

SCOPING AND ENVIRONMENTAL IMPACT REPORTING PROCESS FOR THE DEVELOPMENT OF NEW BERTH 605 AND ASSOCIATED INFRASTRUCTURE TO SUPPORT THE CONTAINER HANDLING FACILITY, PORT OF RICHARDS BAY, KWAZULU-NATAL

**Sediment and Soil quality in the Proposed Berth 605
Development Footprint in the Port of Richards Bay**

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Executive Summary

Background

Transnet National Ports Authority (TNPA) has identified the need to develop a new berth (Berth 605) in the 600 Berth Basin in the Port of Richards Bay, in Richards Bay. The development of Berth 605 will require the excavation and dredging of a considerable volume of soil and sediment. Although some of the soil might be used beneficially on land, most of the sediment and soil will be disposed in open water at a dredged spoil disposal site off Richards Bay.

Report Purpose

In accordance with the National Environmental Management Act: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008), an application for the disposal of the dredged sediment and excavated soil at a dredged spoil disposal site off Richards Bay will be lodged with the Minister of the Department of Forestry, Fisheries and the Environment. In support of the permit application, this study provides the findings of the physical and chemical analysis and toxicity testing of sediment and soil sampled in the proposed Berth 605 development footprint in the Port of Richards Bay in November 2024.

Methods

Soil was sampled at six positions (hereafter referred to as stations) near the 600 Berth Basin, while sediment was sampled at 11 stations in the basin in November 2024. The grain size, total organic content and metal concentrations in the sediment and soil were analysed in the laboratory. The toxicity of the sediment and soil was tested using sediment/soil-water interface and elutriate toxicity tests.

Key Findings

- The sediment sampled at all but one station in the 600 Berth Basin and the soil sampled at all but one station near the basin was comprised largely of mud sized material.
- The total organic content in the soil at two stations was slightly above the baseline, but not in sediment.
- The concentrations of most metals in the sediment and soil sampled at most stations in and near the 600 Berth Basin were within the baseline range for sediment (and presumably soil) in the area.
- However, the concentrations of one or more metals in the sediment and soil at all but station were above the baseline.
- Nine metals were present at a concentration above the baseline in the sediment at one station. Five or six metals were present at a concentration above the baseline in the sediment at most other stations.
- Seven metals were at a concentration above the baseline in the soil at one station. Six metals were at a concentration above the baseline in soil at another station, while two or three metals were at a concentration above the baseline in the soil at other stations.
- Chromium was the most often and significantly enriched metal, present at a concentration above the baseline at all soil stations and at all but one sediment station.
- Copper was present at a concentration above the baseline at ten of the 11 sediment stations and at two of the six soil stations.
- The sediment at most sediment stations and at all soil stations was thus contaminated by metals.
- The Department of Forestry, Fisheries and the Environment uses Action Levels to decide if sediment identified for dredging in South African ports is suitable for open water disposal.
- There are three guidelines, known as the Warning Level, Level I and Level II.
- The Warning Level provides a warning of incipient metal contamination of sediment but is not used for decision-making.
- Sediment with metals at a concentration below the Level I is suitable for open water disposal.

- Sediment with metals at a concentration between the Level I and Level II is cause for concern, the degree increasing as metal concentrations approach the Level II. Decisions on the suitability of the sediment for open water disposal are made after considering the number of metals at a concentration above the Level I, and how much the concentrations are above this level.
- Sediment with metals at a concentration above the Level II is unsuitable for open water disposal unless other evidence (e.g. toxicity testing) shows the metals were not posing a toxic hazard.
- The chromium concentration in the sediment or soil at 15 stations and the copper concentration in the sediment at one station was above the Level II.
- At face value, the sediment and soil in the Berth 605 development footprint is unsuitable for open water disposal.
- The most important finding of the survey, however, is that apart from one soil sample, metals and other chemicals were not remobilised from the sediment and soil at a concentration or in forms that were toxic to sea urchin gametes when tested using sediment/soil-water interface and elutriate toxicity tests.
- Very little dilution with clean seawater of the raw elutriate for the soil sample that was toxic was required to render it non-toxic.
- The absence of toxicity despite the often-significant metal contamination of the sediment and to a lesser degree soil shows the metals were not in a bioavailable form, or if they were they were at too low a concentration to be toxic to sea urchin embryo-larvae.

Key Conclusion

- Metals and other chemicals in the sediment and soil are unlikely to be remobilised into the water column to a degree this will pose a toxic hazard to biological resources at the dredging site and when dredged sediment and excavated soil is disposed in open water at a dredged spoil disposal site off Richards Bay.
- The sediment and soil is thus suitable for open water disposal.

Table of Contents

1. Background and Specialist Study Purpose	1
2. Material and Methods.....	1
2.1. Fieldwork	1
2.2. Laboratory analyses.....	3
2.2.1. Analytical laboratory.....	3
2.2.2. Grain size composition	3
2.2.3. Total organic content	3
2.2.4. Metals	4
2.2.5. Toxicity testing.....	4
3. Results and Discussion.....	7
3.1. Grain size composition.....	7
3.2. Total organic content	10
3.3. Metals.....	11
3.4. Comparison of metal concentrations to Action List	20
3.5. Toxicity testing	22
4. Conclusions	25
5. References	26
6. Appendices.....	27

List of Abbreviations and Units of Measurement

CSIR	Council for Scientific and Industrial Research
TNPA	Transnet National Ports Authority
WSP	WSP Group Africa (Pty) Ltd
km	kilometre
m	metre
mm	millimetre
μm	micrometre
ha	hectare
m^2	square meter
m^3	cubic meter
m.s^{-1}	meters per second
$^{\circ}\text{C}$	degrees Celsius
mg.L^{-1}	milligrams per Liter
$\mu\text{g.L}^{-1}$	micrograms per Liter
mg.g^{-1}	milligrams per gram
$\mu\text{g.g}^{-1}$	micrograms per gram
h	hour
%	percent
<	less than
>	greater than
$\leq$	less than or equal to
$\geq$	greater than or equal to
~	about/approximately
$\pm$	plus or minus

1. Background and Specialist Study Purpose

Transnet National Ports Authority (TNPA) has identified the need to develop a new berth (Berth 605) in the Port of Richards Bay, by lengthening the 600 Berth Basin. The berth and back of berth area will serve as a dedicated container handling facility. Developing Berth 605 will require the excavation and dredging of an estimated 2.5 million m³ of sediment, soil and rock. The anticipated dredging and excavation footprint is provided in Figure 1. About 75% of the material is anticipated to be rock, the remainder being sediment and soil of varying grain sizes. Although some of the soil might be used beneficially on land, no viable reuse applications for the bulk of the material have been identified and the intent is to dispose the material at an open water dredged spoil disposal site off Richards Bay.

In terms of section 71(1) of the National Environmental Management Act: Integrated Coastal Management Act, the open water disposal of waste or other material in the sea requires a permit from the Minister of the Department of Forestry, Fisheries and the Environment. The permitting procedure is aligned with the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972 (the London Convention) and 1996 Protocol thereto, to which South Africa is a signatory. The aim of the permitting is to manage the impacts posed by the disposal of contaminated sediment in the receiving environment. To comply with the Act, TNPA will lodge an application with the Minister of the Department of Forestry, Fisheries and the Environment for a permit to cover the open water disposal of sediment, soil and rock dredged and excavated during the development of Berth 605. An important consideration in the permitting process is the presence and concentrations of toxic substances in the material intended for disposal.

The findings of the physical and chemical analysis and toxicity testing of surficial sediment and soil sampled in the proposed Berth 605 development footprint in November 2024 are discussed in this specialist study. The purpose is to provide the Minister of the Department of Forestry, Fisheries and the Environment with information on the material that is intended for disposal at sea. The study also provides information that will be used to assess the significance of environmental impacts that will or might arise if the development of Berth 605 proceeds, but that are not specifically addressed or considered in the permit application procedure. These impacts are identified and assessed in a companion Estuarine and Marine Ecology Specialist Study for the development of Berth 605.

2. Material and Methods

2.1. Fieldwork

Soil was sampled on 6 November 2024 at six positions (hereafter referred to as stations) on land near the 600 Berth Basin (Figure 1; Global Positioning System coordinates for the stations are provided in Appendix 1). Sediment sampling followed on 7 November 2024 at 11 stations within the 600 Berth Basin and at a sediment toxicity testing reference station in the Richards Bay Coal Terminal Basin (Figure 1; Global Positioning System coordinates for the stations are provided in Appendix 1). Sediment could not be sampled at the designated positions for Stations 6 and 9 in the 600 Berth Basin due to the presence of coal fragments and other debris on the bottom, which became trapped in the grabs jaws and caused sediment washout. The survey boat was thus gradually moved from the designated station position toward the centre of the basin until sediment could be sampled. However, as discussed further below the sediment sampled at Stations 6 and 9 still needed to be processed differently to the sediment sampled at other stations due to the presence of coal fragments and other debris in the sediment. A field split sample for quality assurance and control purposes was prepared using the sediment sampled at Station 4.

The upper 5 - 10 cm of sediment was sampled using a van Veen grab. At least four grab samples were collected at each station, but at some stations more grab samples were required to provide the required volume of sediment for analysis due to the presence of coal fragments and other debris in the sediment. On



Figure 1. Aerial views of the Port of Richards Bay, showing the positions where sediment and soil was sampled in and near the 600 Berth Basin in November 2024 and where soil was sampled in 2008 (CSIR, unpublished data). The red shaded area denotes the proposed Berth 605 dredging and excavation footprint.

retrieval, water overlying sediment in the grab was bled through a bleeder hole in upper corner of the grab, taking care to lose as little of the fine-grained material in the grab as possible in the process. Sediment from the replicate grab samples was composited in a glass bowl.

The sediment was homogenised in the bowl using a high-density polyethylene scoop until it was of a uniform colour and texture. Any small stones, plastic items, or other materials not representative of the sediment were removed if they were encountered. Large benthic invertebrates were also removed if encountered. Characteristics of the sediment, such as its colour, texture and aroma, were noted on field data sheets and the sediment was photographed in the bowl. Aliquots of the sediment were then distributed between pre-labelled and pre-cleaned (acid and solvent rinsed) high-density polyethylene and amber glass jars, depending

on the required analyses. The sediment was homogenised between the transfer of aliquots to sample jars to prevent layering. A deviation from the above-described procedure was followed at Stations 6 and 9 due to the presence of coal fragments in the sediment that were too numerous and small to manually remove. To avoid the fragments unduly affecting the results of physical and particularly metal analyses the sediment was press-sieved in the field using a 2 mm mesh size sieve. The sediment was processed in the same manner described above after sieving.

The sediment sample jars were placed on ice bricks in the field and frozen (-18°C) upon return to the laboratory. The grab and sediment processing equipment were rinsed in site water, scrubbed with a brush if needed, rinsed again in site water, sprayed with acetone and rinsed once more with site water before sampling sediment at a new station to minimise the risk of cross contamination.

Soil was sampled using high-density polyethylene scoop after manually removing surface vegetation and plant debris. Soil was collected from three to four points within a radius of approximately 3-5 m at a designated station. The sampling depth was ~5-10 cm. The soil was transferred to a glass bowl and large fragments of plant material, such as roots and leaves, were removed as thoroughly as possible. Homogenising the soil sampled at most stations in the bowl was not possible since it was moist and clayey and formed clumps that were impossible to homogenise. The soil was thus transferred to Ziploc bags. The soil processing equipment was washed in tap water, sprayed with acetone and again washed in tap water sampling the soil at a new station to minimise the risk of cross contamination. The soil was held in a fridge (4°C) until processing.

The soil was removed from the fridge and transferred to aluminium trays in the laboratory. Small fragments of plant leaf and root material were removed from the soil using plastic forceps. The soil was returned to the Ziploc bags and homogenised by squeezing it in the bag to disaggregate the clumps to the extent possible and then repeatedly inverting the bags. Aliquots of the soil were then transferred to pre-labelled and pre-cleaned (acid and solvent rinsed) high-density polyethylene and amber glass jars depending on the required analyses. A field split sample for quality assurance and control purposes was prepared using the soil sampled at Station 17.

2.2. Laboratory analyses

2.2.1. Analytical laboratory

Metal analyses on the sediment and soil were performed at the Environmental Chemistry Laboratory at the CSIR campus in Stellenbosch. The laboratory is accredited by the South African National Accreditation System (SANAS) for the analysis of marine water, sediment and biological tissue. The laboratory's SANAS accreditation certificate is provided in Appendix 2.

2.2.2. Grain size composition

Sediment and soil samples were oven dried at 30°C and then lightly disaggregated using a mortar and pestle. The grain size composition of the sediment and soil was determined by wet and dry sieving into seven grain size classes according to the Wentworth Scale, namely mud (<0.063 mm), very fine-grained sand (0.063 - 0.125 mm), fine-grained sand (0.125 - 0.250 mm), medium-grained sand (0.25 - 0.50 mm), coarse-grained sand (0.5 - 1.0 mm), very coarse-grained sand (1.0 - 2.0 mm) and gravel (>2.0 mm).

The proportional contribution of each grain size class to the bulk weight of the split sediment sample differed by <5% (Appendix 3), meeting acceptance criteria.

2.2.3. Total organic content

About 10 g of sediment or soil was oven dried at 30°C, lightly disaggregated using a mortar and pestle, weighed into a flat bottom flask and 150 mL of hydrogen peroxide added. The samples were heated to 70°C

on a hot plate, swirling the samples to avoid bubbling over. After completed reaction with the hydrogen peroxide, the samples were placed in an oven to evaporate remaining hydrogen peroxide. The samples were then reweighed. The difference between the initial and final sample weights was used to determine the total organic content.

The Relative Percent Difference for the proportional contribution of total organic content to the bulk weight of the split sediment samples was 22.9% (Appendix 3), which slightly exceeded the acceptance criteria of 20%.

2.2.4. Metals

The sediment/soil was freeze dried and ball milled. About 1 g of dried sediment or soil was weighed into a digestion vessel and digested using a mixture of HNO_3 - HCl - H_2O_2 according to USEPA method 3050B. The digestate was then filtered through a 0.45 μm filter and diluted to volume with Milli-Q water. The concentrations of various major, minor and trace metals were detected in the samples using Inductively Coupled Plasma Optical Emission (ICP-OES) and Mass Spectroscopy (ICP-MS). Mercury was analysed using a direct mercury analyser (DMA).

Method blanks were analysed to assess laboratory contamination. All metals were at a concentration below the method detection limit in method blanks. The precision and extraction efficiency of the analytical procedure was assessed by analysing the marine sediment reference standard PACS-2 (National Research Council of Canada) and laboratory duplicates. USEPA method 3050B is a 'near-total' digestion procedure that dissolves most elements that could be 'environmentally available' in sediment but is not designed to dissolve metals tightly incorporated into silicate structures. Since the reference material is certified for total digestion but a near-total digestion procedure was used, the recovery of refractory metals (*e.g.* aluminium, chromium) was somewhat <100% (Appendix 3). However, recoveries were within acceptance criteria defined by the CSIR Environmental Chemistry Laboratory for quality assurance and quality control purposes based on the results of repeated analysis of the sediment reference standard. The Relative Standard Deviation for laboratory duplicates was within the acceptance criteria of 10% apart from chromium in one sediment sample, which returned a Relative Standard Deviation of 13.4% (Appendix 3). The Relative Percent Difference for metal concentrations in the split sediment samples was <20%, meeting acceptance criteria.

