

**Before the EPA  
Trans-Tasman Resources Ltd Ironsands Extraction Project**

In the matter of the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012

And

In the matter of a board appointed to consider a marine consent application made by Trans-Tasman Resources Ltd to undertake iron ore extraction and processing operations offshore in the South Taranaki Bight

---

**Statement of Evidence in Chief of Dr Kay C. Vopel on  
behalf of Trans-Tasman Resources Ltd**

**13 February 2014**

---

## Executive Summary

1. My full name is Kay Christian Vopel. My evidence provides an assessment of the potential of TTR's iron sand extraction and processing to discharge into the water column of South Taranaki Bight cadmium, chromium, copper, lead, nickel, and zinc (hereafter, trace metals) or to increase the bioavailability of these trace metals in sediment.
2. Considering the results of standard elutriate tests with raw and enriched iron sand, the proposed mass and water balances of TTR's mining operation, and dilution of their wastewater discharge in the receiving South Taranaki Bight, I do not expect concentrations of cadmium, chromium, copper, lead, nickel, and zinc in the water column outside the plume of TTR's wastewater discharge to be elevated to concentrations that adversely affect biota.
3. Because of possible variations in the mass and water balances of TTR's proposed mining operation and remaining uncertainty over spatial variations in the quality of the target iron sand, I recommend implementation of effective monitoring of trace metal concentrations in both the wastewater discharge and the wastewater discharge plume in the South Taranaki Bight water column.
4. Because the concentrations of dilute-acid soluble cadmium, copper, lead and zinc in subseafloor iron sand were of the same order of magnitude as their maximum concentrations in iron sand from the surface of the sea floor, I do not expect adverse effects of these metals on colonising benthic biota should this iron sand be exposed by removal of the overlying iron sand or otherwise displaced to the surface of the seafloor.
5. Uncertainties remain regarding the effects of the elevated dilute-acid soluble concentrations of nickel and chromium in subseafloor iron sand and the observed trends with depth below the seafloor. A precautionary approach to monitoring conditions should assume elevated bioavailability of these trace metals should this iron sand be exposed by removal of the overlying iron sand or otherwise displaced to the surface of the seafloor.

## Introduction

6. My full name is Kay Christian Vopel.
7. I hold a German Diploma in Biology (magna cum laude, equiv. MSc (Hons)) and a Dr. rerum naturalium in Zoology and Marine Ecology (magna cum laude, equiv. Ph.D.) from Rostock University, Rostock, Germany.
8. I am a member of the American Society of Limnology and Oceanography (ASLO), the Oceanography Society (TOS), the American Association for the Advancement of Science (AAAS) and the New Zealand Marine Science Society (NZMSS).
9. I am currently employed as Senior Lecturer at Auckland University of Technology (AUT). I have held this position for the last 6 years. My research at AUT has focused on marine ecology, in particular, the biogeochemistry of marine sediments. Since 1993, I have published 37 peer-reviewed articles in scientific journals, two book chapters, one article in a discussion journal, one article in a conference proceeding (Appendix A), one technical note, 18 technical reports, and 11 popular articles. I have presented my research at more than 35 international conferences; Google Scholar reports that my work has been cited 575 times and that 20 of my articles have been cited at least 10 times.
10. Prior to working at AUT, I was employed as Senior Scientist at the National Institute of Water and Atmospheric Research (NIWA), Hamilton, New Zealand (2003–2008), as Research Associate at the Department of Oceanography, Florida State University, Florida, USA (2001–2003), and as Junior Scientist at the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany (1997–2002).
11. Since 1998, I held visiting appointments as Assistant Professor at the Department of Marine Biology, University of Vienna, Austria (1998–2000), at the Kristineberg Marine Research Station, The Royal Swedish Academy of Science and Goteborg University, Sweden (in 2000), and at the Smithsonian National Museum of Natural History, Caribbean Coral

Reef Ecosystem Program, Washington DC, USA (four appointments, in 2001, 2002, 2004 and 2009).

12. I serve on the Editorial Boards of the *International Journal of Oceanography*, Hindawi Publishing Corporation, USA, and the international journal *Marine Ecology Progress Series*, Inter-Research Science Centre, Germany. In 2013, I was appointed as Academic Editor of the journal *PLOS ONE*, Public Library of Science, USA.
13. I give this evidence in regard to Trans-Tasman Resources Limited's (hereafter, TTR) application for marine consent to extract iron sand in South Taranaki Bight, New Zealand.
14. My work in relation to TTR's marine consent application has been to contribute to the assessment of the potential of their mining operation to cause adverse environmental effects. Specifically, TTR contracted AUT to conduct a series of laboratory tests to investigate as a function of depth below the seafloor
  - (a) selected physical properties of the target sediment;
  - (b) the sediment content of dilute-acid volatile sulfides and the simultaneously extracted trace metals cadmium, chromium, copper, lead, nickel, and zinc; and
  - (c) the concentrations of these trace metals in suspensions of iron sand in seawater.
15. Furthermore, TTR contracted AUT to investigate if grinding magnetically enriched iron sand increases the potential of this sand to release these trace metals when suspended in seawater.
16. The research described in paragraphs 14 and 15 was carried out in collaboration with Dr. John Robertson, also of AUT, and Peter Wilson, a Ph.D. student of AUT. I am the lead author of our report: Vopel K, Robertson J, Wilson PS (2013) *Iron sand extraction in South Taranaki Bight: effects on trace metal contents of sediment and seawater*. AUT

client report TTRL 20138, prepared for Trans-Tasman Resources Ltd., September 2013. I confirm to the best of my knowledge the content of this report is correct, and formed part of TTR's marine consent application. This report was peer reviewed by NIWA.

### **Code of Conduct**

17. I have read the 'Code of Conduct for Expert Witnesses' as contained in Schedule 4 of the Judicature Act 1908 and the Environment Court Consolidated Practice Note 2011. I agree to comply with these Codes of Conduct. In particular, unless I state otherwise, this evidence is within my sphere of expertise and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

### **Scope of Evidence**

18. My evidence provides an assessment of the potential of TTR's iron sand extraction and processing to discharge into the water column of South Taranaki Bight cadmium, chromium, copper, lead, nickel, and zinc (hereafter, trace metals) or to increase the bioavailability of these trace metals in surface sediment. In my assessment, I consider three potential effects of TTR's mining operation:
- (a) TTR's extraction procedure will displace subseafloor iron sand to the surface of the seafloor, which over time will be colonised by biota. The concentrations in this sediment of trace metals may exceed the concentrations in natural surface sediment and, if sufficiently elevated, interfere with the colonisation of this sediment.
  - (b) TTR's extraction and processing of iron sand involves rapid mixing of this sand with fully oxygenated South Taranaki Bight seawater. This mixing may mobilise trace metals.
  - (c) TTR plans to grind iron sand increasing its specific surface area and the potential for the release of trace metals into the seawater

that feeds this sand through TTR's grinding mills. This seawater is returned to South Taranaki Bight.

