.20 Nickel

4.5.20.1 Total

Exceeded SQGV in 25% samples (to 1.4x). High-SQGV was not exceeded in any samples (Figure 73).

4.5.20.2 Bioavailable (1M HCl)

Below SQGV in all 28 tested samples (Figure 74).

4.5.20.3 Elutriates

Total nickel exceeded freshwater toxicant guideline value in around 35% of elutriate samples tested (n = 22). The concentration of nickel in one sample SED1 0-45 was exceptionally high (36x guideline value) with other samples also approaching 3.4x the freshwater guideline value (Figure 75).

Dissolved nickel was below freshwater and marine toxicant guideline values in all elutriate samples (Figure 76).

4.5.20.4 Depth into sediment

Concentrations showed no clear pattern with depth into sediment (Figure 77).

4.5.20.5 Spatial

High in southern corner, along causeway and on the north shore of the river channel. Below SQGV in river channel (Figure 78).

Exceptionally high total concentration in elutriate of SED1 0-45.

4.5.20.6 Ambient water

Below or very near to limits of reporting.

4.5.20.7 Plots

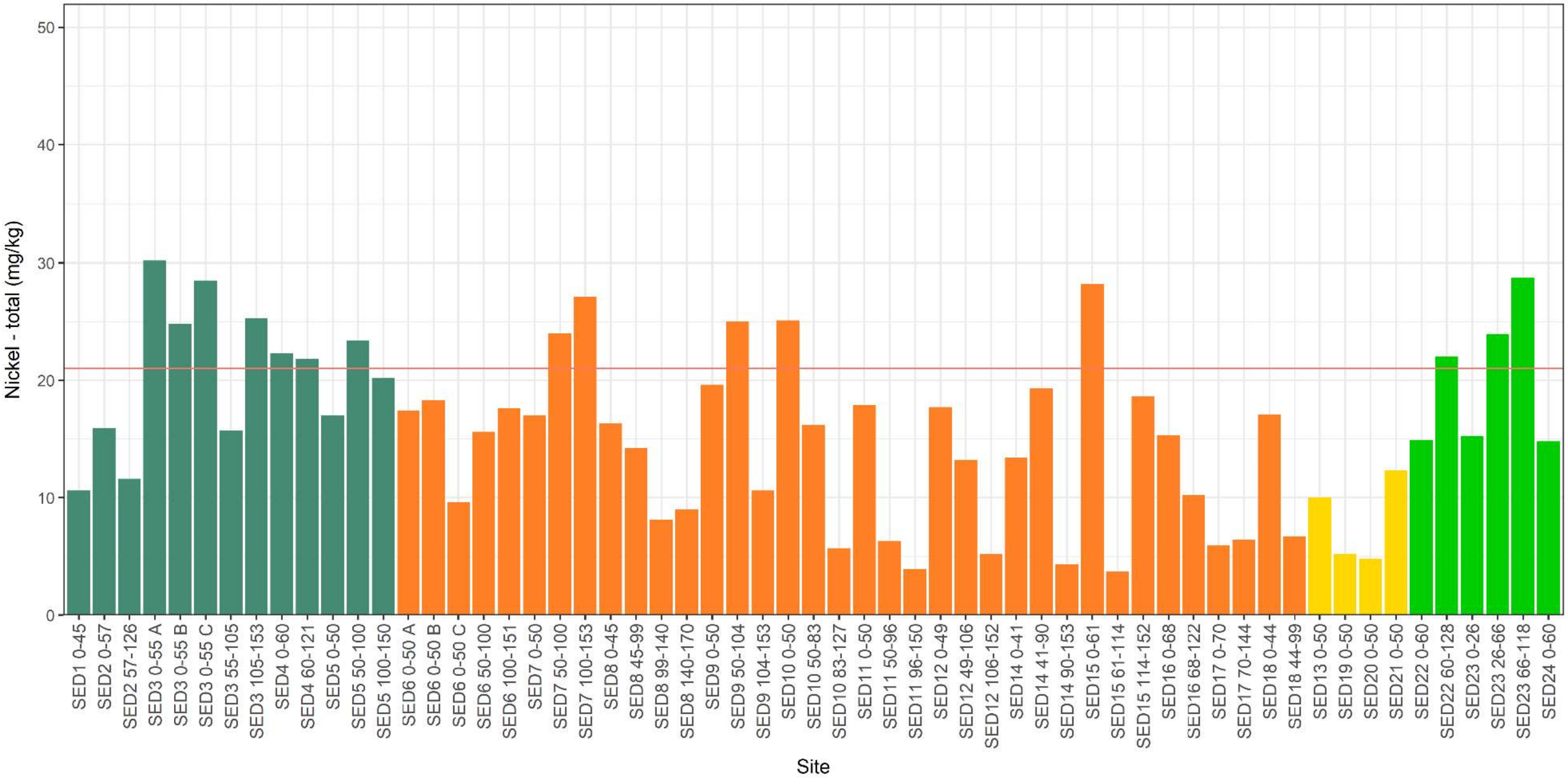

Figure 73. Concentration of total nickel in sediment. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

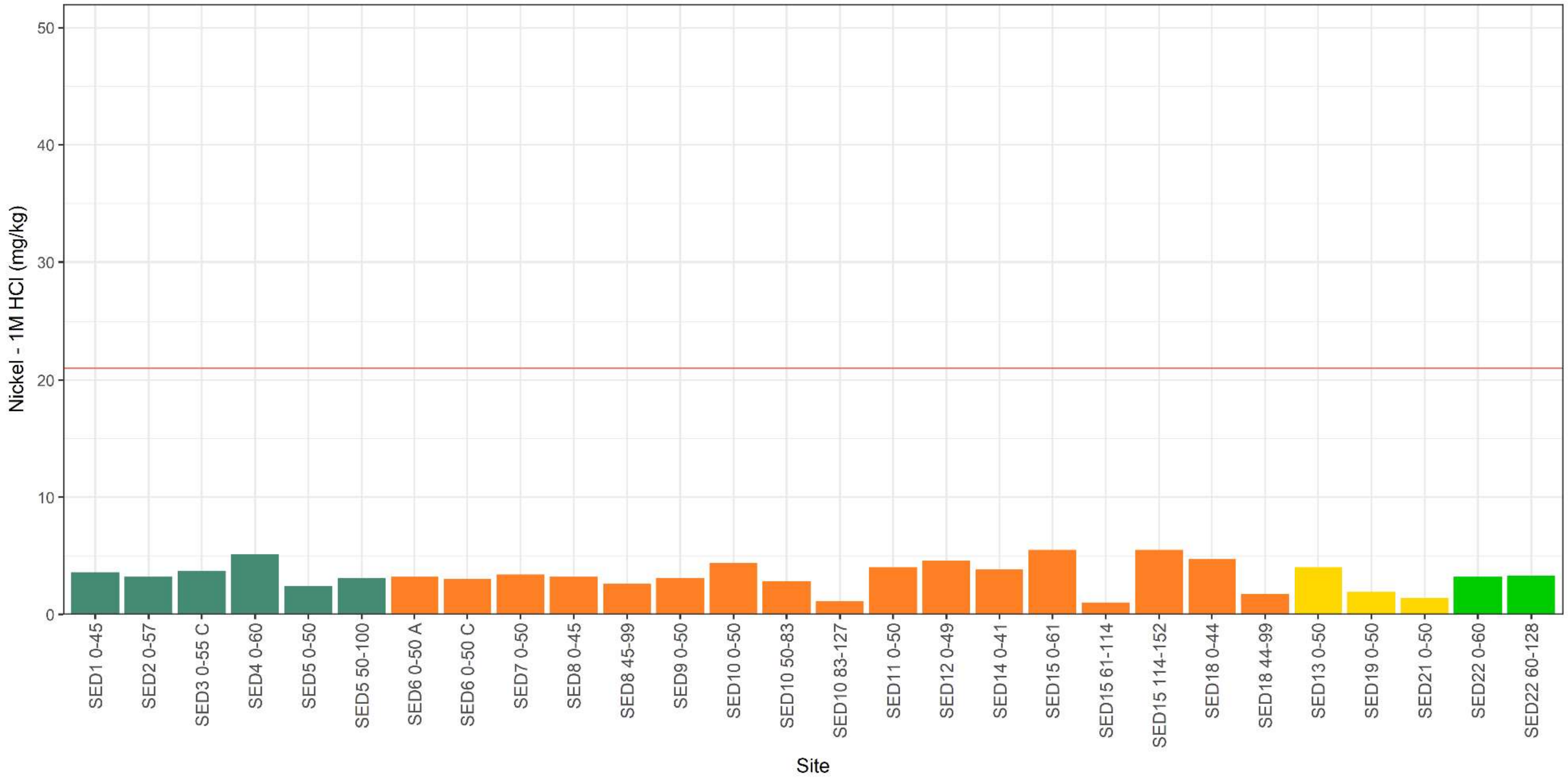

Figure 74. Concentration of bioavailable nickel according to 1M HCl digest. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

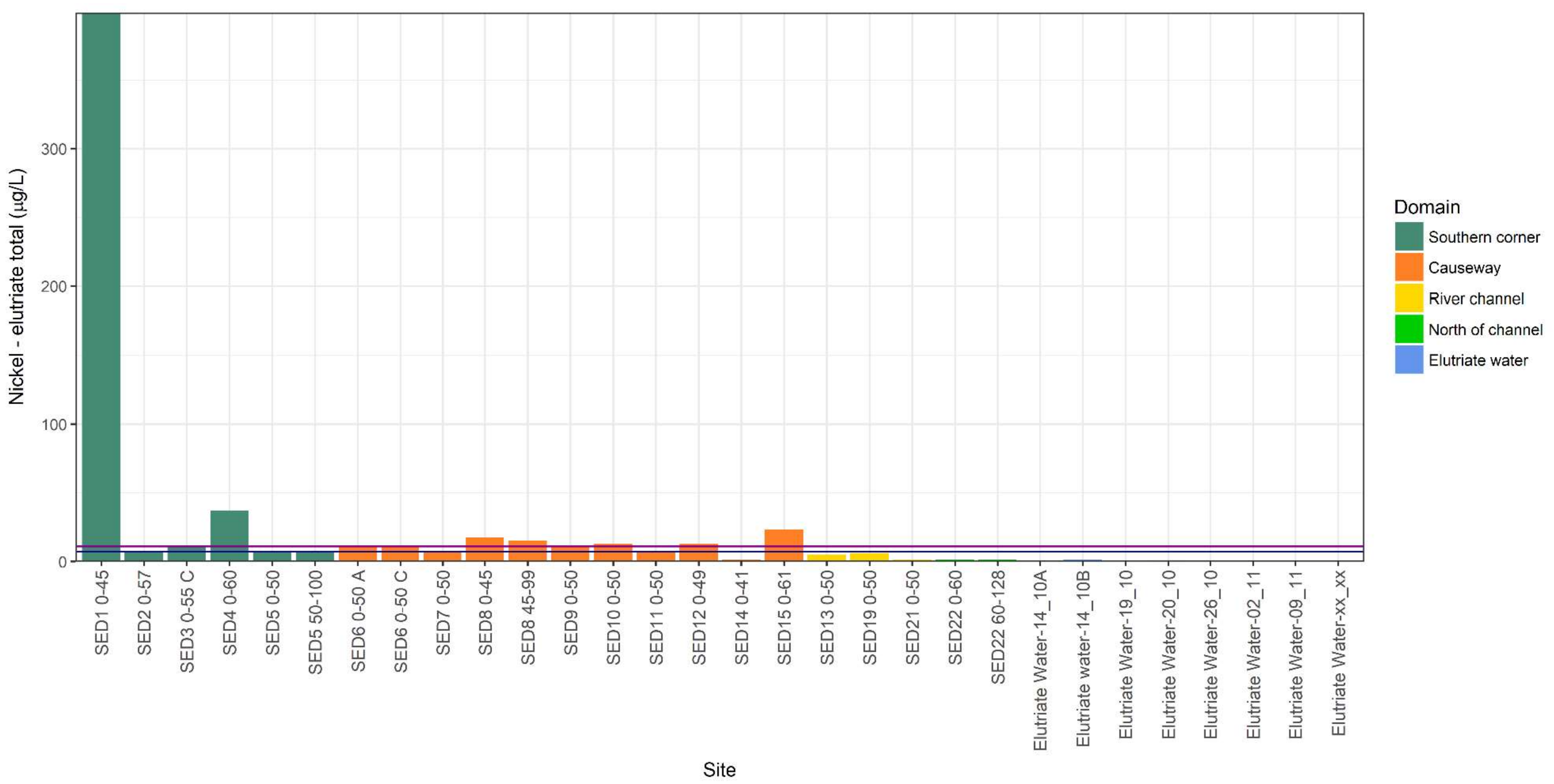

Figure 75. Concentration of total nickel resulting from elutriate testing. DGVs for nickel in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

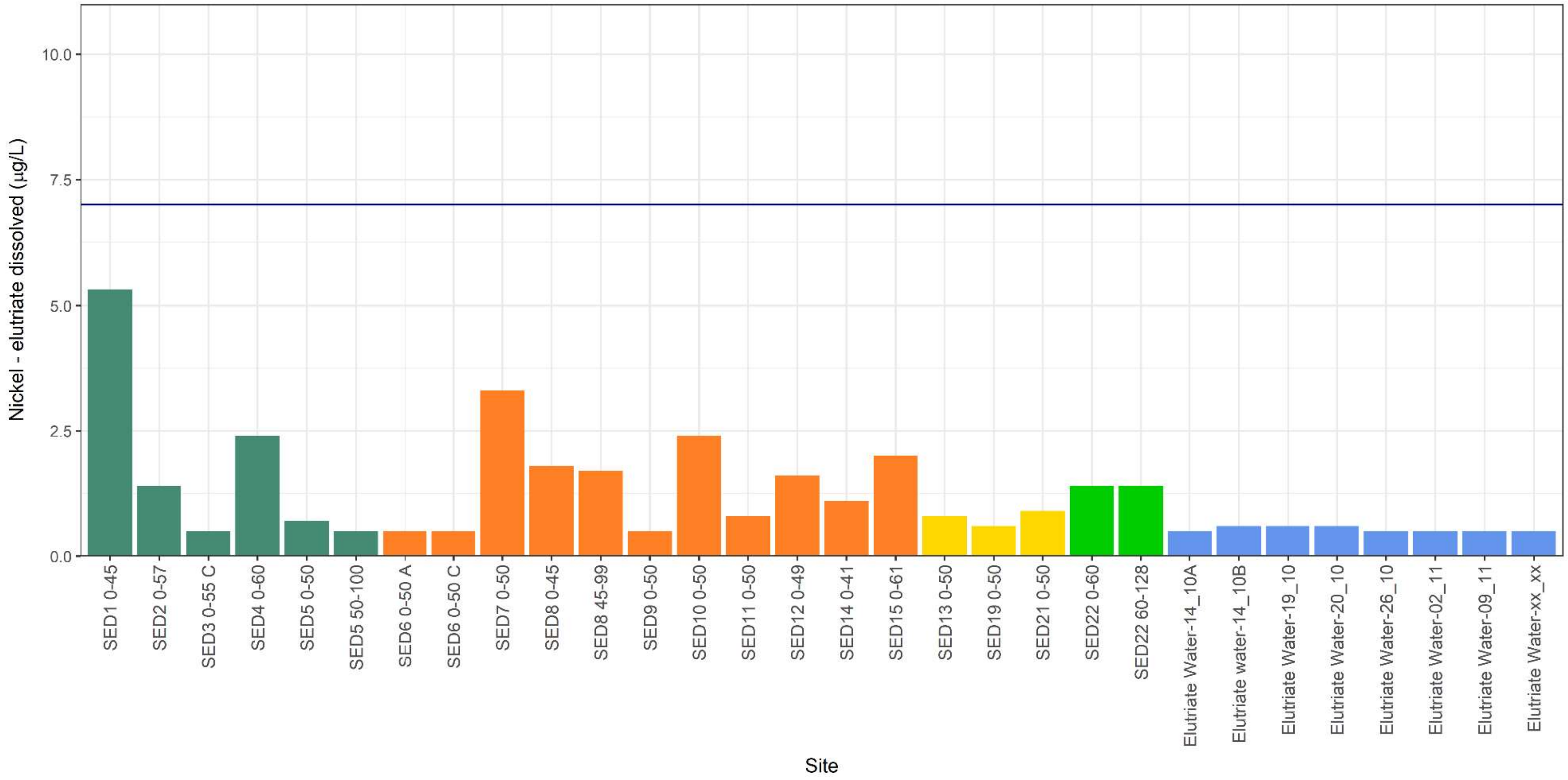

Figure 76. Concentration of dissolved nickel resulting from elutriate testing. DGVs for nickel in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