Although arsenic is technically a metalloid (*i.e.* semi-metal), in the interests of simplicity it is referred to as a metal in this report.

2.2.5. Toxicity testing

The dredging of sediment and its disposal at open water dredged spoil disposal sites can result in numerous predictable and potential environmental impacts. If the sediment is contaminated, chemicals can be remobilised from the sediment into the water column at the dredging and disposal sites to a degree the chemicals pose a toxic hazard to biological resources. Additionally, contaminants in the sediment are transferred to the dredged spoil disposal site, where they may pose a toxic hazard to benthic biological resources. The suitability of sediment identified for dredging for open water disposal is usually assessed by comparing chemical concentrations to sediment quality guidelines. However, this only provides an estimate of the toxic hazard and is most effective for identifying sediment that does not pose a toxic hazard, that is, sediment with chemicals at concentrations below guidelines. The reason is sediment quality guidelines do not account for chemical bioavailability, which fundamentally affects toxicity. There might also be unmeasured chemicals, or chemicals that have no associated sediment quality guideline present in the sediment that pose a toxic hazard to biological resources. A more effective strategy for identifying if chemicals are likely to be remobilised from sediment into the water column during dredging and open water disposal to a degree this poses a toxic hazard to biological resources is to test the toxicity of the sediment. Two types of toxicity tests were performed to identify if chemicals are likely to be remobilised from sediment

and soil sampled in and near the 600 Berth Basin during dredging and open water dredged spoil disposal. The toxicity tests used sea urchin embryo-larval development as the basis for identifying toxicity. Embryo-larval tests with sea urchins are amongst the most sensitive of toxicity tests. In this test, sea urchin embryos are exposed to a testing medium and their development is tracked over a defined period. The test endpoint is the number of embryos that developed to a normal 4-arm pluteus in numbers relative to control treatments. Developmental delays and abnormalities in the 4-arm pluteus are considered to be an indicator of toxicity rendering later stage larvae non-viable.

Sediment/soil-water interface toxicity test

A sediment/soil-water interface toxicity test was performed to evaluate the likelihood of chemicals being remobilised from dredged sediment and excavated soil from the Berth 605 development footprint into the sediment-water interface at concentrations and in forms capable of exerting toxic effects on sea urchin embryo-larvae. The sediment-water interface is ecologically relevant since it is a likely site of contaminant exposure for infaunal, epifaunal and pelagic biological resources.

The sediment was transferred to a glass bowl and homogenised using a high-density polyethylene scoop until it was of a uniform texture and colour. As stated above, the soil sampled at numerous stations formed clumps and it was impossible to homogenise the soil in the same way as sediment. The soil was thus homogenised by repeatedly inverting and swirling the sample containers. Aliquots of sediment and soil were transferred to each of five 100 mL glass beakers to the 20 mL mark. 60 mL of filtered (5 µm) ultraviolet sterilised seawater (salinity of ~35) collected in the Port of Richards Bay was added to the beakers, by pouring the water onto a circular plastic disk attached to a dowel to limit disturbance of the sediment. The exposure setup thus comprised one part sediment and three parts water, but due to spaces between clumps of the soil sampled at some stations the sediment-to-water ratio was slightly larger than one to three. The ratio is lower than the traditional one to four sediment-to-water ratio for elutriate tests, in the interests of conservativeness. The one to four sediment-to-water ratio is based on the generally accepted hydraulic-dredge pumping ratio of one part sediment to four parts dredging-site water (Jones and Lee, 1978). Although a one to four sediment-to-water ratio, various modifications of the test have been used. The beakers were placed in an environmental chamber at 23°C, under a 12:12 h light:dark cycle. Plastic lids were placed on the beakers to limit evaporative water loss. The sediment-water mixture was left to equilibrate overnight. The salinity, pH and dissolved oxygen concentration of water in one of the five replicate beakers for each treatment was measured on the following day using a Multi 3630 IDS (Xylem Analytics, Germany) water quality meter. Probes of the water quality meter were calibrated according to the manufacturer's specifications. The accuracy of the calibration was determined using salinity and pH standards. Plastic tubes with a 30 µm mesh size nylon screen affixed to the bottom were then suspended in the beakers, so the bottom of the tubes was ~1-1.5 cm above the sediment or soil surface. Micropipettes, balances, thermometers, temperature controlled environmental chambers and water baths were calibrated by certified SANAS service providers.

A negative control comprising a tube but no sediment in five glass beakers was used to verify the test setup did not adversely affect developing embryo-larvae. A second negative control consisting of 20 mL of seawater from Vetch's Beach in Durban was tested to verify embryo-larvae health. The control from a concurrent reference toxicant test (see below) was used for this purpose.

A further negative control involved the testing of sediment collected from a reference position in the Richards Bay Coal Terminal Basin in Richards Bay. Earlier surveys have shown the sediment in this area to be uncontaminated, or at most minimally contaminated by metals and polycyclic aromatic hydrocarbons (CSIR, unpublished data). The reference sediment was treated in the same manner described above.

Adult *Tripneustes gratilla* were collected at Vetch's Reef in Durban and maintained in seawater (salinity of ~35) at ambient temperature in flow-through tanks in the laboratory. The urchins were fed on *Ulva* species

seaweed. Gametes (sperm and eggs) were obtained by inducing the sea urchins to spawn by injecting 1-2 mL of a 0.5 molar potassium chloride solution into their coelomic cavity. Gametes from males and females were collected separately. Females were inverted over glass beakers filled with seawater and the eggs allowed to settle. Sperm was collected 'dry' in pasteur pipettes. Sperm was activated by exposure to seawater. The quality of eggs and sperm was evaluated prior to testing by adding diluted sperm from each male to eggs from each female in 20 mL of seawater in vials. Eggs were examined under a microscope for the presence of a fertilization membrane. Combinations of eggs and sperm that did not produce at least 90% fertilisation success and/or showed abnormal membrane development were not considered for toxicity testing. Sperm was then added to eggs to create a fertilised egg stock solution. About 250-300 fertilised eggs from the stock solution were added to the tubes in four of the replicate beakers to initiate the test.

After 96 h, the tubes were removed from the four exposure beakers. Embryos and larvae were gently washed from the tubes into vials and preserved by adding 100 µl of 37% formaldehyde. The salinity, pH and dissolved oxygen concentration of the overlying water in the fifth replicate beaker was then measured.

Embryo-larval health and sensitivity relative to the results of historical testing at the CSIR Marine Ecotoxicology Laboratory was assessed using the reference toxicant (positive control) copper. The test consisted of eight copper concentrations (2.5-40 µg.L⁻¹) in seawater plus a control treatment (5 µm filtered ultraviolet sterilised seawater collected at Vetch's Beach in Durban). Fertilised eggs were added to 20 mL of each copper concentration in four replicate glass vials per concentration and exposed for 96 h under the same temperature and light regime as the sediment/soil-water interface test. At the end of the exposure period the test was terminated by adding 100 µl of 37% formaldehyde to the vials. The Effective Concentration for 50% development to a normal 4-arm pluteus for the reference toxicity test was within acceptable limits (Appendix 3).

The proportion of embryos that developed to a normal 4-arm pluteus was determined by examining the first 100 individuals observed per replicate under an optical microscope. Although the endpoint for the test is the proportion of embryos that develop to a normal 4-arm pluteus, the developmental stage of all individuals examined at test termination was determined.

The results for the split sample toxicity testing are provided in Appendix 3. There was no difference amongst the split samples.

The proportion of sea urchin embryos that developed to a normal 4-arm pluteus in each treatment replicate was arcsine transformed to satisfy parametric testing assumptions of data normality and variance homogeneity. Data normality was determined using a Shapiro-Wilk Test and homogeneity of variance using a Bartlett Test. If the transformation stabilised data normality and variance homogeneity, the data were compared amongst treatments using parametric one-way Analysis of Variance followed by a Dunnett's *post hoc* test if differences were detected. If the transformation did not stabilise data normality and/or variance homogeneity the data were compared amongst treatments using non-parametric Kruskal-Wallis Analysis of Variance followed by a Dunn's *post hoc* test if differences were detected. Seawater was identified as toxic if two criteria were met, namely (1) the difference in the proportion of embryos that developed to a normal 4-arm pluteus compared to the control treatment exceeded the Minimum Significant Difference, and (2) the proportion was statistically significantly lower than for the control treatment. This avoids situations where water is identified as toxic when actual differences to the control treatment are very small and of uncertain (but doubtful) ecological significance. The magnitude of toxicity was classified as:

- Not toxic = Inhibition ≤ Minimum Significant Difference,
- Slightly toxic = Inhibition > Minimum Significant Difference and ≤10%,
- Moderately toxic = Inhibition >20 and ≤50%,
- Highly toxic = Inhibition >50 and ≤75%,

- Severely toxic = Inhibition >75%.

Elutriate toxicity test

A sediment elutriate toxicity test was performed to estimate the likelihood of chemicals being remobilised from sediment into the water during dredging in the 600 Berth Basin (at dredge head and in hopper overflow) and during the descent of sediment and soil at the open water dredged spoil disposal site to a degree the chemicals exert a toxic effect on sea urchin embryo-larvae.

Sediment (including reference sediment) and soil samples were transferred to a glass jar to the 200 mL mark, whereafter 600 mL of filtered (5 µm) ultraviolet sterilised seawater (salinity of ~35) collected in the Port of Richards Bay was added. The jars were sealed and placed on a rotary shaker for 1 h at a speed of 200 revolutions/min. The contents were allowed to settle for 30 min, whereafter the aqueous fraction (elutriate) was extracted. The elutriates for most samples were too turbid to allow for the observation of test organisms at test termination. The elutriates were thus centrifuged at $2750 \times g$ for 5 min to separate the water from the suspended sediment. Aliquots (20 mL) of the aqueous fraction (elutriates) were extracted and transferred to each of five glass vials per sample. The raw elutriates were also diluted to 75%, 50% and 25% by adding appropriate volumes of seawater collected in the Port of Richards Bay. Aliquots of the diluted elutriate were similarly transferred to each of five glass vials per sample. The salinity, pH and dissolved oxygen concentration of water in one of the five replicate vials for each treatment was measured using a Multi 3630 IDS (Xylem Analytics, Germany) water quality meter, in the same manner as for the sediment-water interface test. Micropipettes, balances, thermometers, temperature controlled environmental chambers and water baths were calibrated by certified SANAS service providers.

About 250-300 fertilised eggs from a stock solution were added to four of the vials to initiate the test. The vials were placed in an environmental chamber at 23°C and a 12 h light:dark cycle. The test was terminated after 96 h by adding 100 µl of 37% formaldehyde to each of the four exposure vials. The salinity, pH and dissolved oxygen concentration of the overlying water in a fifth vial was then measured.

Seawater (salinity of ~35) collected in the Port of Richards Bay and seawater collected at Vetch's Beach in Durban, which acted as negative controls, was treated in the same way as the elutriate samples described above but without sediment to verify the test setup did not adversely affect developing embryo-larvae.

The proportion of embryos that developed to a normal 4-arm pluteus was determined by examining the 100 individuals observed per replicate under an optical microscope. Although the endpoint for the test is the proportion of embryos that develop to a normal 4-arm pluteus, the developmental stage of all individuals examined at test termination was determined.

Data analysis procedures were the same as those described for the sediment/soil-water interface test.

3. Results and Discussion

3.1. Grain size composition

In a geologically homogenous area, grain size is the most important factor that controls the natural concentrations of metals in sediment and soil, because aluminosilicates, which are the major natural metal-bearing phase of sediment and soil, predominate in clay. Sand, in contrast, is comprised largely of metal deficient quartz (silica) and acts as a diluent of metal concentrations. Muddy sediment and fine-grained soil thus naturally have a higher metal content than sandy sediment and soil. In aquatic ecosystems, mud also sequesters metals that are anthropogenically introduced in solution to surface waters because of the large surface area provided by the grains for adsorption and because their surface is electrically charged, rendering them chemically reactive. Metals and other particle reactive contaminants also attach to, and are transported in this way with suspended particulate matter in the water column, ultimately accumulating in depositional

zones. These are areas where the sediment is dominated by fine-grained material (*e.g.* mud) and form where water currents are so weak that fine-grained suspended material and any associated contaminants settle from the water column. Generally, therefore, naturally occurring and anthropogenically introduced metal concentrations are highest in muddy sediment and lowest in sandy sediment. There may be exceptions in ports since coarse-grained sediment may contain high metal concentrations due, for example, to the inclusion of metal flecks and metal-impregnated antifouling coating flakes derived from vessel maintenance operations, and metal concentrate and ore particles lost during the loading and offloading of vessels.

The grain size of sediment thus provides important information for identifying areas where particle reactive contaminants have a propensity to accumulate in aquatic ecosystems. The presence of anomalously high metal concentrations in sandy sediment also provides indirect information on the likelihood the metals were present as a solid (*i.e.* largely non-bioavailable form), with implications for understanding the toxicological hazard.

The sediment sampled at all but Station 1 in the 600 Berth Basin and soil at all but Station 12 near the basin was dominated by mud sized material (Figure 2, data in Appendix 4). At most stations, mud sized material contributed >55% and usually >70% of the bulk sediment weight. Various classes of sand contributed more appreciably to the bulk weight of soil than sediment apart from Station 1 in the basin, where medium- and fine-grained sand contributed 88.5% of the bulk weight of the sediment (the highest sand contribution for any station).

The findings of the sediment survey are consistent with the findings of earlier sediment surveys in the 600 Berth Basin (*e.g.* CSIR, unpublished data; Mehlhorn *et al.*, 2021; Izegaegbe *et al.*, 2023; Malan and Clarke, 2023), which also revealed that sediment in the deeper parts of the basin was comprised largely of mud sized material (frequently >80% contribution to the bulk weight of the sediment). However, the sediment grain size is variable across the basin. The most notable recent change in the 600 Berth Basin benthic environment is the accumulation of coal fragments, particles and dust in the sediment, reflecting losses during the loading of coal onto vessels and wind and surface runoff erosion from coal stockpiles near the basin. The export of coal through the basin is a relatively recent development. The dark colour of the sediment at some stations near the quay wall probably reflects the accumulation of coal dust in the sediment (Plates 1 and 2). The sediment in parts of the basin is also characterised by sulphur balls, lost into the port during unloading from vessels. Sulphur balls were also evident along a road verge near Stations 15 and 17.

The other notable change, albeit over the longer-term, is the re-growth of vegetation on soil near the pool like area in the western part of the 600 Berth Basin. A pool like area in this part of the port was created during the development of the 600 Berth Basin in the 1990's. In the mid 2000's, the pool like area was sealed by a berm and enlarged to facilitate the construction of caissons for the development of Berth 306 at the Richards Bay Coal Terminal. The surrounding land area was cleared of vegetation at the time. The berm was subsequently removed to float the caissons to Berth 306. Soil samples collected at eight stations near the basin (Figure 1) in 2008 by the CSIR (CSIR, unpublished data), when the caissons had been floated and the area was still largely devoid of vegetation, had a variable grain size composition. At six stations the soil was comprised largely of mud sized material but with an appreciable contribution of medium- and fine-grained sand. The soil at Stations 6 and 7 was comprised largely of medium-grained sand but with an appreciable contribution of fine-grained sand. The regrowth of vegetation has thus not had a major effect on the grain size of surface soil in the area.