### **Material, Methods, and Limitations**

19. To assess the potential effects described in paragraph 18, TTR contracted AUT to investigate:
  - (a) as a function of depth below the seafloor, physical properties of the target iron sand: particle size distribution, water content, and organic matter content;
  - (b) as a function of depth below the seafloor, the iron sand content of dilute-acid volatile sulfides (AVS) and simultaneously extracted trace metals;
  - (c) as a function of depth below the seafloor, the concentrations of trace metals in 1:4 (by volume) suspensions of iron sand in seawater (standard elutriation) and concentrations of trace metals in iron sand slurry; and
  - (d) if grinding magnetically enriched iron sand increases the potential of this sand to release trace metals when suspended in seawater (grinding trials followed by standard elutriation and standard elutriate tests).

#### *Iron sand cores*

20. For physicochemical analyses (paragraphs 14a, b) and standard elutriate tests (paragraph 14c), TTR collected one iron sand core (max depth below the seafloor = 5 m) and 20 L of seawater at each of five sites within the proposed mining area. Three sampling sites are located within the proposed mining field *Christina* (38–43 m water depth); two sites are located in the proposed mining field *Diana* (32–37 m water depth).
21. The cores of iron sand were extracted from the seafloor with a vibrocorer consisting of a pair of vibrator motors that pushes a stainless-steel core

tube into the seafloor. Each core tube was fitted with an internal Teflon lining and a core nose with fingered core catcher.

22. Inspection of the contents of the Teflon liners revealed that, for each sampling site, the recorded penetration depth of the stainless-steel coring tube exceeded the length of the retrieved iron sand core suggesting that the iron sand had been compressed during coring. Both measures were linearly correlated ( $R^2 = 0.982$ ); we used this correlation to calculate the distances from the core surface (core depth) that corresponded to depths below the seafloor of 0, 1, 2, 3, 4, and 5 m and then removed two aliquots of iron sand at each distance. One aliquote was used for standard elutriation followed by standard elutriate tests; the second aliquote provided iron sand for the determination of organic matter content, particle size distribution, dilute-acid volatile sulfides, and simultaneously extracted metals.

#### *Iron sand slurry*

23. To collect iron sand from depths greater than 5 m, TTR deployed a diveroperated reverse-circulation-drill rig once in each of the mining fields *Diana* and *Christina*. The rig, which uses water from the sea surface as a drilling lubricant and transport medium, was connected to a cyclone on the vessel's working deck. The cyclone released a continuous stream of sediment slurry when the drill descended into the seabed. From this stream, 500 mL aliquots of slurry were collected at depth increments of one metre until the drill reached the maximum depth below the surface of the seafloor of 18 m. The samples of slurry were transported to the laboratory on ice, where they were stored at -20°C until standard elutriation and standard elutriate tests commenced.

#### *Iron sand milling*

24. TTR provided 30 kg of dry iron sand which had been screened to remove >2 mm particles and then concentrated by means of one medium-intensity and two low-intensity magnetic separation steps.

25. We used a Retsch Planetary Ball Mill (PM 100, aluminium oxide jar and balls) at 300 rpm to produce three particle size fractions of this sand—course, medium, and fine—and submitted five samples of each fraction for standard elutriation and standard elutriate tests. The mean grain diameters of these sand fractions were 276 µm, 185 µm, and 23 µm, respectively. Furthermore, we submitted five 400 g samples of the as-received dry iron sand for standard elutriation and standard elutriate tests. The mean grain diameter of this sand was 288 µm.

*Analyses: iron sand cores*

26. Particle size, organic matter and water content: The size distribution of sediment particles was measured with a laser particle size analyser (Malvern Mastersizer 2000). We determined sediment organic matter content as weight loss after combustion in a furnace for 6 h at 400°C, and sediment water content after drying the sediment at 90°C for 24 h.
27. Dilute-acid volatile sulfides (AVS): We followed the method described in Wilson and Vopel (2012)<sup>1</sup>. We removed four aliquots (about 5 g) from each homogenised iron sand sample and added each aliquot to a 40 mL glass vial containing 30 mL deoxygenated hydrochloric acid (1 mol L<sup>-1</sup> HCl, ACS grade). The concentration of hydrogen sulphide (H<sub>2</sub>S) in the HCl extractant was measured with an amperometric H<sub>2</sub>S microelectrode (Unisense A/S, Jeroschewski 1996<sup>2</sup>; Kühl et al. 1998<sup>3</sup>).
28. Dilute-acid extractable trace metals: 10 mL HCl were removed from each of four repeated AVS extracts of each of 28 iron sand samples, filtered (0.45 µm), and combined in one 40 mL vial. Hill Laboratories analysed the concentrations of cadmium, chromium, copper, lead, nickel, and zinc in the 28 combined samples (Hill Laboratories Analysis Report, No 1030579).

---

<sup>1</sup> Wilson PS, Vopel K (2012) Estimating the in situ distribution of acid volatile sulfides from sediment profile images. *Limnology and Oceanography: Methods* 10:1070–1077

<sup>2</sup> Jeroschewski P (1996) An amperometric microsensor for the determination of H<sub>2</sub>S in aquatic environments. *Analytical Chemistry* 68:4351–4357

<sup>3</sup> Kühl M, Steuckart C, Eickert G, Jeroschewski P (1998) A H<sub>2</sub>S microsensor for profiling biofilms and sediments: Application in an acidic lake sediment. *Aquatic Microbial Ecology* 15:201–209



29. Standard elutriation: Hill Laboratories suspended 23 samples of iron sand in seawater from South Taranaki Bight. To do so, they combined iron sand with seawater in a ratio of 1:4 by volumetric displacement. The mixture was stirred vigorously for 30 min and then allowed to settle for one hour (ANZECC Interim Ocean Disposal Guideline<sup>4</sup> and USEPA Evaluation of Dredged Material Proposed for Ocean Disposal – Testing Manual<sup>5</sup>).
30. Standard elutriate test: Hill Laboratories centrifuged the supernatant seawater to remove particulates and then measured the concentrations of dissolved cadmium, chromium, copper, lead, nickel, and zinc (APHA 3125 B 21<sup>st</sup> ed. 2005). Samples of filtered seawater from South Taranaki Bight were analysed separately to assess background trace metal concentrations.

*Analyses: ball milled iron sand*

31. Dilute-acid extractable trace metals: The Australian Government National Measurement Institute (NMI) digested the samples of processed iron sand with 1 M HCl for two hours and determined the concentration of trace metals (NMI Report No RN0981498).
32. Standard elutriation: NMI suspended 20 mL of each of 20 samples of processed iron sand in 80 mL artificial seawater (NMI Report No RN0981494). The suspension was stirred for 30 min before it was allowed to settle for one hour.
33. Standard elutriate test: NMI used high resolution ICP-MS for the determination of cadmium, chromium, copper, lead, nickel, and zinc in the elutriate (NMI Method NT 2.47). Four samples of synthetic seawater were analysed separately to assess background trace metal concentrations.