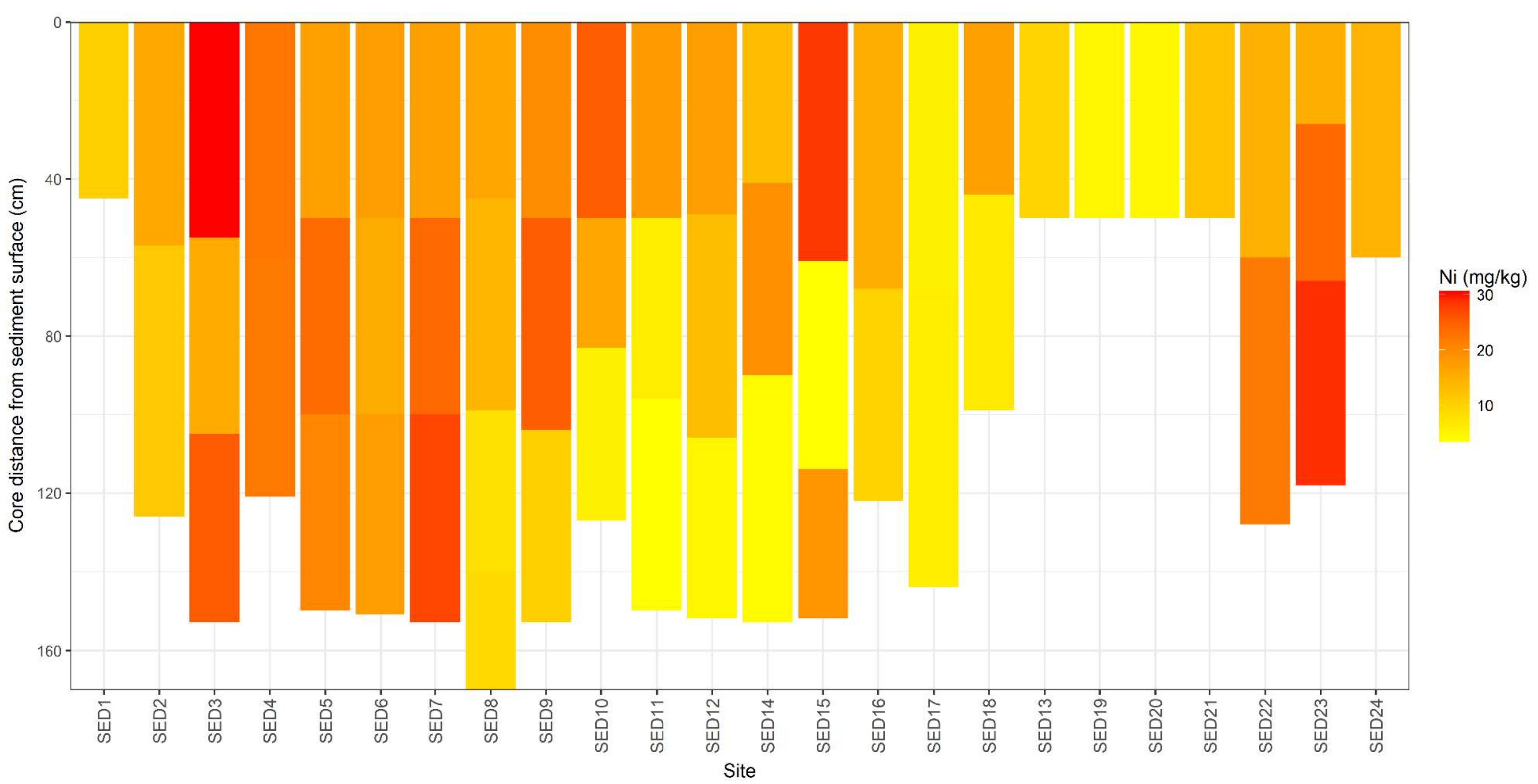

Figure 77. Vertical variation of total nickel in sediment along cores. ANZECC SQGV is 1.5 mg / kg, with high SQGV of 10 mg / kg.

Figure 78. Map of total nickel concentrations in sediment.

4.5.21 Silver

4.5.21.1 Total

Exceeded SQGV in 15% samples (to 2.3x). Did not exceed high-SQGV in any samples (Figure 79).

4.5.21.2 Bioavailable (1M HCl)

Below SQGV in all 28 tested samples (Figure 80).

4.5.21.3 Elutriates

Total silver exceeded the freshwater toxicant guideline value in 85% of elutriate samples (n = 19). The marine toxicant guideline value was exceeded in one elutriate sample. The concentration of silver in one sample SED1 0-45 was exceptionally high (176x freshwater guideline value) with other samples around 40x the freshwater guideline value (Figure 81).

Dissolved silver was below the lower limits of reporting in 95% of elutriate samples and exceeded the freshwater guideline value in 1 elutriate sample (Figure 82).

4.5.21.4 Depth into sediment

Concentrations of arsenic were generally lower in deeper sediment. The key exceptions, where the concentration of silver was higher in the middle section of the core and above SQGV, was at sites SED5. The concentrations was again low in the deepest segment of this core (Figure 83).

4.5.21.5 Spatial

High in corner and along causeway, and highest in center causeway. Below SQGV in channel and north shore of channel (Figure 84).

Exceptionally high total elutriates in SED1 0-45.

4.5.21.6 Ambient water

Below or near to limits of reporting.

4.5.21.7 Plots

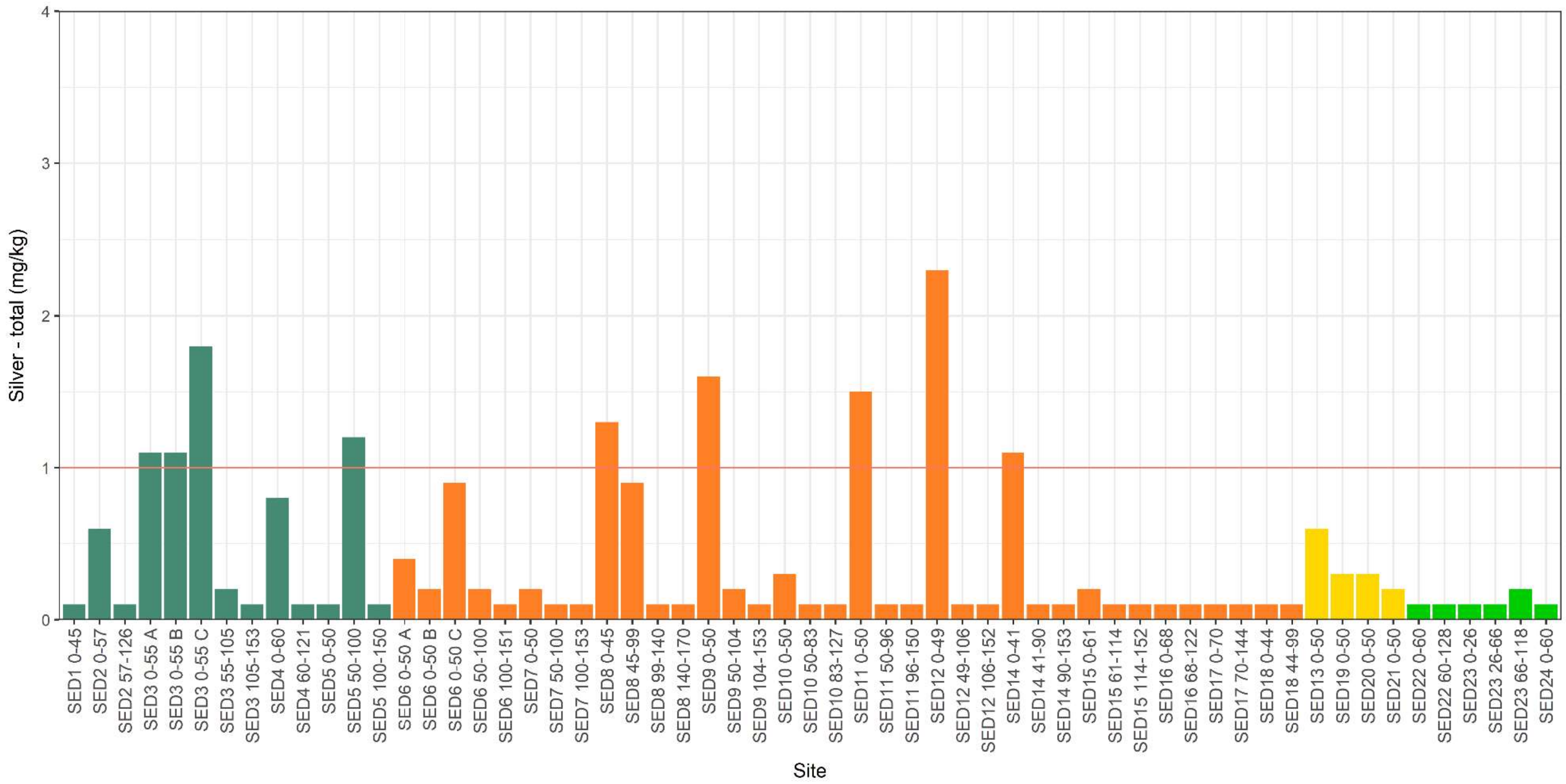

Figure 79. Concentration of total silver in sediment. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

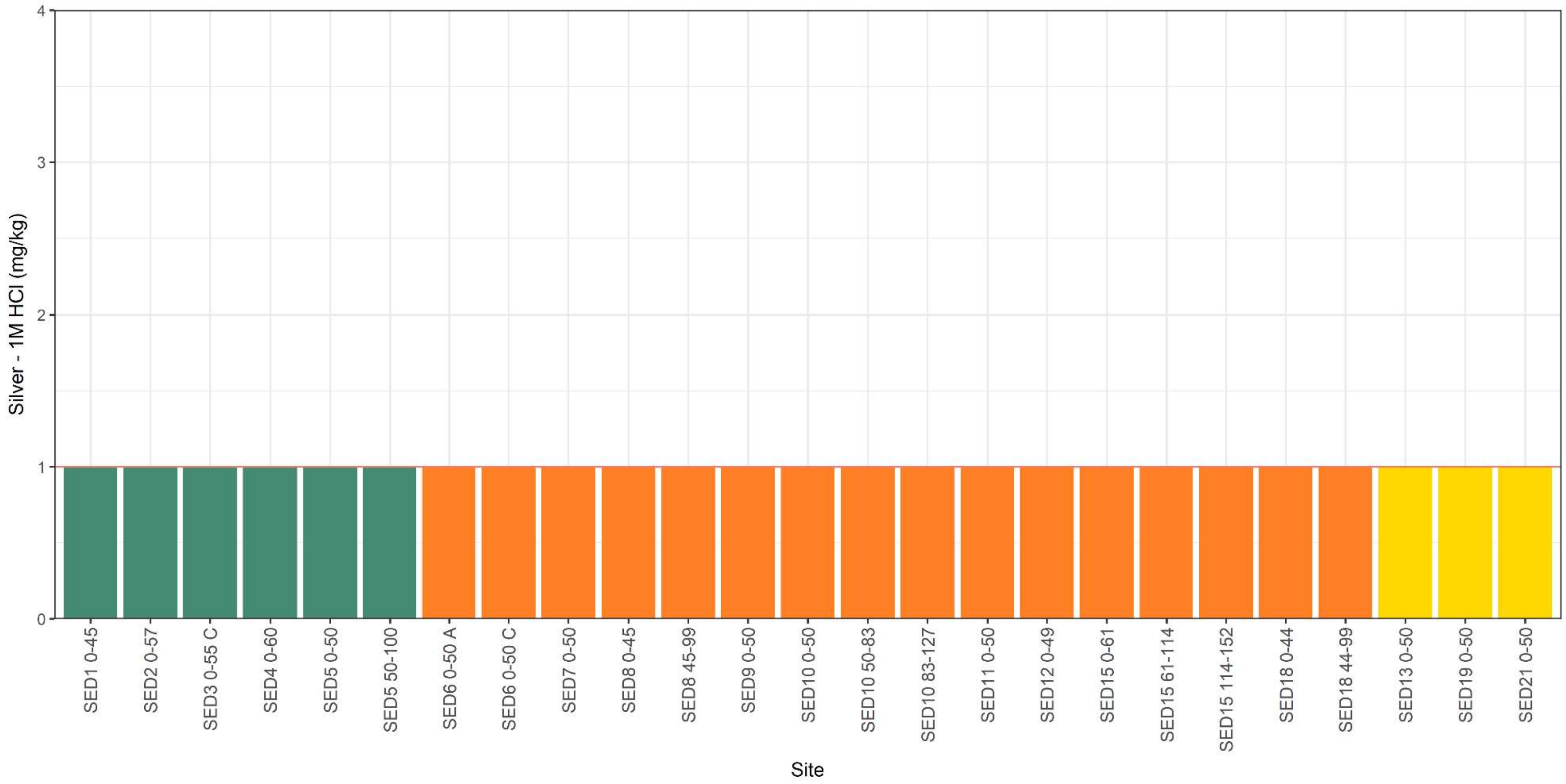

Figure 80. Concentration of bioavailable silver according to 1M HCl digest. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

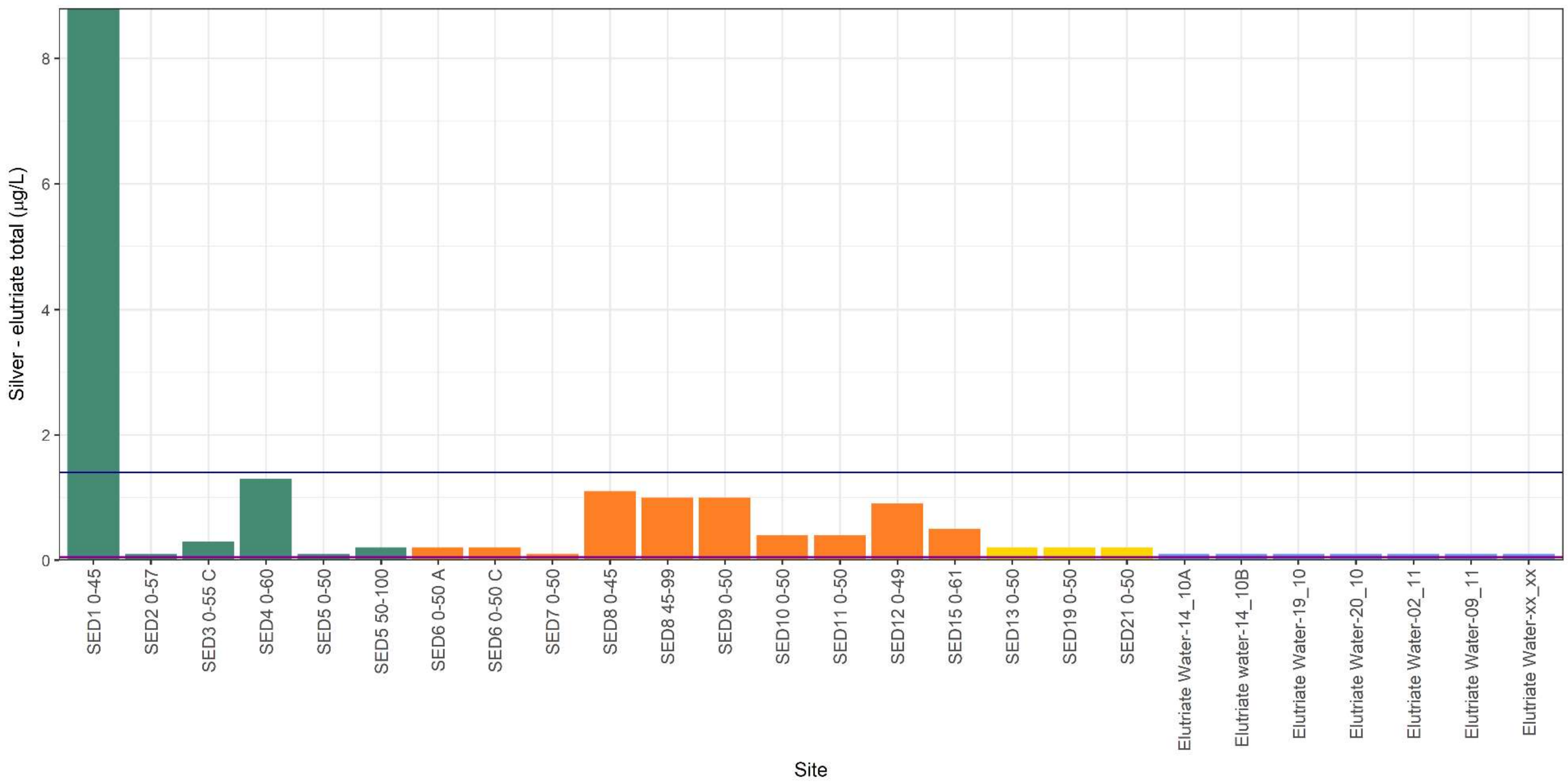

Figure 81. Concentration of total silver resulting from elutriate testing. DGVs for silver in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