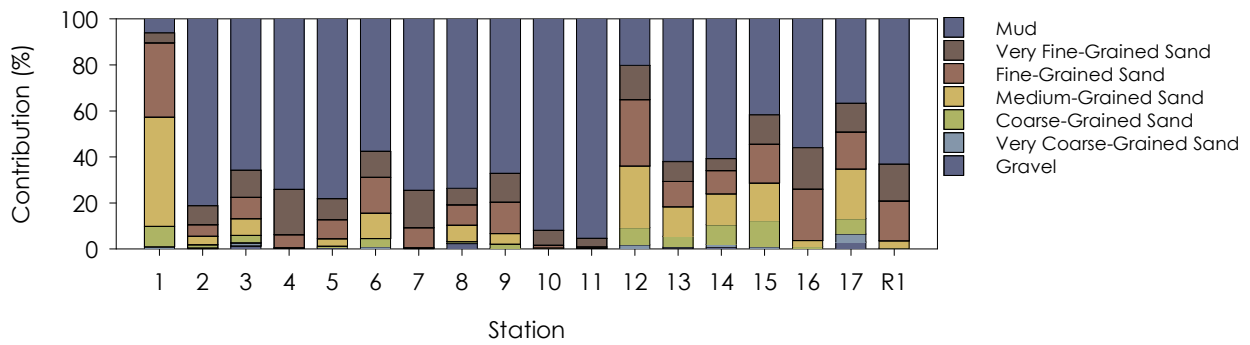


Figure 2. Contribution of various grain size classes to the bulk weight of sediment and soil sampled in and near the 600 Berth Basin in the Port of Richards Bay in November 2024.

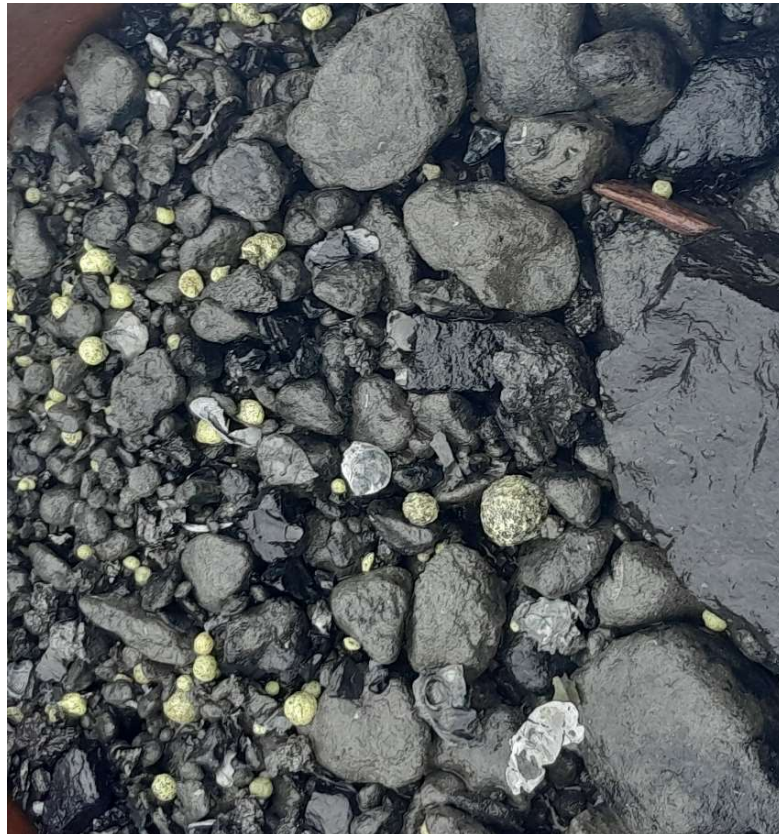


Plate 1. Coal fragments, sulphur balls (yellow-coloured objects) and other debris in sediment sampled near the quay wall in the 600 Berth Basin in the Port of Richards Bay in November 2024.



Plate 2. Sediment sampled at Station 6 (left) and Station 9 (right) in the 600 Berth Basin in the Port of Richards Bay in November 2024. Note the dark colour of the sediment, presumably imparted by coal particles and dust.

3.2. Total organic content

Particulate organic matter provides an additional site for the adsorption and sequestering of contaminants in sediment, including metals such as cadmium and mercury and polycyclic aromatic hydrocarbons. Metals and other contaminants that are particle reactive attach to and are transported with suspended particulate organic matter in the water column, ultimately settling and accumulating in depositional zones. Due to its fine-grained nature, particulate organic matter is deposited on and winnowed from sediment concurrently with mud depending on the prevailing current regime. Mud and particulate organic matter tend, therefore, to accumulate in or be depleted from sediment in the same areas. The total organic content of sediment thus provides important information for identifying major sources of, and depositional zones for particulate organic matter in the Port of Richards Bay and therefore, for identifying parts of the port that are susceptible to the accumulation of contaminants that adsorb onto this matter. The total organic content is also monitored to identify if sediment is so enriched with particulate organic matter that its exposure during dredging may result in an excessive oxygen demand by microorganisms that degrade the organic matter. Dissolved oxygen is a fundamental requirement for the survival of most forms of aquatic life. An excessive oxygen demand has obvious ecological concerns.

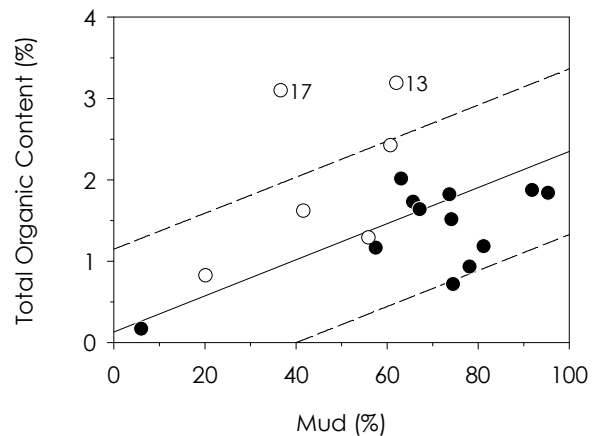


Figure 3. Baseline model for total organic content in sediment in the Port of Richards Bay, with the total organic content in sediment and soil sampled in and near the 600 Berth Basin in November 2024 superimposed. Selected data points are highlighted by station identifiers.

In aquatic ecosystems where the sediment is not enriched with particulate organic matter from anthropogenic sources, there is often a strong positive relationship between the mud fraction and total organic content of the sediment due to the similar deposition and winnowing from sediment of these particles by currents. The relationship is beneficial since it can be used to identify sediment that has an anomalous total organic content. Scientists from the Coastal Systems and Earth Observation research group of the CSIR have defined a baseline model for the total organic content of sediment in the Port of Richards Bay using the results from previous monitoring and research (Figure 4). The total organic content analysis was done using the hydrogen peroxide method and is thus only suitable for interpreting the total organic content of sediment analysed using the same method. The baseline model comprises a linear regression and 99% prediction limits (oblique solid and dashed lines respectively in Figure 4).

The regression defines the average total organic content at co-occurring mud fractions in sediment at baseline locations in the Port of Richards Bay, while the upper and lower prediction limits define the range around the average in which 99% of measurements should fall if the sediment is not enriched with particulate organic matter and the data are normally distributed. A total organic content that plots above the upper prediction limit indicates the sediment has a total organic content above the baseline and is thus deemed to be enriched with particulate organic matter. The magnitude of the enrichment was quantified by calculating an Enrichment Factor. An Enrichment Factor ≤ 1 indicates the total organic content is lower than the amount predicted at the upper prediction limit of the baseline model and is thus within the baseline range while an Enrichment Factor > 1 indicates the total organic content is above the amount expected for baseline sediment at the corresponding mud fraction in the sediment sample. An Enrichment Factor of two, for example, means the total organic content is twice as high as the total organic content predicted in baseline sediment with the corresponding mud fraction.

Superimposing the total organic content measured in sediment and soil sampled in and near the 600 Berth

Basin in November 2024 onto the baseline model identifies the sediment at none of the stations in the basin as enriched with particulate organic matter, but the soil at Stations 13 and 17 near the basin is identified as enriched to a low magnitude (Figure 3; data in Appendix 4).

The findings of the sediment survey are both consistent with and different to the findings of earlier sediment surveys in the 600 Berth Basin (CSIR, unpublished data) in that sediment in parts of the basin has been identified as enriched by particulate organic matter in some surveys, although more often than not as not enriched. Izegaegbe *et al.* (2023) provide a graph that shows an average total organic content of a little <4% for sediment sampled at a station in the 600 Berth Basin in eight quarterly surveys in 2017-2018. The sediment would, on average, be interpreted as slightly enriched with particulate organic matter at the average grain size provided using the baseline model. Mehlhorn *et al.* (2022) used a loss on ignition (high heat combustion) method to measure the total organic content of sediment sampled at four stations in the 600 Berth Basin in 2018. The total organic content measured by this more 'aggressive' method was higher than that measured using the hydrogen peroxide method in surveys by the CSIR and cannot be interpreted by comparing the measured content to the baseline model. The relationship between the total organic content and mud fraction of the sediment analysed by Mehlhorn *et al.* (2022) showed that the sediment at none of the stations was enriched with particulate organic matter. Malan and Clarke (2021) also used a loss on ignition method to measure the total organic content of sediment sampled in the 600 Berth Basin in 2022. The relationship between the total organic content and mud fraction measured in the sediment is very weak and cannot be used to identify sediment with an anomalous total organic content. However, there was no clear evidence the sediment was enriched. As stated above, the most notable recent change in the 600 Berth Basin benthic environment is the accumulation of coal fragments, particles and dust in the sediment, reflecting losses during the loading of coal onto vessels and wind and surface runoff erosion from coal stockpiles near the basin. Some of the organic content measured in the sediment by Malan and Clarke (2021) using the loss on ignition method will reflect the presence and combustion of coal particles in the sediment.

As also stated above, in the mid 2000's the pool like area at the western end of the 600 Berth Basin was sealed and excavated to facilitate the construction of caissons for the development of Berth 306 at the Richards Bay Coal Terminal. The total organic content of soil sampled at eight stations near the basin by the CSIR in 2008, when the area was largely devoid of vegetation, was between 0.40-1.76% (median = 0.73%). In comparison, the total organic content of soil sampled in 2024 was between 0.82-3.19% (median = 2.02%). The area is now (in parts densely) vegetated, which has clearly had an influence on the particulate organic matter content of the surficial soil.

3.3. Metals

It is easy to identify if sediment and soil is contaminated by some chemicals since they are not found naturally in the environment, but are manmade. The mere presence of these chemicals indicates sediment and soil is contaminated. Identifying if sediment and soil is metal contaminated is more complicated because metals are a ubiquitous, naturally occurring component of sediment and soil. The mere presence of metals in sediment and soil does not thus automatically imply it is metal contaminated. Metal concentrations in uncontaminated sediment and soil can vary naturally by several orders of magnitude over a relatively small spatial scale depending on the sediments and soils mineralogy, granulometry and organic content amongst other factors (Loring and Rantala, 1992; Kersten and Smedes, 2002). High metal concentrations in sediment and soil do not imply contamination, but might simply reflect the mineralogy of the parent material and its grain size and organic content. As a further complication, despite input and transport dissimilarities, in aquatic systems naturally occurring and anthropogenically introduced metals tend to accumulate in the same areas (Hanson *et al.*, 1993). As a result of these complexities, an identical metal concentration in two sediment samples from the same aquatic system may reflect contamination in one instance but not the other, because of a difference in the grain size and organic content of the sediment. A low metal concentration might reflect contamination, but a higher concentration might not for the same reason.

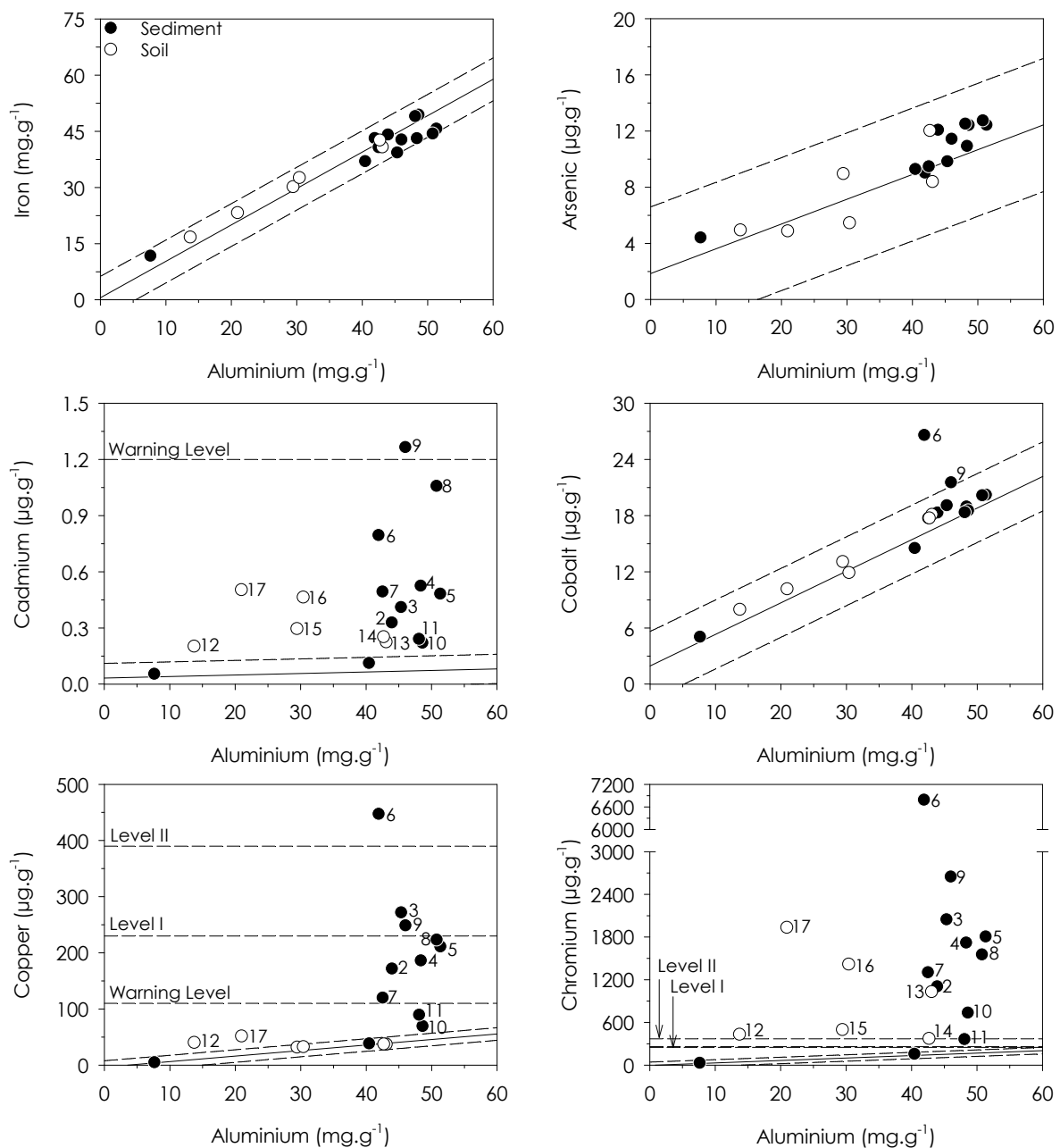


Figure 4. Baseline metal concentration models for sediment in the Port of Richards Bay, with metal concentrations in sediment and soil sampled in and near the 600 Berth Basin in November 2024 superimposed sampled. Action Levels used by the Department of Forestry, Fisheries and the Environment to decide if sediment identified for dredging in South African ports is suitable for open water disposal are included if they fall within the y-axis range. Some metal concentrations are highlighted by station identifiers.