---

<sup>4</sup> *Australian and New Zealand Environment and Conservation Council Interim Ocean Disposal Guidelines*, December 1998 (the ANZECC Guidelines); see also *National Ocean Disposal Guidelines for Dredged Material*, Commonwealth of Australia, Canberra, 2002 (<http://www.environment.gov.au/archive/coasts/pollution/guidelines/pubs/guidelines.pdf>)

*Analyses: trace metals in sediment slurry*

34. Hill Laboratories collected and filtered (0.45 µm membrane) aliquots of seawater from all slurry samples, preserved these aliquots with nitric acid (APHA 3030 B 21<sup>st</sup> ed. 2005) and then measured the concentrations of dissolved chromium and nickel (APHA 3125 B 21<sup>st</sup> ed. 2005).

*Supporting information*

35. In preparing this brief evidence, I have reviewed the following:
- (a) TTR (2013) South Taranaki Bight offshore iron sand extraction and processing project: Supporting information for marine consent application. Prepared under Exclusive Economic Zone and Continental Shelf (Environmental effects) Act 2012, October 2013.
  - (b) ANZECC & ARMCANZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No 4., Australian and New Zealand Environment and Conservation Council, Agricultural and Resource Management Council for Australia and New Zealand, Canberra.
  - (c) NIWA (2013) South Taranaki Bight Iron Sand Extraction Sediment Plume Modelling Phase 3 studies. NIWA Client Report No: WLG2013-36, August 2013.
  - (d) Statement by Andy Sommerville in relation to solid and water balances of TTR's proposed iron sand processing (Email correspondence, 9 January 2014). Andy Sommerville stated that the total amount of dry iron sand to be ground to 125 µm is ~1,500 tonnes per hour. The volume of this iron sand is ~395 m<sup>3</sup>. The total wastewater discharge is 22,280 m<sup>3</sup> per hour.

---

<sup>5</sup> <http://water.epa.gov/type/oceb/oceandumping/dredgedmaterial/upload/gbook.pdf>

### *Comments and Limitations*

36. My assessment is based on analyses of iron sand collected at five sites in TTR's mining area to a maximum depth below the seafloor of five metres. I believe that the results of these analyses are suitable to assess orders of magnitude of trace metal concentrations to be expected in standard elutriates and dilute-acid extractions of iron sand from TTR's mining fields *Diana* and *Christina*. I note, however, that uncertainty remains in regard to variations in iron sand properties across the entire TTR mining area and any changes in these properties at depth below seafloor greater than five meters.
37. To estimate the bioavailable fraction of trace metals in iron sand, we extracted these metals with dilute acid. In an alternative approach, trace metals are extracted with strong acid and the resulting 'total trace metal concentrations' are then compared with ANZECC & ARMCANZ (2000) interim sediment quality guidelines (ISQG), that is, the ISQG-low and -high values, which correspond to the effects range-low and -median used in the NOAA listings (Long et al. 1995<sup>6</sup>).
38. ANZECC & ARMCANZ (2000) acknowledges the 'dilute-acid-soluble metal concentration' as a more meaningful measure than the 'total metal concentration' and that derivations of future guidelines might ultimately be based on 'dilute-acid-soluble metal concentration'. Because no guidelines exist for the latter, I use as a reference the concentrations of trace metals extracted with dilute acid from iron sand at the surface of the seafloor.
39. I compared the results of our elutriate tests against ANZECC & ARMCANZ water quality guidelines for toxicants (ANZECC & ARMCANZ 2000). These guidelines were mainly derived from laboratory tests in clean water and calculated at four different protection levels, 99, 95, 90 and 80%. The protection levels signify the percentage of species expected to be protected. The guidelines represent the best current

---

<sup>6</sup> Long ER, MacDonald DD, Smith SL, Calder FD (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* 19:81–97.

estimates of the concentrations of chemicals that should have no significant adverse effects on the aquatic ecosystem. Note, however, that these guidelines are subject to variations in types of ecosystems, which can affect transport, dilution and degradation of chemicals, and so their bioavailability and toxicity. For TTR's proposed mining operation, I consider two factors: dilution of any trace metal concentrations by processing seawater onboard the floating beneficiation plant and dilution after discharge of this processing seawater (wastewater discharge) into South Taranaki Bight.

40. I have used the results of standard elutriate tests to predict the concentrations of trace metals in TTR's wastewater discharge into South Taranaki Bight. This prediction is subject to various assumptions in regard to trace metal dilution informed by the water and mass balances in TTR's Supporting Information for Marine Consent Application (TTR 2013<sup>7</sup>, their Figures 15 and 16) and information provided by Andy Sommerville of TTR (see paragraph 35d). TTR stated that they are continually optimising process design so that the methodology described in their Supporting Information might differ from that finally selected. Such changes may affect the concentrations of trace metals in their wastewater discharge. TTR stated, however, that any process changes will only be implemented if environmental effects are no greater than those described in their Supporting Information.
41. To calculate copper concentrations in TTR's wastewater discharge after dilution with South Taranaki Bight seawater, I assumed that the average copper concentration in ocean seawater<sup>8</sup> of 0.00025 g m<sup>-3</sup> applies to South Taranaki Bight seawater. Mason (2013) reports copper concentrations in coastal and offshore ocean water ranging between 0.00003 and 0.00029 g m<sup>-3</sup>.

---

<sup>7</sup> TTR (2013) *South Taranaki Bight offshore iron sand extraction and processing project: Supporting information for marine consent application*. Prepared under Exclusive Economic Zone and Continental Shelf (Environmental effects) Act 2012, October 2013

<sup>8</sup> Mason RP (2013) *Trace metals in aquatic systems*. Wiley-Blackwell, Oxford, UK

42. TTR's vibrocorer collected undisturbed cores of iron sand to a maximum depth below the seafloor of five meters. Iron sand from depths greater than five meter was required to investigate a potential trend of increasing nickel and chromium content of the iron sand with increasing depth. TTR's reverse-circulation drill (RC) was able to reach greater depths but the iron sand reached the surface in form of a slurry—a mixture of seawater, air and iron sand—making accurate quantification of dilute-acid soluble nickel and chromium impossible.
43. I noted that the concentrations of dilute-acid soluble nickel in iron sand and the concentrations of nickel in the elutriate extracts of this iron sand were linearly correlated ( $R^2 = 0.837$ ). If this correlation holds for iron sand from >5 m depth below the seafloor, then an increase with depth below the seafloor in the iron sand content of dilute-acid soluble nickel should cause an increase with depth in the concentration of nickel in RC slurry of this sediment.
44. Following this logic, my assessment of the bioavailability of nickel and chromium in iron sand at depth below the seafloor greater than five meters is based on analyses of non-standard elutriates (RC slurry) but not on dilute-acid extractions.
45. The proportions of seawater and iron sand in the RC slurry are unknown. In my assessment, I assume that these proportions remained unchanged as the drill descended into the seabed to a maximum depth below the seafloor of 18 m. If so, the relative changes in the trace metal content of this slurry (not absolute concentrations) can be used to assess if this content is a function of depth below the seafloor.