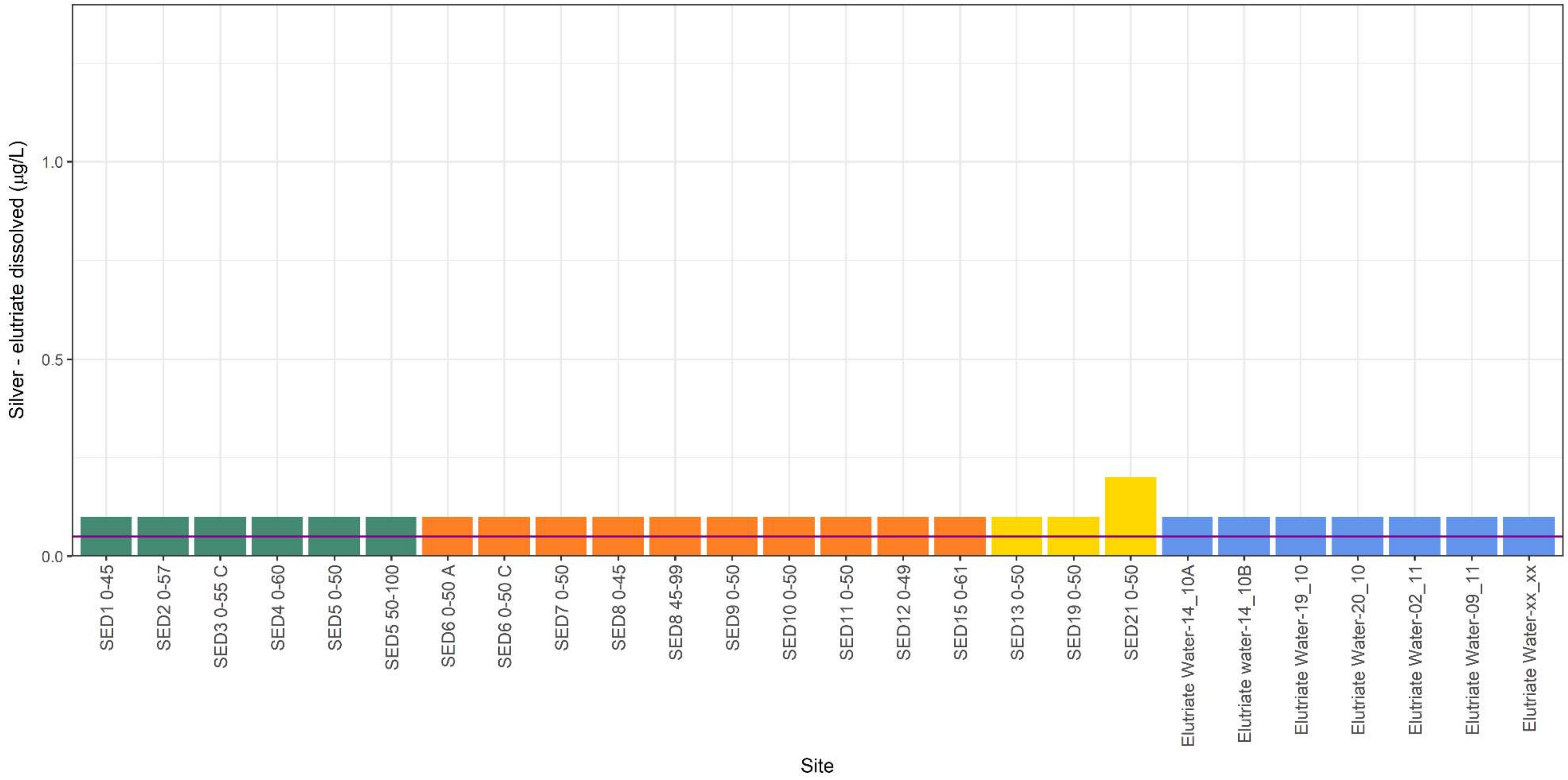

Figure 82. Concentration of dissolved silver resulting from elutriate testing. DGVs for silver in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

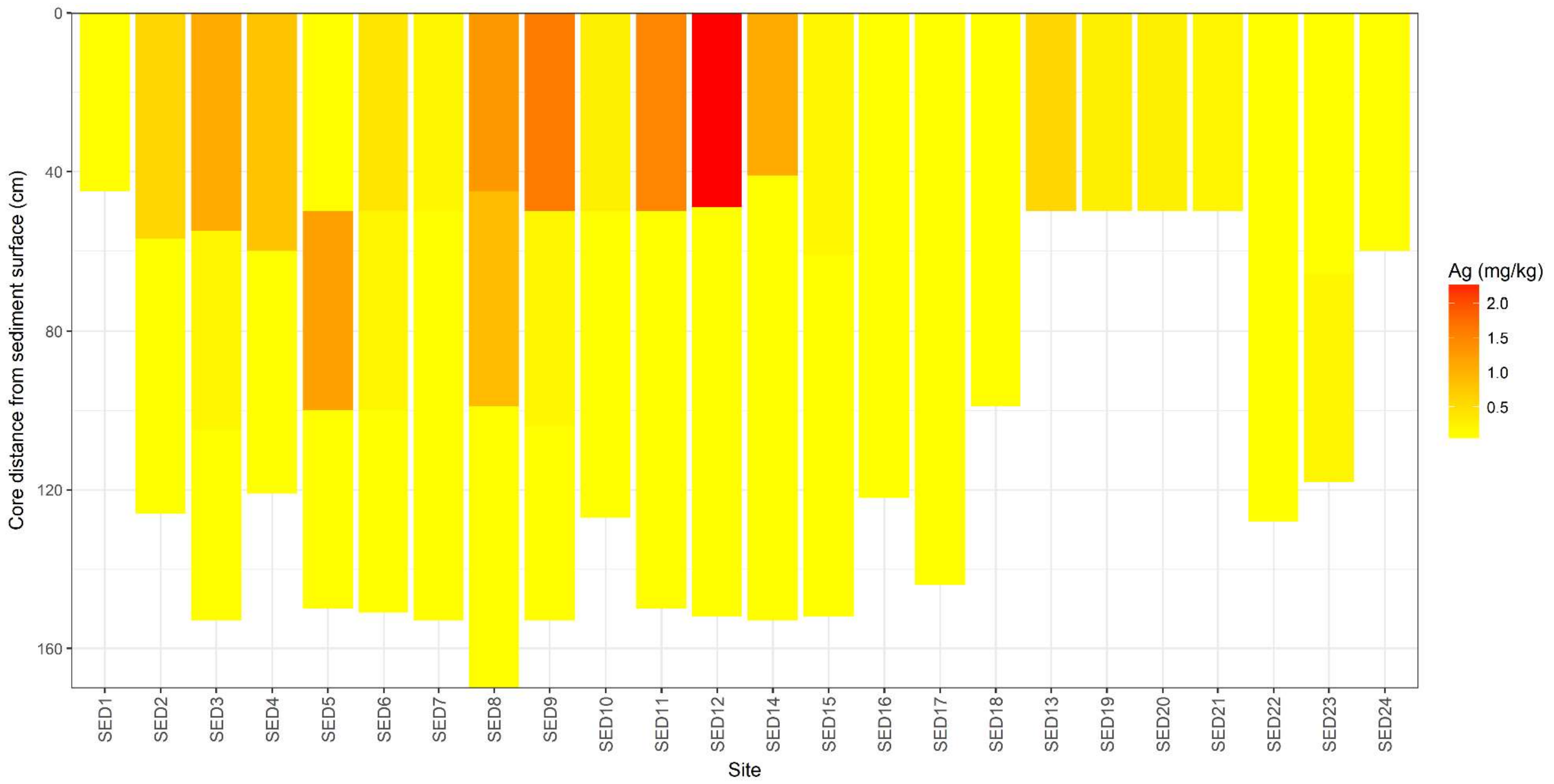

Figure 83. Vertical variation of total silver in sediment along cores. ANZECC SQGV is 1.5 mg / kg, with high SQGV of 10 mg / kg.

Figure 84. Map of total silver concentrations in sediment.

4.5.22 Zinc

4.5.22.1 Total

Exceeded high-SQGV in 25% of samples (to 9.5x) and over SQGV in 32% samples (Figure 85).

4.5.22.2 Bioavailable (1M HCl)

Among the samples treated with weak HCl (n = 28), 50% returned concentrations exceeding the high-SQGV (to 6.6x) and 61% exceeded the SQGV (Figure 86).

4.5.22.3 Elutriates

Total zinc exceeded freshwater and marine toxicant guideline value in 95% of elutriate samples tested (n = 22). The concentration of zinc in one sample SED1 was exceptionally high (1600x guideline value) with other samples also approaching 250x the guideline value (Figure 87).

Dissolved zinc exceeded the freshwater toxicant guideline value in 82% of elutriate samples, up to 205x the threshold (Figure 88).

4.5.22.4 Depth into sediment

Concentrations of zinc were generally lower in deeper sediment. Key exceptions, where the concentration was higher in the middle section of the core and above the SQGV, were at sites SED5 and SED8. At all other sites, zinc concentrations in subsurface sediments (generally <50cm along core) were below the SQGV (Figure 89).

4.5.22.5 Spatial

High in southern corner and along causeway. Mostly below SQGV in river channel and north shore of channel, except SED19 and SED13 on the southern edge of the river channel (Figure 90).

Exceptionally high total concentration in SED12 0-49 and exceptionally high total concentration in the elutriate of SED1 0-45.

4.5.22.6 Ambient water

Concentrations of zinc in ambient water were higher than the freshwater guideline value in 3 of 8 samples (to 4.1x).

4.5.22.7 Plots

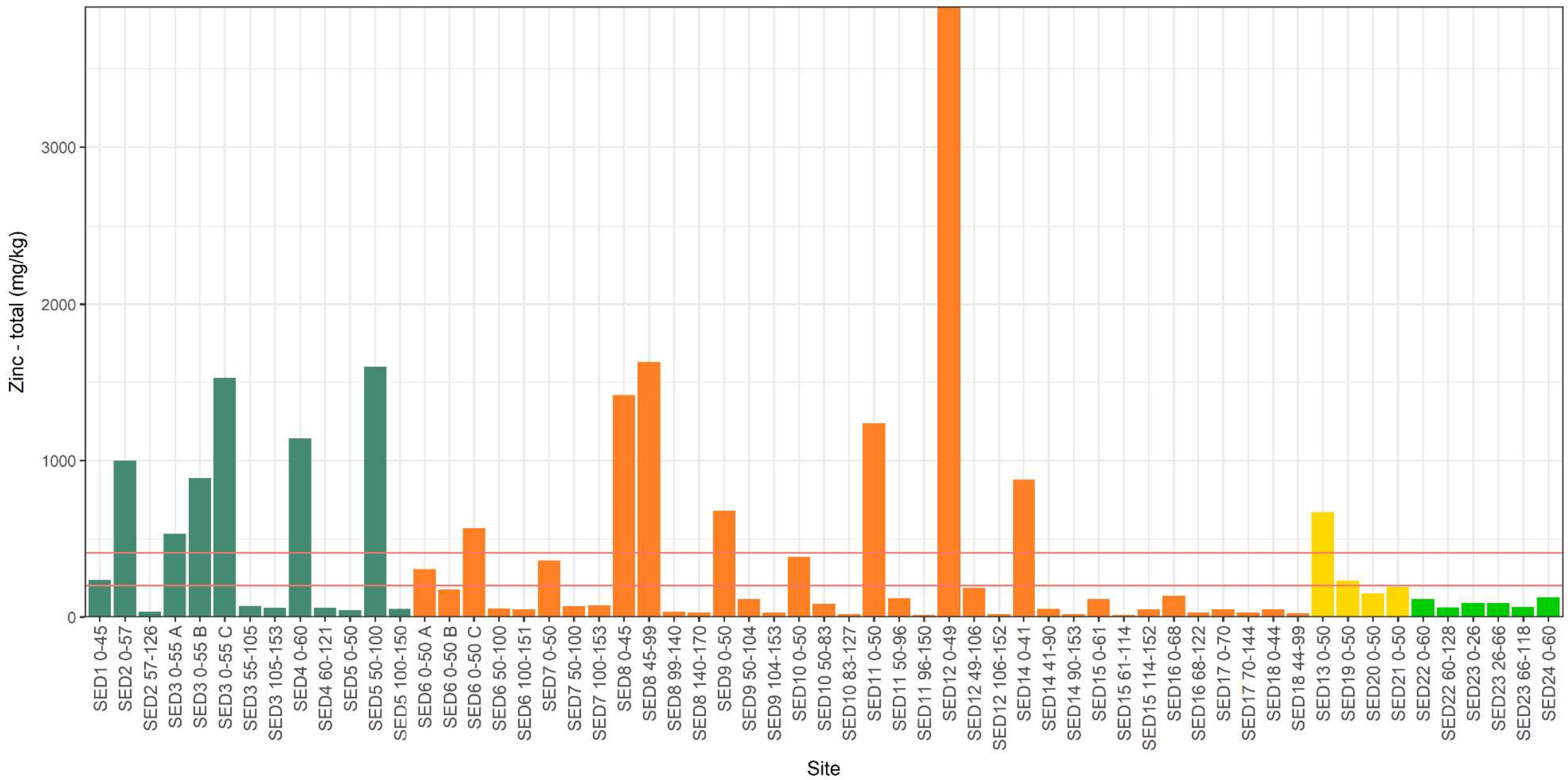

Figure 85. Concentration of total zinc in sediment. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

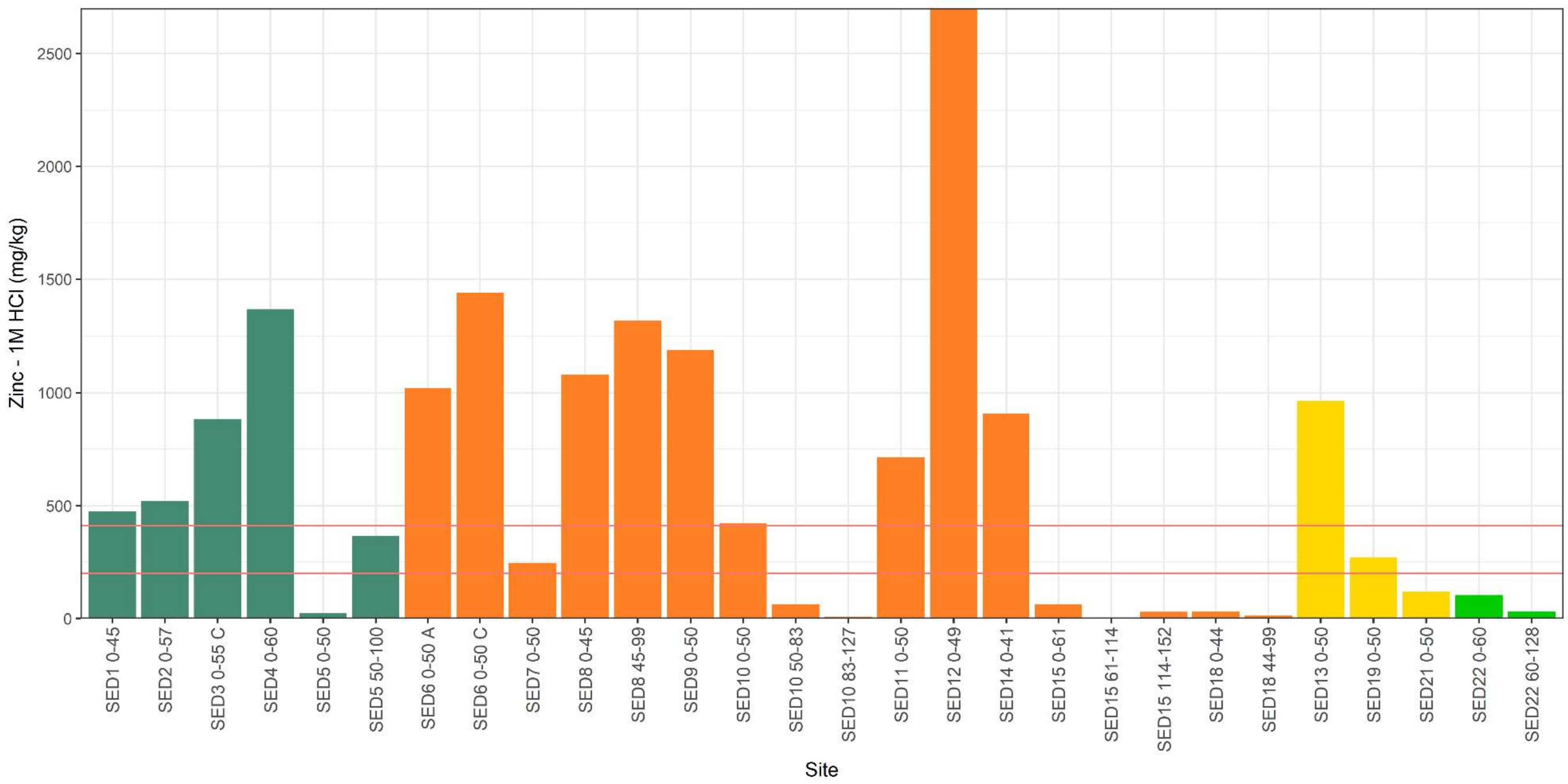

Figure 86. Concentration of bioavailable zinc according to 1M HCl digest. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