To meaningfully interpret metal concentrations in sediment and soil it is necessary to compensate for factors that control their natural variation before background or baseline concentrations can be differentiated from enriched concentrations, which might reflect contamination. This is usually accomplished by the procedure of geochemical normalisation, wherein metal concentrations are mathematically normalised to a co-occurring conservative element in the sediment and soil that provides a tracer of crustal decomposition (Hanson *et al.*, 1993; Kersten and Smedes, 2002). The purpose of geochemical normalization is to compensate for the variables that influence the natural variation of metal concentrations in sediment and soil (principally grain size) such that after normalization concentrations in equally contaminated or uncontaminated sediment and soil with a different granulometry do not differ significantly (Kersten and Smedes, 2002).

Scientists from the Coastal Systems and Earth Observation research group of the CSIR have defined baseline models for 14 metals in sediment in South African ports. The models define the range in baseline concentrations that can be expected in sediment according to its grain size. The procedure used to define the baseline models is too voluminous to discuss in this report. Briefly, metal concentrations were plotted against aluminium concentrations and a simple linear regression and associated 99% prediction limits were fitted to the data. Metal concentrations that fell outside the prediction limits were deemed outliers and trimmed, starting with the concentration with the largest residual, reiterating the regression, and proceeding in this way until all concentrations fell within the prediction limits. The models represent baseline rather than background concentrations since some concentrations that define the models may (and probably do) reflect low magnitude contamination of sediment considering the sediment was sampled in a port. It is not possible to perfectly discriminate between background and contaminated sediment in areas where there is an anthropogenic influence.

The baseline models for the Port of Richards Bay are provided in Figure 4, with aluminium normalised metal concentrations measured in sediment and soil sampled in and near the 600 Berth Basin in November 2024 superimposed (data in Appendix 5). Aluminium was used as the normaliser of metal concentrations since it (a) is highly refractory, (b) is structurally combined to the major metal-bearing phases of sediment and soil, (c) co-varies in proportion to naturally occurring concentrations of other metals in sediment and soil, (d) is insensitive to inputs from anthropogenic sources, and (e) is stable and not subject to environmental influences such as reduction/oxidation, adsorption/desorption and other diagenic processes that may alter its concentration in sediment. Aluminium is used as a proxy for the granulometric variation of sediment, and more specifically the variation in the silt and clay (mud) fraction. A potential limitation to the use of aluminium as a normaliser of metal concentrations in sediment in the Port of Richards Bay is the presence of aluminium smelters nearby and the importing of alumina through the port as a feedstock for the smelters. The aluminium concentration in sediment and soil sampled in and near the 600 Berth Basin in November 2024 was very strongly positively correlated ($r = 0.955$, $p < 0.001$) to the mud sized fraction of the sediment and soil. The use of aluminium as the normaliser of metal concentrations in sediment and soil in and near the port is thus not only founded on valid geochemical principles but also shows the sediment and soil is not significantly contaminated by aluminium. Mehlhorn *et al.* (2024) provide a discussion on the benefits and limitations of using different physical and geochemical normalisers, and using the normalisers in isolation for interpreting metal concentrations in sediment in the Port of Richards Bay.

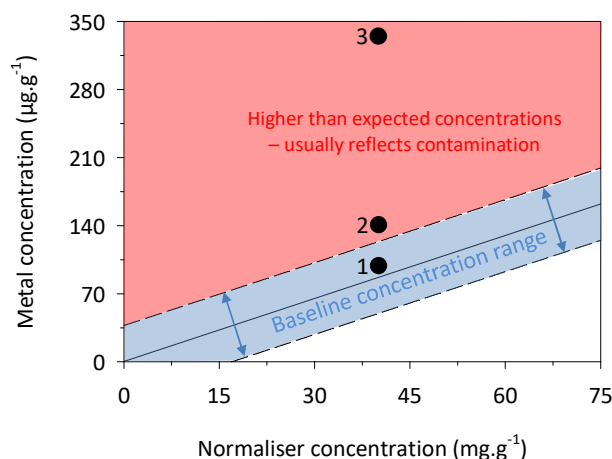


Figure 5. Schematic of a baseline metal concentration model. The oblique solid line and flanking dashed lines are the linear regression and upper and lower 99% prediction limits respectively. The prediction limits define the baseline concentration range for a metal in sediment at any co-occurring aluminium concentration (blue shaded area). If a metal concentration falls within the prediction limits, as is the case for hypothetical concentration 1, then the metal is present at a baseline concentration (not contaminated). If a metal concentration falls above the upper dashed line (i.e. upper prediction limit), as is the case for hypothetical concentrations 2 and 3, then the metal is present at an enriched concentration. Hypothetical metal concentration 2 is only slightly higher than the upper prediction limit and reflects a low degree of contamination. Hypothetical metal concentration 3 far exceeds the upper prediction limit and represents a much higher degree of contamination.

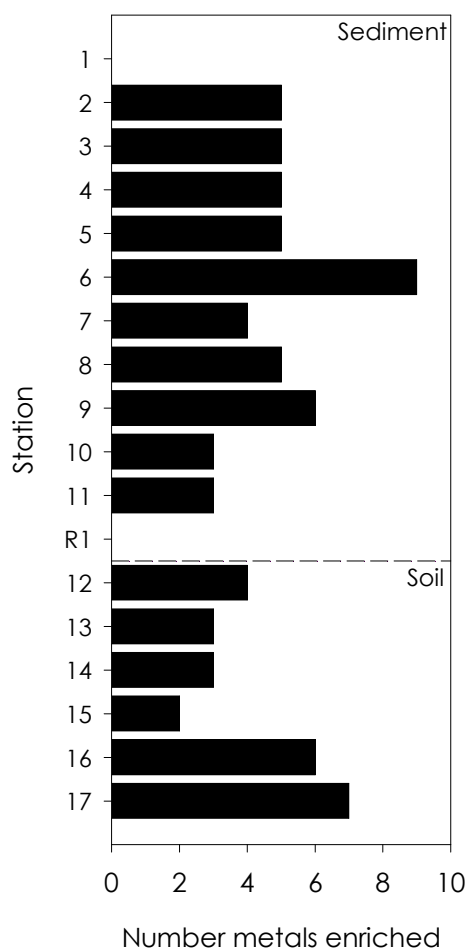


Figure 6. The number of metals enriched in sediment and soil sampled in and near the 600 Berth Basin in the Port of Richards Bay in November 2024.

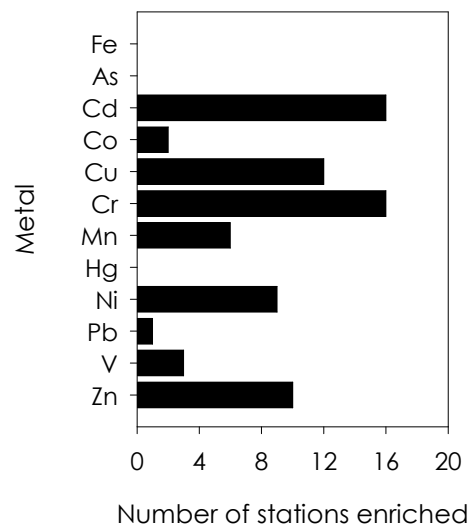


Figure 7. The number of stations in the Port of Richards Bay where the sediment and soil sampled in and near the 600 Berth Basin was enriched by various metals in November 2024.

As stated above, the baseline models comprise a regression line and upper and lower 99% prediction limits (oblique solid and dashed lines in Figures 4 and 5). The regression line defines the average concentration for a metal at co-occurring aluminium concentrations in sediment at baseline locations in the port, while the upper and lower prediction limits define the range in which 99% of the concentrations should fall if the sediment is not enriched by the metal and the concentrations that were used to define the model are normally distributed. Metal concentrations that plot above the upper prediction limit when superimposed onto a baseline model are above the baseline concentration range and indicate the sediment is enriched by the metal (see Figure 5). In other words, the concentration is higher than expected for the sediment in question. A concentration that is above the baseline does not imply it was enhanced by an anthropogenic contribution (*i.e.* reflects contamination), but rather that it is atypical of the data that were used to define the baseline model. Several reasons other than an anthropogenic contribution can result in a metal concentration being above the baseline. These include analytical variability and errors, poor baseline model assumptions, the probability that metal concentrations in some samples will naturally be higher than the upper prediction limit (in a normally distributed population, at the 99% prediction limit one in every 100 concentrations could conceivably naturally be above the upper prediction limit), and natural enrichment that is not captured by the baseline data set (Schropp *et al.*, 1990; Rae and Allen, 1993).

The interpretation of whether metal enrichment reflects contamination thus requires the consideration of ancillary factors, including biogeochemical processes that may naturally lead to the enrichment of certain metals in sediment, the absolute difference between a metal concentration and the upper prediction limit of the baseline model, the location of enriched sediment or soil relative to known or strongly suspected anthropogenic sources of metals, and the number of metals in a sediment or soil sample that are present at

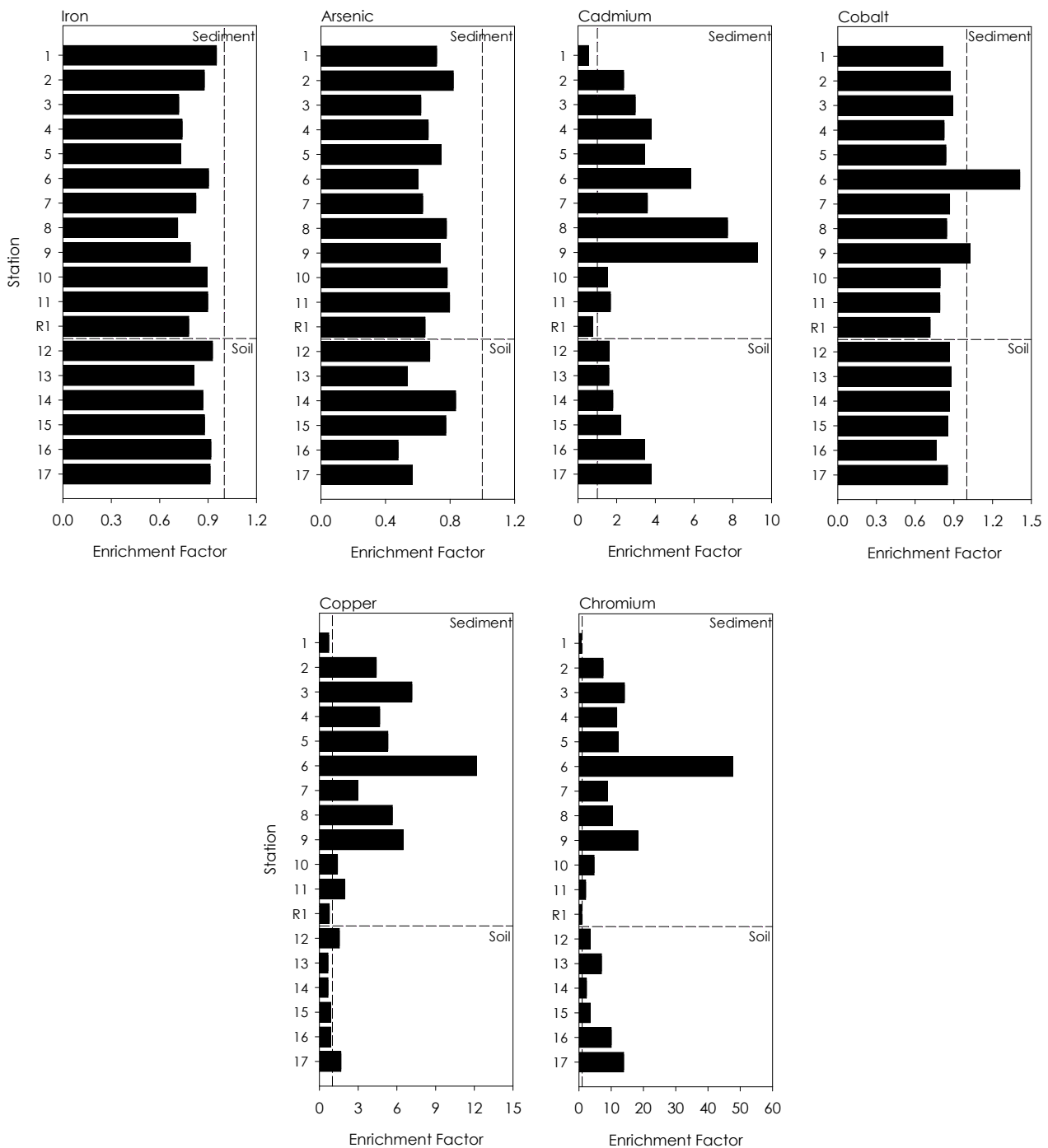


Figure 8. Enrichment Factors for metals in sediment and soil sampled in and near the 600 Berth Basin in the Port of Richards Bay in November 2024. The dashed lines represent an Enrichment Factor = 1. An Enrichment Factor >1 indicates the metal was at a concentration above the baseline and may indicate contamination.

a concentration above the upper prediction limit. The larger the difference between a metal concentration and the upper prediction limit (see Figure 5) and the greater the number of metals that are enriched in a sediment or soil sample the more likely this reflects contamination. This is because the sediment and soil in ports and urban areas is usually contaminated by several metals rather than a single metal, particularly if the anthropogenic sources are diffuse (*e.g.* stormwater runoff, atmospheric deposition). This said, the enrichment of sediment or soil by a single metal could occur in areas where metal ores are exported and there are few other significant anthropogenic sources of metals. However, even in these cases other metals are usually enriched in the sediment or soil as they are impurities of metal ores, and because there are invariably other metal sources such as those leached from vessel hulls and machinery used to load vessels.

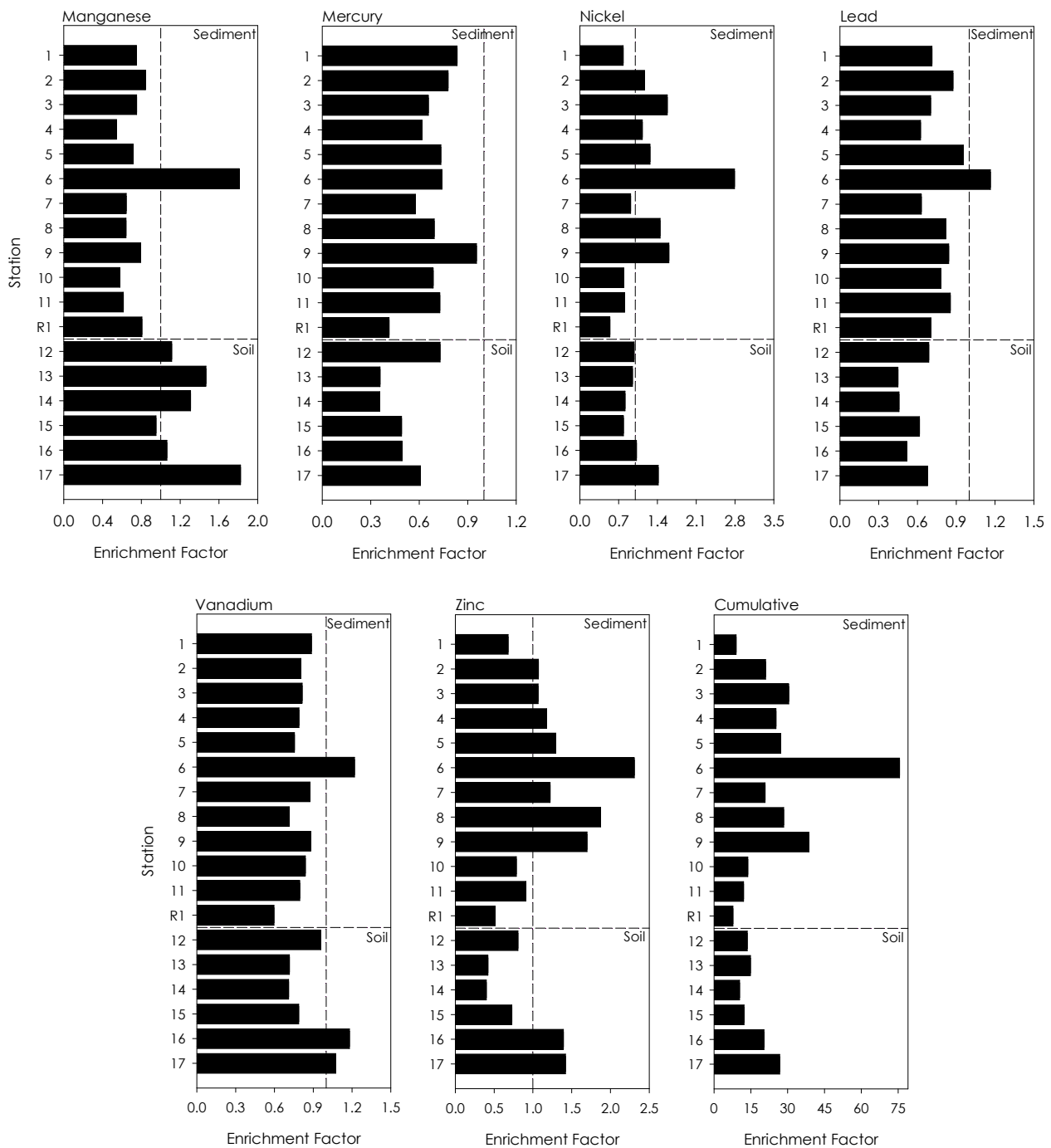


Figure 8 continued. Enrichment Factors for metals in sediment and soil sampled in and near the 600 Berth Basin in the Port of Richards Bay in November 2024. The dashed lines represent an Enrichment Factor = 1. An Enrichment Factor >1 indicates the metal was at a concentration above the baseline and may indicate contamination.

The concentrations of most metals in the sediment and soil sampled at most stations in and near the 600 Berth Basin in the Port of Richards Bay in November 2024 fall within baseline model prediction limits, that is, they are within the baseline range for sediment (and presumably also soil) in the area (Figure 4). The concentrations of one or more metals in the sediment and soil at each station were nevertheless above the baseline apart from Station 1 and the Reference station, where no metals were above the baseline. The sediment with the highest number of metals (nine) present at a concentration above the baseline was at Station 6 (Figures 4 and 6). Five or six metals were present at a concentration above the baseline in the sediment at most other stations. The soil with the highest number of metals (seven) present at a concentration above the baseline was at Station 17 (Figures 4 and 6). Six metals in the soil at Station 16 and two to four metals in the soil at other stations were present at a concentration above the baseline.

Cadmium and chromium were the most often enriched metals, present at a concentration above the baseline at each sediment and soil station apart from sediment at Station 1 in the 600 Berth Basin and at the Reference station in the Richards Bay Coal Terminal Basin (Figure 7). Copper was present at a concentration above the baseline at ten of the 11 sediment stations and at two of the six soil stations. Zinc was present at a concentration above the baseline at eight of the 11 sediment stations and at two of the six soil stations. Cobalt, manganese, lead and vanadium were present at a concentration above the baseline in the sediment at one or two stations, but never in soil. The sediment at most stations in the basin and in soil at all stations near the basin was thus metal enriched.

Interpreting metal contamination of sediment or soil by simply counting the number of metals present at a concentration above the baseline provides useful information because, as stated above, the sediment in ports is usually contaminated by more than one metal. The greater the number of metals at a concentration above the baseline the more likely this reflects contamination. However, a count of the number of metals at a concentration above the baseline does not contextualise by how much the concentrations were above the baseline. There are only two possibilities in following this approach, namely the sediment or soil is either identified as metal enriched or as not enriched. The same weight is thus given to sediment or soil that is enriched by the same number of metals, but the magnitude of the enrichment may be very different and thus have very different toxicological and management implications. To contextualise the magnitude of enrichment, an Enrichment Factor (EF) was computed for each metal concentration. The metal concentrations were first adjusted to the average aluminium concentration for the baseline model data, using the model parameters. The purpose was to avoid the computation of anomalous Enrichment Factors caused by the baseline models not having a zero intercept or a slope of unity, which leads to ratio distortion (variability) across the normaliser range. The Enrichment Factor was then taken as the ratio between the metal concentration in a sediment or soil sample and the concentration predicted at the baseline model upper prediction limit at the corresponding aluminium concentration. The upper prediction limit of the baseline models was thus used to discriminate between metal enriched and non-enriched sediment.

An Enrichment Factor ≤ 1 indicates the metal concentration is lower than the concentration predicted at the upper prediction limit of a baseline model and thus falls within the baseline range, while an Enrichment Factor > 1 indicates the metal concentration is higher than the concentration expected in baseline sediment at the corresponding normaliser concentration. An Enrichment Factor = 2, for example, means the metal concentration is twice as high as the concentration predicted for sediment or soil with the same aluminium concentration.

As expected from the comparison of metal concentrations in the sediment and soil sampled in and near the 600 Berth Basin in November 2024 to the baseline models (Figure 5), the Enrichment Factors for most metals in most sediment and soil samples were ≤ 1 (Figure 8). The Enrichment Factors for one or more metals in the sediment and soil at numerous stations were nevertheless > 1 , in some cases considerably > 1 . The highest Enrichment Factor was 47.7 for the chromium concentration in sediment at Station 6, followed by 18.3 for the chromium concentration in sediment at Station 9, 14.1 for the chromium concentration in sediment at Station 2 and 13.9 for the chromium concentration in soil at Station 17 (Figure 8). In the opinion of scientists from the Coastal Systems and Earth Observation research group of the CSIR these Enrichment Factors are indicative of high or severe metal contamination. However, there is no universally accepted rating system for ranges of Enrichment Factor values. The highest Enrichment Factor for other metals was 12.2 for the copper concentration in sediment at Station 6, 9.3 for the cadmium concentration in sediment at Station 9, 3.8 for the nickel concentration in sediment at Station 6 and 2.3 for the zinc concentration in sediment at Station 6 (Figure 8). The Enrichment Factors were typically higher for sediment than for soil.

The Cumulative Enrichment Factor, which is the sum of the Enrichment Factors for all metals in the sediment or soil at a station provides additional understanding on metal enrichment of sediment and soil. From this

perspective the most metal contaminated sediment was at (in order) Stations 6, 9, 8 and 3, while the most metal contaminated soil was at Stations 17 and 16 (Figure 8).

The findings of the sediment survey are consistent with the findings of earlier sediment surveys in the 600 Berth Basin. In annual surveys over the last 25 years, including a survey earlier in 2024, the CSIR (unpublished data) has regularly identified metal contamination of sediment in the basin, most significantly by cadmium, copper and chromium, but also by other metals (e.g. nickel, zinc). The chromium enrichment of sediment evident at several stations in the 600 Berth Basin in November 2024 was, however, somewhat higher than that evident in recent surveys. Mehlhorn *et al.* (2021) identified cadmium, copper, chromium, nickel and zinc contamination of sediment sampled in the basin in 2018. A reinterpretation of average metal concentrations provided by Izegaegbe *et al.* (2023) for a station sampled in eight seasonal surveys in the basin in 2017 and 2018 suggests the sediment was contaminated by copper, chromium, nickel and zinc. Malan and Clarke (2023) identified cadmium, copper and nickel as contaminants of sediment sampled in the basin in 2022, but not chromium. The reason chromium was not identified as a contaminant of sediment by Malan and Clarke (2023) is interesting in the light of the findings of other surveys, which as stated above regularly identified chromium as a contaminant of sediment in the basin. The cadmium concentrations reported by Malan and Clarke (2023) were generally considerably higher than those reported in earlier surveys.

Copper and chromium, and to a lesser degree cadmium were also widespread and significant contaminants of sediment in the neighbouring 700/800 Berth Basin in earlier surveys (including a survey earlier in 2024). Indeed, records as far back as 1983 (CSIR, unpublished data) reveal that sediment in the 700/800 Berth Basin was significantly contaminated by copper and especially chromium – the 600 Berth Basin had not been developed at the time. The source of the copper and chromium thus appears to be shared amongst the 600 and 700/800 Berth Basins and/or there are hydrodynamic processes that promote their accumulation in sediment in the basins if they were not directly input from vessel loading operations. As discussed elsewhere in this report, the source of the excess chromium in the sediment undoubtedly reflects the loss of ferrochrome particles and chromite sand into the port. Copper concentrate was historically exported through the port, but this practice ceased in about 2012. The loss of copper concentrate particles during vessel loading may have accounted for the copper contamination of sediment evident in the port at and before 2012, and for a period thereafter as copper contaminated sediment was gradually removed by maintenance dredging. As stated above, copper remains a significant contaminant of sediment in the 600 and 700/800 Berth Basin. Whether this reflects a residual impact of the historical export of copper concentrate is uncertain but is difficult to explain in the light of ongoing maintenance dredging that will have removed copper contaminated sediment from the port over time. There are no other obvious sources of copper in or to the port that appear to account for the often-severe copper contamination of sediment by this metal in the 600 and 700/800 Berth Basins, yet infrequent and low magnitude contamination, or absence of contamination of sediment in other parts of the port.

Table 1. Action List used by the Department of Forestry, Fisheries and the Environment to decide if sediment identified for dredging in South African ports is suitable for open water disposal. Concentrations are in $\mu\text{g.g}^{-1}$ dry weight.

Chemical	Warning Level	Level I	Level II
Arsenic	42	57	93
Cadmium	1.2	5.1	9.6
Chromium	135 ^a /250 ^b	260	370
Copper	110	230	390
Mercury	0.43	0.84	1.5
Nickel	62 ^a /88 ^a	140	370
Lead	110	218	530
Zinc	270	410	960

a - for Eastern and Western Cape, b - for KwaZulu-Natal

Apart from manganese, minimal amounts of metals are leached from South African coal immersed in seawater (Cabon *et al.*, 2007). Coal particles and dust has accumulated in sediment in the 600 Berth Basin and elsewhere in the port is not thus expected to contribute metals. This conclusion is supported by the absence or low magnitude metal contamination of sediment in the Richards Bay Coal Terminal Basin.

The metal contamination of sediment in the 600 Berth Basin was anticipated based on the findings of earlier surveys, as discussed above. However, the

metal contamination of soil near the basin was not anticipated, at least not to the magnitude evident for some metals (*e.g.* chromium). A survey of metal concentrations in soil sampled at eight stations near the 600 Berth Basin in 2008 by the CSIR (CSIR, unpublished data; see Figure 1 for station positions) revealed the soil at many or all stations was contaminated by arsenic and cadmium, but not by other metals. The difference between the 2008 and 2024 surveys was thus pronounced for numerous metals. Based on the difference and the difficulty in accounting for the contamination increases for some metals, a magnet was used to identify if metal particles and fragments were present in the soil at one station. A large amount of material was attracted to the magnet, which might account for some of the elevated metal concentrations in the soil. However, the material may also reflect the presence of magnetite, which occurs naturally in soil in the Richards Bay area and is also exported through the port. A more detailed analysis is required to identify the composition of the material (*e.g.* by X-ray diffraction) but is beyond the scope of this study.

It is important to note that the bulk of the sediment and most of the soil that will be dredged and excavated for the development of Berth 605 and disposed in open water off Richards Bay has not been exposed during the Anthropocene and will thus not be contaminated by metals or other chemicals. Available information suggests the contamination of sediment in the basin is restricted to a depth of ~20-30 cm.

3.4. Comparison of metal concentrations to Action List

As discussed above, in terms of section 71(1) of the National Environmental Management Act: Integrated Coastal Management Act, the open water disposal of dredged material requires a permit from the Minister of the Department of Forestry, Fisheries and the Environment. The aim of the permitting is to manage the impacts posed by the disposal of contaminated sediment in the receiving environment. The Department of Forestry, Fisheries and the Environment uses an Action List (sediment quality guidelines) to decide if sediment that is identified for dredging in South African ports is suitable for open water disposal. However, there are only Action Levels for metals. There are three Action Levels, known as the Warning Level, Level I and Level II (Table 1). The Warning Level provides a warning of incipient metal contamination of sediment but is not used for decision-making. Sediment with metals at a concentration below the Level I is not considered to pose a hazard to benthic biological resources and is suitable for open water disposal. Sediment with metals at a concentration between the Level I and Level II is cause for concern to benthic biological resources, the degree of concern increasing as the metal concentrations approach the Level II. Decisions on the suitability of the sediment for open water disposal are made after considering the number of metals at a concentration above the Level I and by how much each concentration is above the level. The Department may request further testing to identify if metals in the sediment pose a toxic hazard to benthic biological resources. Sediment with metals at a concentration above the Level II is considered to pose a high hazard to benthic biological resources. The sediment is unsuitable for open water disposal unless other evidence (*e.g.* toxicity testing) shows the metals are not posing a toxic hazard due, for example, to their incorporation in metal flecks, metal-impregnated paint flakes, metal ores in the sediment, and the entire concentration is thus not in a bioavailable form.

The Action Levels are used to identify sediment identified for dredging in ports is suitable for open water disposal. However, the Action Levels are used in this study to also identify if metal concentrations in soil, which will also be disposed in open water at the dredged spoil disposal site off Richards Bay, may also present a toxic risk.

The number of metals that were present in sediment and soil sampled in and near the 600 Berth Basin in November 2024 at a concentration above the Warning Level, Level I and Level II is provided in Figures 9 and 10 (see also Figure 4). The concentration of chromium in the sediment and soil at all stations apart from sediment at Station 1 and the Reference Station, cadmium in the sediment at one station, copper in the sediment at eight stations, and nickel in the sediment at one station were above the Warning Level.

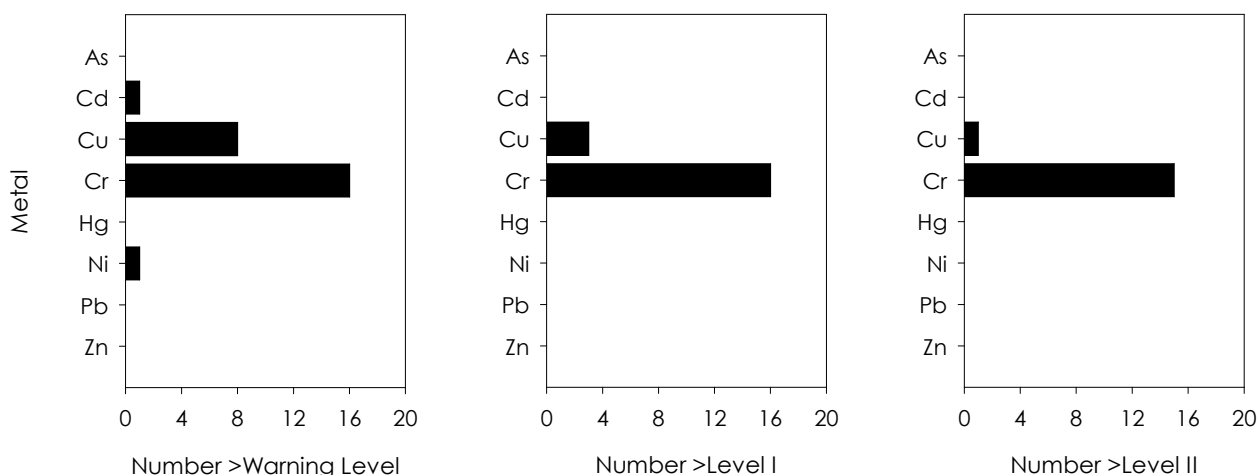


Figure 9. The number of stations at which the concentrations of metals in sediment and soil sampled in and near the 600 Berth Basin in Richards Bay in November 2024 that were above the Warning Level, Level I and Level II of the Action List used by the Department of Forestry, Fisheries and the Environment to decide if sediment identified for dredging in South African ports is suitable for open water disposal.

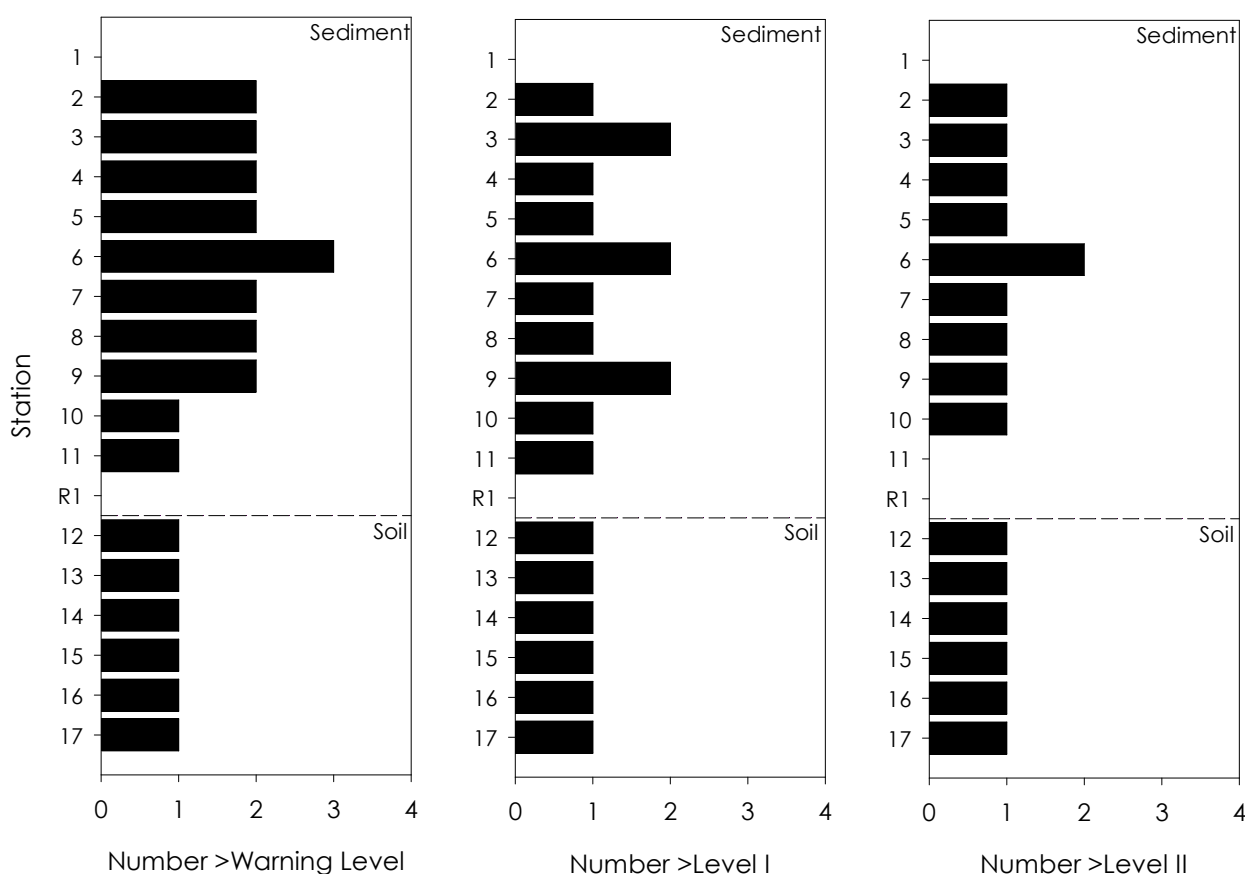


Figure 10. The number of metal concentrations in sediment and soil sampled in and near the 600 Berth Basin in the Port of Richards Bay in November 2024 that were above the Warning Level, Level I and Level II of the Action List used by the Department of Forestry, Fisheries and the Environment to decide if sediment identified for dredging in South African ports is suitable for open water disposal.

The chromium concentration in the sediment or soil at the above stations was also above the Level I, and at 15 of the stations was also above the Level II. The copper concentration in the sediment at three stations was above the Level I, and at one of these stations was also above the Level II (Figures 9 and 10).

The finding of chromium and copper concentrations above Action Levels is consistent with the findings of earlier sediment surveys in the 600 Berth Basin. The CSIR (unpublished data) regularly measured metal concentrations (notably copper and chromium) in sediment sampled in the basin that were above the Level

I and Level II in annual surveys over the last 25 years. Indeed, records as far back as 1983 (CSIR, unpublished data) reveal that the copper concentration in one sediment sampled the 700/800 Berth Basin was above the Level I and at two stations was above the Level II. The copper concentration measured in sediment at one of the two stations sampled in the 600 Berth Basin in an earlier survey in 2024 was above the Level I while the chromium concentration measured in the sediment at both stations was above the Level II. The copper concentration measured in the sediment at two of the four stations sampled in the 600 Berth Basin by Mehlhorn *et al.* (2021) in 2018 was above the Level I, while the chromium concentration measured in the sediment at one of the stations was above the Level I and at two other stations was above the Level II. Izegeagbe *et al.* (2023) provide average metal concentrations in sediment sampled at a station in the 600 Berth Basin in eight surveys in 2017-2018. The average ($\pm$ standard deviation) chromium concentration was $308 \pm 152 \mu\text{g.g}^{-1}$, which is above Level I. The wide standard deviation suggests at least some of the chromium concentrations were above the Level II. The copper concentration measured in the sediment sampled at two of five stations in the 600 Berth Basin by Malan and Clarke (2023) in 2022 was above the Level I.

In the absence of other information, the chromium and copper concentrations above the Level II in the sediment and soil sampled in and near the 600 Berth Basin in November 2024 are interpreted as posing a high toxic hazard to benthic biological resources and hence that the sediment and soil is unsuitable for open water disposal. A limitation of Action Levels, however, is that they assume the entire concentration of chemicals in sediment (and by implication soil) is in a bioavailable form. However, this is not necessarily the case—and is in fact invariably not the case. Many chemicals in sediment are immobilised by complexation and precipitation with sulphides and iron and manganese oxides/hydroxides and/or by their adsorption onto sediment grains and particulate organic matter to form chemical-particle complexes. The complexes are generally stable and largely insoluble in the low oxygen or anoxic conditions that are usually found a few centimetres beneath the sediment surface, limiting their ability to present a toxic risk unless they are ingested by biological resources that feed by ingesting sediment and extracting organic matter from the sediment before egesting it. Action Levels (*i.e.* sediment quality guidelines) are a useful tool for screening sediment samples that require further attention but should not be used in isolation to determine the full extent of impact and hazard—an approach often followed in South Africa. Reliance on chemistry information alone may result in a type II error, or error of omission, leading to an underestimation of risk and inadequate management response for environmental protection.

Research by the Coastal Systems and Earth Observation research group of the CSIR (unpublished data) has shown that a significant proportion of, if not the entire chromium concentration in sediment in parts of the Port of Richards Bay where the sediment is characterised by high concentrations of this metal is not in a bioavailable form. The basis for this conclusion was the absence of toxicity to sea urchin embryo-larvae despite high metal (including chromium) concentrations in the sediment. The CSIR scientists concluded that the high chromium concentrations regularly measured in sediment sampled in the 600 and 700/800 Berth Basins are largely a consequence of the loss of chromite sand and ferrochrome particles into the port during vessel loading and through wind and surface runoff erosion from stockpiles on land. This conclusion was partially supported by the extraction of ferrochrome particles from the sediment by sieving. Chromite sand resembles sand in texture but is dark in colour and is not easily discernible in sediment. Although chromite sand appeared to be extracted from the sediment along with ferrochrome particles, the identity of the material was not confirmed through further analysis. Further studies in the laboratory showed that chromite sand and ferrochrome particles are insoluble in seawater and do not leach chromium into the water column.

3.5. Toxicity testing

General

Considering the above discussion on chromium, copper and nickel concentrations being above Action Level II and the conclusion on this basis that the sediment and soil is unsuitable for open water disposal, yet known limitations of Action Levels in terms of predicting toxic hazards and convincing prior evidence that metals in

the sediment were likely not in a bioavailable form intimated by their absolute concentrations, toxicity testing was performed on the sediment and soil sampled in and near the 600 Berth Basin to identify if chemicals in the sediment and soil were posing a toxic hazard.

Sediment/soil-water interface toxicity testing

A sediment/soil-water interface toxicity test was used to estimate the likelihood that chemicals will remobilised from sediment deposited at the dredged spoil disposal site into the water column at concentrations and in forms that pose a toxic hazard to biological resources.

The proportion of sea urchin embryos that developed to a normal 4-arm pluteus after 96 h exposure to sediment and soil under a sediment/ soil-water interface testing regime is provided in Figure 11. Apart from the soil sampled at Station 15, the sediment and soil samples were not identified as toxic. Toxicity was not evident sediment from the Reference station, indicating its suitability as a reference. The soil at Station 15 was identified as severely toxic, but this terminology is somewhat misleading since embryos developed to a mix of blastula, gastrula and early prism stages (Plate 3). The development of embryos and larvae was thus delayed rather than halted. The chemicals causing the delayed development ('toxicity') were thus not remobilised from the soil at a high enough concentration or in forms to cause the mortality of (all) embryos and larvae, if any. It is uncertain if the delayed development stages would have developed to a normal 4-arm pluteus if the testing period was longer.

Elutriate toxicity testing

An elutriate toxicity test was used to estimate the likelihood of chemicals being remobilised from sediment into the water column at concentrations and in forms that pose a toxic hazard to biological resources when the sediment is agitated by dredging (at dredge head and in hopper overflow water) and during its disposal in open water.

The proportion of sea urchin embryos that developed to a normal 4-arm pluteus after 96 h exposure to sediment and soil elutriates is provided in Figure 12. The elutriates were not identified as toxic apart from soil sampled at Station 15. The absence of toxicity for the sediment elutriates prepared using sediment from the Reference station shows its suitability as a reference. The raw (100%) elutriate prepared using the soil sampled at Station 15 was identified as severely toxic. As in the case for the sediment/soil-water interface test this terminology is somewhat misleading since embryos developed to a mix of blastula, gastrula and early prism stages. The development of embryos and larvae was thus delayed rather than halted. The chemicals causing the delayed development (toxicity) were thus not remobilised from the soil at a high enough concentration or in forms to cause the mortality of all embryos and larvae, if any.

The 75% elutriate for the soil sampled at Station 15 was identified as slightly toxic, but the 50% and 25% elutriates were not toxic. It is uncertain if the delayed development stages evident in the 100% and 75% elutriates would have developed to a normal 4-arm pluteus if the testing period was longer.

Implications of the toxicity testing findings

As stated above, in the absence of other information the chromium and copper concentrations above the Level II in sediment and soil in and near the 600 Berth Basin are interpreted as posing a high toxic hazard to benthic biological resources, if the Level II is considered to also be relevant to soil disposed in water. The conclusion on this basis is that the sediment and soil is unsuitable for open water disposal. However, apart from the soil at Station 15, the sediment and soil was identified as not toxic to sea urchin gametes when tested using sediment/ soil-water interface and elutriate toxicity tests. The inference is that the chromium and copper concentrations, other metals and unmeasured chemicals in the sediment and soil were in a non-bioavailable form under the testing regimes, or if they were bioavailable then they were at too low a concentration to be toxic to sea urchin embryo-larvae.

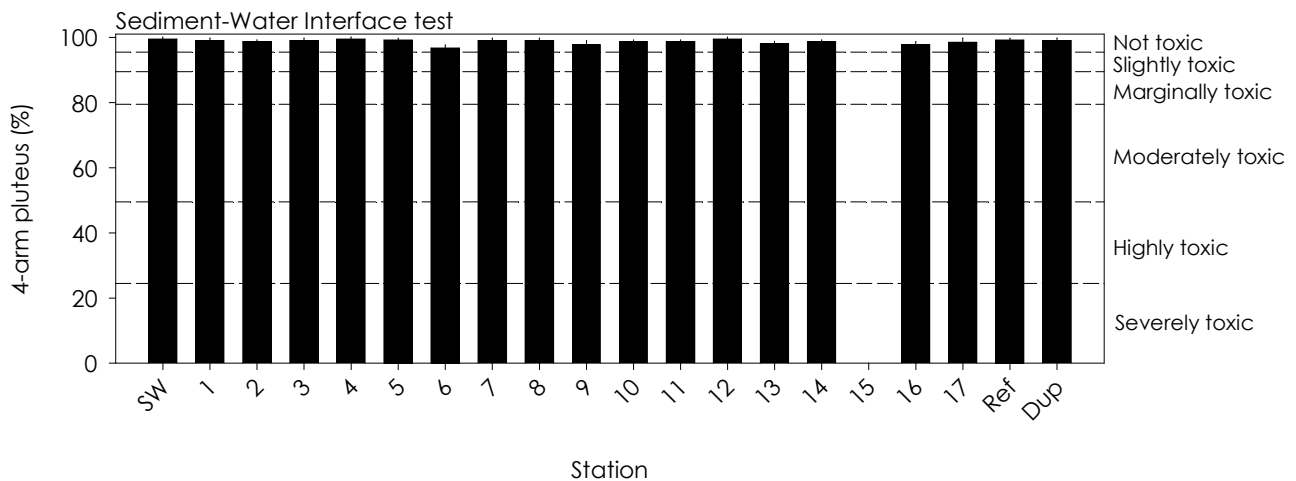


Figure 11. Proportion (mean $\pm$ standard deviation) of sea urchin (*Tripneustes gratilla*) embryos that developed to a normal 4-arm pluteus after exposure to sediment and soil sampled in and near the 600 Berth Basin in the Port of Richards Bay in November 2024 under a sediment/soil-water interface toxicity testing regime. SW = seawater control, Ref = reference sediment, Dup = duplicate.

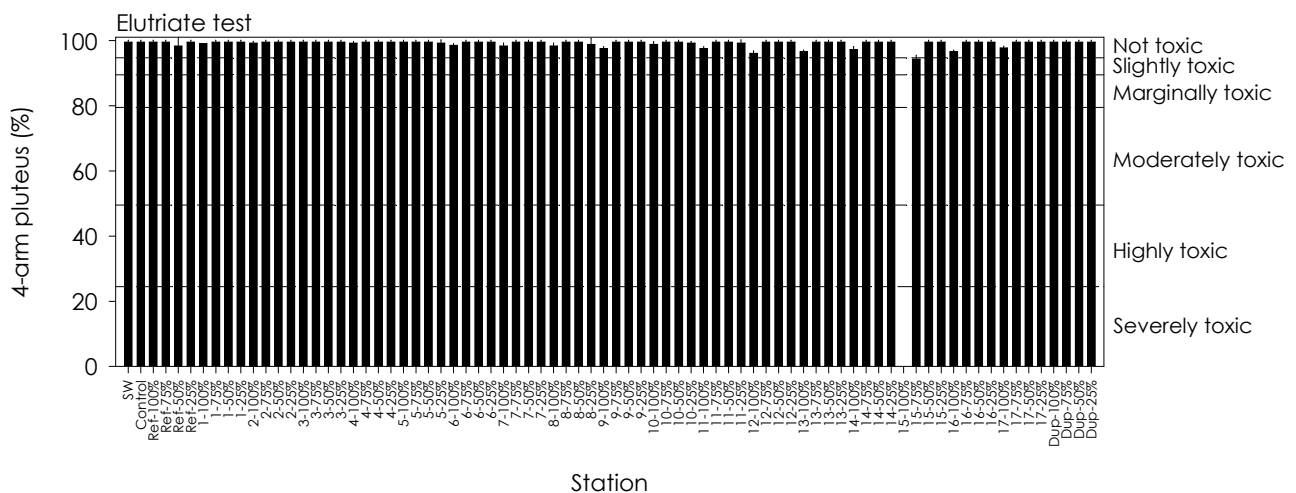


Figure 12. Proportion (mean $\pm$ standard deviation) of sea urchin (*Tripneustes gratilla*) embryos that developed to a normal 4-arm pluteus following exposure to elutriates prepared using sediment and soil sampled in and near the 600 Berth Basin in the Port of Richards Bay in November 2024. SW = seawater control, Ref = reference sediment, Dup = duplicate.



Plate 3. Development stages reached by sea urchin embryos exposed to soil elutriates for Station 15 (left) compared to development to a normal 4-arm pluteus for embryos exposed to sediment/soil elutriates for other stations (right).

Metals and other chemicals that might be present in the sediment and soil are thus unlikely to be remobilised into the water column to a degree this will pose a toxic hazard to biological resources when sediment is dredged in the 600 Berth Basin, nor from dredged sediment and soil excavated across most of the Berth 605 development footprint after it deposits on the seabed at the dredged spoil disposal site off Richards Bay.

There is a possibility there might be a toxic response when soil excavated at and near Station 15 is deposited in water or is disposed at the dredged spoil disposal site. However, only two dilutions with clean seawater were required to render the soil elutriate for this station not toxic. A far higher number (10's to 100's) of dilutions can be expected when the soil is disposed at the dredged spoil disposal site. Any toxic effect that might occur will thus be restricted to a small area at the point of disposal. It is worth noting that while the soil at Station 15 was identified as severely toxic in both toxicity tests, as discussed above this terminology is somewhat misleading since embryos managed to develop to a mix of blastula, gastrula and early prism stages. The chemicals causing the delayed development ('toxicity') were not at a high enough concentration to cause the mortality of (all) embryos.

Sea urchin embryos and larvae represent sensitive developmental stages that provide a conservative assessment of toxicity. Tests by the CSIR, for example, show that sea urchin embryos and larvae show toxic responses in samples wherein amphipods (various species) are unharmed, or at least do not experience mortality. The absence of toxicity to these life stages can be taken as inferring an absence in toxicity for later developmental stages of benthic invertebrates and other biological resources.

4. Conclusions

The sediment and soil sampled at most stations in and near the 600 Berth Basin in the Port of Richards Bay in November 2024 was metal contaminated. The most widespread and significant contaminants of the sediment were cadmium, copper and chromium and of the soil were cadmium and chromium. The chromium contamination of sediment is assumed to reflect the presence of chromite sand and ferrochrome particles that were lost into the port during vessel loading and eroded from stockpiles on land by wind and surface runoff. The source of the cadmium and copper in the sediment and soil is uncertain, but both were common contaminants of sediment in the basin in earlier surveys. Copper and chromium and to a lesser degree cadmium were also widespread and significant contaminants of sediment sampled in the 700/800 Berth Basin in earlier surveys (including one in 2024) but were rarely contaminants of sediment elsewhere in the port.

The toxicological hazard posed by metals in the sediment and soil was estimated by comparing their concentrations to Action Levels used by the Department of Forestry, Fisheries and the Environment to decide if sediment that is identified for dredging in South African ports is suitable for open water disposal. The chromium concentration in the sediment and soil at 15 stations and the copper concentration in the sediment at one station was above the Level II. At face value, the sediment and soil are unsuitable for open water disposal.

The most important finding of the survey, however, is that, apart from the soil sampled Station 15, metals and other potential chemicals in the sediment and soil were not remobilised at concentrations or in forms that were toxic to sea urchin gametes when tested using sediment/soil-water interface and elutriate toxicity tests. Only two dilutions with clean seawater were required to render the raw elutriate for the soil sample from Station 15 non-toxic. The absence of toxicity, despite the often-significant metal contamination of the sediment and to a lesser degree soil shows the metals were not bioavailable, or if they were they were at too low a concentration to be toxic to sea urchin embryo-larvae. The sea urchin embryos and larvae represent sensitive developmental stages that provide a conservative assessment of toxicity. The absence of toxicity to these life stages can be taken as inferring an absence in toxicity for later developmental stages of benthic invertebrates and other biological resources. Metals and other potential chemicals in the sediment and soil

are thus highly unlikely to be remobilised into the water column to a degree this will pose a toxic hazard to biological resources at the dredging site and when sediment and soil are disposed in open water at a dredged spoil disposal site off Richards Bay.

In conclusion, while metals and potentially other contaminants will be transported in sediment and soil to the open water dredged spoil disposal site off Richards Bay, there is no evidence to suggest that these contaminants will pose a toxic hazard to biological resources at or near the disposal site apart possibly from a minimal potential hazard when soil from one area of the development footprint is disposed. Other environmental impacts that might or will arise during dredging and the open water disposal of sediment and soil are identified and evaluated in a companion Estuarine and Marine Ecology Specialist Study for the development of Berth 605.

5. References

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6. Appendices

Appendix 1

Global Positioning System coordinates of stations where sediment and soil were sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024.

Station	Latitude	Longitude
1	-28.796754	32.032949
2	-28.795376	32.033858
3	-28.794198	32.034616
4	-28.795205	32.030652
5	-28.794024	32.031202
6	-28.793538	32.031994
7	-28.793870	32.027965
8	-28.792570	32.029027
9	-28.791974	32.029640
10	-28.792872	32.026465
11	-28.791953	32.027143
12	-28.793658	32.026991
13	-28.792852	32.025319
14	-28.791346	32.025960
15	-28.789923	32.026379
16	-28.790532	32.027965
17	-28.791019	32.028776
R	-28.806852	32.048922

Appendix 2

Copy of South African National Accreditation System (SANAS) certificate for the Environmental Chemistry Laboratory at the CSIR campus in Stellenbosch.



CERTIFICATE OF ACCREDITATION

In terms of section 22(2) (b) of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act 19 of 2006), read with sections 23(1), (2) and (3) of the said Act, I hereby certify that:-

**COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
ANALYTICAL LABORATORY**

STELLENBOSCH

Facility Accreditation Number: **T0093**

is a South African National Accreditation System accredited facility
provided that all conditions and requirements are complied with

This certificate is valid as per the scope as stated in the accompanying schedule of accreditation,
Annexure "A", bearing the above accreditation number for

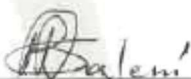
CHEMICAL ANALYSIS

The facility is accredited in accordance with the recognised International Standard

ISO/IEC 17025:2017

The accreditation demonstrates technical competency for a defined scope and the operation of a
quality management system

While this certificate remains valid, the Accredited Facility named above is authorised to
use the relevant accreditation symbol to issue facility reports and/or certificates



Mr T Baleni
Acting Chief Executive Officer

Effective Date: 01 August 2023
Certificate Expires: 31 July 2028



Appendix 3

Quality Assurance and Quality Control Results

Split sample results for grain size and total organic content analyses of sediment sampled in the proposed Berth 605 development footprint in the Port of Richards Bay in November 2024.

Sample	Gravel	Very coarse-grained sand	Coarse-grained sand	Medium-grained sand	Fine-grained sand	Very fine-grained sand	Mud	Total Organic Content
Split 1	0.00	0.00	0.29	0.29	5.64	19.68	74.12	1.51
Split 2	0.00	0.18	0.36	0.36	4.90	16.89	77.29	1.20

Recovery (%) of metals from standard reference material PACS-3 (National Research Council of Canada).

Replicate	Al	Fe	As	Cd	Cu	Cr	Mn	Hg	Ni	Pb	V	Zn
1	46.4	86.6	82.1	91.5	72.6	66.7	97.9	85.8	88.7	73.0	92.0	91.5
2	46.0	86.1	82.3	93.4	72.1	66.4	91.8	86.4	89.7	72.8	92.7	93.4
3	46.7	85.8	82.9	93.3	72.1	66.4	93.0	86.4	88.6	72.9	92.8	93.3
Mean	46.4	86.1	82.4	92.7	72.3	66.5	94.2	86.2	89.0	72.9	92.5	92.7
Standard deviation	0.3	0.4	0.5	1.0	0.3	0.2	3.3	0.3	0.6	0.1	0.4	1.0
Minimum	46.0	85.8	82.1	91.5	72.1	66.4	91.8	85.8	88.6	72.8	92.0	91.5
Maximum	46.7	86.6	82.9	93.4	72.6	66.7	97.9	86.4	89.7	73.0	92.8	93.4
Variance	0.1	0.2	0.2	1.1	0.1	0.0	10.6	0.1	0.4	0.0	0.2	1.1

Laboratory duplicate results for metals in sediment and soil sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024. RPD = Relative Percent Difference.

Metal	Original Result $\mu\text{g.g}^{-1}$	Duplicate Result $\mu\text{g.g}^{-1}$	RPD %	Acceptable RPD %
Al	7723	7518	2.7	10
Fe	11803	11699	0.9	10
As	4.4	4.4	0.6	10
Cd	0.0578	0.0571	1.3	10
Co	5.0	5.1	1.5	10
Cu	4.9	5.0	1.6	10
Cr	28.7	32.8	13.4	10
Mn	160	156	2.2	10
Hg	0.0275	0.0281	2.2	10
Ni	9.4	9.5	0.1	10
Pb	4.8	4.7	1.7	10
V	26.1	26.3	0.6	10
Zn	21	20	8.4	10

Appendix 3 Continued

Quality Assurance and Quality Control Results

Laboratory duplicate results for metals in sediment and soil sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024. RPD = Relative Percent Difference.

Metal	Original Result $\mu\text{g.g}^{-1}$	Duplicate Result $\mu\text{g.g}^{-1}$	RPD %	Acceptable RPD %
Al	28118	28701	2.1	10
Fe	32353	32861	1.6	10
As	5.4	5.5	2.1	10
Cd	462	466	0.8	10
Co	15.5	16.3	4.7	10
Cu	32.8	32.5	0.7	10
Cr	360.0	358.2	0.5	10
Mn	341	350	2.9	10
Hg	-	-	-	10
Ni	42.8	44.0	2.9	10
Pb	10.5	10.4	0.7	10
V	83.4	85.3	2.2	10
Zn	146	149	2.1	10

Metal	Original Result $\mu\text{g.g}^{-1}$	Duplicate Result $\mu\text{g.g}^{-1}$	RPD %	Acceptable RPD %
Al	58239	58949	1.2	10
Fe	49230	49623	0.8	10
As	12.5	12.4	0.6	10
Cd	0.222	0.222	0.1	10
Co	18.5	18.6	0.4	10
Cu	69.7	69.1	0.9	10
Cr	304.2	305.1	0.3	10
Mn	516	517	0.3	10
Hg	0.027	0.028	2.2	10
Ni	51.0	53.0	3.8	10
Pb	24.4	24.7	1.6	10
V	84.9	88.4	4.1	10
Zn	122	123	1.1	10

Appendix 3 Continued

Quality Assurance and Quality Control Results

Split sample results for metals in sediment sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024. RPD = Relative Percent Difference.

Metal	Split 1 Result $\mu\text{g.g}^{-1}$	Split 2 Result $\mu\text{g.g}^{-1}$	RPD %	Acceptable RPD %
Al	48343	49265	1.9	20
Fe	43146	43443	0.7	20
As	10.9	10.5	3.9	20
Cd	0.526	0.526	0.0	20
Co	19.0	19.7	3.9	20
Cu	186	176	5.5	20
Cr	1721	2103	20.0	20
Mn	567	569	0.4	20
Hg	0.03	0.02	14.8	20
Ni	66.0	67.0	1.5	20
Pb	20.8	23.1	10.2	20
V	83	86	3.6	20
Zn	163	163	0.0	20

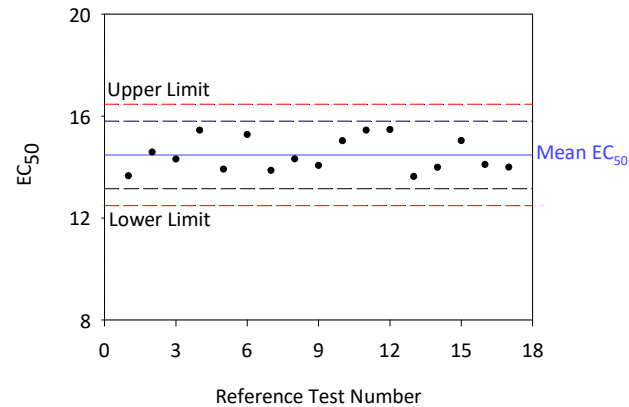
Laboratory duplicate results for metals in soil sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024. RPD = Relative Percent Difference.

Metal	Split 1 Result $\mu\text{g.g}^{-1}$	Split 2 Result $\mu\text{g.g}^{-1}$	RPD %	Acceptable RPD %
Al	20965	19093	9.3	20
Fe	23241	22757	2.1	20
As	4.9	4.2	14.5	20
Cd	0.502	0.505	0.7	20
Co	10.2	10.2	0.4	20
Cu	52	49	5.1	20
Cr	1936	1811	6.6	20
Mn	1053	1042	1.1	20
Hg	0.01	0.01	1.0	20
Ni	50.0	47.0	6.2	20
Pb	9.9	10.2	3.6	20
V	61	60	1.7	20
Zn	129	127	1.6	20

Appendix 3 Continued

Quality Assurance and Quality Control Results

Control chart for toxicity testing using the sea urchin (*Tripneustes gratilla*) embryo-larval test. The Effective Concentration for fifty percent (EC_{50}) development to a normal 4-arm pluteus for the Berth 605 reference toxicity test is the last data point in the control chart.



Results for sediment/soil (SW)-water interface and elutriate toxicity testing of the split sediment sample collected in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024.

Test	Treatment	Salinity (start)	pH (start)	Dissolved oxygen (start) (mg.L ⁻¹)	Salinity (end)	pH (end)	Dissolved oxygen (end) (mg.L ⁻¹)	Normal 4-arm pluteus Replicate 1 (%)	Normal 4-arm pluteus Replicate 2 (%)	Normal 4-arm pluteus Replicate 3 (%)	Normal 4-arm pluteus Replicate 4 (%)
SW-interface	4 Split	35.1	7.95	8.1	35.1	7.96	6.5	100	100	99	99
		35.0	7.88	7.9	35.1	7.97	6.5	98	99	100	99
Elutriate	4-100%	35.2	7.89	7.8	35.1	8.05	8.5	100	99	99	99
	4-75%	35.0	7.87	7.9	35.1	8.04	8.5	100	100	99	99
	4-50%	35.0	7.90	8.1	35.1	8.03	8.6	100	99	100	99
	4-25%	35.0	7.96	8.5	35.1	8.04	8.5	99	99	100	100
	Split-100%	35.2	7.93	7.4	35.1	8.06	8.5	100	100	99	99
	Split-75%	35.0	7.82	7.8	35.1	8.06	8.5	99	99	100	100
	Split-50%	35.1	7.87	8.4	35.1	8.07	8.5	99	100	100	99
	Split-25%	35.0	7.94	8.6	35.1	8.07	8.5	100	100	99	99

Appendix 4

Contribution (%) of grain size class fractions and total organic content to the bulk weight of sediment sampled sediment and soil sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024. TOC = total organic content.

Station	Gravel	Very coarse-grained sand	Coarse-grained sand	Medium-grained sand	Fine-grained sand	Very fine-grained sand	Mud	Total Organic Content
1	0.07	0.86	8.90	47.43	32.35	4.39	5.99	0.17
2	0.17	0.25	1.43	3.71	4.97	8.26	81.20	1.18
3	1.28	1.35	3.30	7.21	9.30	11.86	65.70	1.73
4	0.00	0.00	0.29	0.29	5.64	19.68	74.12	1.51
5	0.41	0.16	0.65	3.25	8.28	9.17	78.08	0.93
6	0.00	0.89	3.66	10.98	15.63	11.34	57.50	1.17
7	0.00	0.00	0.15	0.37	8.70	16.30	74.48	0.72
8	2.32	0.05	0.80	7.19	8.85	7.10	73.69	1.82
9	0.00	0.28	1.76	4.64	13.65	12.53	67.13	1.64
10	0.00	0.00	0.00	0.43	1.19	6.57	91.81	1.87
11	0.00	0.00	0.00	0.27	0.67	3.74	95.32	1.84
12	0.00	1.62	7.63	26.79	28.88	14.97	20.11	0.82
13	0.25	0.51	4.75	12.85	11.01	8.61	62.03	3.19
14	0.68	1.27	8.48	13.49	10.18	5.17	60.73	2.42
15	0.19	0.71	11.35	16.39	16.90	12.84	41.61	1.62
16	0.00	0.20	0.76	2.70	22.38	18.04	55.91	1.29
17	3.00	3.46	6.66	21.61	16.12	12.53	36.62	3.10
R	0.06	0.06	0.19	3.21	17.37	16.03	63.08	2.01

Appendix 5

Metal concentrations (Al and Fe as mg.g⁻¹, other metals as µg.g⁻¹ dry weight) in sediment and soil sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024. Al = aluminium, Fe = iron, As = arsenic, Cd = cadmium, Co = cobalt, Cu = copper, Cr = chromium, Mn = manganese, Hg = mercury, Ni = nickel, Pb = lead, V = vanadium, Zn = zinc, < = concentration below the method detection limit as indicated. Bold text in coloured cells indicates the concentration exceeds the Warning Level, Level I and Level II of the sediment quality guidelines used by the Department of Forestry, Fisheries and the Environment to decide if sediment identified for dredging in South African ports is of a suitable quality for open water disposal.

Station	Al	Fe	As	Cd	Co	Cu	Cr	Mn	Hg	Ni	Pb	V	Zn
1	7.6	11.8	4.4	0.055	5.1	5	32	158	<0.01	10	5	26	21
2	43.9	44.1	12.1	0.329	18.3	172	1106	707	0.028	63	25	77	142
3	45.3	39.3	9.8	0.411	19.1	272	2047	665	0.025	82	21	80	145
4	48.3	43.1	10.9	0.526	19.0	186	1721	567	0.025	66	21	83	163
5	51.3	45.7	12.4	0.482	20.2	211	1807	721	0.030	75	30	85	182
6	41.9	43.2	9.0	0.796	26.6	447	6788	1326	0.025	130	30	105	269
7	42.5	40.8	9.5	0.494	17.7	120	1304	557	0.021	51	18	80	155
8	50.8	44.4	12.7	1.058	20.2	223	1553	665	0.029	82	26	81	242
9	46.0	42.8	11.4	1.265	21.6	249	2648	702	0.034	84	25	86	213
10	48.6	49.4	12.4	0.221	18.5	69	737	593	0.027	52	25	87	122
11	48.1	49.0	12.5	0.241	18.4	89	364	611	0.028	52	26	83	134
12	13.7	16.7	5.0	0.203	8.0	40	433	483	<0.01	24	7	41	48
13	43.1	40.8	8.4	0.225	18.1	37	1031	1112	0.014	53	15	69	71
14	42.7	42.6	12.0	0.253	17.7	37	373	1002	0.014	47	15	68	68
15	29.5	30.2	9.0	0.296	13.1	32	498	585	0.011	32	12	53	74
16	30.4	32.6	5.5	0.464	11.9	33	1418	674	0.012	43	10	84	147
17	21.0	23.2	4.9	0.504	10.2	52	1936	1053	0.010	50	10	61	129
R	40.4	37.0	9.3	0.112	14.5	38	157	637	0.014	33	19	56	75
Warning Level	-	-	42	1.2	-	110	250	-	0.43	88	110	-	270
Level I	-	-	57	5.1	-	230	260	-	0.84	140	218	-	410
Level II	-	-	93	9.6	-	390	370	-	1.5	370	530	-	960

Appendix 6

Results for sediment/soil-water interface and elutriate toxicity testing of sediment and soil sampled in the proposed Berth 605 footprint in the Port of Richards Bay in November 2024. SW = seawater, Ref = reference sample, Split = split sample (Station 4).

Test	Treatment	Salinity (start)	pH (start)	Dissolved oxygen (start) (mg.L ⁻¹)	Salinity (end)	pH (end)	Dissolved oxygen (end) (mg.L ⁻¹)	Normal 4-arm pluteus Replicate 1 (%)	Normal 4-arm pluteus Replicate 2 (%)	Normal 4-arm pluteus Replicate 3 (%)	Normal 4-arm pluteus Replicate 4 (%)
Sediment/soil-water interface	SW Control	34.9	7.98	8.6	35.0	8.03	8.4	99	100	99	100
	1	35.1	7.93	8	35.2	8.00	7.4	99	98	99	100
	2	35.1	7.95	8.3	35.1	7.69	5.6	99	99	99	98
	3	35.0	7.97	8.3	35.1	8.15	5.9	99	99	100	98
	4	35.1	7.95	8.1	35.1	7.96	6.5	100	100	99	99
	5	35.0	7.84	7.1	35.2	7.78	6.5	100	99	99	99
	6	35.1	7.92	7.3	35.1	7.68	7.7	97	96	96	98
	7	35.1	7.86	8.2	35.0	7.99	6.1	99	98	99	100
	8	35.1	7.91	8.2	35.2	7.98	6.6	100	99	98	99
	9	35.0	7.93	8.1	35.1	7.86	7.1	96	98	98	99
	10	35.0	7.92	8.2	35.1	8.19	6.0	99	99	98	99
	11	35.1	7.83	7.2	35.2	8.20	6.3	99	99	98	99
	12	34.2	7.75	7.7	34.2	7.82	7.4	100	100	99	99
	13	32.9	7.25	6.7	32.9	7.14	6.2	97	98	99	98
	14	33.2	7.38	5.6	33.2	7.27	6.7	99	99	98	99
	15	32.8	6.97	7.4	32.8	7.11	7.3	0	0	0	0
	16	32.6	7.65	8.0	32.9	7.63	7.2	99	98	97	97
	17	34.2	7.68	7.6	34.2	7.90	6.3	97	100	99	98
	Ref	35.1	7.85	7.9	35.3	7.84	7.2	99	99	99	100
Elutriate	SW Control	35.0	8.09	8.6	35.0	8.09	8.4	100	100	99	99
	1-100%	35.1	7.94	8.8	35.2	8.07	8.5	99	99	99	99
	1-75%	35.0	7.36	8.8	35.1	8.05	8.5	100	100	99	99
	1-50%	35.0	7.81	8.8	35.1	8.06	8.5	100	100	99	99
	1-25%	35.0	7.96	8.8	35.1	8.07	8.5	99	99	100	100
	2-100%	35.1	7.90	7.7	35.2	8.08	8.5	99	99	99	100
	2-75%	35.1	7.90	7.8	35.1	8.07	8.5	100	100	99	99
	2-50%	35.1	7.93	8.3	35.1	8.07	8.5	100	100	99	99
	2-25%	35.0	7.96	8.5	35.1	8.05	8.5	99	99	100	100
	3-100%	35.2	8.04	7.5	35.2	8.06	8.5	100	99	100	99

Test	Treatment	Salinity (start)	pH (start)	Dissolved oxygen (start) (mg.L ⁻¹)	Salinity (end)	pH (end)	Dissolved oxygen (end) (mg.L ⁻¹)	Normal 4-arm pluteus Replicate 1 (%)	Normal 4-arm pluteus Replicate 2 (%)	Normal 4-arm pluteus Replicate 3 (%)	Normal 4-arm pluteus Replicate 4 (%)
	3-75%	35.1	8.08	8.1	35.1	8.07	8.4	100	100	99	99
	3-50%	35.0	8.07	8.2	35.1	8.07	8.5	99	100	99	100
	3-25%	35.0	8.06	8.5	35.1	8.07	8.5	100	100	99	99
	4-100%	35.2	7.89	7.8	35.1	8.05	8.5	100	99	99	99
	4-75%	35.0	7.87	7.9	35.1	8.04	8.5	100	100	99	99
	4-50%	35.0	7.90	8.1	35.1	8.03	8.6	100	99	100	99
	4-25%	35.0	7.96	8.5	35.1	8.04	8.5	99	99	100	100
	5-100%	35.1	7.86	7.5	35.2	8.06	8.5	100	99	100	99
	5-75%	35.0	7.87	7.9	35.1	8.04	8.5	99	100	99	100
	5-50%	35.0	7.89	8.3	35.1	8.03	8.5	99	99	100	100
	5-25%	35.0	7.95	8.6	35.1	8.04	8.5	100	98	99	100
	6-100%	35.3	7.78	7.8	35.0	8.07	8.5	98	99	98	99
	6-75%	35.1	7.86	7.5	35.2	8.06	8.5	100	100	99	99
	6-50%	35.1	7.90	8.3	35.1	8.07	8.5	99	100	99	100
	6-25%	35.1	7.94	8.6	35.1	8.07	8.5	99	99	100	100
	7-100%	35.2	7.80	7.8	35.0	8.01	8.5	98	99	97	99
	7-75%	35.1	7.81	8.1	35.1	8.04	8.5	100	100	99	99
	7-50%	35.1	7.89	8.4	35.1	8.06	8.5	100	100	99	99
	7-25%	35.0	7.93	8.6	35.1	8.06	8.5	100	100	99	99
	8-100%	35.2	7.75	7.8	35.2	8.03	8.5	97	99	99	98
	8-75%	35.1	7.85	8.0	34.9	8.06	8.5	100	100	99	99
	8-50%	35.1	7.90	8.3	35.2	8.07	8.5	100	99	99	100
	8-25%	35.1	7.97	8.6	35.1	8.08	8.5	100	100	99	96
	9-100%	35.1	7.76	7.3	35.1	8.06	8.6	97	97	98	98
	9-75%	35.0	7.56	8.1	35.1	8.05	8.4	99	99	100	100
	9-50%	35.0	7.79	8.5	35.1	8.06	8.5	100	100	99	99
	9-25%	35.0	7.90	8.6	35.1	8.07	8.5	100	100	99	99
	10-100%	35.2	7.83	7.5	35.2	8.06	8.6	100	98	99	98
	10-75%	35.0	7.85	7.8	35.2	8.02	8.5	100	100	99	99
	10-50%	35.0	7.89	8.3	35.2	8.07	8.5	100	99	100	99
	10-25%	35.0	7.95	8.6	35.2	8.09	8.4	99	99	100	99
	11-100%	35.3	7.89	7.5	35.1	8.03	8.5	98	97	97	98
	11-75%	35.1	7.95	8.2	35.1	8.09	8.4	100	100	99	99

Test	Treatment	Salinity (start)	pH (start)	Dissolved oxygen (start) (mg.L ⁻¹)	Salinity (end)	pH (end)	Dissolved oxygen (end) (mg.L ⁻¹)	Normal 4-arm pluteus Replicate 1 (%)	Normal 4-arm pluteus Replicate 2 (%)	Normal 4-arm pluteus Replicate 3 (%)	Normal 4-arm pluteus Replicate 4 (%)
	11-50%	35.0	7.97	7.2	35.1	8.07	8.5	100	100	99	99
	11-25%	35.0	7.96	8.5	35.1	8.64	8.4	100	99	98	100
	12-100%	34.5	7.57	8.5	34.5	7.86	8.4	95	96	96	97
	12-75%	34.6	7.77	8.7	34.6	7.98	8.4	100	100	99	99
	12-50%	34.7	7.82	8.7	34.8	8.02	8.5	100	99	99	100
	12-25%	34.9	7.92	8.7	35.0	8.03	8.4	99	100	100	99
	13-100%	33.3	7.37	8.5	33.3	7.73	8.4	97	97	96	96
	13-75%	33.6	7.40	8.6	33.7	7.95	8.4	100	100	99	99
	13-50%	34.1	7.49	8.7	34.3	7.96	8.4	100	100	99	99
	13-25%	34.6	7.94	8.7	34.7	7.96	8.4	100	100	99	99
	14-100%	33.5	7.13	8.6	33.5	7.76	8.5	96	98	97	98
	14-75%	33.7	7.46	8.6	34.0	7.90	8.4	100	100	99	99
	14-50%	34.2	7.54	8.7	34.5	7.96	8.5	100	99	99	100
	14-25%	34.6	7.71	8.7	34.8	8.01	8.4	99	99	100	100
	15-100%	33.2	6.65	8.5	33.3	7.80	8.4	0	0	0	0
	15-75%	33.6	7.38	8.6	33.7	8.96	8.4	94	96	93	94
	15-50%	34.1	7.46	8.6	34.3	7.97	8.4	99	100	99	100
	15-25%	34.6	7.68	8.7	34.7	8.00	8.5	100	100	99	99
	16-100%	32.7	7.46	8.6	32.7	7.83	8.4	96	97	97	96
	16-75%	33.1	7.38	8.7	33.3	7.98	8.4	100	100	99	99
	16-50%	34.0	7.59	8.7	34.2	8.02	8.4	100	100	99	99
	16-25%	34.5	7.89	8.7	34.8	8.05	8.4	99	99	100	100
	17-100%	34.3	7.07	8.5	34.3	7.89	8.4	98	97	98	98
	17-75%	34.4	7.53	8.7	34.5	7.99	8.4	100	100	99	99
	17-50%	34.7	7.64	8.7	34.7	8.02	8.4	99	100	99	100
	17-25%	34.8	7.94	8.7	34.9	8.05	8.4	100	100	99	99
	Ref-100%	35.2	7.89	8.1	35.1	8.06	8.5	99	100	99	100
	Ref-75%	35.1	7.88	7.6	35.1	7.98	8.4	100	100	99	99
	Ref-50%	35.0	7.91	8.2	35.1	8.04	8.4	99	100	94	100
	Ref-25%	35.0	7.95	8.4	35.1	8.01	8.4	100	100	99	99