#### **Key findings from report and additional assessment of dilution**

46. As expected for high-energy offshore environments, the low organic matter content (<1% dry weight) of the medium sand in the mining areas *Christina* and *Diana* explained the low sediment content of dilute-acid volatile sulfides (AVS). We found no evidence for an increase with depth below the seafloor in sediment organic matter and AVS contents. I infer

a low probability of trace metal mobilisation through oxidative dissolution of dilute-acid soluble sulfides.

47. The concentrations of dilute-acid soluble cadmium, copper, lead and zinc in subseafloor iron sand were of the same order of magnitude as their maximum concentrations in iron sand from the surface of the seafloor (Appendix B). For cadmium, copper and zinc, there was no evidence for consistent trend of increasing concentrations with increasing depth below the seafloor. The concentrations of lead decreased with depth below the seafloor at three of five sites.
48. The concentrations of dilute-acid soluble chromium and nickel in subseafloor iron sand were often one order of magnitude higher than their maximum concentrations in iron sand at the surface of the seafloor. Furthermore, at four of five sites, chromium and nickel concentrations increased with increasing depth below the seafloor.
49. For both metals, nickel and chromium, the majority of the dilute-acid soluble fraction is likely not associated with the AVS fraction. For example, if the average dilute-acid soluble nickel concentration in sediment of the mining field *Christina* is taken around  $9 \text{ mg kg}^{-1}$ , this corresponds to  $\sim 152 \text{ } \mu\text{mol kg}^{-1}$ . The corresponding sediment AVS content, however, does not exceed  $\sim 13 \text{ } \mu\text{mol kg}^{-1}$ , which is >10-times less than the concentration of nickel. That is, the majority of dilute-acid soluble nickel is likely not associated with the AVS fraction and oxidation of AVS upon resuspension of anoxic iron sand may not be responsible for any elevated concentration in iron sand suspensions.
50. Following the reasoning in paragraphs 42–45, we analysed iron sand slurry from mining fields *Diana* and *Christina* sampled in one-metre increments starting one metre below the seafloor to a maximum depth below the seafloor of 18 m. This analysis failed to reveal evidence for a trend of increasing nickel concentrations with increasing depth below the seafloor. The concentrations of chromium were below detection limit.
51. For all metals except nickel, the concentration in seawater suspensions of subseafloor iron sand (elutriate) were either below detection limit

(chromium, copper, lead, zinc) or, if a metal was detected (cadmium), the concentration did not exceed the ANZECC & ARMCANZ guidelines for the protection of 99% of species (Appendix B). I note that the detection limit of copper ( $0.0011 \text{ g m}^{-3}$ ) was greater than the ANZECC & ARMCANZ guideline for the protection of 99% of species ( $0.0003 \text{ g m}^{-3}$ ) but below the guidelines for the protection of 95% of species ( $0.0013 \text{ g m}^{-3}$ ).

52. The above comparison of elutriate concentrations and ANZECC & ARMCANZ guidelines did not consider the effect of dilution onboard the floating beneficiation plant and dilution in the receiving South Taranaki Bight. Assuming a worst-case copper concentration in the elutriate of raw iron sand at detection limit ( $0.0011 \text{ g m}^{-3}$ ), hourly suspension of  $2,105 \text{ m}^3$  raw iron sand, hourly discharge of  $22,280 \text{ m}^3$  wastewater (paragraph 30d), and a copper concentration in South Taranaki Bight seawater of  $0.00025 \text{ g m}^{-3}$ , an estimated 1.5-fold dilution onboard the beneficiation plant would lower the concentration of the standard elutriate to  $0.00056 \text{ g m}^{-3}$  before discharge into South Taranaki Bight. Further 15-fold dilution after discharge into South Taranaki Bight would lower this concentration below the ANZECC & ARMCANZ guideline for the protection of 99%.
53. The concentrations of nickel in the elutriate of subseafloor iron sand (all five sites) and iron sand from the surface of the seafloor (reference, three of five sites) were equal or larger than the ANZECC & ARMCANZ guideline concentrations for the protection of 99% of species (Appendix B). However, the nickel concentration never exceeded the ANZECC & ARMCANZ guideline concentrations for the protection of 95% of species.
54. The concentration of nickel in the South Taranaki Bight seawater was consistently below detection limit. Assuming that this concentration equals the detection limit for nickel ( $0.0063 \text{ g m}^{-3}$ ), hourly suspension of  $2,105 \text{ m}^3$  raw iron sand, hourly discharge of  $22,280 \text{ m}^3$  wastewater (paragraph 30d), an estimated 1.5-fold dilution onboard the beneficiation plant would decrease the highest standard elutriate concentration measured ( $0.065 \text{ g m}^{-3}$ ) to  $0.03 \text{ g m}^{-3}$  before discharge into South

Taranaki Bight. Further 82-fold dilution in South Taranaki Bight would decrease this concentration below guideline concentrations for the protection of 99% of species.

55. We conducted standard elutriation and elutriate tests with magnetically enriched and ball milled iron sand to investigate if grinding of iron sand will increase trace metal concentrations in the seawater that feeds the iron sand through TTR's grinding mills. These tests revealed concentrations of cadmium, lead and nickel below the limits of reporting for all sediment fractions (Appendix B). Chromium was detected only in elutriates of the fine sediment fraction; zinc was detected in elutriates of all sediment samples. For both metals, the concentration averages for each sand size fraction did not exceed the ANZECC & ARMCANZ guideline for the protection of 99% of species.
56. The concentration of copper in seawater suspensions of the enriched iron sand was negatively linearly correlated ( $r = -0.89$ ) with the size of the suspended iron sand particles. The average elutriate copper concentrations of as-received and the coarse iron sand fractions ( $0.0013 \text{ g m}^{-3}$ ) exceeded the ANZECC & ARMCANZ guideline for the protection of 99% of species. Assuming hourly milling of  $395 \text{ m}^3$  raw iron sand, hourly discharge of  $22,280 \text{ m}^3$  wastewater (paragraph 35d), and a copper concentration in South Taranaki Bight seawater of  $0.00025 \text{ g m}^{-3}$ , an estimated 13-fold dilution onboard the beneficiation plant would lower the concentration of the standard elutriate to  $0.00033 \text{ g m}^{-3}$  before discharge into South Taranaki Bight. Further 7-fold dilution after discharge into South Taranaki Bight would lower this concentration below the ANZECC & ARMCANZ guideline for the protection of 99%.
57. In contrast, the average copper concentrations in standard elutriates of medium and fine iron sand equalled the guideline for the protection of 80% of species ( $\sim 0.008 \text{ g m}^{-3}$ , Appendix B). Applying the same assumptions as in the previous paragraph, an estimated 13-fold dilution onboard the beneficiation plant would lower this concentration by an order of magnitude to  $0.00081 \text{ g m}^{-3}$  before discharge into South Taranaki Bight. This concentration is below the ANZECC & ARMCANZ



guideline for the protection of 95% of species. Further 143-fold dilution after discharge into South Taranaki Bight would decrease this concentration below the ANZECC & ARMCANZ guideline for the protection of 99%.