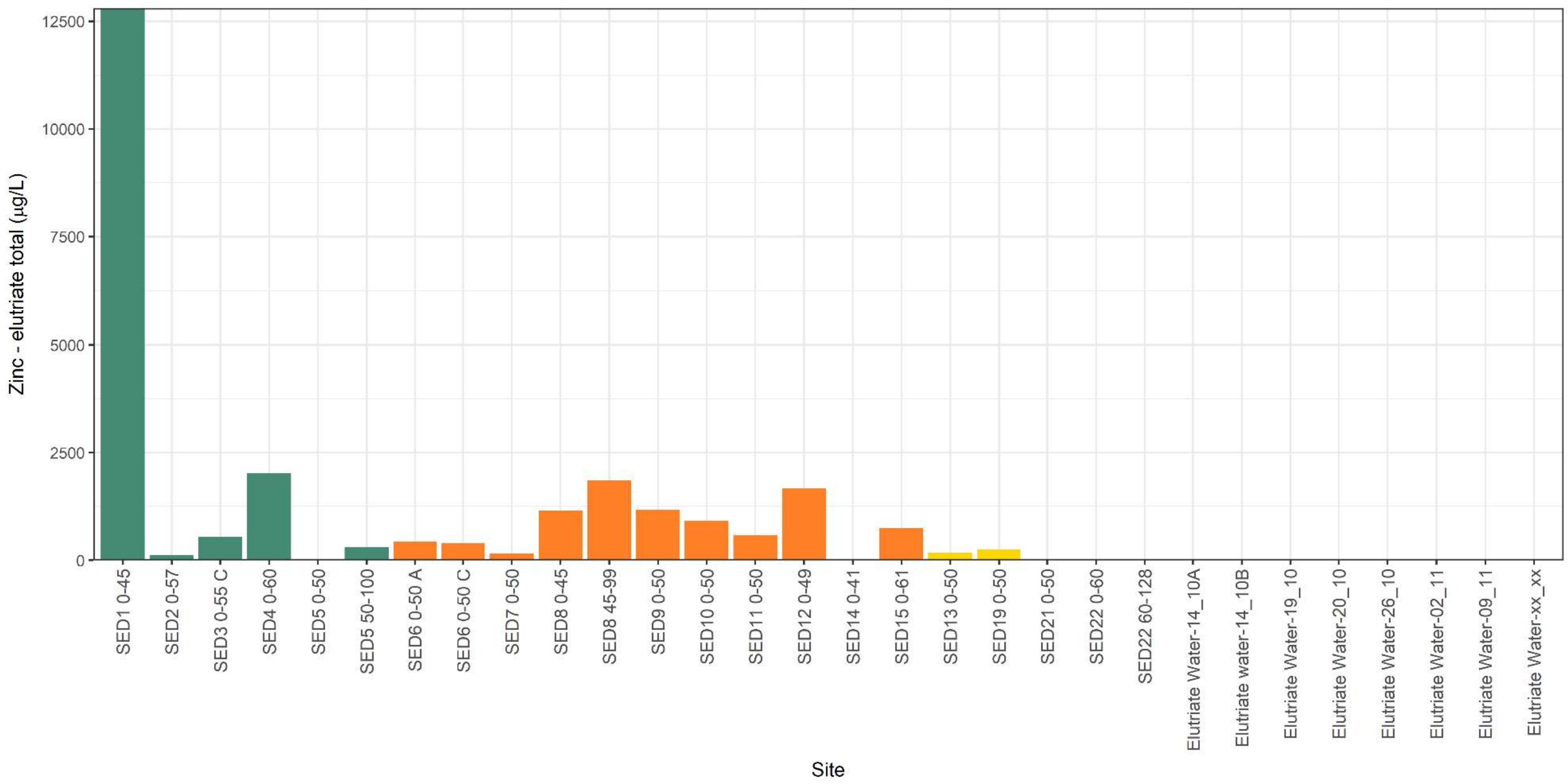

Figure 87. Concentration of total zinc resulting from elutriate testing. DGVs for zinc in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

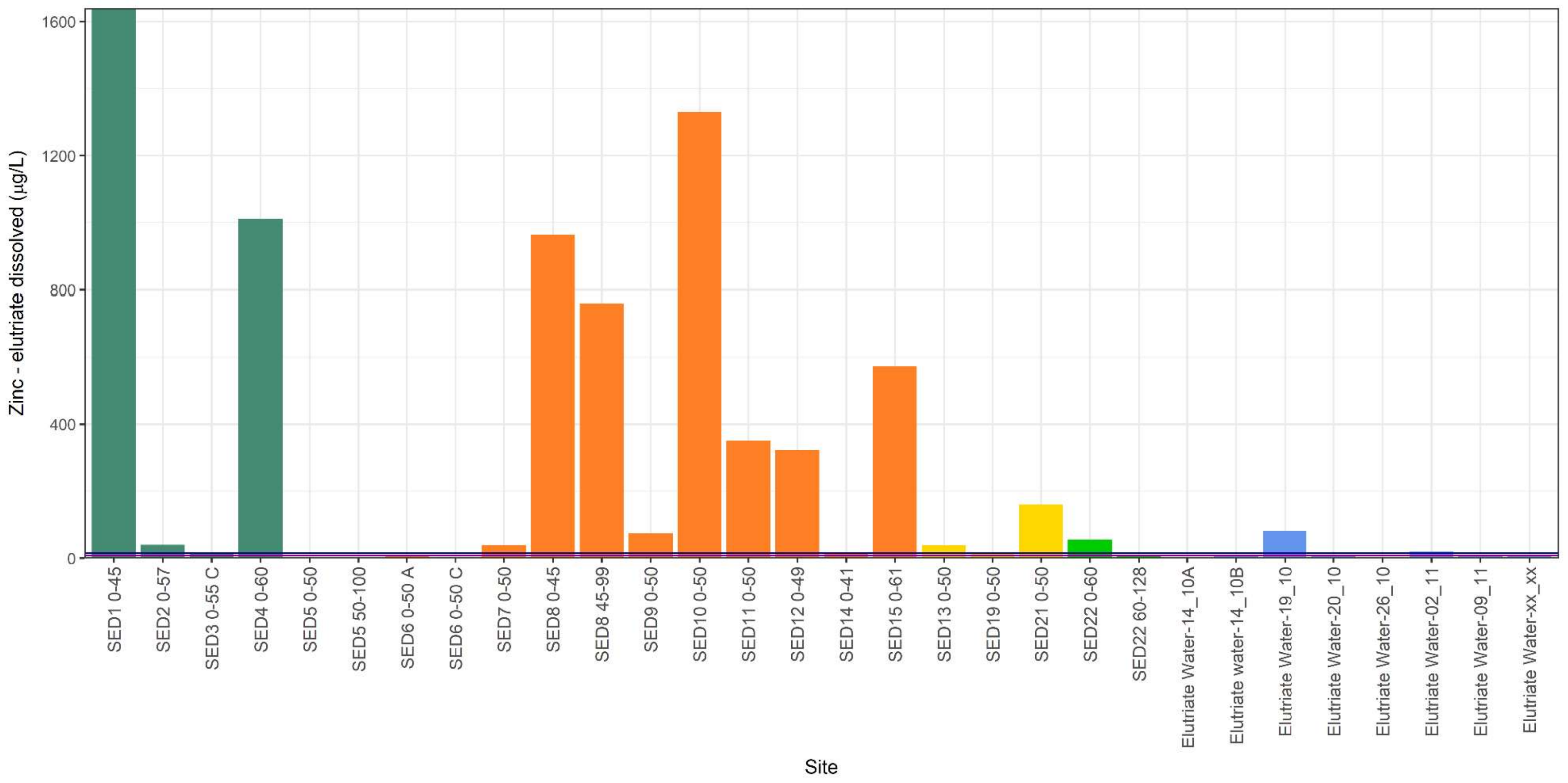

Figure 88. Concentration of dissolved zinc resulting from elutriate testing. DGVs for zinc in fresh and marine water are shown in dark magenta and blue respectively. Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway and light green on the north shore of the river channel.

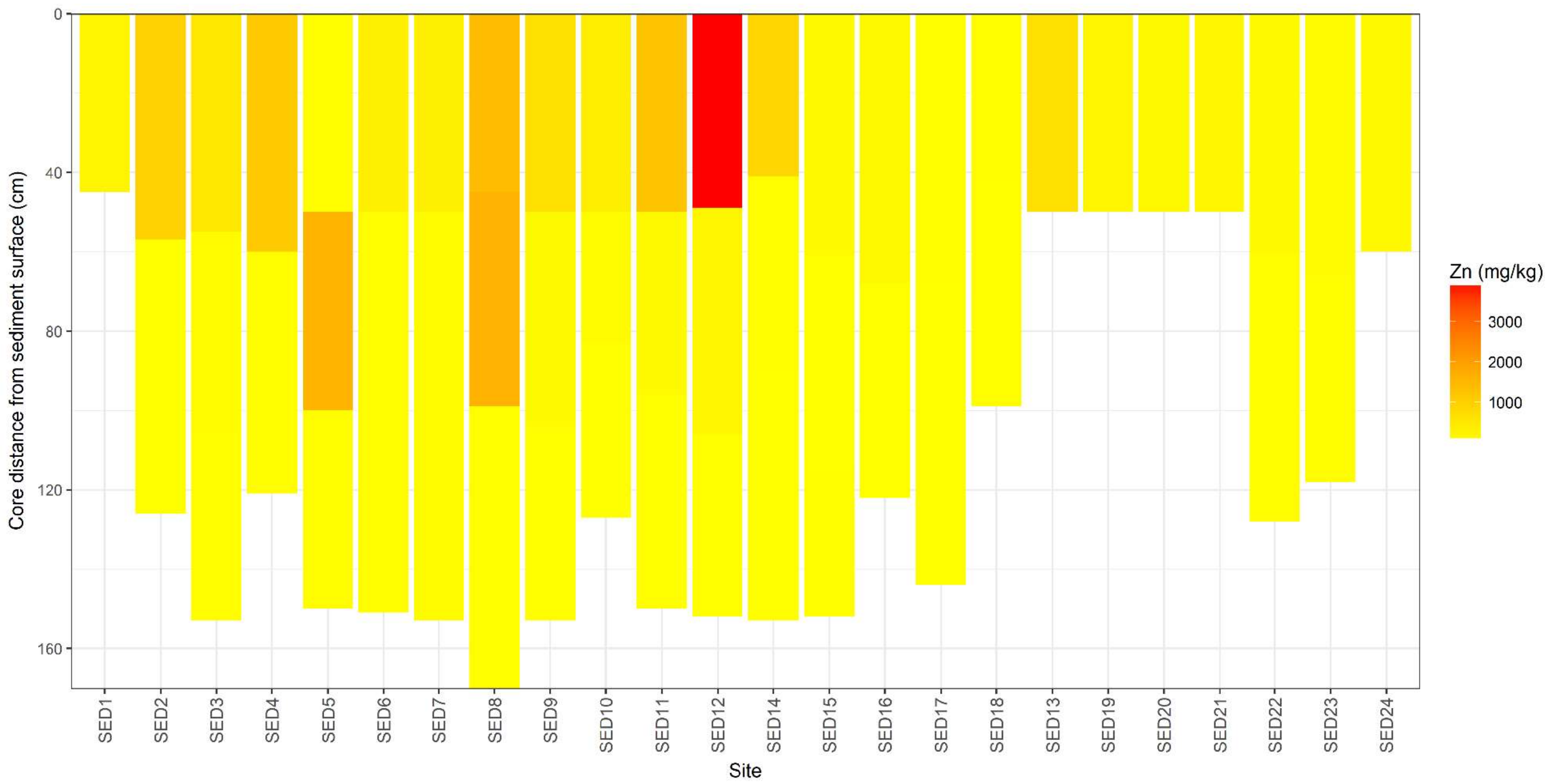

Figure 89. Vertical variation of total zinc in sediment along cores. ANZECC SQGV is 1.5 mg / kg, with high SQGV of 10 mg / kg.

Figure 90. Map of total zinc concentrations in sediment.

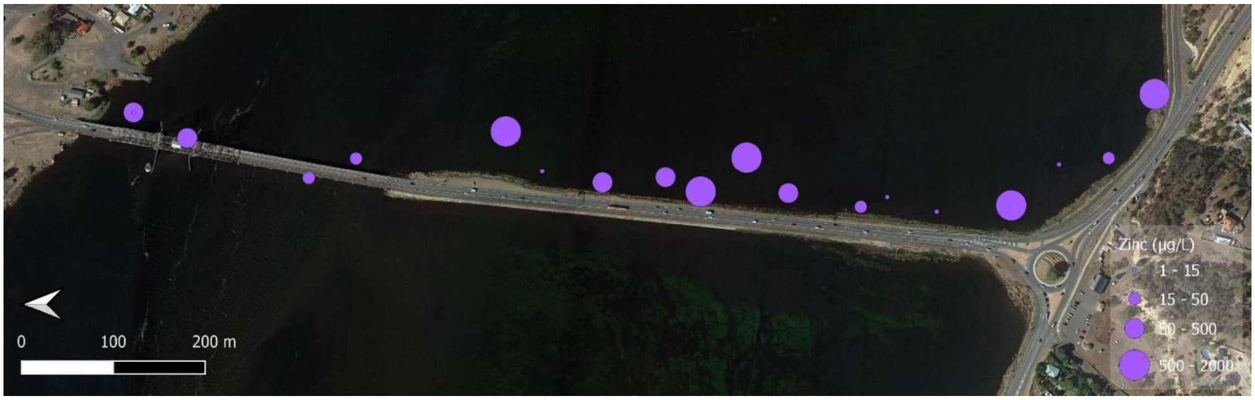

Figure 91. Map of dissolved zinc in water from elutriate analyses.

4.5.23 Other metals

The results for other metals with sediment quality guideline values were as follows:

Antimony: total concentrations in sediment just over low SQGV in one sample. All samples below SQGV for the bioavailability tetsting. All elutriate samples below the mDGV.

Chromium: all samples below relevant guidelines.

4.5.24 Intercorrelations between metals

Intercorrelations were evident between two different sets of metals (Figure 92):

- Antimony, arsenic, cadmium, copper, lead, mercury, silver, zinc (pearson correlation *r* > 0.75).
- Chromium, cobalt, nickel, selenium (pearson correlation *r* > 0.8), with manganese also showing a slightly weaker correlation with this set (*r* > 0.6).

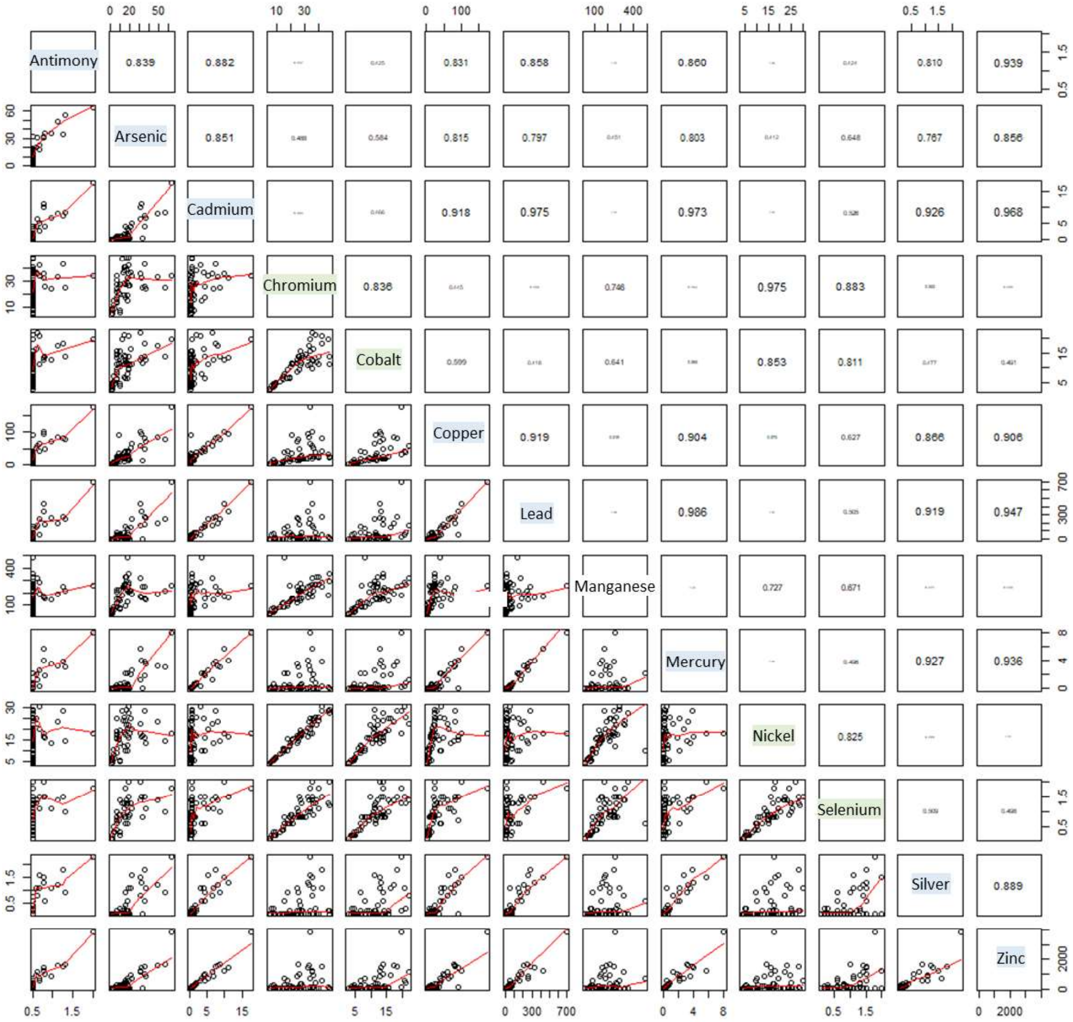

Figure 92. Intercorrelations between metals and metalloids.

4.5.25 Tributyltin

Raw concentrations of TBT exceeded the SQGV in some samples (Figure 93), however normalizing the data to 1% organic carbon, as required by the sediment quality guidelines, brought all values well below the guideline value (Figure 94).

Concentrations of TBT in elutriate tests were below the limits of reporting.

4.5.26 Polycyclic Aromatic Hydrocarbons

Raw concentrations of the sum of PAHs exceeded the high-SQGV in one sample (SED26) and SQGV in three other samples (figure not shown). One sample was from the river channel with others on the northern side of the river channel. Normalizing the data to 1% organic carbon, as required by the sediment quality guidelines, brought all values below the SQGV except SED26 at around 1.5x the guideline value (Figure 95).

All component PAHs were below the limits of reporting for elutriate analysis of SED26.

4.5.27 Other contaminants

Other contaminants tested did not exceed ANZECC sediment quality guidelines. These included: OC/OP pesticides, herbicides, polychlorinated biphenyls (PCBs), total petroleum hydrocarbons, total recoverable hydrocarbons, BTEXN, phenolic compounds and other organotin compounds.

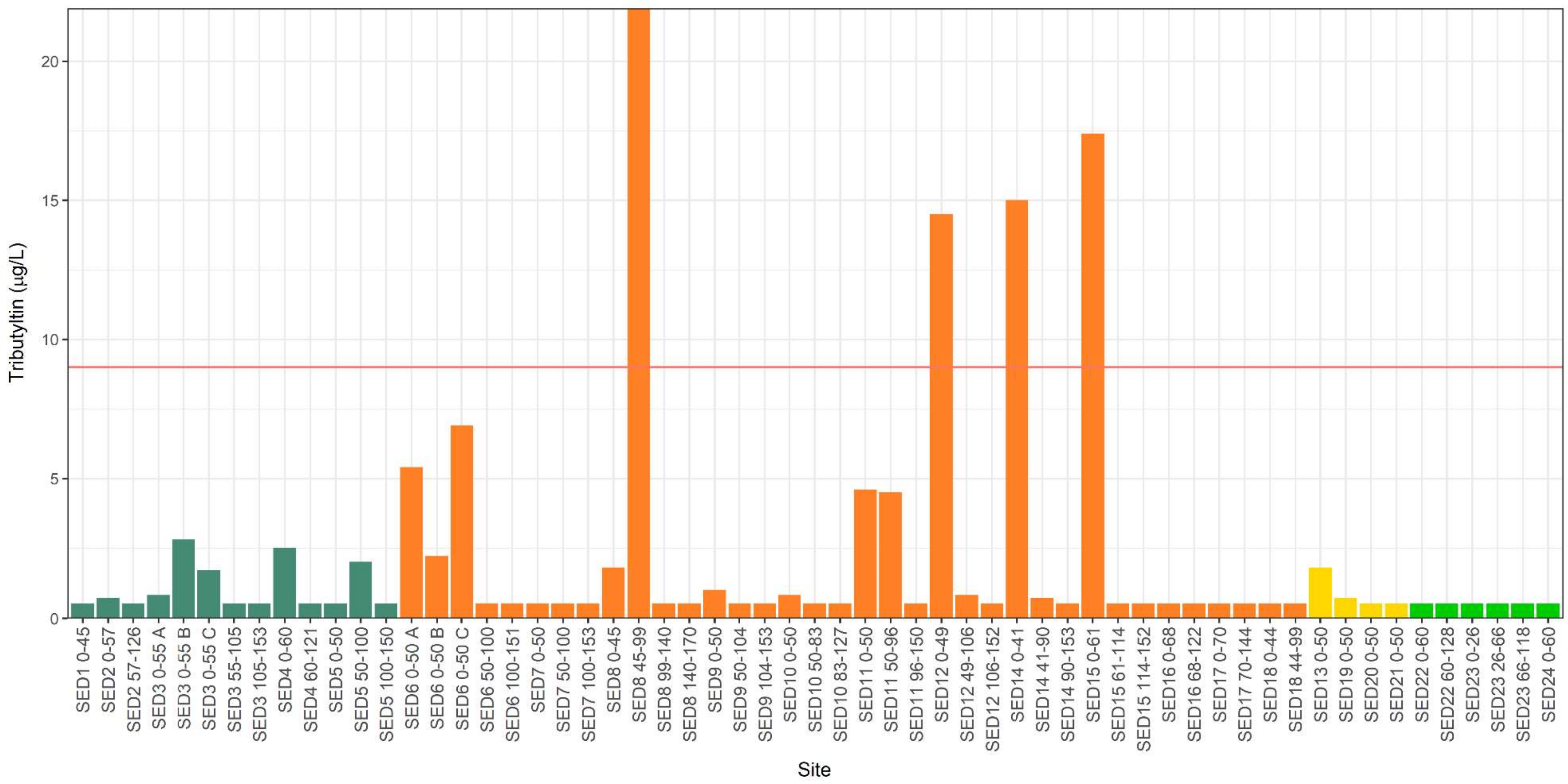

Figure 93. Raw concentrations of TBT in sediment. Red lines indicate SQGV from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel. Normalised concentrations of TBT are shown in Figure 94.

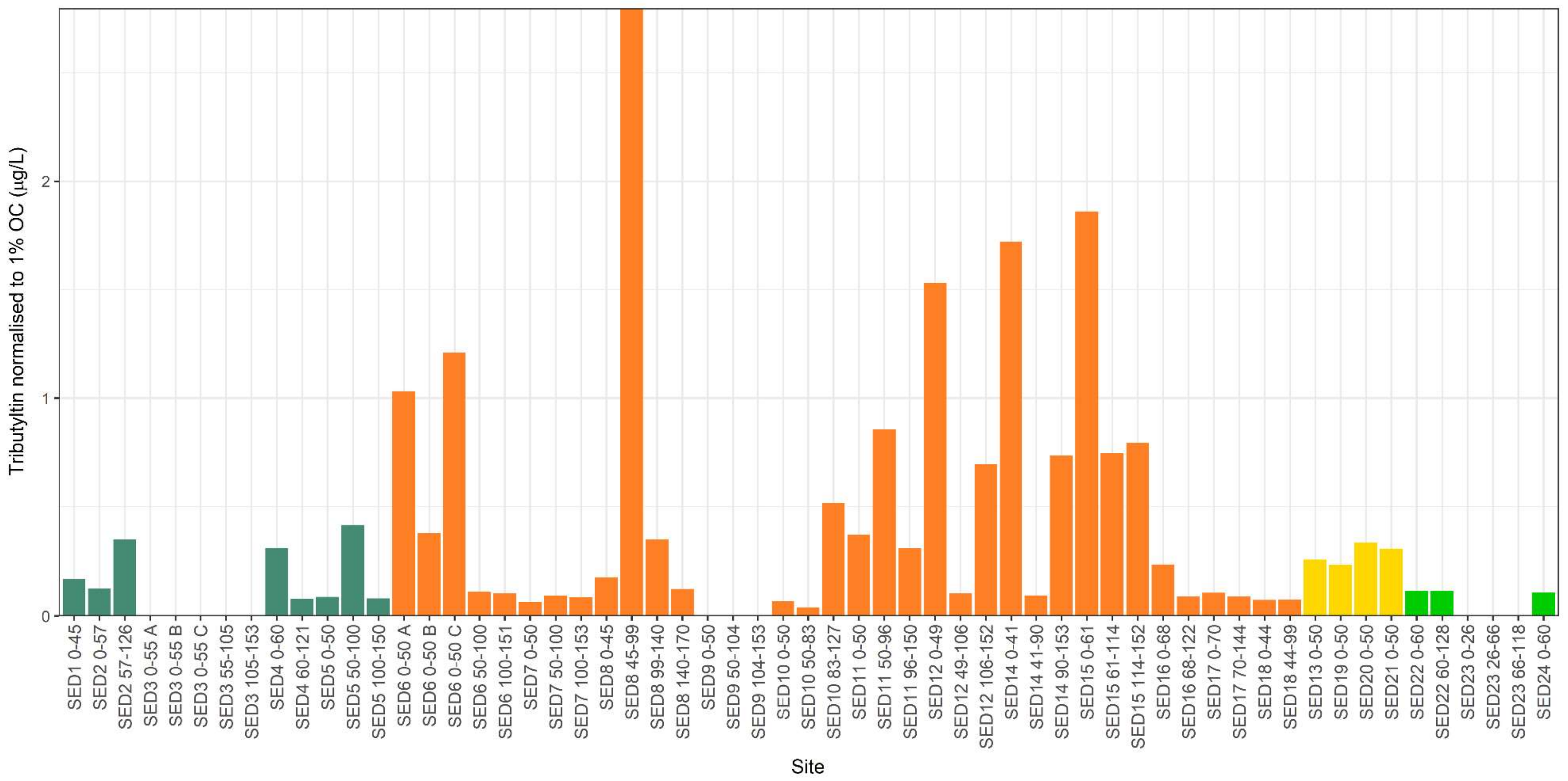

Figure 94. Concentrations of TBT normalised to 1% organic carbon. Values were well below the SQGV from ANZECC/ARMCANZ of 9 µg/kg (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

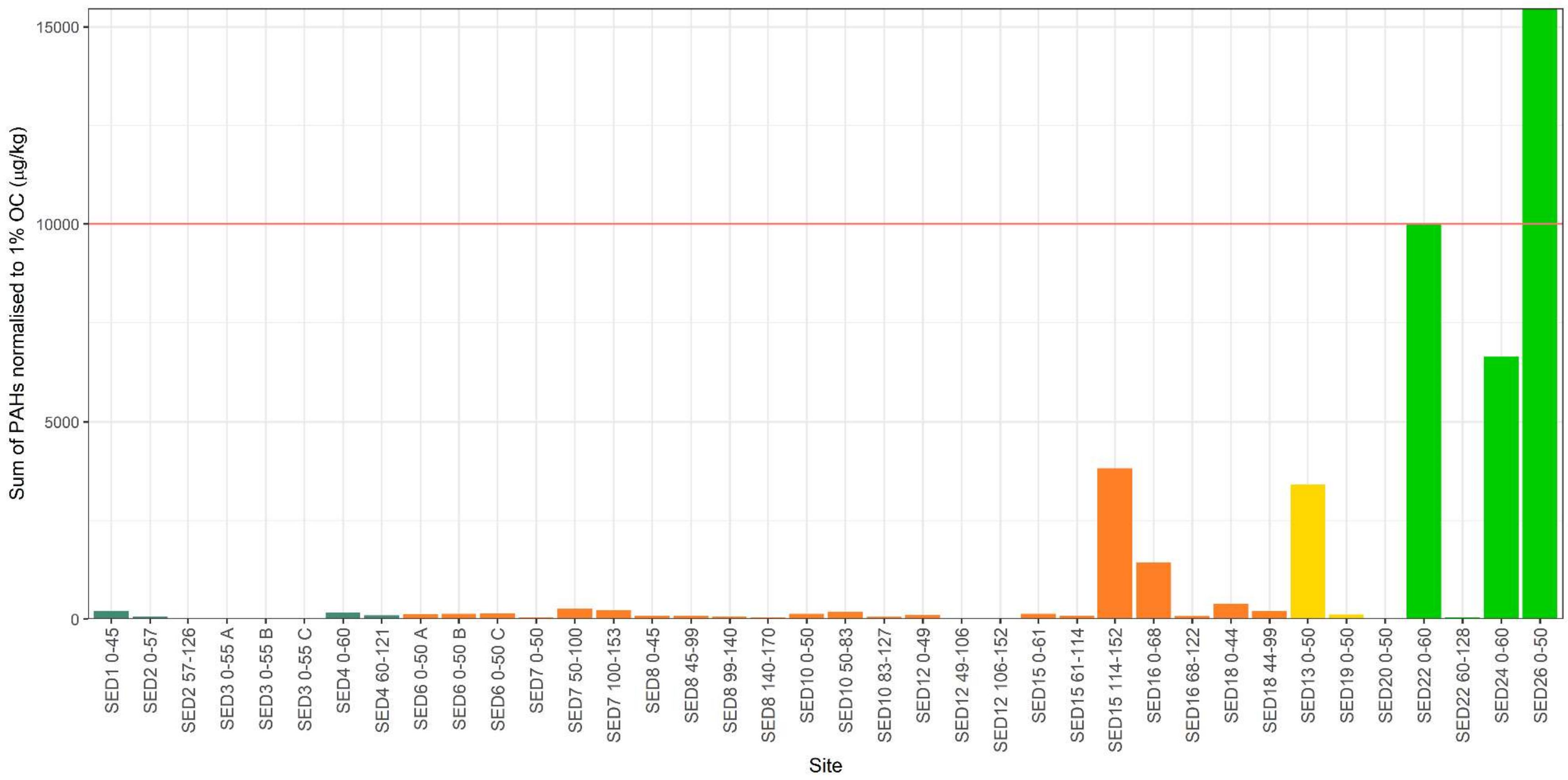

Figure 95. Concentrations of sum of PAHs normalised to 1% organic carbon. Red lines indicate the SQGV and SQGV-high from ANZECC/ARMCANZ (Simpson and Batley 2016). Sites are approximately ordered from south to north, with dark green in southern corner, orange along the causeway, yellow in the river channel and light green on the north shore of the river channel.

4.5.28 Acid sulfate sediment

4.5.28.1 Actual acidity

Actual acidity of the sediment was generally close to neutral, with average 7.2 and 50% of samples between 6.8 and 7.9 (Figure 96). Two samples with lower pH of 5.7 and 6 were located in the southern corner of the causeway. Samples in the river channel and northern shore of the river were all alkaline, over pH 7.5, with one sample reaching pH 9.

4.5.28.2 Potential acidity

Concentrations of sulfur from the chromium reducible sulfur test were above the action criteria of the Tasmania Acid Sulfate Soil Management Guidelines (DPIPWE 2009) in all except two samples when including the inherent acid neutralizing capacity (ANC; Figure 97). The two samples with lower potential acidity were from the river channel. Excluding the ANC, all samples were far above the action criteria (Figure 98). A chip-tray incubation indicated that the ANC should not be used in the determination of net acidity or the associated liming rate (section 4.5.28.6; Sullivan et al 2018).

4.5.28.3 Liming rate

Liming rates including ANC ranged from 1 to 107 kilograms of $CaCO_3$ per tonne of sediment, with an average of 49 kg $CaCO_3$ / t.

Liming rates excluding ANC ranged from 9 to 128 kg $CaCO_3$ / t, average 69 kg $CaCO_3$ / t (Figure 99).

4.5.28.4 Spatial

Consistently high potential acidity in the southern corner and southern end of the causeway (Figure 97). More variable on the northern half of the causeway, with some lower concentrations of sulfur in samples from deeper core sections.

4.5.28.5 Depth into sediment

No clear patterns in potential acidity with depth into the sediment (Figure 100). Lower concentrations of sulfur tended to be in deeper sediments, however some of the highest values of %S also came from deeper sediments.

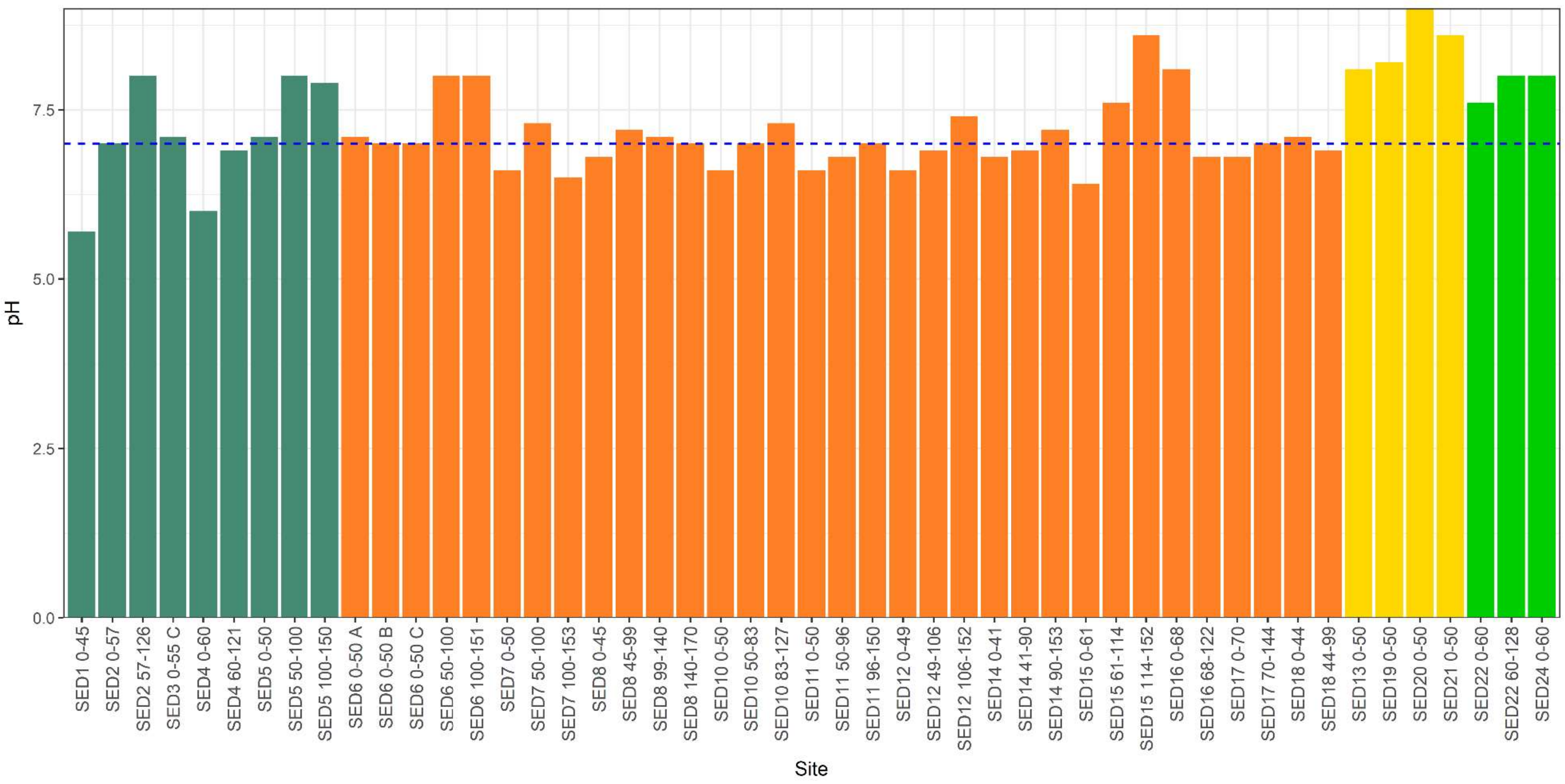

Figure 96. Actual acidity in terms of pH KCl. Dashed blue line indicates pH neutral (pH 7).

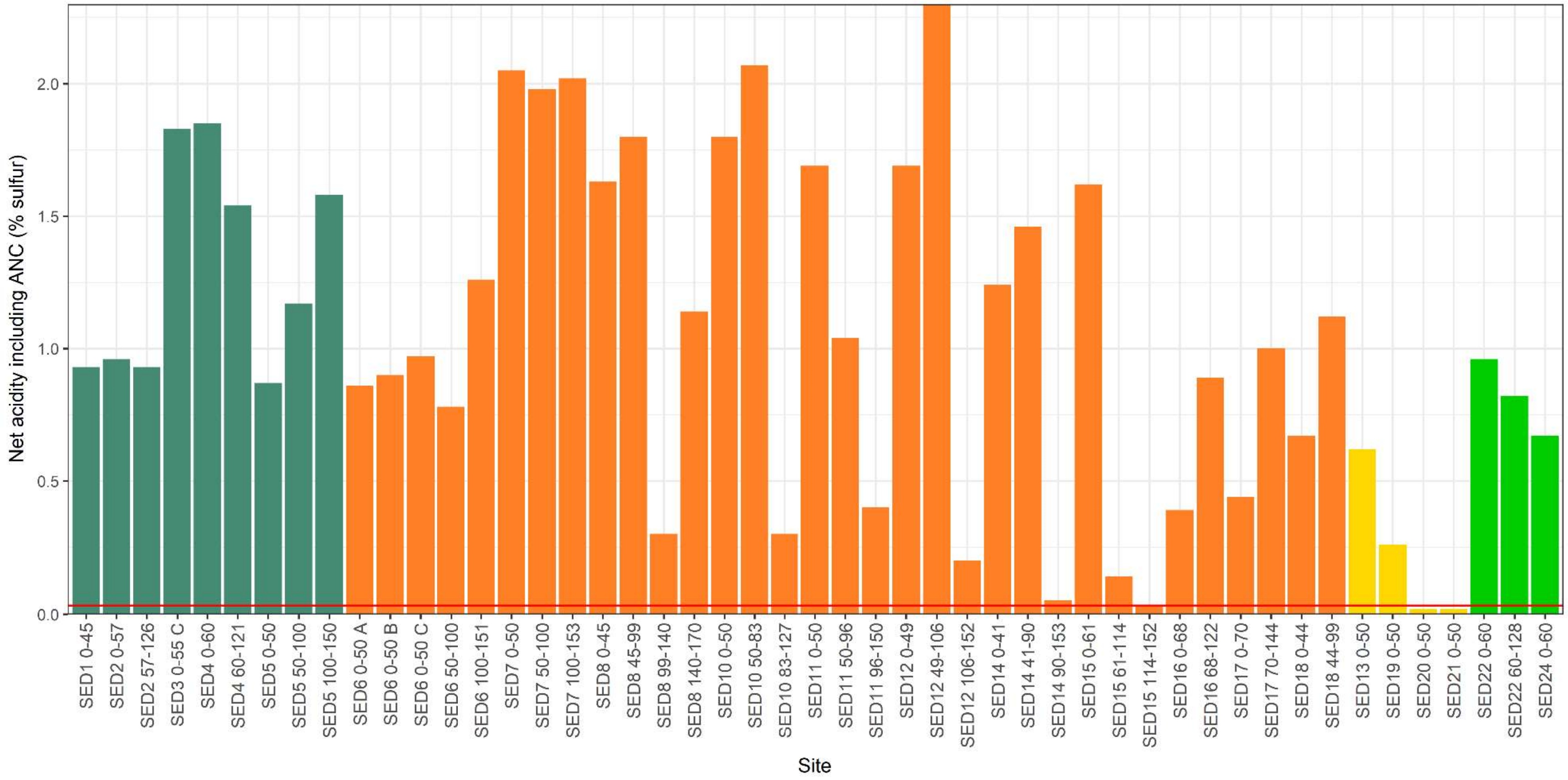

Figure 97. Net acidity including ANC**.** Net acidity excluding ANC. The action criteria of 0.03% from DPIPWE (2009) is indicated by the red line.

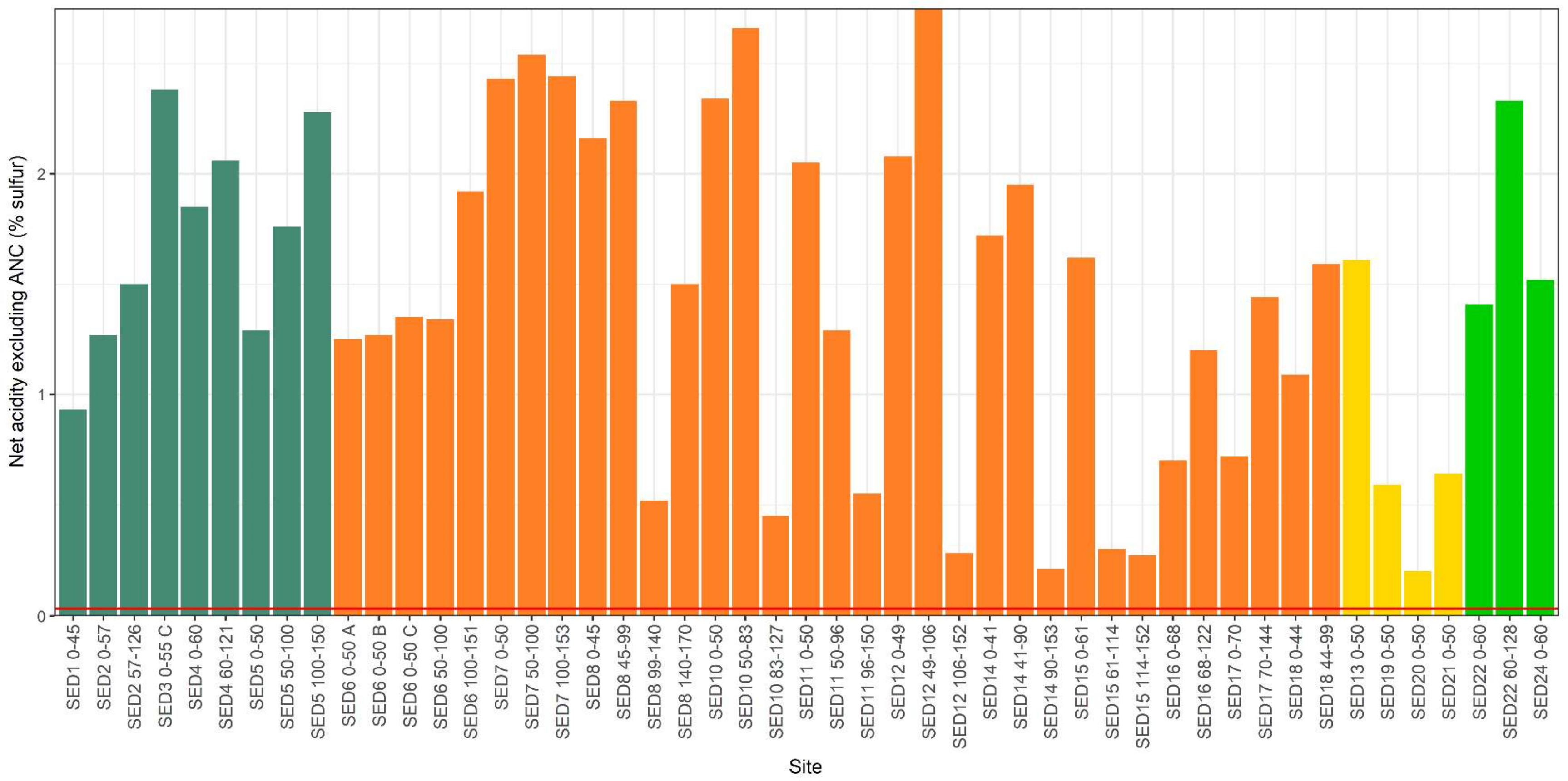

Figure 98. Net acidity excluding ANC. The action criteria of 0.03% from DPIPWE (2009) is indicated by the red line.

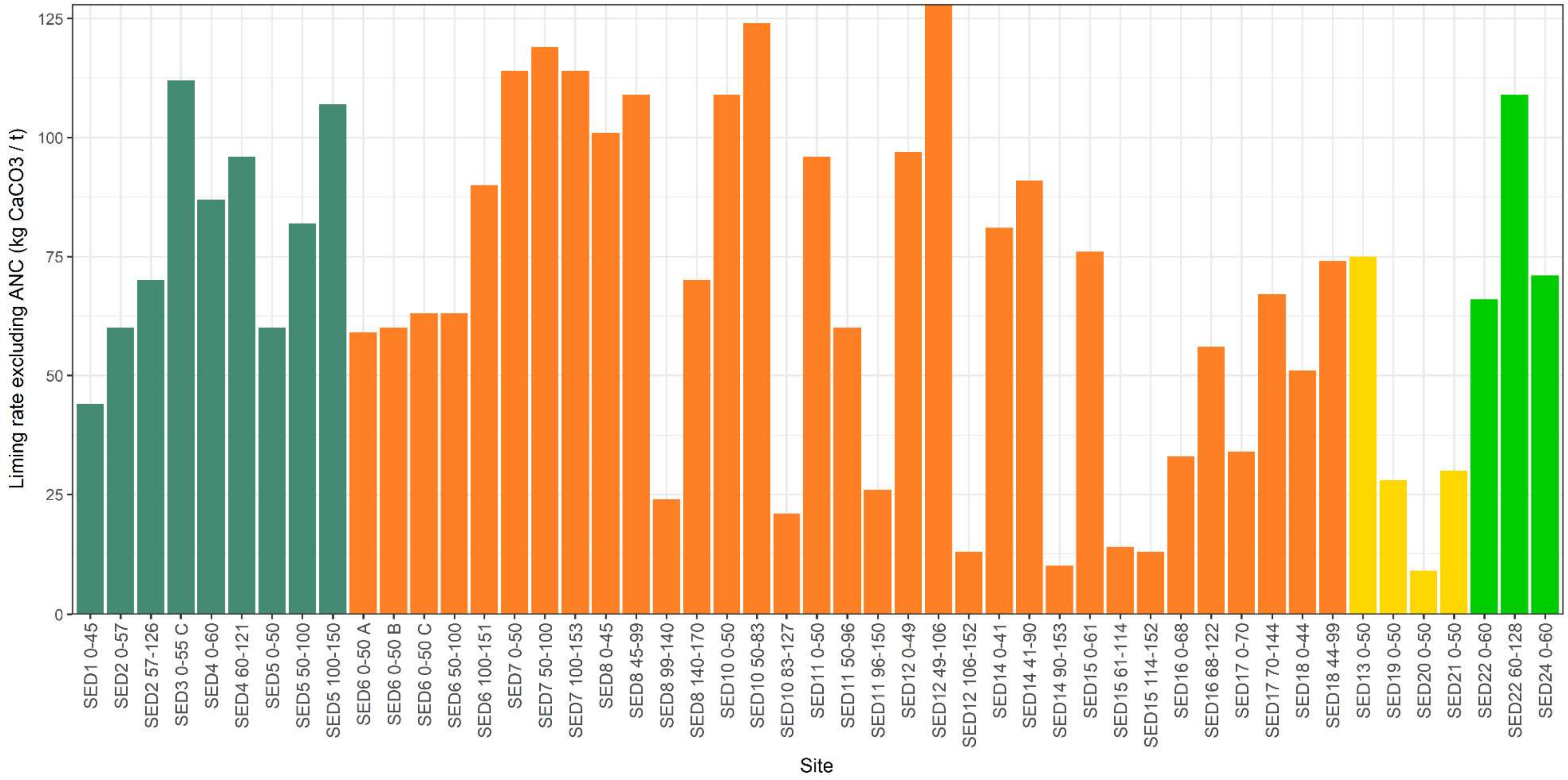

Figure 99. Liming rate excluding ANC.

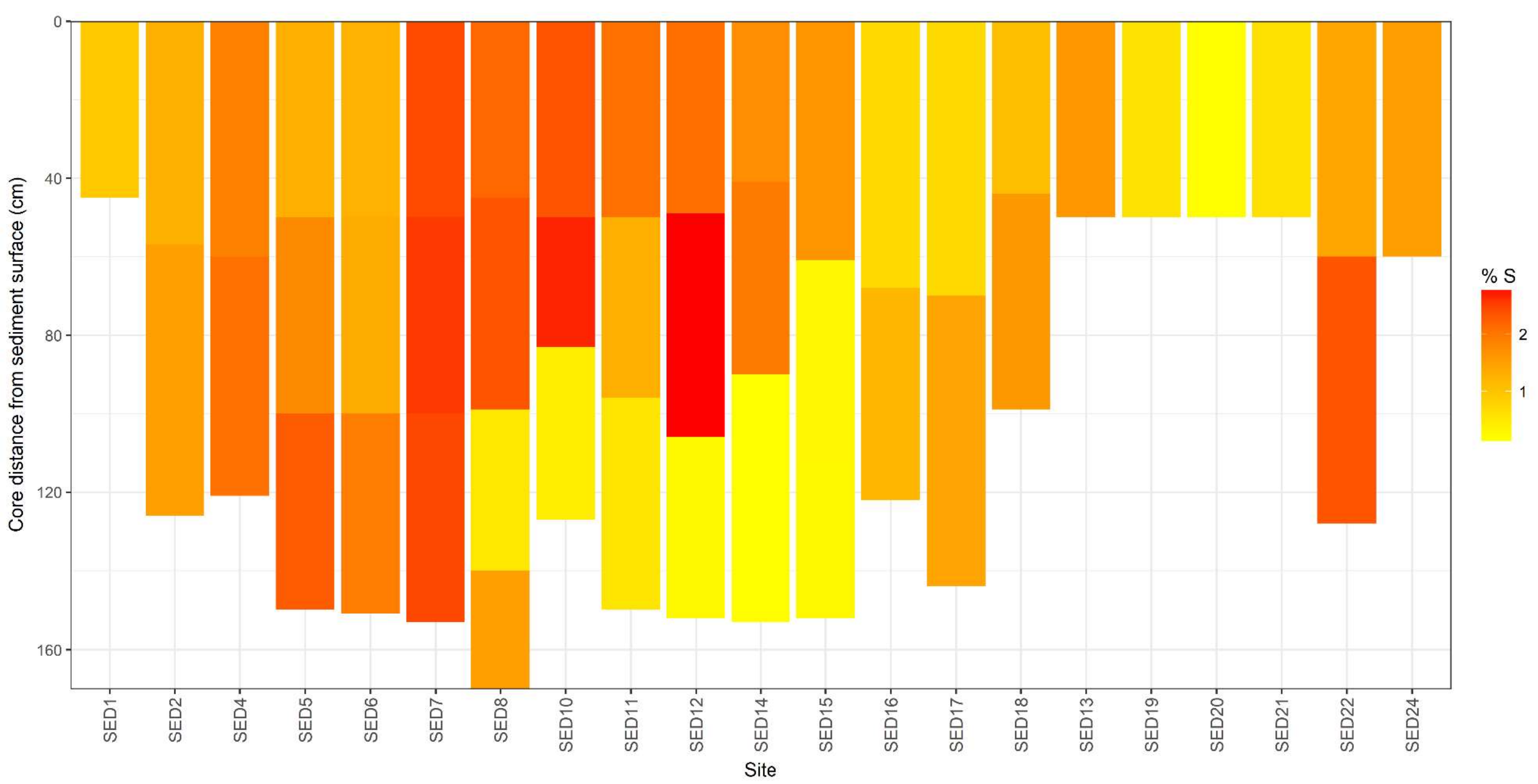

Figure 100. Vertical variation of PASS in terms of %S (excluding ANC) with distance along core.

4.5.28.6 Acid sulfate sediment incubation

A chip-tray incubation was conducted according to Sullivan et al (2018). Sediment from a selection of sites and depths was distributed among the compartments of a chip-tray in order to track the pH of air-exposed sediments through time (Figure 101). Note that SED2 0-57 may have been exposed to air prior to commencing the experiment, resulting in the lower initial pH. Samples were maintained with a slightly higher moisture content than recommended by Sullivan et al (2018) for the first month, potentially resulting in a slower rate of oxidation (slower decrease in pH).

From an initial pH around 7, values between 3.3 to 4.8 were recorded after four weeks. At the end of the incubation, after 35 weeks, pH ranged from 2.4 to 3.4, with the exception of one sample containing a 1 cm bivalve (SED6 50-100), which had pH 5.8. Given that the pH of all samples was less than 6.5, the acid neutralising capacity cannot be included in the determination of net acidity or the associated liming rate (Sullivan et al 2018). The final pH for most samples of less than 4 at the end of the incubation confirms the results of the lab analyses, that the sediment is sulfidic (Sullivan et al 2018).

Figure 101. Chip-tray incubation of acid sulfate sediment.

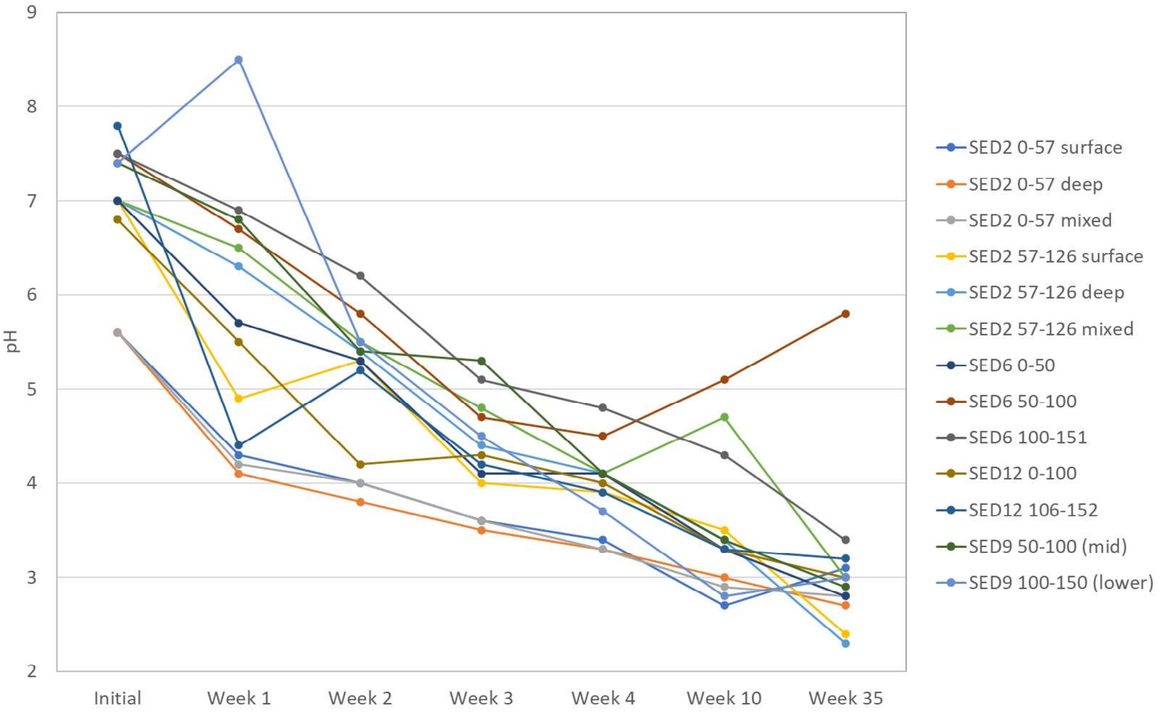

Figure 102. Results of chip-tray incubation of sediment to empirically determine potential acidity.

4.5.29 Nutrients

Nutrient concentrations in the sediment, and concentrations of nutrients released from the sediment during elutriate testing were both quantified. Only the latter are discussed here. In the figures below, the default guideline value indicated is the lowest of the seasonal values for the parameter in the Upper Derwent Estuary.

Significant concentrations of nitrogen and phosphorus in various forms were released from disturbed sediment. These exceeded EPA default guideline values for the Upper Derwent in elutriate samples, with ammonia concentrations exceeding the ANZECC default guideline values for slightly to moderately disturbed ecosystems (95% species protection level).

Elevated nutrient concentrations can result in accellerated growth of aquatic plants, including algal blooms (phytoplankton) and epiphytic algae growing on aquatic macrophytes (*Ruppia* and seagrass).

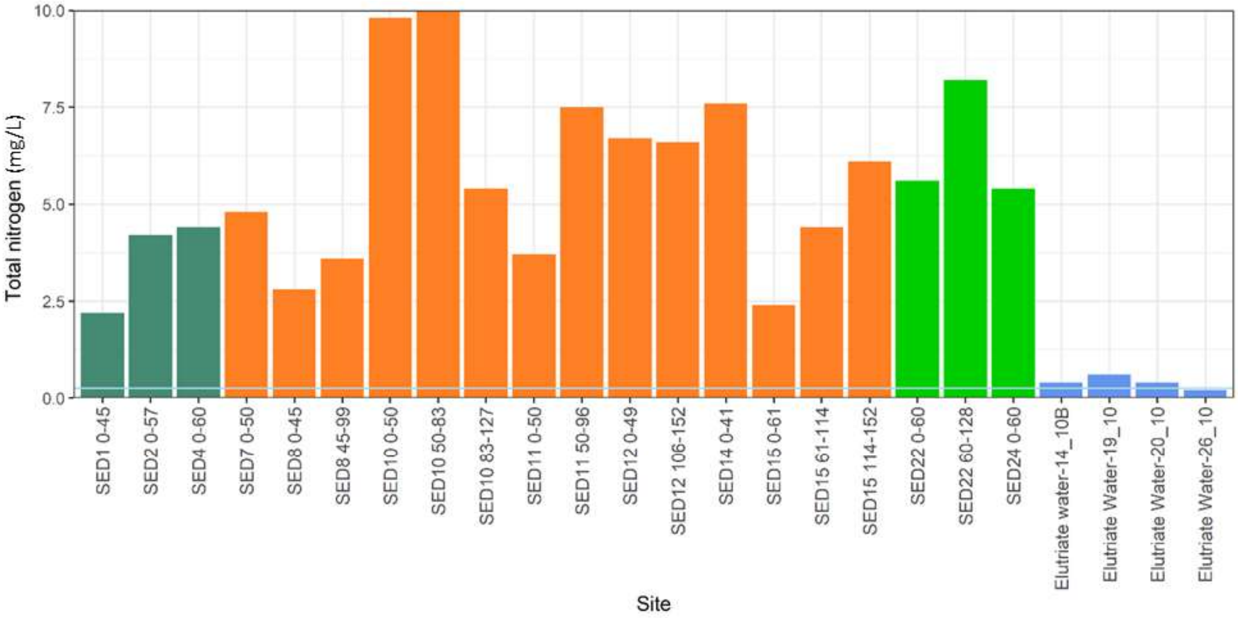

Figure 103. Concentrations of total nitrogen released from the sediment during elutriate testing and in ambient water (right columns in blue). Default guideline value for the Upper Derwent is indicated by the horizontal aqua line.

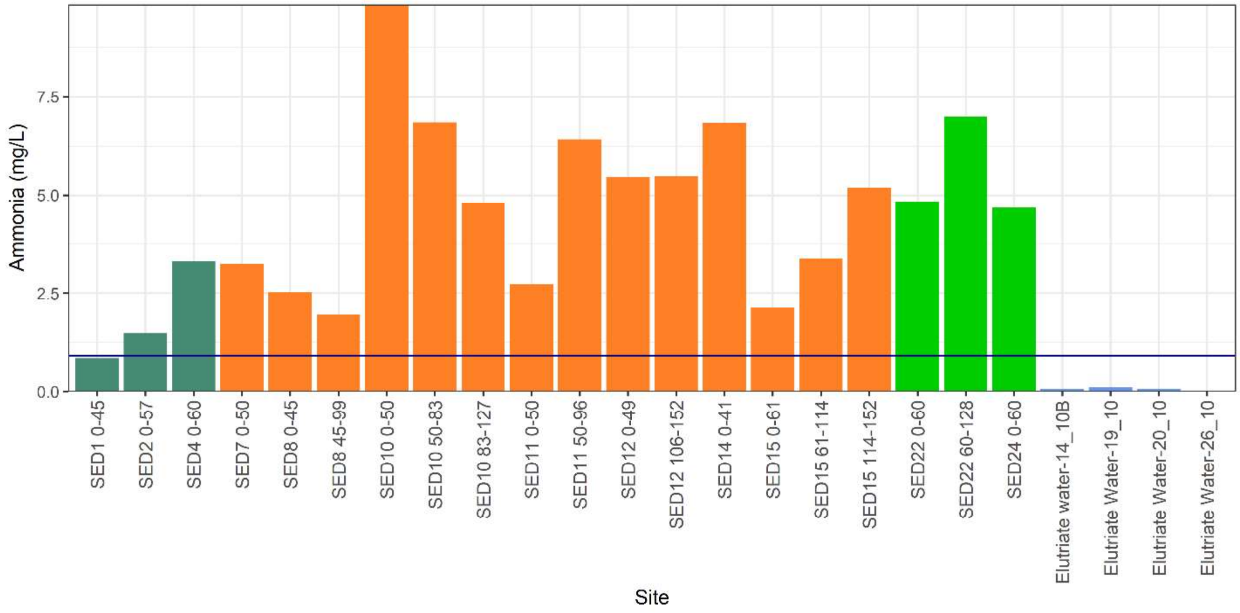

Figure 104. Concentrations of ammonia released from the sediment during elutriate testing and in ambient water (right columns in blue). ANZECC default guideline values for fresh and marine water shown in magenta and blue respectively (lines are near-overlapping in this figure). The lowest default guideline value for the Upper Derwent for ammonia is 0.004 mg/L in summer, with an annual DGV of 0.01 mg/L.

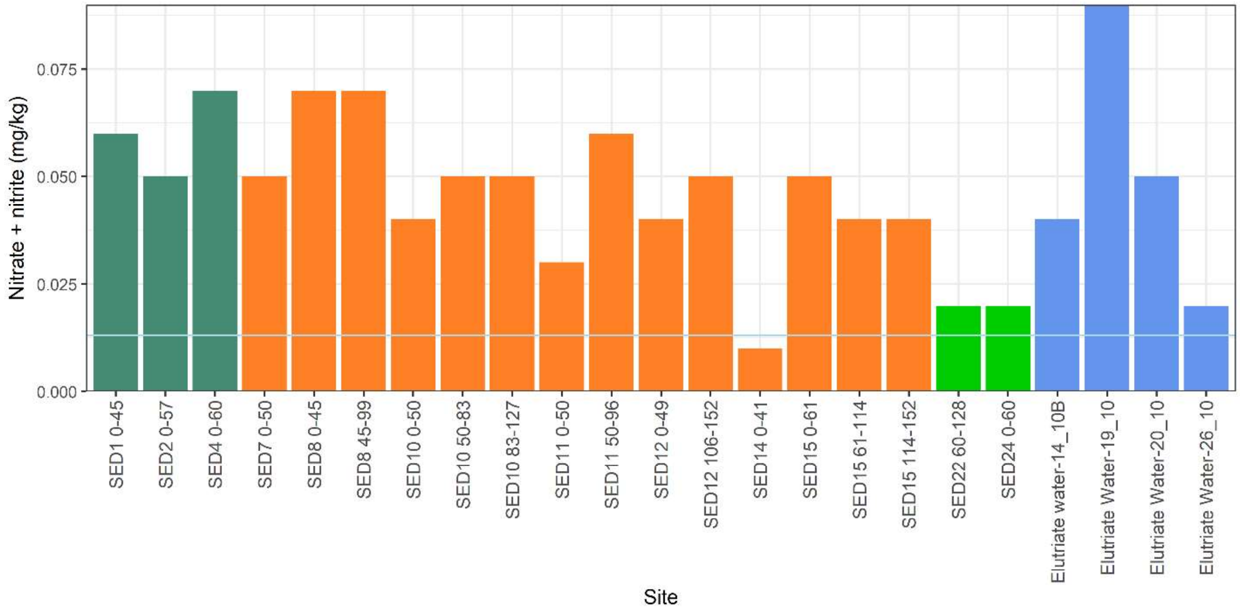

Figure 105. Concentrations of nitrate and nitrite released from the sediment during elutriate testing and in ambient water (right columns in blue). Default guideline value for the Upper Derwent is indicated by the horizontal aqua line. Nitrate is the main contributor, with negligible contributions from nitrite.

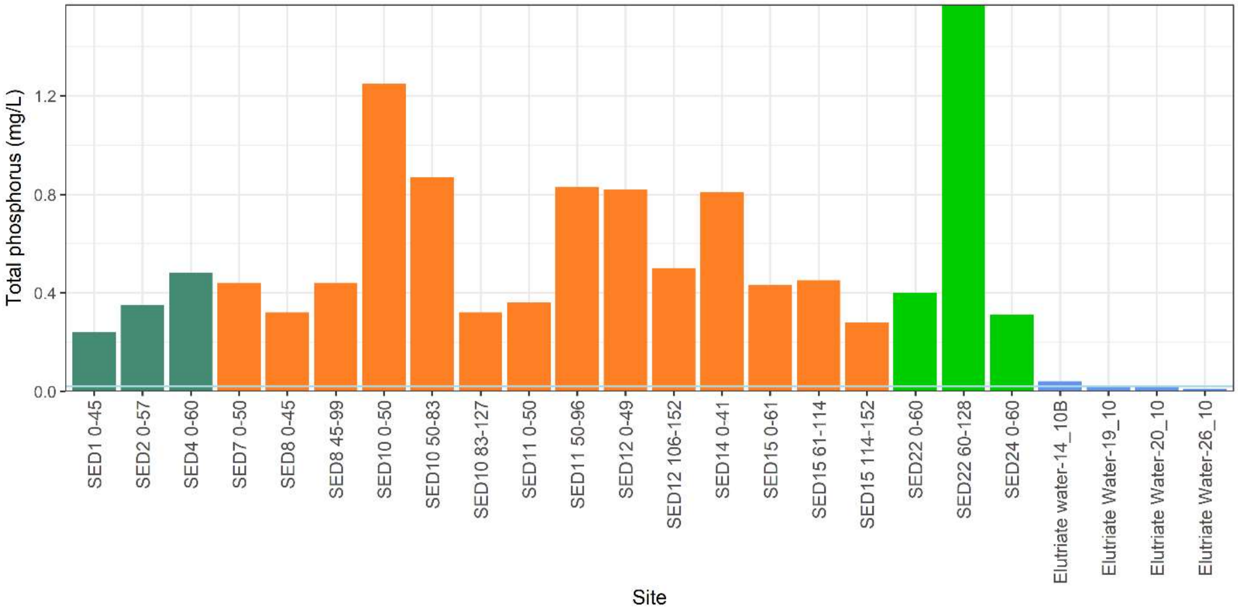

Figure 106. Concentrations of total phosphorus released from the sediment during elutriate testing and in ambient water (right columns in blue). Default guideline value for the Upper Derwent is indicated by the horizontal aqua line.

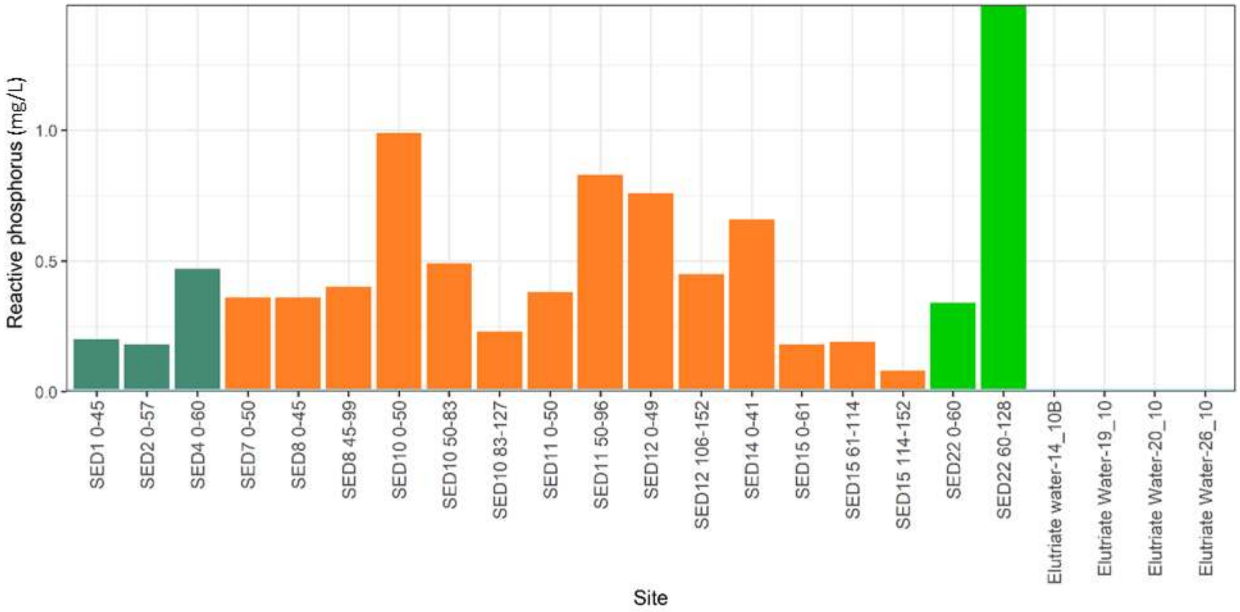

Figure 107. Concentrations of reactive phosphorus released from the sediment during elutriate testing and in ambient water (right columns in blue; very low).

4.5.30 Dissolved oxygen consumption

Sediment containing high concentrations of sulphur and other reactive substances can consume oxygen from the water column if disturbed. Oxidation of sulphur can also reduce pH, causing the release of bound metals. A laboratory experiment was conducted to determine the effect of disturbance of Bridgewater sediment on conditions in the water column.

Sediment from a selection of sites and depths was stirred through water collected from the estuary in a contained vessel. The sediment:water ratio was approximately 3:1. An EXO multi-parameter sonde logged dissolved oxygen and pH every 10 seconds.

Several variables were explored in the experiment, including the influence of:

- continuous versus intermittent disturbance
- sediment : water ratio
- depth into the sediment that the sample was collected

4.5.30.1 Dissolved oxygen

The concentration of dissolved oxygen (DO) decreased swiftly and severely, even with a single disturbance event. A single disturbance of one sample reduced DO from near saturation (100%) to below 50% in 2 minutes, and as low as 20% (less than 2 mg/L) in just over 5 minutes (Figure 108). A second disturbance of the sediment in the same sample reduced DO to less than 5% (< 0.5 mg/L). Continuous disturbance of the same sample caused DO to fall more rapidly to <10% after 5 minutes (Figure 108). Decreasing the proportion of sediment (versus water) in the treatment slowed the rate of DO decline (Figure 109). Deeper sediment generally consumed more oxygen than shallower sediment from the same site (Figure 110).

Dissolved oxygen requirements vary among estuarine species, but for example, larval black bream experienced reduced survival with DO of 30% in experimental tests (Hassel et al 2008). Mobile organisms may simply avoid an area of low DO given sufficient time to vacate the area. The area next to the causeway would be particularly vulnerable to oxygen deficiencies if large volumes of sediment were disturbed due to the shallow water. The situation would be worse in summer with warmer water able to hold less oxygen.

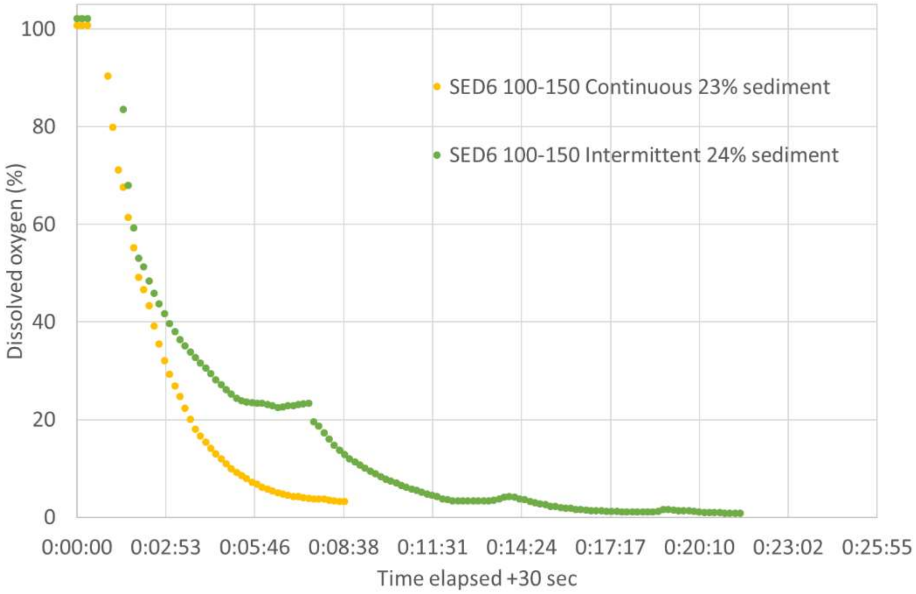

Figure 108. Agitation frequency comparison: continuous versus intermittent (SED6 100-150 cm - 25% sediment).

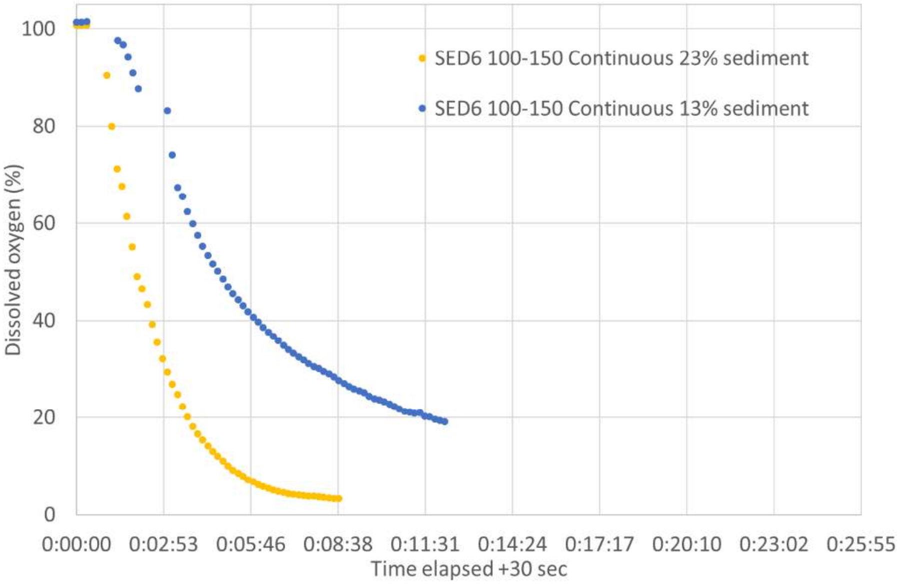

Figure 109. Sediment-water ratio comparison (SED6 100-150 cm - continuous agitation). Blue points show a treatment of 13% sediment : 87% water, with yellow points showing 23% sediment : 77% water.

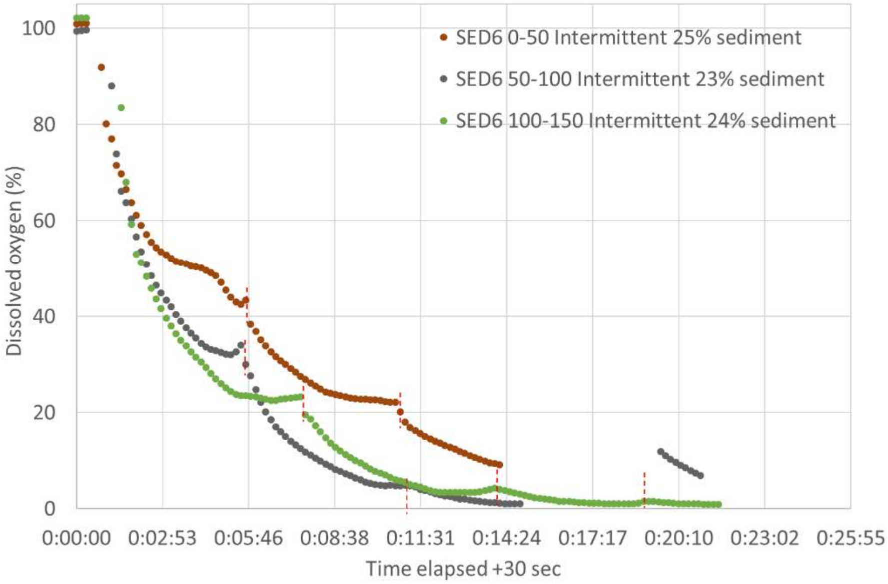

Figure 110. Sediment depth comparison (SED6 - 25% sediment - intermittent agitation). Dashed red lines indicate agitation. Note: first agitation for SED6 100-150 (green) was at 7:30, rather than 5:30.

4.5.30.2 pH

pH changed little during the experiments. The variation at the beginning of the experiments shown in Figure 111 may be due a delay in the pH probe stabilising.

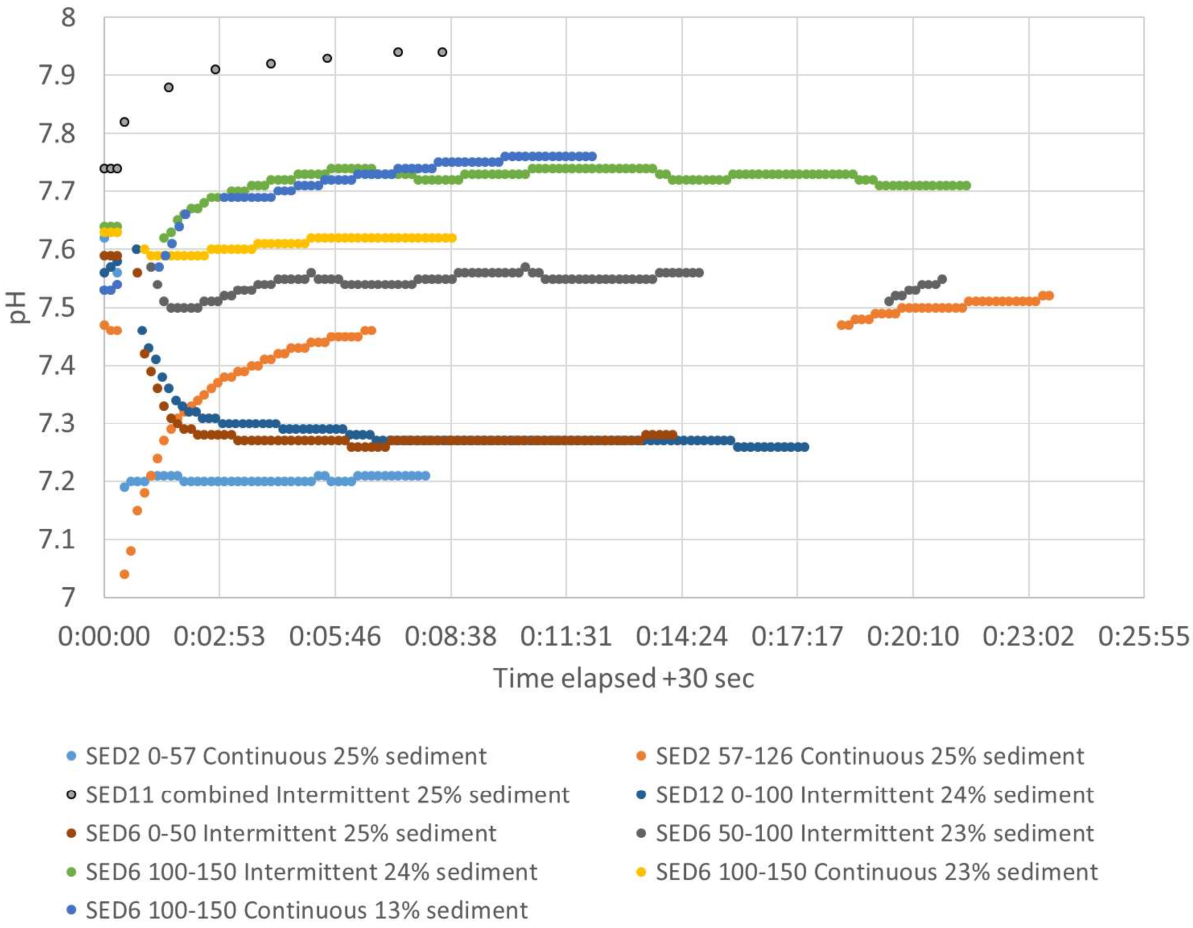

Figure 111. Variation in pH in sediment:water experiments.

4.5.31 Toxic dinoflagellate cysts

The risk of toxic dinoflagellates blooms was considered within the scope of works, however the risk was deemed very low and sediment cyst sampling was not pursued as part of baseline monitoring works. The risk was assessed in consultation with Professor Gustaaf Hallegraeff, an internationally recognised expert in harmful algal blooms. Prof Hallegraeff was part of an environmental monitoring study in the Boyer-Bridgewater area in 1999-2000. On the basis of the plankton community results and the predominantly freshwater regime around the bridge, Prof Hallegraeff does not consider that any of the known toxic dinoflagellates (*Gymnodinium catenatum* or *Alexandrium tamarense/catenella*) are likely to extend into the area.

4.5.32 Summary

ANZECC high sediment quality guidelines were exceeded in the aquatic sediment of the project area for zinc, mercury, lead and cadmium. Low guideline values were also exceeded for arsenic, nickel, copper and silver. TBT and PAHs were slightly elevated in isolated samples, however correction for organic carbon content brought concentrations below SQGVs in all except one sample for PAH (northern shore of the main river channel). The concentration of PAHs in elutriate analyses for this sample were below the limits of detection (and below DGVs). Other tested contaminants did not exceed ANZECC sediment quality guidelines, including OC/OP pesticides, herbicides, PCBs, total petroleum hydrocarbons, total recoverable hydrocarbons, BTEXN and phenolic compounds.

Concentrations of multiple metals in elutriates exceeded water quality guideline values. In terms of the *proportion* of elutriate samples exceeding guideline values, the metals are ordered: copper > arsenic > zinc > lead > cadmium > mercury (Table 4). In terms of the *magnitude* of the exceedances for dissolved concentrations of metals in elutriates, the metals are ordered: zinc > arsenic > copper > lead > cadmium (Table 15). It is unclear why concentrations of zinc, arsenic, copper, lead and cadmium were significantly higher in the elutriate analyses of this study compared to elutriate analyses in 2009 by GHD. One factor may be the closer proximity of the recent sampling to the causeway. However, the mechanism by which this may lead to higher metal concentrations in elutriate water is uncertain. Total concentrations of metals in the sediment were similar.

Concentrations of key metals in sediment (Zn, Hg, Pb, Cd) were highly intercorrelated. Concentrations of these metals were higher in the sediment of the shallow area adjacent to the causeway compared to the sediment of the main river channel (section 9.2.4).

Deeper samples were consistently less contaminated, with metals in most samples below SQGVs. Of the core segments not including the upper layers of the sediment, only two samples contained concentrations of metals above the SQGVs for zinc, lead and mercury, with another four samples elevated in mercury. Elutriate testing of these deeper sediment samples indicated that total concentrations of metals released into the water were very high, however all dissolved concentrations were below the mDGV, except zinc in one sample (SED8 45-99).

It is noteworthy that copper was not markedly elevated in the sediment, however significant quantities of copper were released in the elutriate testing, such that total concentrations in all samples exceeded the mDGV, with dissolved concentrations also exceeding the mDGV in most samples. A similar situation occurred for arsenic.

Sample SED1 0-45 was an outlier in many respects. This sample showed extremely high total concentrations of multiple metals in elutriates, e.g. arsenic, with dissolved concentrations usually similar to those of other samples. This site was located several meters from the shore was one of the few cores to encounter hard refusal with a plug of hard grey sand (appendix C, section 9.2.2). It is unclear whether its outlying qualities were a result of sample contamination or sample mixup. ALS investigated the outliers but all seemed to be in order in terms of the sample handling and analyses. A plausible explanation is that the sediment contained a particularly high proportion fine material that was readily mobilised during elutriate testing into the particulate fraction of the elutriate.

All sediment samples showed high potential to acidify when exposed to oxygen, i.e. PASS. This was reflected in the results of laboratory acid-base accounting and by an incubation test. Small amounts of sediment exposed to air dropped at least 2 pH units in the first month, with all-but-one samples below pH 3.5 at the completion of the incubation (35 weeks). The single sample with higher pH was buffered by the carbonate of a 1 cm bivalve shell.

Significant quantities of nutrients were released from the sediment in during elutriate testing. Quantities of ammonia exceeded the mDGV in all except one samples tested for elutriates, consituting potential toxicity effects. Total nitrogen, ammonia, nitrate+nitrite, total phosphorus and reactive phosphorus all exceeded their respective EPA DGVs for the Upper Derwent Estuary.

Disturbance of the sediment resulted in the consumption of dissolved oxygen from the water. This was presumably caused by oxidation of sulfur and other reduced substances. pH remained remained relatively stable throughout the sediment disturbance experiment.

Table 4. Summary of sediment analyses for metals and metalloids according to NAGD and ANZECC sediment and water guidelines. fDGV and mDGV refer to freshwater and marine default guideline values respectively. Freshwater DGVs are not adjusted for water hardness.

	Sediment		Elutriate		Ambient	
Analyte	**Total**	**Weak acid**	**Total**	**Dissolved**	**Total**	**Dissolved**
Arsenic	20% above low	7% above low	All samples for As(V)	-	Below (LOR)	Below (LOR)
Cadmium	3% above high 27% above low	4% above high 57% above low	77% above fDGV 64% above mDGV	SED1 0-45 above mDGV 36% above fDGV	Below (LOR)	Below (LOR)
Copper	15% above low	Below	All above	90% above mDGV 85% above fDGV	75% above mDGV 63% above fDGV	34% above mDGV/fDGV
Lead	12% above high 35% above low	25% above high 65% above low	64% above mDGV/fDGV	27% above mDGV 32% above fDGV	13% above mDGV 38% above fDGV	Below
Mercury	22% above high 47% above low	Below	61% above mDGV/fDGV	SED12 0-49 above mDGV 17% above fDGV	Below (LOR)	Below (LOR)
Nickel	25% above low	Below	36% above mDGV/fDGV	Below	Below	Below
Silver	15% above low	Below	SED1 0-45 above mDGV 72% above fDGV	SED21 0-50 above fDGV	Below (LOR)	Below (LOR)
Zinc	24% above high 32% above low	50% above high 60% above low	95% above mDGV/fDGV	68% above mDGV 82% above fDGV	13% above mDGV 38% above fDGV	25% above mDGV/fDGV