58. NIWA's modelling of the plume of  $1,375 \text{ m}^3 \text{ h}^{-1}$  hyperbaric filter discharge of freshwater from the FSO provides an estimate of the dilution of any dissolved substances after discharge. Assuming that trace metals mobilised by grinding of  $395 \text{ m}^3 \text{ h}^{-1}$  iron sand are not discharged in  $22,280 \text{ m}^3 \text{ h}^{-1}$  (paragraph 35d) but in only  $1,375 \text{ m}^3 \text{ h}^{-1}$  freshwater (worst-case scenario), the dilution before discharge would equal that used for a standard elutriation. That is, we assume a worst-case discharge copper concentration of  $0.0081 \text{ g m}^{-3}$ . The 99<sup>th</sup> percentile concentration in the resulting plume is less than 0.1% (NIWA 2013<sup>9</sup>). This equals a 1000-fold dilution; only 156-fold dilution, however, would be required to lower the copper concentration below ANZECC & ARMCANZ guideline for the protection of 99%.
59. I note that because copper has a strong affinity for particulate surfaces, most copper in natural seawater is bound to naturally occurring organic particles. Complexation with organic ligands further removes copper from the bioavailable fraction. Although some copper in organic complexes maybe be bioavailable, these effects would likely further lower the concentration of any free bioavailable copper ion within the vicinity of TTR's wastewater discharge.

## Conclusions and recommendations

60. Considering the results of our standard elutriate tests with raw and enriched iron sand, the proposed mass and water balances of TTR's mining operation, and dilution of their wastewater discharge in the receiving South Taranaki Bight, I do not expect concentrations of cadmium, chromium, copper, lead, nickel, and zinc in the water column

---

<sup>9</sup> NIWA (2013) *South Taranaki Bight Iron Sand Extraction Sediment Plume Modelling Phase 3 studies*. NIWA Client Report No: WLG2013-36, August 2013.

outside the plume of TTR's wastewater discharge to be elevated to concentrations that adversely affect biota.

61. Because of possible variations in the mass and water balances of TTR's proposed mining operation and remaining uncertainty over spatial variations in the quality of the target iron sand, I recommend implementation of effective monitoring of trace metal concentrations in both the wastewater discharge and the wastewater discharge plume in the South Taranaki Bight water column. Such monitoring can ensure a timely management response where trace metal concentrations exceed ANZECC & ARMCANZ guidelines. In this regard, it is important that the ANZECC & ARMCANZ guidelines not only be used to set suitable standards but as a process of further development of standards specific for the water column of South Taranaki Bight.
62. Because the concentrations of dilute-acid soluble cadmium, copper, lead and zinc in subseafloor iron sand were of the same order of magnitude as their maximum concentrations in iron sand from the surface of the sea floor, I do not expect adverse effects of these metals on colonising benthic biota should this iron sand be exposed by removal of the overlying iron sand or otherwise displaced to the surface of the seafloor.
63. Uncertainties remain regarding the effects of the elevated dilute-acid soluble concentrations of nickel and chromium in subseafloor iron sand and the observed trends with depth below the seafloor. A precautionary approach to monitoring conditions should assume elevated bioavailability of these trace metals should this iron sand be exposed by removal of the overlying iron sand or otherwise displaced to the surface of the seafloor. I understand that this matter will be addressed in the evidence of Mr Venus.

## Response to EPA Staff Report

64. The EPA identified the following gaps in the information provided by TTR:<sup>10</sup>
- (a) The trace metals analysis does not include mercury, which the EPA staff expect would be present considering the volcanic source of some sediment and that mercury is a highly toxic metal.
  - (b) TTR's application documents did not include an assessment of the potential for mercury to be released from the seabed sediments, but this metal is associated with volcanic activity in New Zealand and is considered highly toxic to people and marine organisms.
65. Related to the above, the EPA has suggested that the Decision-making Committee considers requesting information regarding the potential for mercury to be released from sediments during the mining operation, the effects of this, and mitigation measures to manage any adverse effects.
66. Mercury was not included in our analyses because I did not expect the offshore iron sand of South Taranaki Bight to contain elevated quantities of anthropogenically or naturally derived mercury. The volcanic activity that produced the iron resource in South Taranaki Bight will not have resulted in accumulation of mercury in the offshore iron sands. Volcanoes discharge mercury into the atmosphere along with high temperature ejecta. Ultimately, the oceanic environment receives part of this mercury through atmospheric deposition but this deposition is a global rather than a local process. Overall, the average yearly emission of mercury from volcanoes into the atmosphere is small relative to natural terrestrial fluxes to the atmosphere and modern anthropogenic (pollution) mercury fluxes<sup>11</sup>.

---

<sup>10</sup> The SKM review on 'Oceanographic processes and the physical environment' dated 13 December 2013 also raised the issue that my report did not include mercury as additional trace metal analyte.

<sup>11</sup> Lollar BS (2005) Environmental Geochemistry. Treatise on Geochemistry, 2<sup>nd</sup> Edition, Volume 9, Elsevier Science

67. I note that Chrystall and Rumsby (2009)<sup>12</sup> identified geothermal emissions as a natural sources of mercury in New Zealand with local effects on freshwater biota, that is, increased mercury concentrations in fish caught in geothermally-influenced lakes (Kim 1995<sup>13</sup>) or in sediment of a lake that contains a natural geothermal spring. The authors noted that most concerns are over the issue of accumulation of *anthropogenic* mercury in aquatic ecosystems. I argue that such accumulation is unlikely in the offshore sand of South Taranaki Bight. Elevated mercury concentrations in offshore sediment have been detected elsewhere near oil drilling sites (Gulf of Mexico) and such concentrations were associated with discharge of cuttings drilled with synthetic-based mud (Trefry 2007<sup>14</sup>) or, for methyl mercury, related to higher sediment organic matter content in the vicinity of offshore oil production platforms (DeLaune et al. 2008<sup>15</sup>).

#### **Response to EPA request for further information**

68. To understand the effects of allowing the activity on the oceanographic processes and the physical environment, and the extent to which imposing conditions might avoid remedy and mitigate the adverse effects of the activity, the EPA requested further information from TTR how concentrations of nickel and copper will comply with recommended levels.
69. The dilution required for nickel and copper to meet the ANZECC & ARMCANZ guideline for the protection of 99% species is discussed in my evidence (paragraphs 52–58). Information on the time required to achieve this dilution and the field around the discharge point within which

---

<sup>12</sup> Chrystall L, Rumsby A (2009) *Mercury inventory for New Zealand*. Technical Report prepared for the Ministry for the Environment. Pattle Delamore Partners Limited, August 2009.

<sup>13</sup> Kim JP (1995) Methylmercury in rainbow trout (*Oncorhynchus mykiss*) from Lakes Okareka, Okaro, Rotomahana, Rotorua and Tarawera, North Island, New Zealand. *Science of the Total Environment* 164:209–219.


<sup>14</sup> Trefry JH, Trocine RP, McElvaine ML, Rember RD, Hawkins LT (2007) Total mercury and methylmercury in sediments near offshore drilling sites in the Gulf of Mexica. *Environ. Geol.* 53:375–385.

<sup>15</sup> DeLaune RD, Devai I, Hou A, Jugsujinda A (2008) Total and methyl Hg in sediment adjacent to offshore platforms of the Gulf of Mexica. *Soil & Sediment Contaminations* 17:98–106.

guidelines are expected to be exceeded will be discussed in the evidence of Dr McClary.

### **Response to Issues in Submissions**

70. A number of submitters have raised concerns about the discharges of trace metals. I have responded to the point about dilution in the section above. Dr McClary will address the ecological effects of trace metals which was the cause of concern for most submitters.

A small, square image showing a handwritten signature in black ink on a light-colored background. The signature is stylized and appears to read 'K. Vopel'.

Dr Kay C. Vopel

13 February 2014

## Appendix A

Journal articles published since 1993:

41. Hohaia A, **Vopel K**, Pilditch C (2013) Thin terrestrial sediment deposits on intertidal sandflats: effects on pore water solutes and juvenile bivalve burial behavior. *Biogeosciences Discussions* 10:14835–14860.
40. Wilson P, **Vopel K** (2012) Estimating the in situ distribution of acid volatile sulfides from sediment profile images. *Limnology and Oceanography: Methods* 10:1070–1077.
39. MacTavish T, Savage C, Stenton-Dozey J, **Vopel K** (2012) Deposit-feeding sea cucumbers enhance mineralization and nutrient cycling in organically-enriched coastal sediments. *PLOS ONE* 7: e50031.
38. **Vopel K**, Wilson P, Zeldis J (2012) Sediment–seawater solute flux in a polluted New Zealand estuary. *Marine Pollution Bulletin* 64:2885–2891.
37. **Vopel K**, Thistle D (2011) Cues not a clock control the water-column entry of benthic copepods. *Estuaries and Coasts* 34:1194–1204.
36. Larned ST, Packman AI, Plew D, **Vopel K** (2011) Interactions between a mat-forming riverine diatom, *Didymosphenia geminata*, and its hydrodynamic environment. *Limnology and Oceanography: Fluids and Environments* 1:4–22.
35. **Vopel K**, Pilditch CA, Wilson P, Ellwood M (2009) Oxidation of surface sediment: effects of disturbance depth and seawater flow speed. *Marine Ecology Progress Series* 392:43–55.
34. Cummings V, **Vopel K**, Thrush S (2009) Terrigenous deposits in coastal marine habitats: influences on sediment geochemistry and behaviour of post-settlement bivalves. *Marine Ecology Progress Series* 383:173–185.
33. Røy H, **Vopel K**, Huettel M, Jørgensen BB (2009) Sulfide assimilation by ectosymbionts of the sessile ciliate, *Zoothamnium niveum*. *Marine Biology* 156:669–677.
32. **Vopel K**, Gibbs M, Quinn J, Hickey C (2008) Modification of sediment–water solute exchange by sediment-capping agents: effects on O<sub>2</sub> and pH. *Marine and Freshwater Research* 59:1101–1110.
31. Ellwood MJ, Wilson P, **Vopel K**, Green M (2008) Trace metal cycling in the Whau estuary, Auckland. *Environmental Chemistry* 5:289–298.
30. Packman AI, Larned S, Plew D, **Vopel K** (2008) Modification of river hydraulics by the invasive diatom *Didymosphenia geminata*. *World Environmental and Water Resources Congress 2008: Ahupua'a - Proceedings of the World Environmental and Water Resources Congress*, p 316
29. **Vopel K**, Vopel A, Thistle D, Hancock N (2007) Effects of spatangoid heart urchins on O<sub>2</sub> supply into coastal sediment. *Marine Ecology Progress Series* 333:161–171.
28. **Vopel K**, Hawes I (2006) Photosynthetic performance of benthic microbial mats in Lake Hoare, Antarctica. *Limnology and Oceanography* 51:1801–1812.
27. Lohrer AM, Thrush SF, Lundquist CJ, **Vopel K**, Hewitt JE, Nicholls PE (2006) Deposition of terrigenous sediment on subtidal marine macrobenthos: response of two contrasting community types. *Marine Ecology Progress Series* 307:115–125.
26. **Vopel K**, Thistle D, Ott J, Bright M, Roy H (2005) Wave-induced H<sub>2</sub>S flux sustains a chemoautotrophic symbiosis. *Limnology and Oceanography* 50:128–133.
25. Fechter A, Thistle D, Arlt G, Suderman K, **Vopel K** (2004) Do harpacticoids (Copepoda) use water-borne cues to aid in locating food parcels? *P.S.Z.N.: Marine Ecology* 25:217–23.
24. Teasdale M, **Vopel K**, Thistle D (2004) The timing of benthic copepod emergence. *Limnology and Oceanography* 49:884–889.
23. **Vopel K**, Thistle D, Rosenberg R (2003) Effect of the brittle star *Amphiura filiformis* (Amphiuridae, Echinodermata) on oxygen flux into the sediment. *Limnology and Oceanography* 48:2034–2045.
22. Soltwedel T, Miljutina M, Mokievsky V, Thistle D, **Vopel K** (2003) The meiobenthos of the Molloy Deep (5600 m), Fram Strait, Arctic Ocean. *Vie et Milieu* 53:1–13.
21. Soltwedel T, Quéric N, **Vopel K** (2002). Effects of micro-scale environmental heterogeneity on small sediment-inhabiting organisms. *Berichte zur Polar- und Meeresforschung* 422: 11–20.
20. **Vopel K**, Reick CH, Arlt G, Pöhn M, Ott JA (2002) Flow microenvironment of two marine peritrich ciliates with ectobiotic chemoautotrophic bacteria. *Aquatic Microbial Ecology* 29:19–28.
19. Soltwedel T, Quéric N, **Vopel K** (2002) Effects of micro-scale environmental heterogeneity on small sediment-inhabiting organisms. *Berichte zur Polar- und Meeresforschung* 422:11–20.

18. **Vopel K**, Thiel H (2001) Comparing abyssal nematode assemblages of physically disturbed and adjacent sites of the eastern equatorial Pacific. *Deep Sea Research II* 48:3795–3808.
17. Thiel H, Schriever G, Ahnert A, Bluhm H, Borowski C, **Vopel K** (2001) The large-scale environment impact experiment DISCOL – reflection and foresight. *Deep Sea Research II* 48:3869–3882.
16. Thiel H and Forschungsverbund Tiefsee-Umweltschutz (2001) Evaluation of the environmental consequences of polymetallic nodule mining based on the results of the TUSCH Research Association. *Deep Sea Research II* 48:3433–3452.
15. Soltwedel T, **Vopel K** (2001) Bacterial abundance and biomass in response to organism-generated habitat heterogeneity in deep-sea sediments. *Marine Ecology Progress Series* 219:291–298.
14. Pöhn M, **Vopel K**, Grünberger E, Ott J (2001) Microclimate of the brown-alga *Feldmannia caespitula* interstitium under zero-flow conditions. *Marine Ecology Progress Series* 210:285–290.
13. Klages M, **Vopel K**, Bluhm H, Brey T, Soltwedel T, Arntz WE (2001) Deep-sea food falls: First observation of a natural event in the Arctic Ocean. *Polar Biology* 24:292–295.
12. **Vopel K**, Pöhn M, Sorgo A, Ott J (2001) Ciliate-generated advective seawater transport supplies chemoautotrophic ectosymbionts. *Marine Ecology Progress Series* 210:93–99.
11. Bussau C, **Vopel K** (1999) New nematode species and genera (Chromadorida, Microlaimidae) from the deep sea of the eastern tropical South Pacific. *Annalen des Naturhistorischen Museums Wien* 101B: 405–421.
10. Bluhm H, Borowski C, Ahnert A, **Vopel K**, Schriever G, Thiel H (1999) Reaktionen benthischer Tiefsee-Lebensgemeinschaften auf mechanische Störungen der Sedimente. *German Journal of Hydrography* 51(10):149–152.
9. Bluhm H, Klages M, Soltwedel T, **Vopel K** (1999) Advantages of a deep-diving ROV over traditional sampling methods for deep-sea research and recommendations for future work. *Berichte zur Polar- und Meeresforschung* 339:14–15.
8. **Vopel K**, Soltwedel T (1999) Small-scale heterogeneity and diversity of meiofauna at the deep seafloor. *Berichte zur Polar- und Meeresforschung* 339:9–11.
7. **Vopel K**, Dehmlow J, Johansson M, Arlt G (1998) Effects of anoxia and sulphide on populations of *Cletocamptus confluens* (Copepoda: Harpacticoida). *Marine Ecology Progress Series* 175:121–128.
6. **Vopel K**, Dehmlow J, Arlt G (1996) Vertical distribution of *Cletocamptus confluens* (Copepoda, Harpacticoida) in relation to oxygen and sulphide microprofiles of a brackish water sulphuretum. *Marine Ecology Progress Series* 141:129–137.
5. Gamenick I, Jahn A, **Vopel K**, Giere O (1996) Hypoxia and sulphide as structuring factors in a macrozoobenthic community on the Baltic Sea shore: colonisation studies and tolerance experiments. *Marine Ecology Progress Series* 144:73–85.
4. **Vopel K**, Dehmlow J, Arlt G (1996) Living in light exposed anaerobic systems—field and laboratory studies on the sulphide resistance of *Cletocamptus confluens* (Schmeil, 1894) (Copepoda, Harpacticoida). In: Fischer U, Grieshaber MK (eds) *Processes and Structures in Marine Methane and Sulphide Biotopes*. Shaker Verlag, Aachen
3. **Vopel K**, Arlt G (1995) The fauna of floating cyanobacterial mats in the oligohaline eu littoral zone off Hiddensee (south-west coast of the Baltic Sea). *P.S.Z.N.: Marine Ecology* 16:217–231.
2. **Vopel K**, Arlt G (1995) Cyanobakterienmatten – ein attraktiver Lebensraum fuer Meiofauna. *Bodden* 2:37–52.
1. Arlt G and **Vopel K** (1993) Fluktuationen des Meiobenthos in reduzierenden Lebensräumen: Abschlußbericht zum Teilprojekt B. In: *Dynamik in Sulfid- und Methanbiotopen der Ost- und Nordsee (DYSMON) [Dynamics in sulphide and methan biotops of the Baltic and North Sea (DYSMON).]* OCLC Number: 257944899, BMFT 03F0028A0

## Appendix B<sup>16</sup>

Table 5. Concentration of simultaneously (dilute-acid) extracted metals (mg kg<sup>-1</sup> dry weight) in the sediment of the proposed mining area in South Taranaki Bight. Ref, reference sediment.

Site ID	Sediment depth						
	(m)	Cd	Cr	Cu	Pb	Ni	Zn
C1	0 (Ref)	<0.007	0.34	0.42	1.68	0.61	3.17
C1	1	<0.005	8.23	0.67	1.24	6.37	2.35
C1	2	0.011	15.92	0.53	1.29	12.25	1.59
C1	3	0.015	27.75	0.88	0.86	21.58	2.93
C1	4	0.020	42.70	0.99	0.74	29.89	2.24
C2	0 (Ref)	0.011	2.44	0.57	1.25	2.51	1.25
C2	1	0.012	10.76	0.69	1.05	8.19	1.96
C2	2	0.009	12.01	0.45	0.83	8.20	1.74
C2	3	0.010	9.35	0.48	0.78	6.68	1.64
C2	4	<0.005	5.37	0.37	0.47	3.88	1.12
C2	5	<0.004	6.84	0.58	0.26	5.05	1.54
C3	0 (Ref)	0.006	0.36	0.31	1.92	0.34	1.69
C3	1	0.039	13.87	0.94	1.96	10.00	2.46
C3	2	0.020	15.88	0.75	1.82	12.48	2.14
D2	0 (Ref)	<0.005	0.51	0.30	1.26	0.63	1.08
D2	1	0.013	3.70	0.39	1.28	2.68	1.98
D2	2	0.009	4.60	0.43	1.26	3.45	2.18
D3	0 (Ref)	<0.008	0.30	0.46	1.21	0.43	1.39
D3	1	<0.004	1.33	0.40	1.06	1.15	2.11
D3	2	<0.007	1.20	0.72	0.62	0.96	1.87
D3	3	0.006	3.95	0.46	0.66	2.60	2.91
D3	4	<0.008	10.01	0.56	0.73	6.36	2.48
D3	5	0.007	13.54	0.54	0.51	8.73	2.60

<sup>16</sup> Extracted from Vopel K, Robertson J, Wilson PS (2013) *Iron sand extraction in South Taranaki Bight: effects on trace metal contents of sediment and seawater*. AUT Client Report TTR 20138, September 2013



Table 6. ANZECC & ARMCANZ guidelines ( $\text{g m}^{-3}$ ) for six trace metals at alternative levels of protection of species (ANZECC & ARMCANZ 2000).

Level of protection (% species)	Cd	Cr III	Cu	Pb	Ni	Zn
99%	0.0007 <sup>B</sup>	0.0077	0.0003	0.0022	0.007	0.007
95%	0.0055 <sup>B, C</sup>	0.0274	0.0013	0.0044	0.070 <sup>C</sup>	0.015 <sup>C</sup>
90%	0.0140 <sup>B, C</sup>	0.0486	0.003 <sup>C</sup>	0.0066 <sup>C</sup>	0.200 <sup>A</sup>	0.023 <sup>C</sup>
80%	0.0360 <sup>A, B</sup>	0.0906	0.008 <sup>A</sup>	0.0120 <sup>C</sup>	0.560 <sup>A</sup>	0.043 <sup>C</sup>

A = Figure may not protect key test species from acute toxicity (and chronic)—check NWQMS, No. 4, Section 8.3.7 for spread of data and its significance. 'A' indicates that trigger value > acute toxicity figure; note that trigger value should be <1/3 of acute figure (NWQMS, No. 4, Section 8.3.4.4).

B = Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered (see NWQMS, No. 4, Sections 8.3.3.4 and 8.3.5.7).

C = Figure may not protect key test species from chronic toxicity (this refers to experimental chronic figures or geometric mean for species)—check NWQMS, No. 4, Section 8.3.7 for spread of data and its significance.

Table 7. Concentrations of six trace metals in seawater and sediment elutriates (g m<sup>-3</sup>). Numbers in parenthesis represent the limits of detection (LOD, g m<sup>-3</sup>). <LOD, below limits of detection. Note that for all metals except Cu, the detection limits were below the ANZECC & ARMCANZ guidelines for the protection of 99% of species. For Cu, the detection limit was below the guidelines for the protection of 95% of species.

Site ID	Sediment (m)	Cd (0.00021)	Cr (0.0011)	Cu (0.0011)	Pb (0.0011)	Ni (0.0063)	Zn (0.0042)
C1	0	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
C1	1	0.00041	<LOD	<LOD	<LOD	0.030	<LOD
C1	2	0.00041	<LOD	<LOD	<LOD	0.037	<LOD
C1	3	0.00064	<LOD	<LOD	<LOD	0.044	<LOD
C1	4	0.00063	<LOD	<LOD	<LOD	0.065	<LOD
Seawater		<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
C2	0	0.00029	<LOD	<LOD	<LOD	0.012	<LOD
C2	1	0.00038	<LOD	<LOD	<LOD	0.021	<LOD
C2	2	<LOD	<LOD	<LOD	<LOD	0.023	<LOD
C2	3	0.00027	<LOD	<LOD	<LOD	0.016	<LOD
C2	4	0.00025	<LOD	<LOD	<LOD	0.016	<LOD
C2	5	<LOD	<LOD	<LOD	<LOD	0.020	<LOD
Seawater		<LOD	<LOD	<LOD	<LOD	<LOD	0.008
C3	0	0.00028	<LOD	<LOD	<LOD	0.008	<LOD
C3	1	0.00045	<LOD	<LOD	<LOD	0.027	<LOD
C3	2	0.00063	<LOD	<LOD	<LOD	0.043	<LOD
Seawater		<LOD	<LOD	<LOD	<LOD	<LOD	0.005
D2	0	<LOD	<LOD	<LOD	<LOD	0.007	<LOD
D2	1	<LOD	<LOD	<LOD	<LOD	0.007	<LOD
D2	2	0.00023	<LOD	<LOD	<LOD	0.017	<LOD
Seawater		<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
D3	0	0.00027	<LOD	<LOD	<LOD	0.007	<LOD
D3	1	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
D3	2	0.00030	<LOD	<LOD	<LOD	0.014	<LOD
D3	3	<LOD	<LOD	<LOD	<LOD	0.007	<LOD
D3	4	<LOD	<LOD	<LOD	<LOD	0.012	<LOD
D3	5	<LOD	<LOD	<LOD	<LOD	0.028	<LOD
Seawater		<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

Table 11. Concentrations of simultaneously extracted metals (mg kg<sup>-1</sup> dry weight) in processed South Taranaki Bight sediment. NMI reporting limits = 0.5 mg kg<sup>-1</sup> dry weight. <LOR, below NMI reporting limits.

Sample ID	Cd	Cr	Cu	Pb	Ni	Zn
BL-R1	<LOR	45	16	1.6	19	200
BL-R2	<LOR	44	16	1.6	19	200
BL-R3	<LOR	48	16	1.5	21	220
BL-R4	<LOR	43	16	1.6	20	200
BL-R5	<LOR	45	16	1.5	19	200
BL-C1	<LOR	42	15	1.7	18	190
BL-C2	<LOR	42	15	1.6	18	190
BL-C3	<LOR	42	15	1.6	17	190
BL-C4	<LOR	38	14	1.6	16	170
BL-C5	<LOR	40	15	1.7	17	170
BL-M1	<LOR	35	14	1.8	15	160
BL-M2	<LOR	38	16	1.7	16	180
BL-M3	<LOR	37	15	1.8	15	170
BL-M4	<LOR	39	15	1.7	15	170
BL-M5	<LOR	40	17	1.8	15	180
BL-F1	<LOR	76	31	1.9	28	330
BL-F2	<LOR	78	30	2.0	29	330
BL-F3	<LOR	78	32	2.3	32	340
BL-F4	<LOR	75	31	2.0	28	320
BL-F5	<LOR	77	30	2.1	30	330

Table 12. Concentrations of six trace metals in synthetic seawater (Syn sw) and synthetic seawater elutriates of processed sediment ( $\text{g m}^{-3}$ ). Numbers in parenthesis represent Limits of Reporting (LOR,  $\text{g m}^{-3}$ ). <LOR, below Limits of Reporting. Note that for all metals except Cu, the LOR were below the ANZECC & ARMCANZ guidelines for the protection of 99% of species. For Cu, the LOR was below the guidelines for the protection of 95% of species.

Site ID	Cd (0.0001)	Cr (0.001)	Cu (0.001)	Pb (0.001)	Ni (0.001)	Zn (0.001)
BL-R1	<LOR	<LOR	0.0014	<LOR	<LOR	0.0041
BL-R2	<LOR	<LOR	<LOR	<LOR	<LOR	0.0038
BL-R3	<LOR	<LOR	<LOR	<LOR	<LOR	0.0056
BL-R4	<LOR	<LOR	0.0011	<LOR	<LOR	0.0052
BL-R5	<LOR	<LOR	0.0013	<LOR	<LOR	0.0080
BL-C1	<LOR	<LOR	0.0011	<LOR	<LOR	0.0035
BL-C2	<LOR	<LOR	0.0012	<LOR	<LOR	0.0035
BL-C3	<LOR	<LOR	0.0016	<LOR	<LOR	0.0057
BL-C4	<LOR	<LOR	0.0014	<LOR	<LOR	0.0043
BL-C5	<LOR	<LOR	0.0013	<LOR	<LOR	0.0070
BL-M1	<LOR	<LOR	0.0150	<LOR	<LOR	0.0075
BL-M2	<LOR	<LOR	0.0068	<LOR	<LOR	0.0069
BL-M3	<LOR	<LOR	0.0063	<LOR	<LOR	0.0044
BL-M4	<LOR	<LOR	0.0060	<LOR	<LOR	0.0027
BL-M5	<LOR	<LOR	0.0062	<LOR	<LOR	0.0051
BL-F1	<LOR	0.0019	0.0077	<LOR	<LOR	0.0039
BL-F2	<LOR	0.0021	0.0085	<LOR	<LOR	0.0039
BL-F3	<LOR	0.0025	0.0073	<LOR	<LOR	0.0035
BL-F4	<LOR	0.0025	0.0074	<LOR	<LOR	0.0073
BL-F5	<LOR	0.0027	0.0080	<LOR	<LOR	0.0030
Syn sw 1	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
Syn sw 2	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
Syn sw 3	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
Syn sw 4	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
Syn sw 5	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR