Iron sand extraction in South Taranaki Bight: effects on trace metal contents of sediment and seawater

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Content

Executive summary

Trans–Tasman Resources Limited (hereafter, TTR) plans to exploit a source of vanadium-titanomagnetite in South Taranaki Bight, New Zealand, with an offshore dredge-mining operation. Because this operation will displace, suspend and modify deep anoxic sediment, it may make sediment-bound contaminants available to pelagic and benthic biota.

To assess the potential of their mining operation for causing adverse effects, TTR contracted Auckland University of Technology (AUT) to investigate as a function of depth below the seafloor (1) selected physical properties of the target sediment, (2) the sediment content of acid volatile sulfides and simultaneously extracted trace metals, and (3) the concentrations of trace metals in suspensions of sediment in seawater. TTR also contracted AUT to investigate if grinding enriched iron sand increases the potential of this sand to release trace metals when suspended in seawater.

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

The concentrations of dilute-acid soluble cadmium, copper, lead and zinc in deep sediment were of the same order of magnitude as their maximum concentrations in surface (reference) sediment. For cadmium, copper and zinc, there was no evidence for consistent trend of increasing concentrations with increasing sediment depth below the seafloor. The sediment concentrations of lead decreased with depth below the seafloor at three of five sites. Overall, we infer a low probability of adverse effects of these dilute-acid soluble metals on benthic ecosystem functioning.

The concentrations of dilute-acid soluble chromium and nickel in deep sediment were often one order of magnitude higher than their maximum concentrations in surface (reference) sediment. Furthermore, at four of five sites, chromium and nickel concentrations increased with increasing depth below the seafloor. Additional analyses of sediment slurry collected to a maximum depth below the seafloor of 18 m, however, did not reveal evidence for such trend. We found no consistent increase with depth in the concentrations of dissolved nickel in the slurry. The concentrations of chromium in the slurry were below the detection limit.

For all metals except nickel, the concentration in seawater suspensions of deep sediment (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 guideline for the protection of 99% of species. The detection limit of copper was below the guidelines for the protection of 95% of species.

The concentrations of nickel in the seawater suspensions of deep sediments (all five sites) and surface (reference) sediment (three of five sites) were equal or larger than the ANZECC & ARMCANZ guideline concentrations for the protection of 99% of species. However, the nickel concentration never exceeded the guideline concentrations for the protection of 95% of species. Assuming that the nickel concentration in South Taranaki Bight seawater equals the detection limit for nickel, it would only require an 83-fold dilution of the elutriate extract to decrease the highest nickel concentration measured to below guideline concentrations for the protection of 99% of species.

A sample of magnetically enriched iron sand was ball milled to three average sizes, 276 µm, 183 µm and 23 µm. The average concentrations in this iron sand of dilute-acid soluble chromium, nickel and zinc decreased after each of the first two grinds but increased after the third grind to 171, 150, and 162% of that in the extract of the as-received enriched iron sand. In contrast, for copper and lead, the average concentrations in the extracts of the first two grinds did not significantly differ from that of the as-received iron sand but the third grind increased these concentrations to 193 and 132% of the concentration in the extract of the as-received iron sand. The concentrations of dilute-acid soluble cadmium were below reporting limits in both as-received and ball-milled magnetically enriched iron sand.

We conducted elutriate tests with magnetically enriched and ball milled iron sand to investigate if grinding of iron sand will increase trace metals 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 samples. 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. We infer a low probability of adverse effects of these metals on ecosystem functioning of the South Taranaki Bight water column.

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 fraction exceeded the ANZECC & ARMCANZ guideline for the protection of 99% of species. Assuming that South Taranaki Bight seawater contains 0.25 ppb copper an only 20-fold dilution would decrease this concentration to below the concentration limit for the protection of 99% of species. In contrast, the average copper concentrations in elutriates of medium and fine coarse iron sand exceeded the guideline for the protection of 80% of species. Here, a 160-fold dilution would decrease these concentrations to below the concentration limit for the protection of 99% of species.

Introduction

Trans-Tasman Resources Limited (hereafter, TTR) plans to exploit a source of vanadium-titanomagnetite in South Taranaki Bight, North Island, New Zealand (Fig. 1), combining an offshore dredge-mining operation with an offshore beneficiation plant. Vanadium-titanomagnetite is a black iron ore that comprises vanadium pentoxide (V_2O_2), titanium oxide (TiO_2), and magnetite (Fe_3O_3), a form of iron oxide with natural magnetic properties. It originates as crystals in volcanic rocks, washed down rivers, largely from Mount Taranaki but also from the Central Plateau of the North Island, to Taranaki Bight (Carter 1980). Specialised steel mills use vanadium-titanomagnetite to manufacture steel, either as a blend with other ores, e.g., haematite, or as a dedicated steel-making feed.

To source iron sand from South Taranaki Bight, TTR envisages deploying seabed dredges that pump a slurry of sediment and seawater to their offshore beneficiation plant. This plant will screen the slurry to remove >2 mm particles and then extract and concentrate vanadium-titanomagnetite with alternating steps of magnetic separation and grinding. TTR plans to grind iron sand particles to 150 µm (first grind) and 75 µm (second grind) with IsaMill^{TM} technology. Each of the processing steps aboard the beneficiation plant results in tailings and loss of seawater. In the final step, TTR will use freshwater to rinse chlorides from the concentrated iron ore. They will return the de-ored sediment to the seafloor and transfer the concentrated iron ore to a storage vessel. This ore will eventually be transhipped to a capesize vessel for export to customers.

The proposed mining operation involves two activities that may result in the release of contaminants into the water column of South Taranaki Bight. (1) TTR will displace and suspend anoxic sediment from depths up to 15 m below the seafloor (50–100 million tons per year for 10–20 years, A. Sommerville pers. comm.). Suspension of this sediment may mobilise trace metals. (2) Aboard their beneficiation plant, TTR will grind the suspended sediment increasing its specific surface area and so the potential for the release of trace metals into the seawater tailings.

One mechanism mobilising trace metals involves the oxidation of metal sulfides. Most trace metals, however, do not form distinct sulfides but adsorb onto pyrite and iron monosulfides, the most abundant solid sulfide phases in marine sediments. Oxidation of these sulfide phases upon contact with oxygenated seawater may release the adsorbed trace metals making them available for benthic and pelagic biota.

The oxidation rates of iron and other metal monosulfides are measured in hours (Burton et al. 2006); pyrite (FeS_2) oxidation rates, however, are measured in months, although some pyrite fractions can oxidise in less than a few days (Morse, 1994). Such slow oxidation of pyrite may alter the bioavailability of metals in the pore water of deep sediment that has been displaced to the surface of the seafloor but less so in "short-lived" suspensions of this sediment in seawater. In such suspensions, oxidation of iron monosulfides, measured as so-called acid volatile sulfides (AVS), will be a more important factor in increasing metal bioavailability (for a critical discussion of the AVS concept, see Morse and Rickard 2004; ANZECC & ARMCANZ 2000).

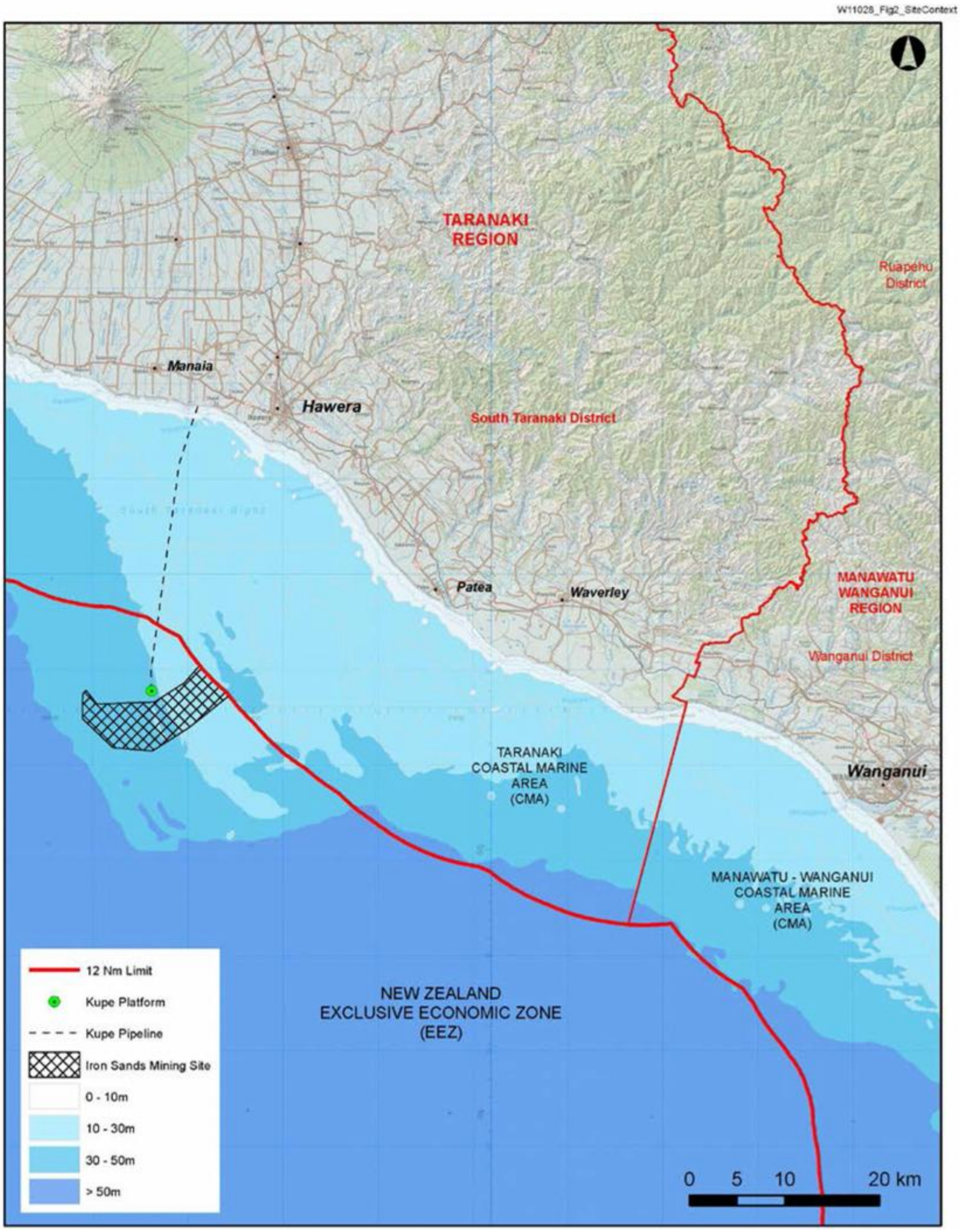

Figure 1. Map showing the location of the proposed iron sand mining area in South Taranaki Bight, North Island, New Zealand.

To assess the potential of their mining operation for causing adverse effects, TTR contracted Auckland University of Technology (AUT) to conduct a series of laboratory tests to investigate as a function of depth below the seafloor (1) selected physical properties of the target sediment, (2) the sediment content of acid volatile sulfides and simultaneously extracted trace metals, and (3) the concentrations of trace metals in suspensions of sediment in seawater. Furthermore, TTR contracted AUT to investigate if grinding enriched iron sand increases the potential of this sand to release trace metals when suspended in seawater.

The objectives of this investigation were as follows:

Section A

1. Describe selected properties of the target sediments: particle size distribution, water content, organic matter content, acid volatile sulfide content, and simultaneously extracted metal content (cadmium, chromium, copper, lead, nickel, and zinc).

2. Evaluate trace metal concentrations (cadmium, chromium, copper, lead, nickel, and zinc) in seawater suspensions of the target sediments.

Section B

3. Investigate if grinding of magnetically enriched iron sand increases the potential of the iron sand to release trace metals when suspended in seawater.

Material and methods

Approach

Section A

We conducted physicochemical analyses and standard elutriate tests on sediment collected at five sites within the proposed mining area from sediment depths up to 5 m (Table 1). Reference sediment comprised South Taranaki Bight sediment collected at the same sites from the surface of the seafloor. This sediment is subject to resuspension by waves and currents and any release of trace metals represents natural background processes. Furthermore, we analysed slurries of sediment collected at two additional sites within the proposed mining area from sediment depths up to 18 m (Table 1).

Section B

TTR provided a sample of processed (enriched) iron sand, part of which we ball-milled to produce three particle size fractions. We used these fractions and a sample of the as-received iron sand to conduct physicochemical analyses and standard elutriate tests.

Sample collection and preparation

South Taranaki Bight sediment

TTR collected one sediment core and 20 L of seawater at each of five sites within the proposed mining area on the 12th and 13th of June 2012, and sediment slurry and 20 L of seawater at each of two sites on the 26th and 27th of February 2013 (Table 1).

Table 1. Geographic coordinates and water depth (m) of seven sampling sites. At sites C1–3 and D2–3, the recorded penetration depth of the coring tube (PD) exceeded the length of the retrieved sediment core (CL). PD and CL were linearly correlated: CL = 0.981 × PD – 0.802 (R^2 = 0.982). VC, vibrocorer; RC, reverse circulation corer.

ID	Mining field	Sampling Device	Sample Type	Latitude	Longitude	Water depth (m)	PD (m)	CL (m)
C1	Christina	VC	Core	S 39° 53.637′	E 174° 6.696′	38	4.3	3.6
C2	Christina	VC	Core	S 39° 53.560′	E 174° 4.565′	40	5.0	4.1
C3	Christina	VC	Core	S 39° 52.128′	E 174° 3.268′	43	3.0	2.2
C4	Christina	RC	Slurry	S 39° 53.161′	E 174° 4.192′	42	18	-
D2	Diana	VC	Core	S 39° 52.636′	E 174° 7.744′	32	3.2	2.2
D3	Diana	VC	Core	S 39° 52.003′	E 174° 6.775′	37	5.0	4.0
D4	Diana	RC	Slurry	S 39° 52.431′	E 174° 6.898′	38	18	-

The sampling sites are located ~32 km offshore within an area of ~3.5 km diameter. Four sites are located within the proposed mining field *Christina* (C1–C4, 38–43 m water depth); three sites are located in the proposed mining field *Diana* (D2–4; 32–38 m water depth).

(i) Vibrocoring

To collect a sediment core, TTR deployed an underwater electrical vibrocorer (Model P-5b, Rossfelder Corporation) seated in a custom-built rigid frame. They lowered this frame to the seafloor from the vessel Islander Leader II with a pivoting A-frame, a winch line and the vibrocorer's electrical cable.

The vibrocorer consists of a pair of vibrator motors in a contra-rotating configuration that pushes a stainless-steel core tube into the seafloor (ID = 9.7 cm, 2 mm wall thickness, length = 5 m). The core tube is fitted with a 3 mm internal Teflon lining (OD = 9.6 cm) and a core nose with fingered (orange-peel) core catcher.

Table 2. Sediment core subsampling and sample identification.

Site ID	Sediment depth (m)	Core depth (m)	Sample ID Elutriation	 AVS, SEM, OM
C1	0	0.0	C1-0-A	C1-0-B
C1	1	0.8	C1-1-A	C1-1-B
C1	2	1.6	C1-2-A	C1-2-B
C1	3	2.4	C1-3-A	C1-3-B
C1	4	3.2	C1-4-A	C1-4-B
C2	0	0.0	C2-0-A	C2-0-B
C2	1	0.8	C2-1-A	C2-1-B
C2	2	1.6	C2-2-A	C2-2-B
C2	3	2.4	C2-3-A	C2-3-B
C2	4	3.2	C2-4-A	C2-4-B
C2	5	4.0	C2-5-A	C2-5-B
C3	0	0.0	C3-0-A	C3-0-B
C3	1	0.8	C3-1-A	C3-1-B
C3	2	1.6	C3-2-A	C3-2-B
D2	0	0.0	D2-0-A	D2-0-B
D2	1	0.8	D2-1-A	D2-1-B
D2	2	1.6	D2-2-A	D2-2-B
D3	0	0.0	D3-0-A	D3-0-B
D3	1	0.8	D3-1-A	D3-1-B
D3	2	1.6	D3-2-A	D3-2-B
D3	3	2.4	D3-3-A	D3-3-B
D3	4	3.2	D3-4-A	D3-4-B
D3	5	4.0	D3-5-A	D3-5-B

After returning to Port Wanganui, we hydraulically extruded all five Teflon-liners and enclosed sediment cores from their stainless steel tubes. We then cut the liners into sections (0–1.5, 1.5–2.5, 2.5–3.5, and 3.5–5 m), airtight sealed the ends of each section with plastic bags and transported them to Auckland on ice. In Auckland, the sections were stored in a refrigerated container at -20°C until sediment analyses commenced.

Inspection of the contents of the sections of Teflon liner revealed that, for each sampling site, the recorded penetration depth (PD) of the stainless-steel coring tube exceeded the length of the retrieved sediment core (CL) suggesting that the sediment had been compressed during coring. PD and CL were linearly correlated: $CL = 0.981 \times PD - 0.802$ ($R^2 = 0.982$).

We used this correlation to calculate the distances from the core surface (core depth, Table 2) that corresponded to sediment depths of 0, 1, 2, 3, 4, and 5 m and then removed two aliquots of sediment (samples A, B) at each distance. Each aliquot was filled into one 500 mL HDPE sample jar. Sample A was used for sediment elutriation tests; sample B provided sediment for the determination of organic matter content, particle size distribution, acid volatile sulfides, and simultaneously extracted metals.

All sample jars used here and in the analyses described below were rinsed with tap water, then 100 mL of 10% v/v nitric acid followed by 300 mL of deionised water and allowed to drain. The jars were then placed in a cupboard and allowed to air dry until used.

(ii) Reverse-circulation drilling (RC)

To collect sediment from depths greater than 5 m, TTR deployed a diver-operated reverse-circulation-drill (RC) rig from the vessel PGM Pride once in each of the mining fields *Diana* and *Christina*.

The rig uses water from the sea surface as a drilling lubricant and transport medium. It pumps this seawater under high pressure down the outer tube of a triple tube system to suspend sediment mobilised by a tri-cone roller drill bit. High-pressure air pumped through the second tube lifts this sediment through the third tube, the centre tube. A return sample hose connects the centre tube with a cyclone on the vessel's working deck.

The cyclone releases a continuous stream of sediment slurry when the drill descends into the seabed. From this stream, we collected 500 mL aliquots of slurry (in HDPE sample jars, see above) at depth increments of one metre until the drill reached the maximum depth of 18 m. Furthermore, at each of the two drill sites, we filled one 20 L-container with seawater from sea surface.

We transported the samples of slurry and surface seawater to the laboratory on ice, were they were stored at -20°C until analyses commenced.

Magnetically enriched iron sand

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.

We used a Retsch Planetary Ball Mill (PM 100) to produce three particle size fractions of this sand—a course fraction (BL-C), a medium fraction (BL-M), and a fine fraction (BL-F)—and submitted five aliquots of each fraction for analysis (see below). The Planetary Ball Mill was equipped with a 500 mL sintered aluminium oxide jar and 90 sintered aluminium oxide 10-mm balls. It was operated at 300 rpm.

In addition to the above samples, we removed five 400 ± 10 g samples from the as-received dry iron sand, placed each off these samples in a 500 mL HDPE sample jar (sample ID, as received = BLR), and submitted them for analyses.

Ball milling

Initial ball-milling trials revealed the approximate milling conditions needed to achieve mean particle sizes of approximately 200 (coarse), 100 (medium), and 30 µm (fine). The iron sand as received consisted of particles between 100 and 200 µm with minor percentages of smaller and larger particles.

The samples were prepared as follows:

BL-C, coarse sand: we dry-milled five 400 ± 10 g samples with 90 balls for two minutes. This milling was intended to fracture the large particles but have only a minor effect on the smaller particles to give a suitable coarse sample.

BL-M, medium sand: we milled seven 300 ± 10 g samples, each with an added 75 mL of synthetic seawater (to give a 20% by weight mixture) with 90 balls for 10 min. We made synthetic seawater from a 3% w/w solution of analytical reagent grade sodium chloride (Sharlau, SO0227005P) in milli-Q water. The resulting pastes were transferred to acid-washed beakers and dried for 2 h in a fan oven at an indicated 105°C, cooled for 30 min. Thereafter, we separated balls from the milled sand and used a repeated milling for 30 sec to break up the small lumps. Finally, we combined all samples into a composite and then sealed five 400 ± 10 g subsamples of this composite into the sample jars for analysis.

BL-F, fine fraction: we milled seven 300 ± 10 g samples each with an added 75 mL of synthetic seawater (to give a 20% by weight mixture) with 90 balls for 30 min. The resulting pastes were treated as described above. We combined all samples into a composite and then sealed five 350 ± 10 g subsamples of this composite into the sample jars for analysis.

Analyses

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.

Sediment extractions: AVS

Acid volatile sulfides (AVS): We followed the method described in Wilson and Vopel (2012). We removed four aliquots (about 5 g) from each homogenised sediment sample and added each aliquot to a 40 mL glass vial containing 30 mL deoxygenated HCl (1 mol L^{-1}, ACS grade). The vial was closed with an airtight lid and briefly shaken; the extraction lasted one hours. We weighed each HCl filled vial before and after adding sediment to determine the exact mass of sediment used in the extraction.

To measure the concentration of H_2S in the HCl extractant, we used an amperometric H_2S microelectrode (Unisense A/S, 500-µm tip diameter, response time ~1 sec). The microelectrode is filled with a ferricyanide solution ($K_3[Fe(CN)_6]$) that is reduced to ferrocyanide ($K_4[Fe(CN)_6]$) in the presence of H_2S, which diffuses from the surrounding HCl extractant through the silicone membrane of the microelectrode tip (Jeroschewski 1996; Kühl et al. 1998). Re-oxidation of the reduced ferrocyanide produces a current that is linearly proportional to the concentration of H_2S.

We calibrated the microelectrode with freshly prepared sulfide standards. To prepare the standards, 0, 150, and 300 µmol L^{-1}, aliquots of a stock solution of $Na_2S\,9H_2O$ (0.1 mol L^{-1}) were added to 30 mL deoxygenated HCl (1 mol L^{-1}). The concentration of sulfide in the stock solution was measured by iodometric titration using standard iodine (0.05 mol L^{-1}) and sodium thiosulfate (0.1 mol L^{-1}) solutions (Vogel 1989).

Sediment extractions: trace metals

Sediment core samples: 10 mL HCl were removed from each of four repeated AVS extracts of each of 28 sediment sample (see above), filtered (0.45 µm), and combined in one 40 mL vial. We sent the 28 combined samples to Hill Laboratories for analyses of cadmium, chromium, copper, lead, nickel, and zinc concentrations (ICP-MS, screen level, APHA 3125B 21st ed. 2005, see Appendix for Hill Laboratories Analysis Report, No 1030579).

Processed iron sand samples: The Australian Government National Measurement Institute (hereafter, NMI) digested the samples of processed iron sand with 1 M HCl for two hours and determined the concentration of trace metals with high resolution ICP-MS (Finnigan Element 2, method NT 2.49, ANZECC Guidelines 2000, Section 3.5.5, NMI Report No RN0981498).

Standard elutriation

The elutriation methods used by Hill Laboratories and NMI are based on the ANZECC Interim Ocean Disposal Guideline Section 3.4.2 and USEPA Evaluation of Dredged Material Proposed for Ocean Disposal – Testing Manual, Section 10.1.2.1.

Sediment core samples: Hill Laboratories suspended 23 samples of South Taranaki Bight sediment in seawater from South Taranaki Bight. To do so, they combined the sediment 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.

Processed iron sand samples: NMI suspended 20 mL of each of 20 samples of processed iron sand in 80 mL artificial seawater (method NW.SL17, NMI Report No RN0981494). To facilitate reproducibility and to maximise contact between the solid and liquid phase, a TCLP end-over-end tumbler was used to stir the suspension 30 min before it was allowed to settle for one hour.

Standard elutriate test

Sediment core samples: Hill Laboratories centrifuging the supernatant seawater to remove particulates and then measured the concentrations of dissolved cadmium, chromium, copper, lead, nickel, and zinc (nitric acid digestion, ICP-MS, APHA 3125B 21st ed. 2005). Samples of filtered seawater from South Taranaki Bight were analysed separately to assess background trace metal concentrations.

Processed iron sand samples: NMI used high resolution ICP-MS (Finnigan Element 2) 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.

Trace metals in sediment slurry

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

Results and discussion

Section A: sediment cores and slurry

Sediment properties and AVS content

With our analyses of core sediment, we assess the sediment grain size and the sediment contents of acid volatile sulfides (AVS), simultaneously extracted metals (SEM) and organic matter as a function of sediment depth below the seafloor. Furthermore, we compare these properties with the properties of reference sediment collected from the surface of the seafloor.

Table 3. Granulometric analyses of sediment core samples. Mass median diameter [d(0.5), µm], mean diameter (µm), mode (µm), standard deviation (SD), kurtosis (Ks), skewness (Sk), and proportion larger than 2 mm (%) of sediment particles at sites C1-C3, D2, D3.

Site ID	Sediment depth (m)	d(0.5) (µm)	Mean (µm)	Mode (µm)	SD (µm)	Ks[1]	Sk[2]	>2 mm %
C1	0	365	400	360	171	1.3	1.1	5.1
C1	1	302	318	302	116	0.8	0.6	1.2
C1	2	283	297	286	111	0.7	0.6	3.4
C1	3	241	249	247	100	0.5	0.2	0.0
C1	4	213	221	217	86	0.6	0.3	0.0
C2	0	305	334	299	142	1.6	1.2	14.4
C2	1	244	257	247	95	0.6	0.5	0.9
C2	2	228	244	227	101	29.4	2.5	0.0
C2	3	224	240	223	90	0.5	0.9	0.0
C2	4	304	384	268	267	4.6	1.9	2.8
C2	5	412	471	427	263	2.2	1.3	0.6
C3	0	243	255	243	82	0.5	0.8	0.7
C3	1	235	244	239	96	0.6	0.3	0.0
C3	2	238	252	242	101	0.5	0.6	1.1
D2	0	264	280	264	97	0.5	0.8	0.0
D2	1	239	255	239	97	0.5	0.8	0.0
D2	2	232	252	231	103	0.8	1.0	0.0
D3	0	249	265	249	95	0.8	0.9	3.9
D3	1	243	261	243	100	0.7	0.9	4.2
D3	2	208	224	207	86	0.8	0.9	0.0
D3	3	226	245	223	98	1.0	1.0	0.0
D3	4	211	223	210	76	0.5	0.8	0.0
D3	5	256	291	248	151	5.7	1.7	0.0

[1] Kurtosis is the measure of peakedness (width of peak) or flatness of the distribution related to normal distribution.

[2] Skewness is a measure of the asymmetry of the particle size frequency distribution.

The mean particle diameter of sediment from mining field *Christina* ranged from 221 to 471 µm (sample IDs: C1–C3, Table 3). We classify this sediment as medium sand

(ISO 14688-1). The range of particle sizes was smaller in sediment samples from mining field *Diana* (sample IDs: D2, D3); here the mean particle diameter was between 223 and 291 µm. With the exception of site C3, the size of sediment particles decreased from the surface of the sediment to a depth of two meter. Deeper, however, particles increased in size at site C2 (4 and 5 m depth) and D3 (5 m depth).

Table 4. Acid volatile sulfides (AVS) content (nmol g^{-1} wet weight), water content (% wet weight) and organic matter content (OM, % dry weight) of sediment in the proposed South Taranaki Bight mining area.

Site ID	Sediment depth (m)	AVS (nmol g^{-1} ww)	Water content (% ww)	OM content (% dw)
C1	0	9.6	13	0.71
C1	1	6.7	18	0.88
C1	2	10.6	15	0.92
C1	3	6.6	16	0.93
C1	4	13.2	16	0.57
C2	0	5.5	17	0.87
C2	1	4.3	19	0.83
C2	2	12.3	19	0.85
C2	3	10.0	18	0.88
C2	4	5.8	16	0.63
C2	5	9.8	12	0.31
C3	0	5.2	18	0.84
C3	1	4.5	17	0.69
C3	2	7.1	15	1.02
D2	0	4.8	14	0.39
D2	1	3.9	14	0.40
D2	2	2.8	14	0.24
D3	0	10.0	17	0.72
D3	1	8.5	17	0.82
D3	2	9.8	19	0.87
D3	3	131.7	17	0.86
D3	4	32.6	20	0.89
D3	5	4.8	17	0.82

There was no evidence for a consistent change with increasing depth below the seafloor in sediment organic matter, water and acid volatile sulfide contents in the two proposed mining fields. The sediment pore water contributed 12–20% to the sediment wet weight and the contribution of organic matter to the sediment dry weight was generally below one percent (Table 4). Note that the organic matter content of sediment at site D2 was about half of that of sediment at the nearby site D3; the reason for this difference is unknown.

The low sediment organic matter contents in mining fields *Christina* and *Diana* explain the generally low sediment AVS contents (~9 µmol kg^{-1}, Table 4). Sediment from three meter depth at site D3 makes an exception; here the AVS concentration was an order of magnitude higher.

Simultaneously extracted metals

We extracted trace metals from the deep anoxic sediments to assess the likelihood of adverse effects on the benthic biota should this sediment be exposed by removal of the overlying sediment or otherwise displaced to the surface of the seafloor. To do so, we compare the trace metal concentration in the dilute-acid extracts from the deep sediment with that in extracts from surface (reference) sediment. We argue that adverse effects of trace metals on the functioning of the benthic ecosystem are unlikely if the dilute-acid soluble metal concentration in the deep sediment is of the same order of magnitude than that in the reference sediment.

Table 5. Concentration of simultaneously (dilute-acid) extracted metals (mg kg^{-1} 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

An alternative approach compares concentrations of metals extracted with strong acid (total metal concentration) against ANZECC & ARMCANZ (2000) interim sediment quality guidelines (ISQG). The ISQG-low and -high values, which correspond to the effects range-low and -median used in the NOAA listings (Long et al. 1995), represent a statistical probability of effects when tested against one or two species, usually amphipods. The values do not, however, consider antagonism or synergism between chemicals. Note that 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.

The concentrations of dilute-acid soluble cadmium, copper, lead and zinc in deep sediment were of the same order of magnitude as their maximum concentrations in surface (reference) sediment (Table 5). For dilute-acid soluble cadmium, copper and zinc, there was no evidence for consistent trend of increasing concentrations with increasing sediment depth below the seafloor. The sediment concentrations of lead decreased with depth below the seafloor at sites C1, C2 and D3. We infer a low probability of adverse effects of these dilute-acid soluble metals on benthic ecosystem functioning.

The concentrations of dilute-acid soluble chromium and nickel in deep sediment were often one order of magnitude higher than their maximum concentrations in surface (reference) sediment (Table 5). At sites C1, C3, D2, and D3, chromium and nickel concentrations increased with increasing depth below the seafloor. Because TTR's mining operation will likely extend beyond 5 m depth, the maximum depth measured, this trend initiated additional tests with slurries of sediment from depth below the seafloor of up to 18 m (see below, RC slurry analyses).

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 mg kg^{-1}, this corresponds to ~152 µmol kg^{-1}. The corresponding sediment AVS content, however, does not exceed ~13 µmol 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 sediment may not be responsible for any elevated concentration in the sediment suspension.

Trace metals in sediment suspensions

In the following we compare 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% (Table 6). The protection levels signify the percentage of species expected to be protected.

The guidelines represent the best current estimates of the concentrations of chemicals that should have no significant adverse effects on the aquatic ecosystem. Note, however, that these guidelines are not blanket guidelines; variations in types of ecosystems can affect transport, dilution and degradation of chemicals, and so their bioavailability and toxicity.

The guidelines for toxicants were derived with a statistical distribution approach, modified from Aldenberg and Slob (1993), based on calculations of a probability distribution of aquatic toxicity end-points (ANZECC & ARMCANZ 2000). It attempts to protect a percentage of species, usually 95%, a protection level that is commonly applied to ecosystems classified as slightly or moderately disturbed.

We compare the results of our elutriate tests against guidelines for the 95 and 99% protection level. We include the highest protection level (99%) because we consider (i) South Taranaki Bight as undisturbed ecosystem and (ii) the general lack of biological and chemical baseline data for this particular environment.

Table 6. ANZECC & ARMCANZ guidelines (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^{B}	0.0077	0.0003	0.0022	0.007	0.007
95%	0.0055$^{B, C}$	0.0274	0.0013	0.0044	0.070^{C}	0.015^{C}
90%	0.0140$^{B, C}$	0.0486	0.003^{C}	0.0066^{C}	0.200^{A}	0.023^{C}
80%	0.0360$^{A, B}$	0.0906	0.008^{A}	0.0120^{C}	0.560^{A}	0.043^{C}

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.

Our standard elutriate test revealed that,

(1) For all metals except nickel, the concentration in the elutriate extract were either below detection limit (chromium, copper, lead, zinc) or, if a metal was detected, concentrations did not exceed the ANZECC & ARMCANZ guideline concentrations for the protection of 99% of species (cadmium, Table 7). Note that for copper, the detection limit was below the guidelines for the protection of 95% of species.

(2) The concentrations of nickel in the elutriate extracts of deep sediments (all sites) and surface (reference) sediment (sites C2, C3, D2) were equal or larger than the ANZECC & ARMCANZ guideline concentrations for the protection of 99% of species

(Table 7). However, the nickel concentration never exceeded the ANZECC & ARMCANZ guideline concentrations for the protection of 95% of species.

The concentration of nickel in the South Taranaki Bight seawater was consistently below detection limit (Table 7). Assuming that this nickel concentration equals the detection limit for nickel (0.0063 g m^{-3}), an only 83-fold dilution of the elutriate extract would decrease the highest nickel concentration measured (0.065 g m^{-3}) to below ANZECC & ARMCANZ guideline concentrations for the protection of 99% of species.

Table 7. Concentrations of six trace metals in seawater and sediment elutriates (g m^{-3}). Numbers in parenthesis represent the limits of detection (LOD, g m^{-3}). <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 depth (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

Chromium and nickel in RC slurry

We used sediment slurry to assess the potential release of nickel and chromium from sediment deeper than five meter below the surface of the seafloor. We did so because the above described SEM analyses revealed that the nickel and chromium content of the sediment at four of the five sites (C1, C3, D2, and D3) increased from the surface to five meter below the surface of the seafloor (see Table 5).

A repeat of the above described SEM analyses with sediment from greater depth was not possible because TTR's vibrocorer collects cores of undisturbed sediment to a maximum depth below the seafloor of only five meter. TTR's reverse-circulation drill, however, provided sediment from greater depth but this sediment reached the surface in form of a slurry, a mixture of seawater, air and sediment.

We note that the concentration of dilute-acid soluble nickel in core sediment (Table 5) and the concentration of nickel in the elutriate extract of this sediment (Table 7) were linearly correlated ($R^2 = 0.837$). If this correlation holds for sediment from >5 m depth below the seafloor, then an increase with depth in the sediment content of dilute-acid soluble metal should cause an increase with depth in the concentration of metals in slurry of this sediment.

Table 8. Concentrations of nickel and chromium in RC sediment slurry (g m^{-3}) from the proposed mining fields *Diana* and *Christina*. Numbers in parenthesis represent the limits of detection (LOD, g m^{-3}). <LOD, below limits of detection.

	Diana		**Christina**	
Sediment depth (m)	Cr (0.001)	Ni (0.006)	Cr (0.001)	Ni (0.006)
1	<LOD	0.016	<LOD	0.011
2	<LOD	0.007	<LOD	0.008
3	<LOD	0.012	<LOD	<LOD
4	<LOD	<LOD	<LOD	<LOD
5	<LOD	<LOD	<LOD	<LOD
6	<LOD	<LOD	<LOD	0.013
7	<LOD	<LOD	<LOD	<LOD
8	<LOD	<LOD	<LOD	0.007
9	<LOD	<LOD	<LOD	<LOD
10	<LOD	<LOD	<LOD	<LOD
11	<LOD	<LOD	<LOD	<LOD
12	<LOD	<LOD	<LOD	<LOD
13	<LOD	0.007	<LOD	<LOD
14	<LOD	<LOD	<LOD	<LOD
15	<LOD	<LOD	<LOD	<LOD
16	<LOD	<LOD	<LOD	0.007
17	<LOD	<LOD	<LOD	0.013
18	<LOD	<LOD	<LOD	0.008
Seawater	<LOD	<LOD	<LOD	<LOD

Following this logic, we analysed RC slurry of sediment from mining fields *Diana* and *Christina* sampled in one-metre increments starting one metre below the surface of the seafloor to a maximum depth of 18 m. This analysis failed to reveal evidence for a trend of increasing metal concentrations with increasing sediment depth below the seafloor. That is, we found no consistent increase with depth in the concentrations of dissolved nickel. The concentrations of chromium were below detection limit.

Section B: processed iron sand

With their offshore beneficiation plant, TTR plans to extract and concentrate vanadium-titanomagnetite with alternating steps of magnetic separation and grinding. TTR will keep the sediment suspended in seawater to feed it through a series of grinding mills. This seawater, and any dissolved trace metals released from the sediment particles during grinding, will eventually be returned to South Taranaki Bight.

Table 10. Processed iron sand. Characteristics of particle size frequency distributions. [d(0.5)], mass median diameter (µm); Mean, mean diameter (µm); Mode (µm), SD, ±1 standard deviation (µm); Ks, kurtosis; Sk, skewness.

Sample ID	d(0.5) (µm)	Mean (µm)	Mode (µm)	SD (µm)	Ks	Sk
BL-R1	259.7	291.2	253.8	139.7	0.6	1.0
BL-R2	243.1	282.2	226.2	149.8	2.3	1.4
BL-R3	257.5	292.9	247.7	147.3	2.0	1.3
BL-R4	249.3	288.3	234.1	152.7	2.3	1.4
BL-R5	251.2	286.5	240.1	145.0	2.3	1.4
BL-C1	230.6	262.5	220.7	131.8	0.8	1.1
BL-C2	239.4	273.7	229.6	140.3	0.9	1.1
BL-C3	254.7	289.4	251.5	152.4	0.6	1.0
BL-C4	261.4	299.8	254.9	158.4	0.8	1.1
BL-C5	225.2	255.0	215.4	125.5	0.5	1.0
BL-M1	173.4	187.0	183.1	98.8	0.2	0.6
BL-M2	177.0	191.4	186.4	101.4	0.1	0.6
BL-M3	176.4	189.9	187.6	101.4	0.1	0.5
BL-M4	172.7	185.8	183.3	98.7	0.2	0.6
BL-M5	160.3	171.3	175.0	95.5	0.0	0.5
BL-F1	10.7	27.8	23.2	53.4	25.7	4.6
BL-F2	10.4	20.2	21.9	24.1	2.9	1.8
BL-F3	10.8	21.2	24.2	25.8	3.6	1.9
BL-F4	12.2	25.6	33.0	36.1	14.3	3.2
BL-F5	10.6	21.0	22.7	28.4	12.1	3.0

[1] Kurtosis is the measure of peakedness (width of peak) or flatness of the distribution related to normal distribution.

[2] Skewness is a measure of the asymmetry of the particle size frequency distribution.

The following analyses assist us to assess the potential of grinding sediment particles to affect the concentration of trace metals in the seawater that suspends such particles. To do so, we ask if grinding changes (i) the dilute-acid soluble metal content of magnetically enriched iron sand and (ii) the concentrations of trace metals in elutriates of such iron sand. To include a range of possible grain sizes, we conducted our analyses on four sediment fractions (as received iron sand, coarse grind, medium grind, and fine grind), which we characterise by granulometric analyses.

Sediment properties

We found that the average mass median diameters of the as-received iron sand (287 ± 4 µm) and the coarse sand fraction of the first grind (BL-C, 276 ± 19 µm) did not differ significantly. The first grind, however, decreased kurtosis and skewness of the iron sand particle size distribution (Table 10).

Our second grind (BL-M) lowered the average mass median diameter by ~33% to 186 ± 8 µm and again decreased kurtosis and skewness of the particle size distribution. The third grind (BL-F) decreased the average mass diameter by an order of magnitude to 23 ± 3 µm; kurtosis and skewness of the particle size distribution, however, increased by two and one order of magnitude, respectively.

Table 11. Concentrations of simultaneously extracted metals (mg kg^{-1} dry weight) in processed South Taranaki Bight sediment. NMI reporting limits = 0.5 mg kg^{-1} 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

Simultaneously extracted metals

We extracted dilute-acid soluble trace metals from as-received and ball-milled iron sand to assess the effect of grinding on the metal content of the magnetically enriched iron sand.

The extracts of the magnetically enriched iron sands (Table 11) contained two orders of magnitude higher concentrations of zinc and copper than the extracts of natural "unprocessed" sediment analysed in Section A (Table 5). These differences, which may have resulted from differences in the extraction procedure (see Material and methods), are irrelevant because we do not compare the dilute-acid soluble metal contents of "natural sediment" and magnetically enriched iron sand.

Furthermore, note that we do not attempt to assess potential adverse effects of the magnetically enriched (and ball-milled) iron sand on benthic biota (as in Section A) but instead simply ask if the dilute-acid soluble metal content of this iron sand changes through grinding. (Processed iron sand will not be returned to the seafloor but shipped to customers). That is, we compare the dilute-acid soluble metal content of raw and ground magnetically enriched iron sands.

If grinding increases the dilute-acid soluble metal content of the iron sand, then we can expect an increase in the metal content of the seawater elutriates of this iron sand. Such increase would be of interest because the seawater that suspends and feeds iron sand through the TTR's grinding mills eventually returns to South Taranaki Bight.

Our analyses showed that the average concentrations in magnetically enriched iron sand of dilute-acid soluble chromium, nickel and zinc decreased after each of the first two grinds (average d(0.5) = 242 and 172 µm) but increased after the third grind (average d(0.5) = 11 µm) to 171, 150, and 162% of that in the extract of the as-received (raw) iron sand (average d(0.5) = 252 µm, Table 11).

In contrast, for copper and lead, the average concentrations in the extracts of the first two grinds did not significantly differ from that of the as-received iron sand but the third grind increased these concentrations to 193 and 132% of the concentration in the extract of the as-received iron sand. Because TTR plans to grind their iron sand particles to sizes less than 172 µm (our second grind), their final product will likely contain a larger content of these dilute-acid soluble trace metals.

The concentrations of dilute-acid soluble cadmium were below reporting limits in both raw and ball-milled magnetically enriched iron sand.

Trace metals in sediment suspensions

Our elutriate tests revealed concentrations of cadmium, lead and nickel below the limits of reporting for all sediment samples (Table 12). Chromium was detected only in the fine sediment fraction but its average concentration was below the ANZECC & ARMCANZ guideline for the protection of 99% of species.

We detected zinc in the elutriates of all sediment samples but the concentration averages for each sand size fraction did not exceeded the ANZECC & ARMCANZ guideline for the protection of 99% of species (Tables 12).

The elutriate concentration of copper was negatively linearly correlated (*r* = -0.89, outlier BL-M1 excluded) with the particle size of the suspended iron sand. That is, the concentration of copper in iron sand suspensions increased with decreasing size of the suspended iron sand particles.

Table 12. Concentrations of six trace metals in synthetic seawater (Syn sw) and synthetic seawater elutriates of processed sediment (g m^{-3}). Numbers in parenthesis represent Limits of Reporting (LOR, 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

The average elutriate copper concentrations of as-received and coarse iron sand (0.0013 g m^{-3}) exceeded the ANZECC & ARMCANZ guideline for the protection of 99% of species. Assuming that South Taranaki Bight seawater contains 0.00025 g m^{-3} (0.25 ppb) copper an only 20-fold dilution would decrease this concentration to below the concentration limit for the protection of 99% of species (Table 6).

The average copper concentrations in the elutriates of medium and fine coarse iron sand (0.0081 and 0.0078 g m^{-3}) exceeded the ANZECC & ARMCANZ guideline for the protection of 80% of species. Here, a 160-fold dilution would decrease these concentrations to below the concentration limit for the protection of 99% of species.

Summary and conclusions

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

Dilute-acid soluble metals in deep sediment

The concentrations of dilute-acid soluble cadmium, copper, lead and zinc in deep sediment were of the same order of magnitude as their maximum concentrations in surface (reference) sediment. For dilute-acid soluble cadmium, copper and zinc, there was no evidence for a trend of increasing concentrations with increasing sediment depth below the seafloor. The sediment concentrations of lead decreased with depth below the seafloor at sites C1, C2 and D3. We infer a low probability of adverse effects of these dilute-acid soluble metals on benthic ecosystem functioning.

The concentrations of dilute-acid soluble chromium and nickel in deep sediment were often one order of magnitude higher than their maximum concentrations in surface (reference) sediment. Furthermore, at sites C1, C3, D2, and D3, chromium and nickel concentrations increased with increasing depth below the seafloor. Additional analyses of sediment slurry collected to a maximum sediment depth of 18 m, however, did not reveal evidence for such trends. We found no consistent increase with depth in the concentrations of dissolved nickel in the slurry. The concentrations of chromium were below the detection limit.

Trace metals in sediment suspensions

For all metals except nickel, the concentrations in the elutriate extract were either below detection limit (chromium, copper, lead, zinc) or, if a metal was detected (cadmium), concentrations did not exceed the ANZECC & ARMCANZ guideline concentrations for the protection of 99% of species. The detection limit for copper was below the guidelines for the protection of 95% of species.

The concentrations of nickel in the elutriate extracts of deep sediments (all sites) and surface (reference) sediment (sites C2, C3, D2) were equal or larger than the ANZECC & ARMCANZ guideline concentrations for the protection of 99% of species. However, the concentration never exceeded the guideline concentrations for the protection of 95% of species. Assuming that the nickel concentration in South Taranaki Bight seawater equals the detection limit for nickel, it would only require an 83-fold dilution of the elutriate extract to decrease the highest nickel concentration measured to below guideline concentrations for the protection of 99% of species.

Effect of grinding on the dilute-acid soluble metal content of enriched iron sand

A sample of magnetically enriched iron sand was ball milled to three average sizes, 276 µm, 183 µm and 23 µm. The average concentrations in this iron sand of dilute-acid soluble chromium, nickel and zinc decreased after each of the first two grinds but increased after the third grind to 171, 150, and 162% of that in the extract of the as-received enriched iron sand. In contrast, for copper and lead, the average concentrations in the extracts of the first two grinds did not significantly differ from that of the as-received iron sand but the third grind increased these concentrations to 193 and 132% of the concentration in the extract of the as-received iron sand. The concentrations of dilute-acid soluble cadmium were below reporting limits in both as-received and ball-milled magnetically enriched iron sand.

TTR plans to grind iron sand particles to sizes less than 172 µm (our second grind); this grinding may gradually enrich the recirculated seawater that feeds the iron sand through TTR's grinding mills with trace metals. Our elutriate tests revealed, however, concentrations of cadmium, lead and nickel below the limits of reporting for all sediment samples. Chromium was detected only in 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 exceeded the ANZECC & ARMCANZ guideline for the protection of 99% of species. We infer a low probability of adverse effects of these metals on ecosystem functioning of the South Taranaki Bight water column.

The elutriate concentration of copper was negatively linearly correlated (r = -0.89) with the particle size of the suspended iron sand. The average elutriate copper concentrations of as-received and the coarse iron sand fraction exceeded the ANZECC & ARMCANZ guideline for the protection of 99% of species. Assuming that South Taranaki Bight seawater contains 0.25 ppb copper an only 20-fold dilution would decrease this concentration to below the concentration limit for the protection of 99% of species. In contrast, the average copper concentrations in elutriates of medium and fine coarse iron sand exceeded the guideline for the protection of 80% of species. Here, a 160-fold dilution would decrease these concentrations to below the concentration limit for the protection of 99% of species.

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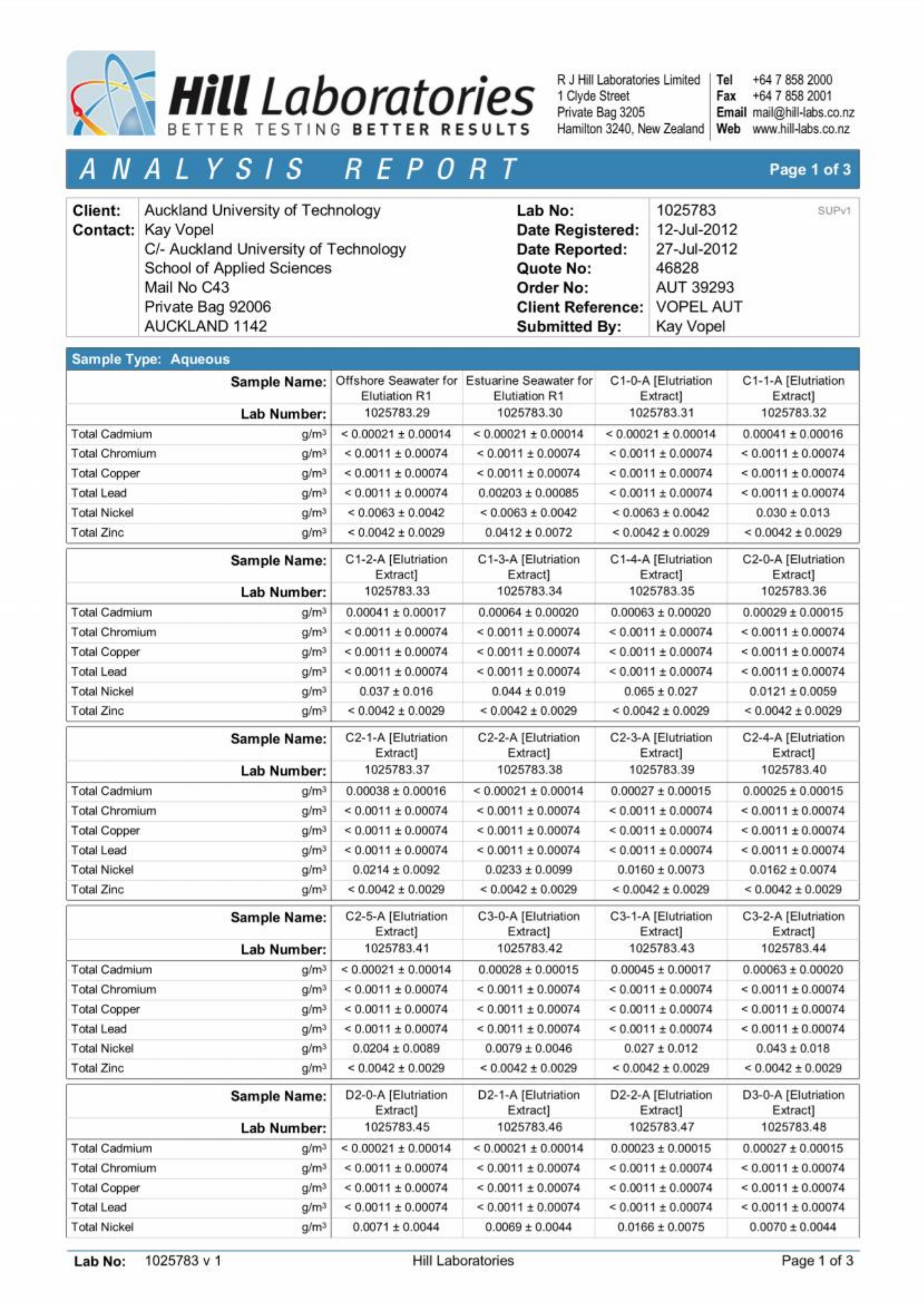
Appendix



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ANALYSIS REPORT

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SUPv1

Client:	Auckland University of Technology	**Lab No:**	1025783
Contact:	Kay Vopel C/- Auckland University of Technology School of Applied Sciences Mail No C43 Private Bag 92006 AUCKLAND 1142	**Date Registered:**	12-Jul-2012
		Date Reported:	27-Jul-2012
		Quote No:	46828
		Order No:	AUT 39293
		Client Reference:	VOPEL AUT
		Submitted By:	Kay Vopel

Sample Type: Aqueous

	Sample Name:	Offshore Seawater for Elutiation R1	Estuarine Seawater for Elutiation R1	C1-0-A [Elutriation Extract]	C1-1-A [Elutriation Extract]
	Lab Number:	1025783.29	1025783.30	1025783.31	1025783.32
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	0.00041 ± 0.00016
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	0.00203 ± 0.00085	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042	0.030 ± 0.013
Total Zinc	g/m^3	< 0.0042 ± 0.0029	0.0412 ± 0.0072	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029

	Sample Name:	C1-2-A [Elutriation Extract]	C1-3-A [Elutriation Extract]	C1-4-A [Elutriation Extract]	C2-0-A [Elutriation Extract]
	Lab Number:	1025783.33	1025783.34	1025783.35	1025783.36
Total Cadmium	g/m^3	0.00041 ± 0.00017	0.00064 ± 0.00020	0.00063 ± 0.00020	0.00029 ± 0.00015
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	0.037 ± 0.016	0.044 ± 0.019	0.065 ± 0.027	0.0121 ± 0.0059
Total Zinc	g/m^3	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029

	Sample Name:	C2-1-A [Elutriation Extract]	C2-2-A [Elutriation Extract]	C2-3-A [Elutriation Extract]	C2-4-A [Elutriation Extract]
	Lab Number:	1025783.37	1025783.38	1025783.39	1025783.40
Total Cadmium	g/m^3	0.00038 ± 0.00016	< 0.00021 ± 0.00014	0.00027 ± 0.00015	0.00025 ± 0.00015
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	0.0214 ± 0.0092	0.0233 ± 0.0099	0.0160 ± 0.0073	0.0162 ± 0.0074
Total Zinc	g/m^3	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029

	Sample Name:	C2-5-A [Elutriation Extract]	C3-0-A [Elutriation Extract]	C3-1-A [Elutriation Extract]	C3-2-A [Elutriation Extract]
	Lab Number:	1025783.41	1025783.42	1025783.43	1025783.44
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	0.00028 ± 0.00015	0.00045 ± 0.00017	0.00063 ± 0.00020
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	0.0204 ± 0.0089	0.0079 ± 0.0046	0.027 ± 0.012	0.043 ± 0.018
Total Zinc	g/m^3	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029

	Sample Name:	D2-0-A [Elutriation Extract]	D2-1-A [Elutriation Extract]	D2-2-A [Elutriation Extract]	D3-0-A [Elutriation Extract]
	Lab Number:	1025783.45	1025783.46	1025783.47	1025783.48
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	0.00023 ± 0.00015	0.00027 ± 0.00015
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	0.0071 ± 0.0044	0.0069 ± 0.0044	0.0166 ± 0.0075	0.0070 ± 0.0044

Lab No: 1025783 v 1 Hill Laboratories Page 1 of 3

Sample Type: Aqueous

Sample Name:		D2-0-A [Elutriation Extract]	D2-1-A [Elutriation Extract]	D2-2-A [Elutriation Extract]	D3-0-A [Elutriation Extract]
Lab Number:		1025783.45	1025783.46	1025783.47	1025783.48
Total Zinc	g/m^3	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029

Sample Name:		D3-1-A [Elutriation Extract]	D3-2-A [Elutriation Extract]	D3-3-A [Elutriation Extract]	D3-4-A [Elutriation Extract]
Lab Number:		1025783.49	1025783.50	1025783.51	1025783.52
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	0.00030 ± 0.00015	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	< 0.0063 ± 0.0042	0.0139 ± 0.0065	0.0074 ± 0.0045	0.0123 ± 0.0060
Total Zinc	g/m^3	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029

Sample Name:		D3-5-A [Elutriation Extract]	Ref-1 [Elutriation Extract]	Ref-2 [Elutriation Extract]	Ref-3 [Elutriation Extract]
Lab Number:		1025783.53	1025783.54	1025783.55	1025783.56
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	0.028 ± 0.012	0.0092 ± 0.0050	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042
Total Zinc	g/m^3	< 0.0042 ± 0.0029	0.0139 ± 0.0036	0.0049 ± 0.0029	< 0.0042 ± 0.0029

Sample Name:		Ref-4 [Elutriation Extract]	Ref-5 [Elutriation Extract]	Offshore Seawater for Elutiation R2	Offshore Seawater for Elutiation R3
Lab Number:		1025783.57	1025783.58	1025783.59	1025783.60
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074
Total Nickel	g/m^3	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042
Total Zinc	g/m^3	< 0.0042 ± 0.0029	0.0075 ± 0.0030	0.0082 ± 0.0031	0.0048 ± 0.0029

Sample Name:		Offshore Seawater for Elutiation R4	Offshore Seawater for Elutiation R5	Estuarine Seawater for Elutiation R2	Estuarine Seawater for Elutiation R3
Lab Number:		1025783.61	1025783.62	1025783.63	1025783.64
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	0.00150 ± 0.00076	< 0.0011 ± 0.00074
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	0.00189 ± 0.00083	< 0.0011 ± 0.00074
Total Lead	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	0.00217 ± 0.00086	0.00210 ± 0.00085
Total Nickel	g/m^3	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042
Total Zinc	g/m^3	< 0.0042 ± 0.0029	< 0.0042 ± 0.0029	0.0352 ± 0.0063	0.0346 ± 0.0062

Sample Name:		Estuarine Seawater for Elutiation R4	Estuarine Seawater for Elutiation R5		
Lab Number:		1025783.65	1025783.66		
Total Cadmium	g/m^3	< 0.00021 ± 0.00014	< 0.00021 ± 0.00014	-	-
Total Chromium	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	-	-
Total Copper	g/m^3	< 0.0011 ± 0.00074	< 0.0011 ± 0.00074	-	-
Total Lead	g/m^3	0.00222 ± 0.00087	0.00204 ± 0.00085	-	-
Total Nickel	g/m^3	< 0.0063 ± 0.0042	< 0.0063 ± 0.0042	-	-
Total Zinc	g/m^3	0.0420 ± 0.0073	0.0362 ± 0.0064	-	-

The reported uncertainty is an expanded uncertainty with a level of confidence of approximately 95 percent (i.e. two standard deviations, calculated using a coverage factor of 2). Reported uncertainties are calculated from the performance of typical matrices, and do not include variation due to sampling.

For further information on uncertainty of measurement at Hill Laboratories, refer to the technical note on our website: www.hill-laboratories.com/files/Intro_To_UOM.pdf, or contact the laboratory.

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Samples
Elutriation testing	Extn with (client supplied) water, eg seawater, Sed:Water 1:4 by vol, mix 30 min, settle 1 hr, filtration or centrifugation. US EPA 503/8-91/001, "Evaluation of Dredged Material for Ocean Disposal".	-	1-28

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Total Digestion of Saline Samples	Nitric acid digestion. APHA 3030 E 21st ed. 2005.	-	29-66
Total Cadmium	Nitric acid digestion, ICP-MS, ultratrace level. APHA 3125 B 21st ed. 2005.	0.00021 g/m^3	29-66
Total Chromium	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0011 g/m^3	29-66
Total Copper	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0011 g/m^3	29-66
Total Lead	Nitric acid digestion, ICP-MS, ultratrace level. APHA 3125 B 21st ed. 2005.	0.0011 g/m^3	29-66
Total Nickel	Nitric acid digestion, ICP-MS, ultratrace level. APHA 3125 B 21st ed. 2005.	0.0063 g/m^3	29-66
Total Zinc	Nitric acid digestion, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0042 g/m^3	29-66

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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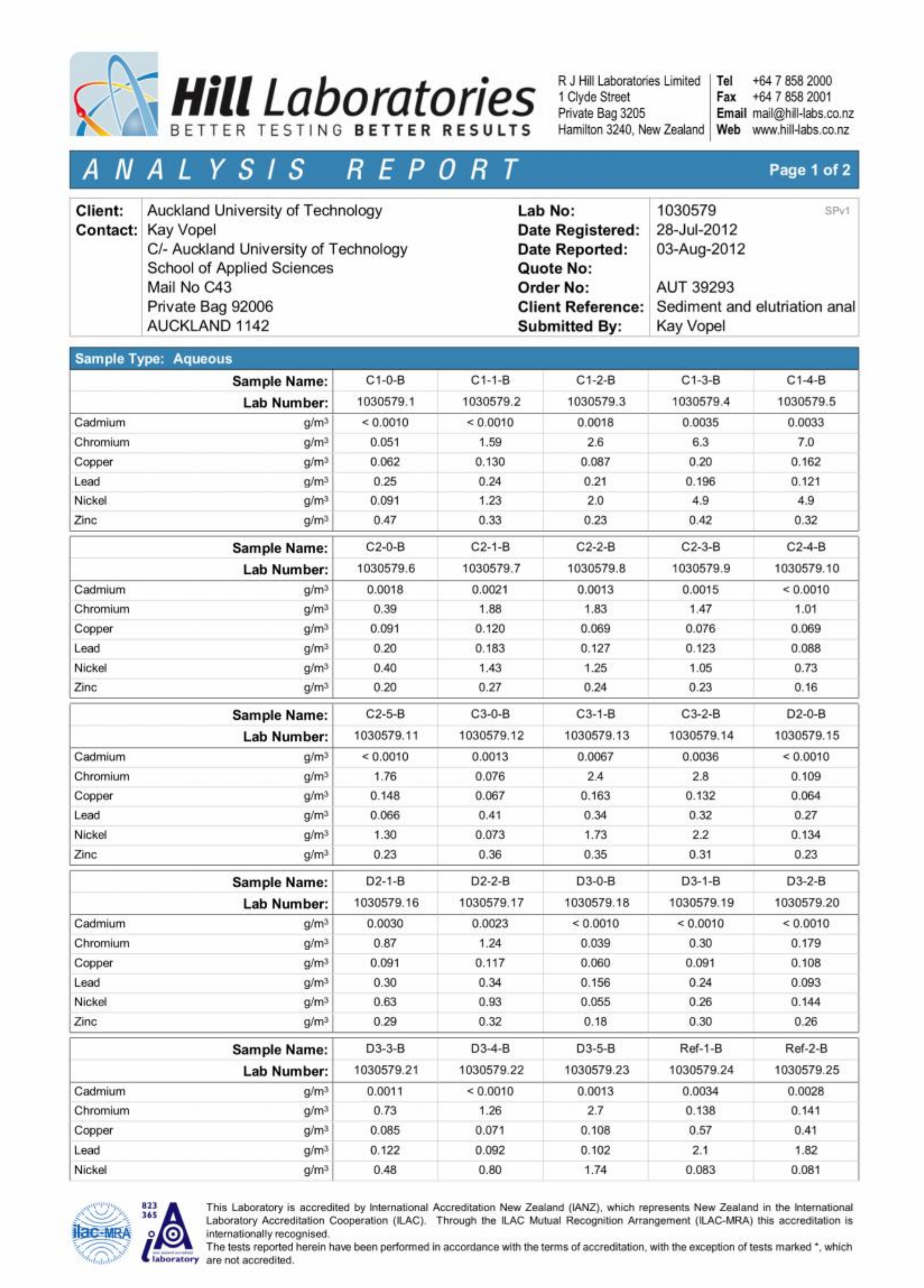
Carole Rodgers-Carroll

Carole Rodgers-Carroll BA, NZCS
Client Services Manager - Environmental Division



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ANALYSIS REPORT

Page 1 of 2

Client:	Auckland University of Technology	**Lab No:**	1030579	SPv1
Contact:	Kay Vopel C/- Auckland University of Technology School of Applied Sciences Mail No C43 Private Bag 92006 AUCKLAND 1142	**Date Registered:**	28-Jul-2012	
		Date Reported:	03-Aug-2012	
		Quote No:		
		Order No:	AUT 39293	
		Client Reference:	Sediment and elutriation anal	
		Submitted By:	Kay Vopel	

Sample Type: Aqueous

	Sample Name:	C1-0-B	C1-1-B	C1-2-B	C1-3-B	C1-4-B
	Lab Number:	1030579.1	1030579.2	1030579.3	1030579.4	1030579.5
Cadmium	g/m^3	< 0.0010	< 0.0010	0.0018	0.0035	0.0033
Chromium	g/m^3	0.051	1.59	2.6	6.3	7.0
Copper	g/m^3	0.062	0.130	0.087	0.20	0.162
Lead	g/m^3	0.25	0.24	0.21	0.196	0.121
Nickel	g/m^3	0.091	1.23	2.0	4.9	4.9
Zinc	g/m^3	0.47	0.33	0.23	0.42	0.32

	Sample Name:	C2-0-B	C2-1-B	C2-2-B	C2-3-B	C2-4-B
	Lab Number:	1030579.6	1030579.7	1030579.8	1030579.9	1030579.10
Cadmium	g/m^3	0.0018	0.0021	0.0013	0.0015	< 0.0010
Chromium	g/m^3	0.39	1.88	1.83	1.47	1.01
Copper	g/m^3	0.091	0.120	0.069	0.076	0.069
Lead	g/m^3	0.20	0.183	0.127	0.123	0.088
Nickel	g/m^3	0.40	1.43	1.25	1.05	0.73
Zinc	g/m^3	0.20	0.27	0.24	0.23	0.16

	Sample Name:	C2-5-B	C3-0-B	C3-1-B	C3-2-B	D2-0-B
	Lab Number:	1030579.11	1030579.12	1030579.13	1030579.14	1030579.15
Cadmium	g/m^3	< 0.0010	0.0013	0.0067	0.0036	< 0.0010
Chromium	g/m^3	1.76	0.076	2.4	2.8	0.109
Copper	g/m^3	0.148	0.067	0.163	0.132	0.064
Lead	g/m^3	0.066	0.41	0.34	0.32	0.27
Nickel	g/m^3	1.30	0.073	1.73	2.2	0.134
Zinc	g/m^3	0.23	0.36	0.35	0.31	0.23

	Sample Name:	D2-1-B	D2-2-B	D3-0-B	D3-1-B	D3-2-B
	Lab Number:	1030579.16	1030579.17	1030579.18	1030579.19	1030579.20
Cadmium	g/m^3	0.0030	0.0023	< 0.0010	< 0.0010	< 0.0010
Chromium	g/m^3	0.87	1.24	0.039	0.30	0.179
Copper	g/m^3	0.091	0.117	0.060	0.091	0.108
Lead	g/m^3	0.30	0.34	0.156	0.24	0.093
Nickel	g/m^3	0.63	0.93	0.055	0.26	0.144
Zinc	g/m^3	0.29	0.32	0.18	0.30	0.26

	Sample Name:	D3-3-B	D3-4-B	D3-5-B	Ref-1-B	Ref-2-B
	Lab Number:	1030579.21	1030579.22	1030579.23	1030579.24	1030579.25
Cadmium	g/m^3	0.0011	< 0.0010	0.0013	0.0034	0.0028
Chromium	g/m^3	0.73	1.26	2.7	0.138	0.141
Copper	g/m^3	0.085	0.071	0.108	0.57	0.41
Lead	g/m^3	0.122	0.092	0.102	2.1	1.82
Nickel	g/m^3	0.48	0.80	1.74	0.083	0.081

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The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

Sample Type: Aqueous

Sample Name:		D3-3-B	D3-4-B	D3-5-B	Ref-1-B	Ref-2-B
Lab Number:		1030579.21	1030579.22	1030579.23	1030579.24	1030579.25
Zinc	g/m^3	0.41	0.34	0.37	8.4	6.8

Sample Name:		Ref-3-B	Ref-4-B	Ref-5-B		
Lab Number:		1030579.26	1030579.27	1030579.28		
Cadmium	g/m^3	0.0044	0.0029	0.0031	-	-
Chromium	g/m^3	0.174	0.124	0.112	-	-
Copper	g/m^3	0.58	0.52	0.33	-	-
Lead	g/m^3	2.4	2.1	1.71	-	-
Nickel	g/m^3	0.087	0.071	0.063	-	-
Zinc	g/m^3	9.4	7.6	7.1	-	-

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Cadmium	Analysed as received following client preparation (after acid preservation, if required), ICP-MS, screen level. APHA 3125 B 21st ed. 2005.	0.0010 g/m^3	1-28
Chromium	Analysed as received following client preparation (after acid preservation, if required), ICP-MS, screen level. APHA 3125 B 21st ed. 2005.	0.010 g/m^3	1-28
Copper	Analysed as received following client preparation (after acid preservation, if required), ICP-MS, screen level. APHA 3125 B 21st ed. 2005.	0.010 g/m^3	1-28
Lead	Analysed as received following client preparation (after acid preservation, if required), ICP-MS, screen level. APHA 3125 B 21st ed. 2005.	0.002 g/m^3	1-28
Nickel	Analysed as received following client preparation (after acid preservation, if required), ICP-MS, screen level. APHA 3125 B 21st ed. 2005.	0.010 g/m^3	1-28
Zinc	Analysed as received following client preparation (after acid preservation, if required), ICP-MS, screen level. APHA 3125 B 21st ed. 2005.	0.02 g/m^3	1-28

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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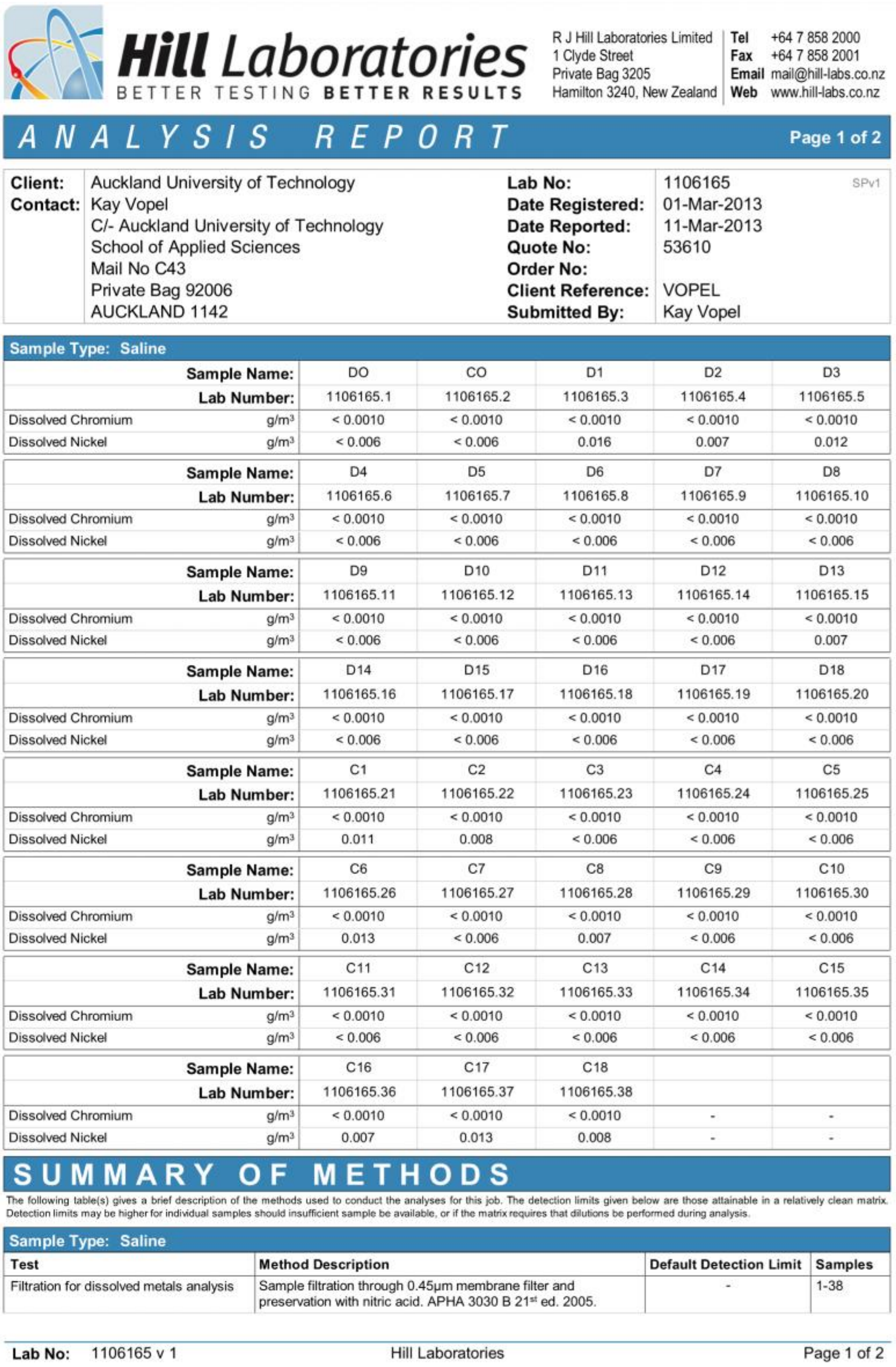
Carole Rodgers-Carroll

Carole Rodgers-Carroll BA, NZCS
Client Services Manager - Environmental Division



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Fax +64 7 858 2001
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Web www.hill-labs.co.nz

ANALYSIS REPORT

Page 1 of 2

SPv1

Client:	Auckland University of Technology	**Lab No:**	1106165
Contact:	Kay Vopel	**Date Registered:**	01-Mar-2013
	C/- Auckland University of Technology	**Date Reported:**	11-Mar-2013
	School of Applied Sciences	**Quote No:**	53610
	Mail No C43	**Order No:**	
	Private Bag 92006	**Client Reference:**	VOPEL
	AUCKLAND 1142	**Submitted By:**	Kay Vopel

Sample Type: Saline

	Sample Name:	DO	CO	D1	D2	D3
	Lab Number:	1106165.1	1106165.2	1106165.3	1106165.4	1106165.5
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Dissolved Nickel	g/m³	< 0.006	< 0.006	0.016	0.007	0.012
	Sample Name:	D4	D5	D6	D7	D8
	Lab Number:	1106165.6	1106165.7	1106165.8	1106165.9	1106165.10
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Dissolved Nickel	g/m³	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
	Sample Name:	D9	D10	D11	D12	D13
	Lab Number:	1106165.11	1106165.12	1106165.13	1106165.14	1106165.15
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Dissolved Nickel	g/m³	< 0.006	< 0.006	< 0.006	< 0.006	0.007
	Sample Name:	D14	D15	D16	D17	D18
	Lab Number:	1106165.16	1106165.17	1106165.18	1106165.19	1106165.20
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Dissolved Nickel	g/m³	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
	Sample Name:	C1	C2	C3	C4	C5
	Lab Number:	1106165.21	1106165.22	1106165.23	1106165.24	1106165.25
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Dissolved Nickel	g/m³	0.011	0.008	< 0.006	< 0.006	< 0.006
	Sample Name:	C6	C7	C8	C9	C10
	Lab Number:	1106165.26	1106165.27	1106165.28	1106165.29	1106165.30
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Dissolved Nickel	g/m³	0.013	< 0.006	0.007	< 0.006	< 0.006
	Sample Name:	C11	C12	C13	C14	C15
	Lab Number:	1106165.31	1106165.32	1106165.33	1106165.34	1106165.35
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Dissolved Nickel	g/m³	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
	Sample Name:	C16	C17	C18		
	Lab Number:	1106165.36	1106165.37	1106165.38		
Dissolved Chromium	g/m³	< 0.0010	< 0.0010	< 0.0010	-	-
Dissolved Nickel	g/m³	0.007	0.013	0.008	-	-

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Saline

Test	Method Description	Default Detection Limit	Samples
Filtration for dissolved metals analysis	Sample filtration through 0.45µm membrane filter and preservation with nitric acid. APHA 3030 B 21st ed. 2005.	-	1-38

Lab No: 1106165 v 1 Hill Laboratories Page 1 of 2

Sample Type: Saline			
Test	**Method Description**	**Default Detection Limit**	**Samples**
Dissolved Chromium	Filtered sample, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 21st ed. 2005.	0.0010 g/m^3	1-38
Dissolved Nickel	Filtered sample, ICP-MS, ultratrace level. APHA 3125 B 21st ed. 2005.	0.006 g/m^3	1-38

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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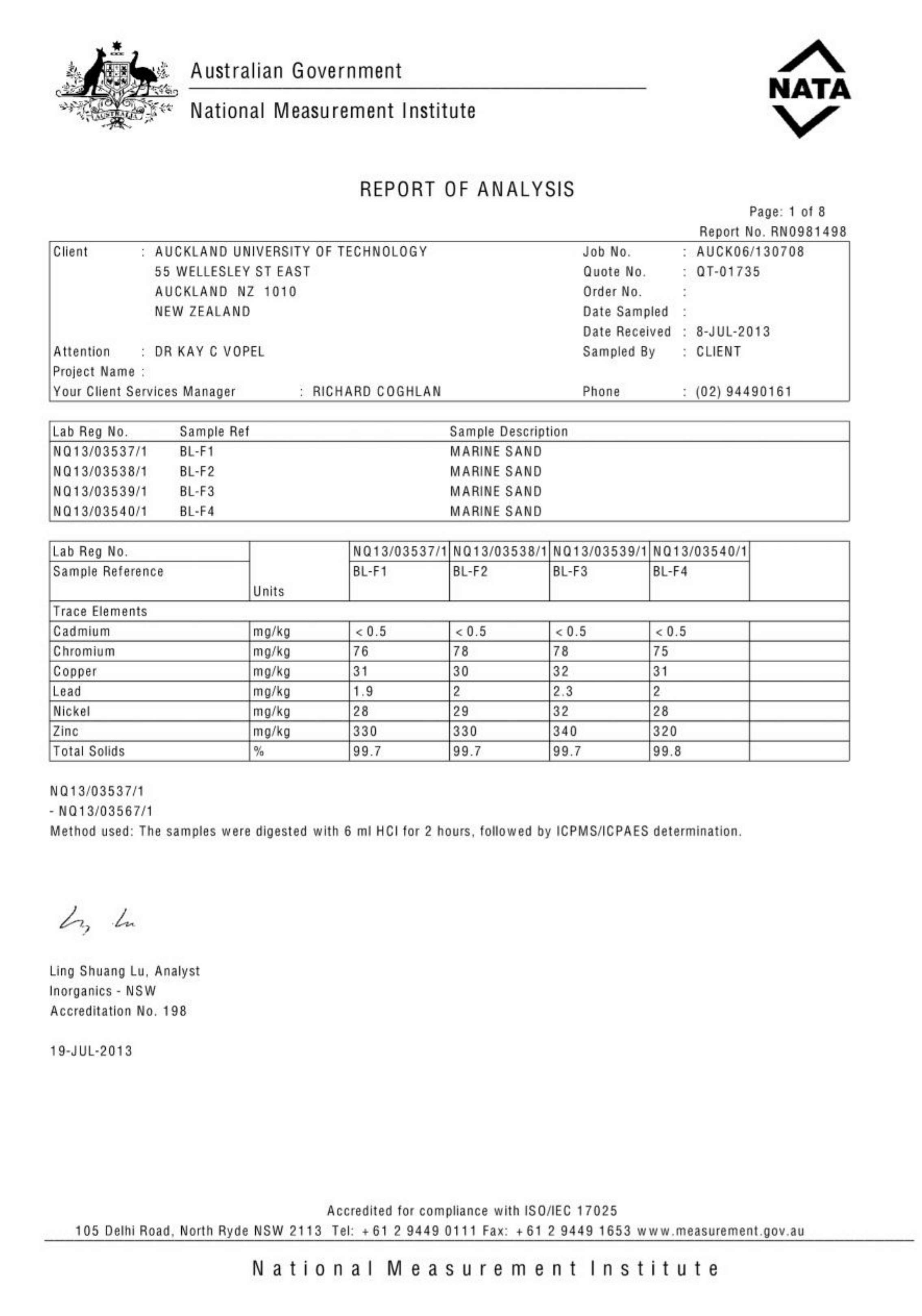
Martin Cowell - BSc (Chem)
Client Services Manager - Environmental Division



Australian Government
National Measurement Institute

NATA

REPORT OF ANALYSIS

Page: 1 of 8
Report No. RN0981498

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No.	: AUCK06/130708
		Quote No.	: QT-01735
		Order No.	:
		Date Sampled	:
		Date Received	: 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03537/1	BL-F1	MARINE SAND
NQ13/03538/1	BL-F2	MARINE SAND
NQ13/03539/1	BL-F3	MARINE SAND
NQ13/03540/1	BL-F4	MARINE SAND

Lab Reg No.		NQ13/03537/1	NQ13/03538/1	NQ13/03539/1	NQ13/03540/1	
Sample Reference	Units	BL-F1	BL-F2	BL-F3	BL-F4	
Trace Elements						
Cadmium	mg/kg	< 0.5	< 0.5	< 0.5	< 0.5	
Chromium	mg/kg	76	78	78	75	
Copper	mg/kg	31	30	32	31	
Lead	mg/kg	1.9	2	2.3	2	
Nickel	mg/kg	28	29	32	28	
Zinc	mg/kg	330	330	340	320	
Total Solids	%	99.7	99.7	99.7	99.8	

NQ13/03537/1
- NQ13/03567/1
Method used: The samples were digested with 6 ml HCl for 2 hours, followed by ICPMS/ICPAES determination.

Ling Shuang Lu, Analyst
Inorganics - NSW
Accreditation No. 198

19-JUL-2013

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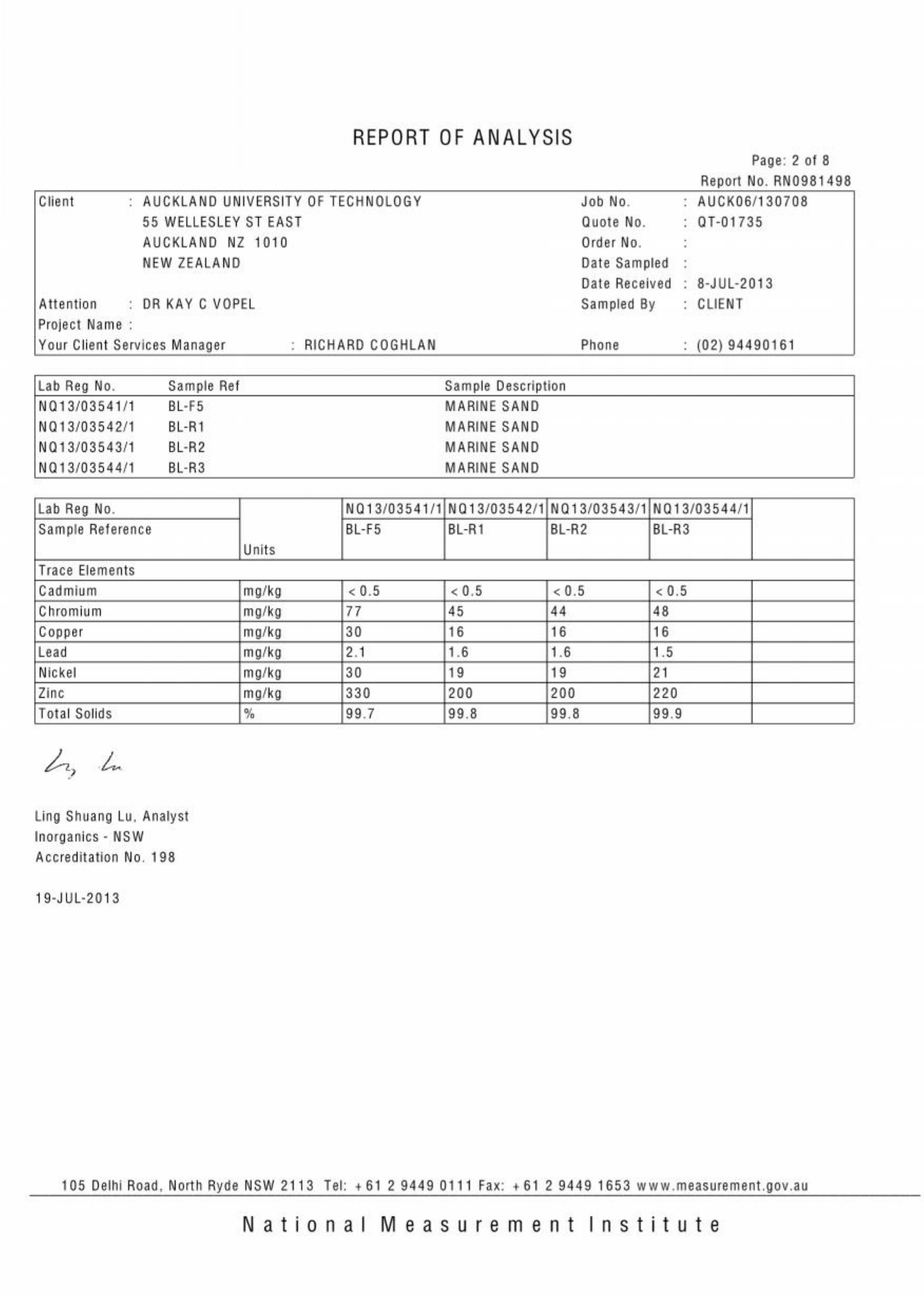

REPORT OF ANALYSIS

Page: 2 of 8
Report No. RN0981498

Client : AUCKLAND UNIVERSITY OF TECHNOLOGY
55 WELLESLEY ST EAST
AUCKLAND NZ 1010
NEW ZEALAND
Attention : DR KAY C VOPEL
Project Name :
Your Client Services Manager : RICHARD COGHLAN

Job No. : AUCK06/130708
Quote No. : QT-01735
Order No. :
Date Sampled :
Date Received : 8-JUL-2013
Sampled By : CLIENT
Phone : (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03541/1	BL-F5	MARINE SAND
NQ13/03542/1	BL-R1	MARINE SAND
NQ13/03543/1	BL-R2	MARINE SAND
NQ13/03544/1	BL-R3	MARINE SAND

Lab Reg No.		NQ13/03541/1	NQ13/03542/1	NQ13/03543/1	NQ13/03544/1	
Sample Reference	Units	BL-F5	BL-R1	BL-R2	BL-R3	
Trace Elements						
Cadmium	mg/kg	< 0.5	< 0.5	< 0.5	< 0.5	
Chromium	mg/kg	77	45	44	48	
Copper	mg/kg	30	16	16	16	
Lead	mg/kg	2.1	1.6	1.6	1.5	
Nickel	mg/kg	30	19	19	21	
Zinc	mg/kg	330	200	200	220	
Total Solids	%	99.7	99.8	99.8	99.9	

Ling Shuang Lu, Analyst
Inorganics - NSW
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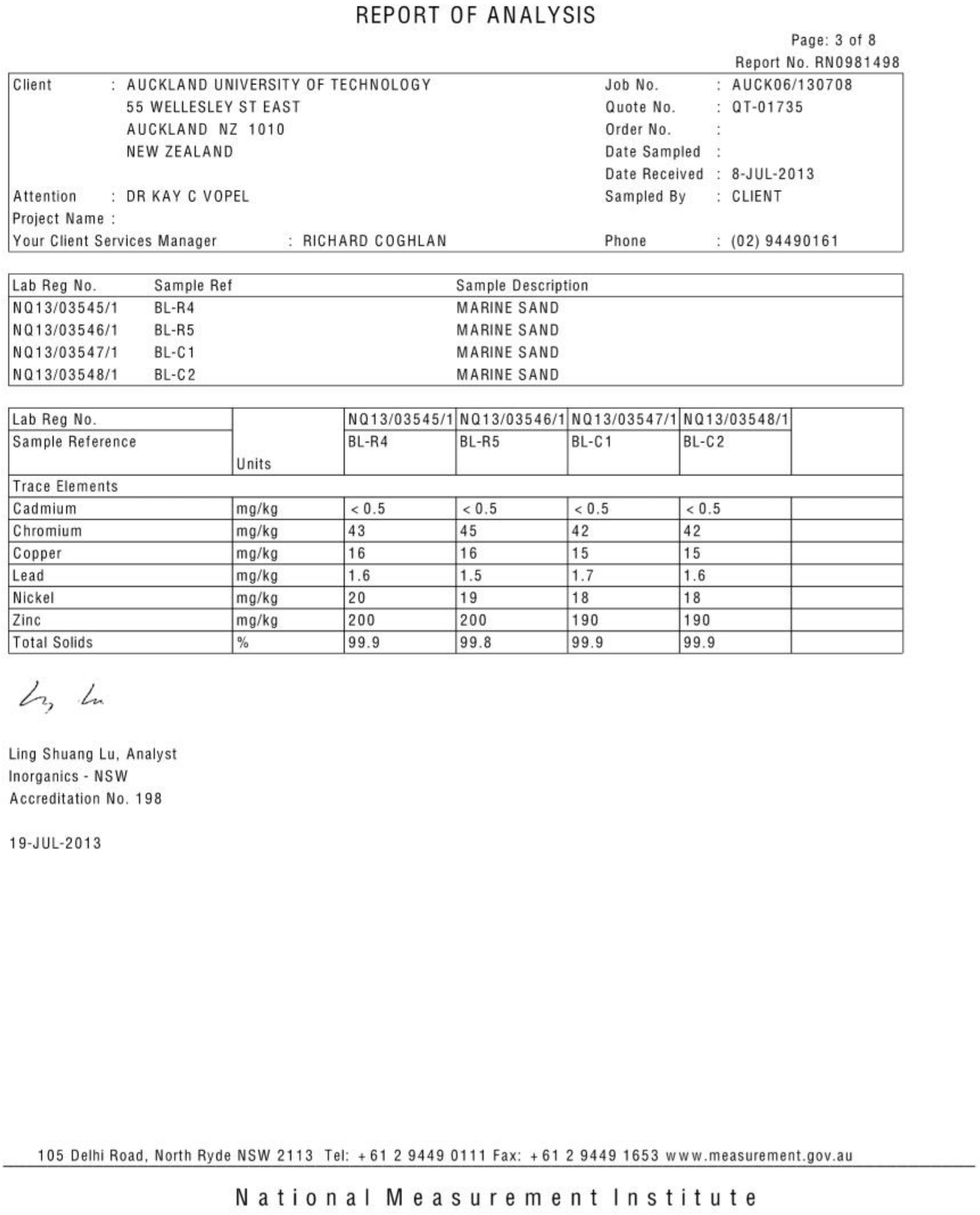

REPORT OF ANALYSIS

Page: 3 of 8
Report No. RN0981498

Client : AUCKLAND UNIVERSITY OF TECHNOLOGY
55 WELLESLEY ST EAST
AUCKLAND NZ 1010
NEW ZEALAND
Attention : DR KAY C VOPEL
Project Name :
Your Client Services Manager : RICHARD COGHLAN

Job No. : AUCK06/130708
Quote No. : QT-01735
Order No. :
Date Sampled :
Date Received : 8-JUL-2013
Sampled By : CLIENT
Phone : (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03545/1	BL-R4	MARINE SAND
NQ13/03546/1	BL-R5	MARINE SAND
NQ13/03547/1	BL-C1	MARINE SAND
NQ13/03548/1	BL-C2	MARINE SAND

Lab Reg No.		NQ13/03545/1	NQ13/03546/1	NQ13/03547/1	NQ13/03548/1	
Sample Reference	Units	BL-R4	BL-R5	BL-C1	BL-C2	
Trace Elements						
Cadmium	mg/kg	< 0.5	< 0.5	< 0.5	< 0.5	
Chromium	mg/kg	43	45	42	42	
Copper	mg/kg	16	16	15	15	
Lead	mg/kg	1.6	1.5	1.7	1.6	
Nickel	mg/kg	20	19	18	18	
Zinc	mg/kg	200	200	190	190	
Total Solids	%	99.9	99.8	99.9	99.9	

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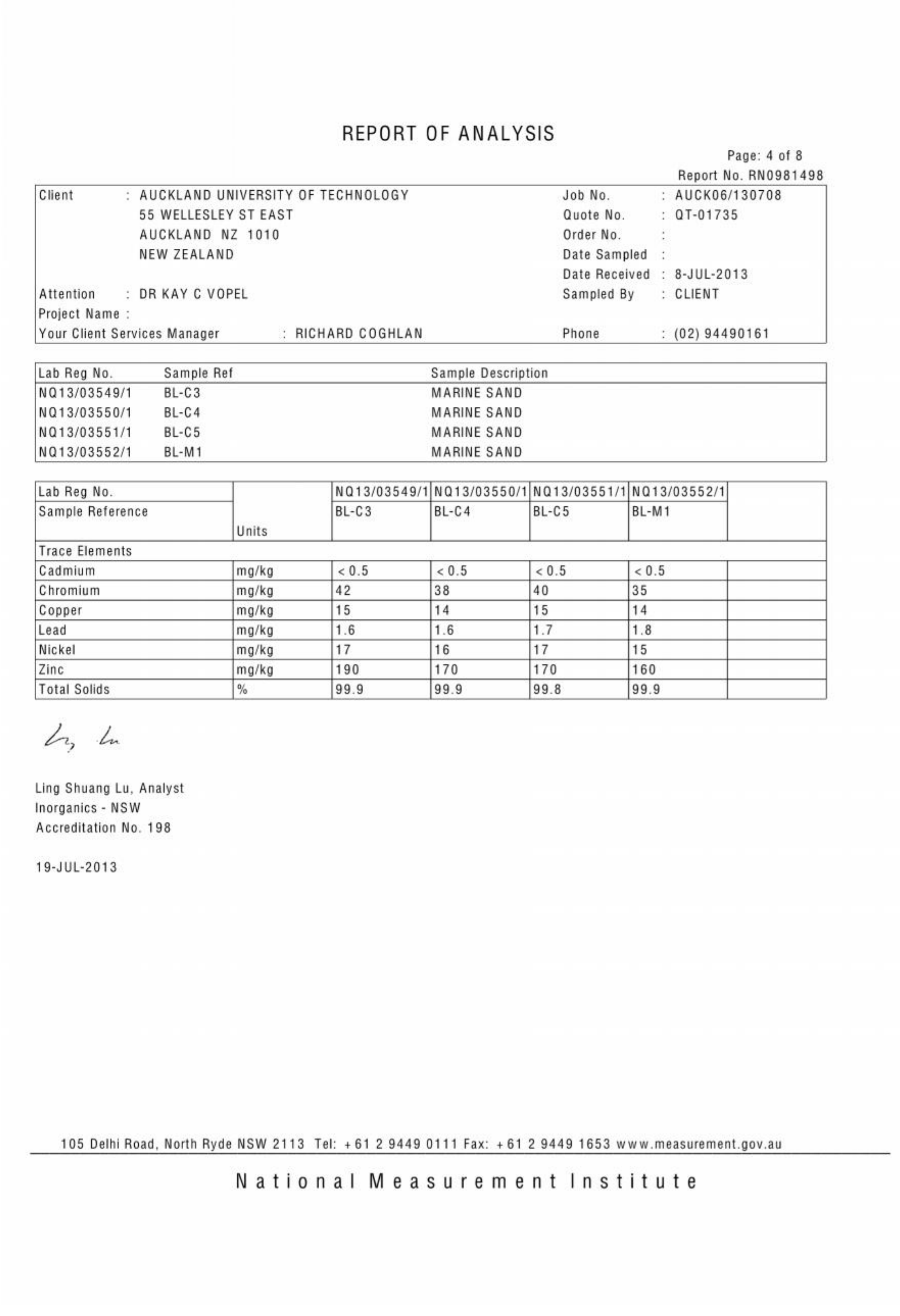

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Report No. RN0981498

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No.	: AUCK06/130708
		Quote No.	: QT-01735
		Order No.	:
		Date Sampled	:
		Date Received	: 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03549/1	BL-C3	MARINE SAND
NQ13/03550/1	BL-C4	MARINE SAND
NQ13/03551/1	BL-C5	MARINE SAND
NQ13/03552/1	BL-M1	MARINE SAND

Lab Reg No.		NQ13/03549/1	NQ13/03550/1	NQ13/03551/1	NQ13/03552/1	
Sample Reference	Units	BL-C3	BL-C4	BL-C5	BL-M1	
Trace Elements						
Cadmium	mg/kg	< 0.5	< 0.5	< 0.5	< 0.5	
Chromium	mg/kg	42	38	40	35	
Copper	mg/kg	15	14	15	14	
Lead	mg/kg	1.6	1.6	1.7	1.8	
Nickel	mg/kg	17	16	17	15	
Zinc	mg/kg	190	170	170	160	
Total Solids	%	99.9	99.9	99.8	99.9	

Ling Shuang Lu, Analyst
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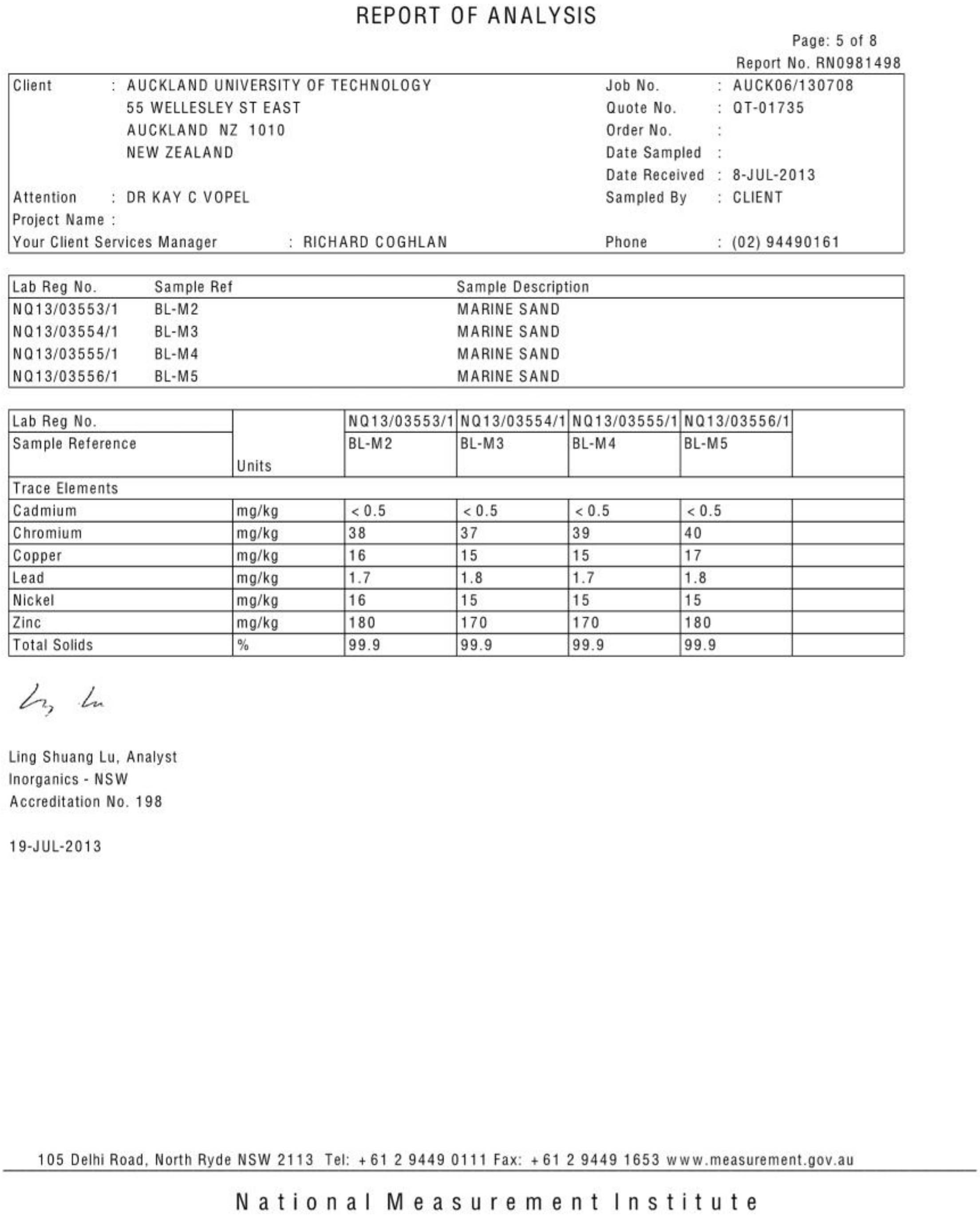

REPORT OF ANALYSIS

Page: 5 of 8
Report No. RN0981498

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No. Quote No. Order No. Date Sampled Date Received	: AUCK06/130708 : QT-01735 : : : 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03553/1	BL-M2	MARINE SAND
NQ13/03554/1	BL-M3	MARINE SAND
NQ13/03555/1	BL-M4	MARINE SAND
NQ13/03556/1	BL-M5	MARINE SAND

Lab Reg No.		NQ13/03553/1	NQ13/03554/1	NQ13/03555/1	NQ13/03556/1	
Sample Reference	Units	BL-M2	BL-M3	BL-M4	BL-M5	
Trace Elements						
Cadmium	mg/kg	< 0.5	< 0.5	< 0.5	< 0.5	
Chromium	mg/kg	38	37	39	40	
Copper	mg/kg	16	15	15	17	
Lead	mg/kg	1.7	1.8	1.7	1.8	
Nickel	mg/kg	16	15	15	15	
Zinc	mg/kg	180	170	170	180	
Total Solids	%	99.9	99.9	99.9	99.9	

Ling Shuang Lu, Analyst
Inorganics - NSW
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19-JUL-2013

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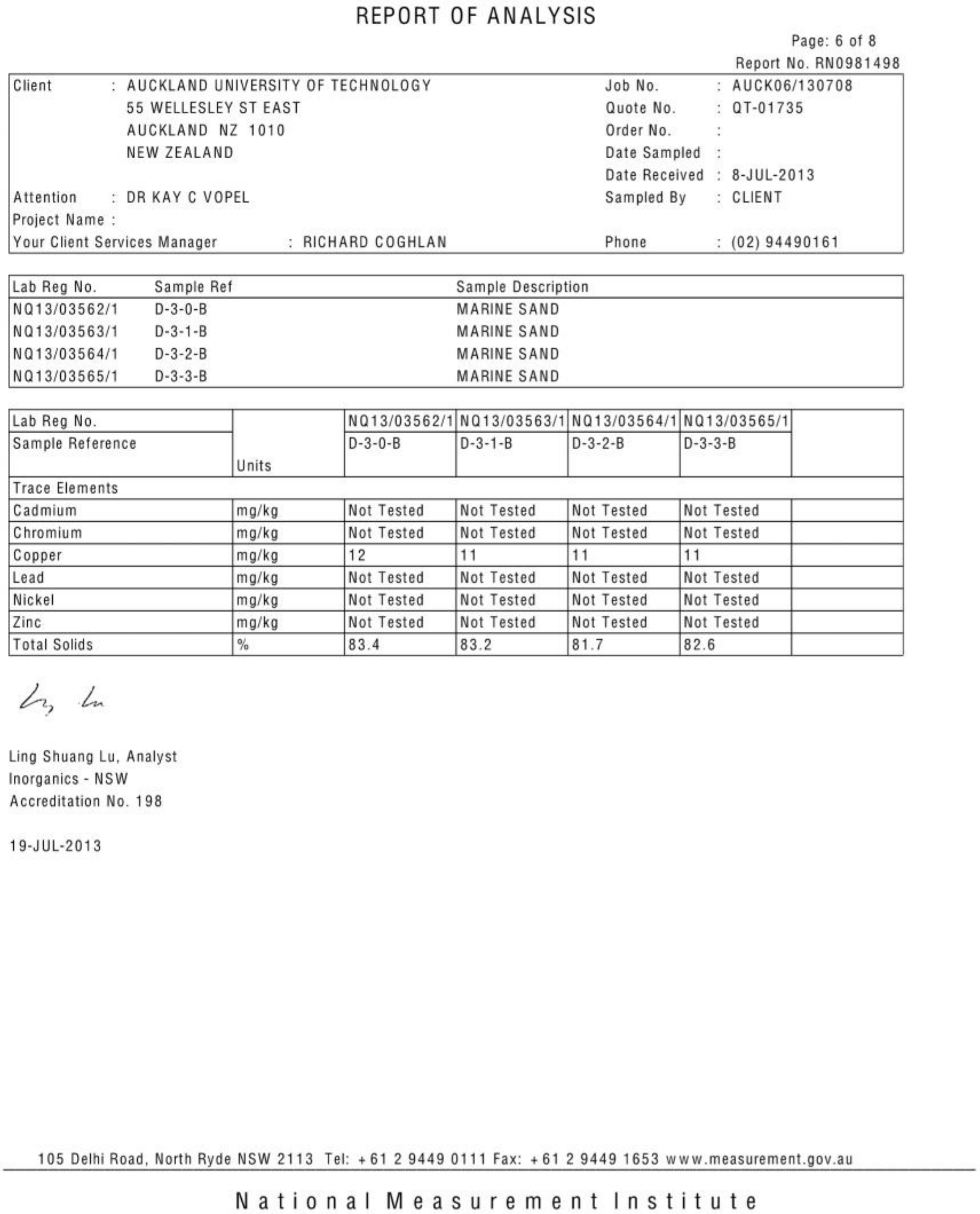

REPORT OF ANALYSIS

Page: 6 of 8
Report No. RN0981498

Client : AUCKLAND UNIVERSITY OF TECHNOLOGY
55 WELLESLEY ST EAST
AUCKLAND NZ 1010
NEW ZEALAND
Attention : DR KAY C VOPEL
Project Name :
Your Client Services Manager : RICHARD COGHLAN

Job No. : AUCK06/130708
Quote No. : QT-01735
Order No. :
Date Sampled :
Date Received : 8-JUL-2013
Sampled By : CLIENT
Phone : (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03562/1	D-3-0-B	MARINE SAND
NQ13/03563/1	D-3-1-B	MARINE SAND
NQ13/03564/1	D-3-2-B	MARINE SAND
NQ13/03565/1	D-3-3-B	MARINE SAND

Lab Reg No.		NQ13/03562/1	NQ13/03563/1	NQ13/03564/1	NQ13/03565/1	
Sample Reference	Units	D-3-0-B	D-3-1-B	D-3-2-B	D-3-3-B	
Trace Elements						
Cadmium	mg/kg	Not Tested	Not Tested	Not Tested	Not Tested	
Chromium	mg/kg	Not Tested	Not Tested	Not Tested	Not Tested	
Copper	mg/kg	12	11	11	11	
Lead	mg/kg	Not Tested	Not Tested	Not Tested	Not Tested	
Nickel	mg/kg	Not Tested	Not Tested	Not Tested	Not Tested	
Zinc	mg/kg	Not Tested	Not Tested	Not Tested	Not Tested	
Total Solids	%	83.4	83.2	81.7	82.6	

Ling Shuang Lu, Analyst
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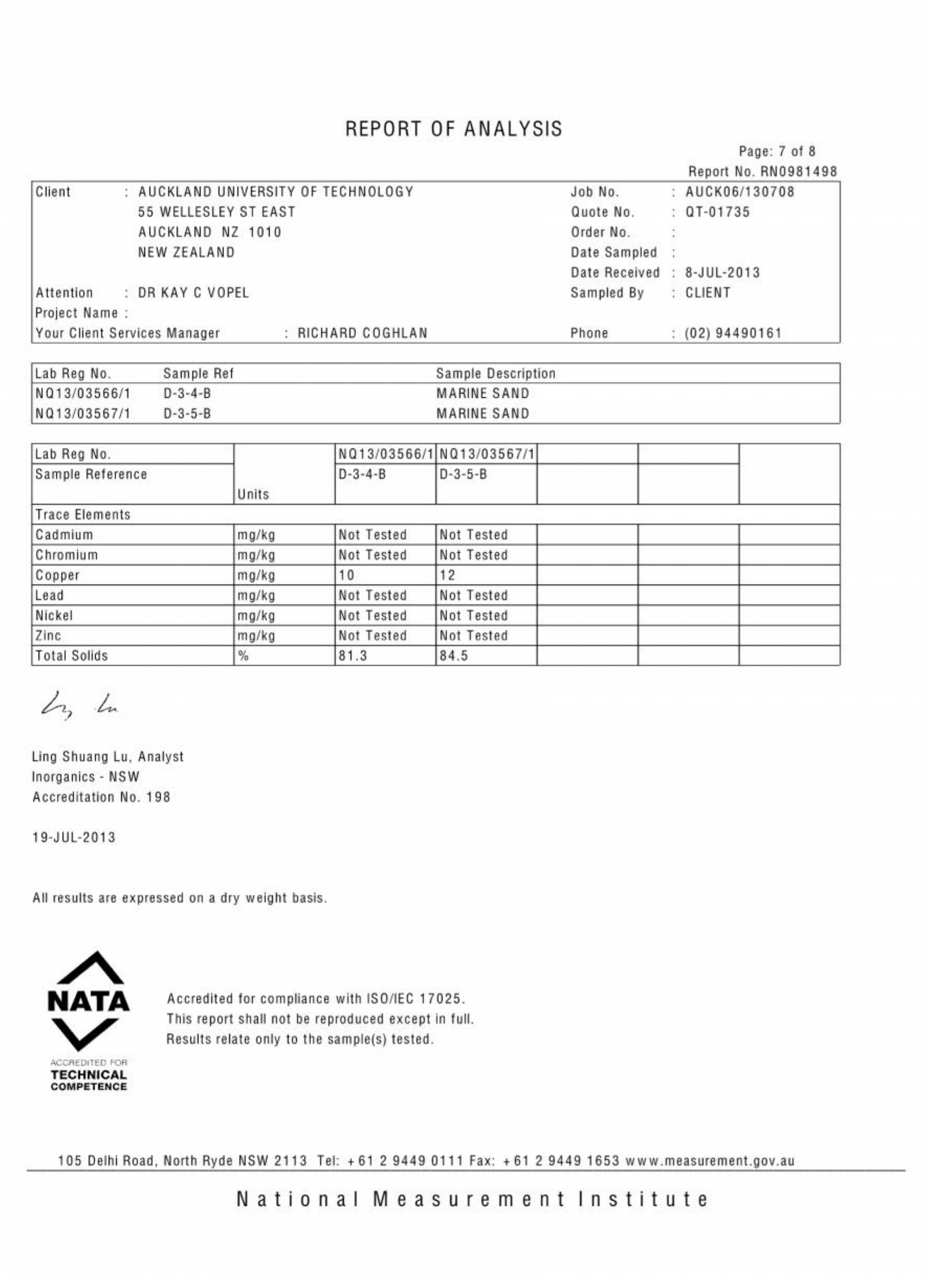

REPORT OF ANALYSIS

Page: 7 of 8
Report No. RN0981498

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No.	: AUCK06/130708
		Quote No.	: QT-01735
		Order No.	:
		Date Sampled	:
		Date Received	: 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03566/1	D-3-4-B	MARINE SAND
NQ13/03567/1	D-3-5-B	MARINE SAND

Lab Reg No.		NQ13/03566/1	NQ13/03567/1			
Sample Reference	Units	D-3-4-B	D-3-5-B			
Trace Elements						
Cadmium	mg/kg	Not Tested	Not Tested			
Chromium	mg/kg	Not Tested	Not Tested			
Copper	mg/kg	10	12			
Lead	mg/kg	Not Tested	Not Tested			
Nickel	mg/kg	Not Tested	Not Tested			
Zinc	mg/kg	Not Tested	Not Tested			
Total Solids	%	81.3	84.5			

Ling Shuang Lu, Analyst
Inorganics - NSW
Accreditation No. 198

19-JUL-2013

All results are expressed on a dry weight basis.

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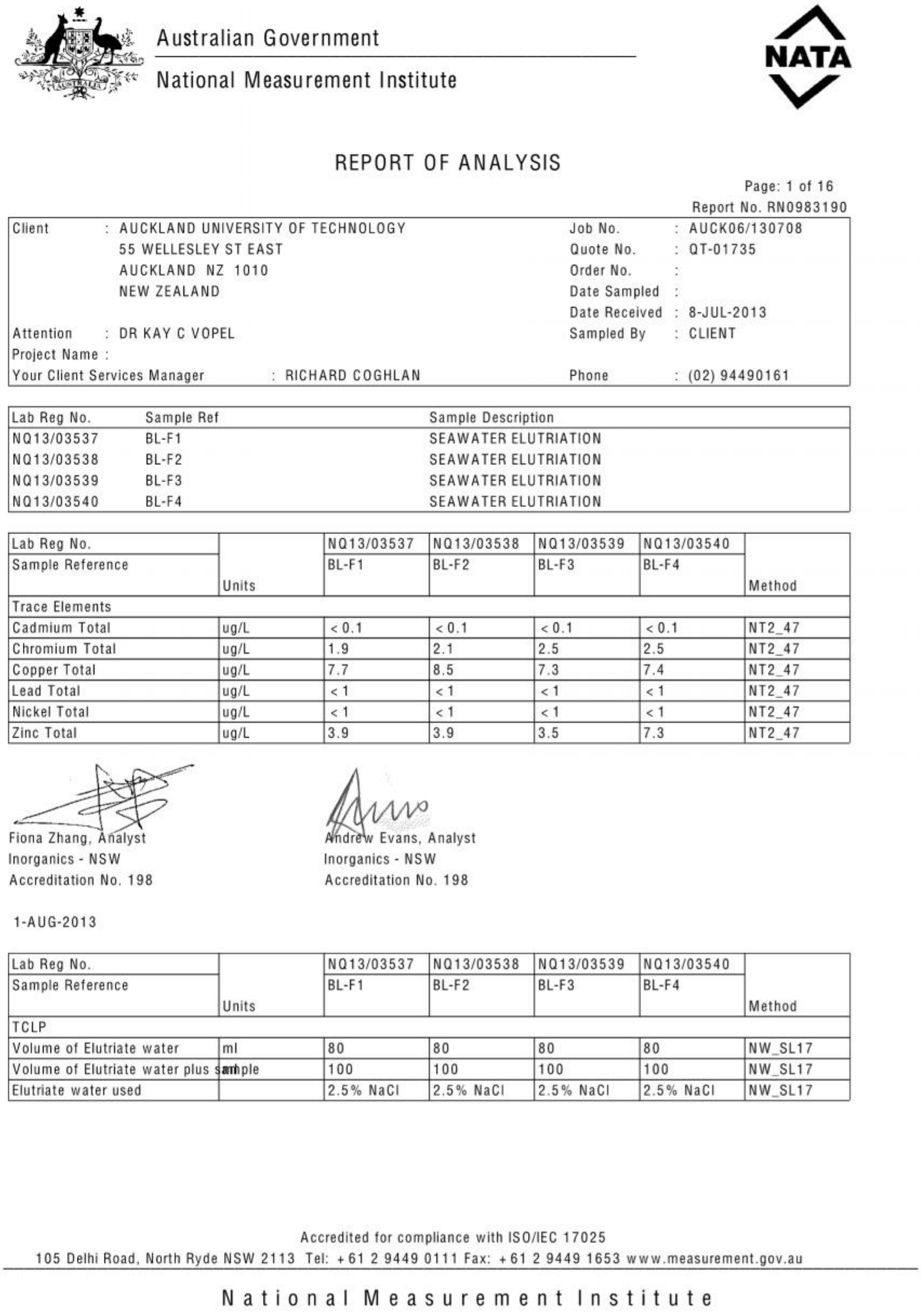
REPORT OF ANALYSIS

This Report supersedes reports: RN0981447



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REPORT OF ANALYSIS

Page: 1 of 16

Report No. RN0983190

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No. Quote No. Order No. Date Sampled Date Received	: AUCK06/130708 : QT-01735 : : : 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03537	BL-F1	SEAWATER ELUTRIATION
NQ13/03538	BL-F2	SEAWATER ELUTRIATION
NQ13/03539	BL-F3	SEAWATER ELUTRIATION
NQ13/03540	BL-F4	SEAWATER ELUTRIATION

Lab Reg No.		NQ13/03537	NQ13/03538	NQ13/03539	NQ13/03540	
Sample Reference	Units	BL-F1	BL-F2	BL-F3	BL-F4	Method
Trace Elements						
Cadmium Total	ug/L	< 0.1	< 0.1	< 0.1	< 0.1	NT2_47
Chromium Total	ug/L	1.9	2.1	2.5	2.5	NT2_47
Copper Total	ug/L	7.7	8.5	7.3	7.4	NT2_47
Lead Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Nickel Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Zinc Total	ug/L	3.9	3.9	3.5	7.3	NT2_47

Fiona Zhang, Analyst
Inorganics - NSW
Accreditation No. 198

Andrew Evans, Analyst
Inorganics - NSW
Accreditation No. 198

1-AUG-2013

Lab Reg No.		NQ13/03537	NQ13/03538	NQ13/03539	NQ13/03540	
Sample Reference	Units	BL-F1	BL-F2	BL-F3	BL-F4	Method
TCLP						
Volume of Elutriate water	ml	80	80	80	80	NW_SL17
Volume of Elutriate water plus sample	ml	100	100	100	100	NW_SL17
Elutriate water used		2.5% NaCl	2.5% NaCl	2.5% NaCl	2.5% NaCl	NW_SL17

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REPORT OF ANALYSIS

Lab Reg No.		NQ13/03537	NQ13/03538	NQ13/03539	NQ13/03540	
Sample Reference	Units	BL-F1	BL-F2	BL-F3	BL-F4	Method

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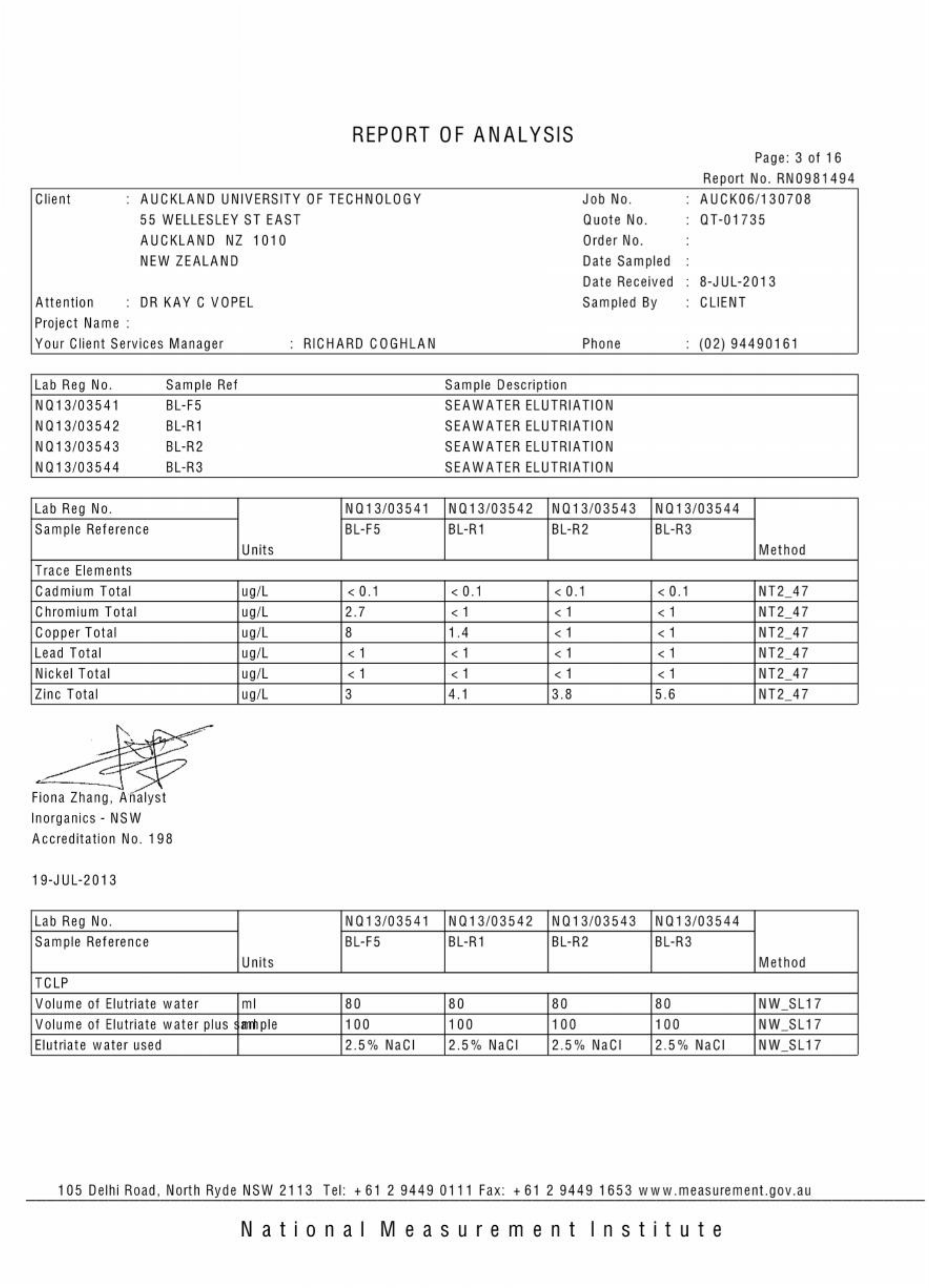
Accreditation No. 198

19-JUL-2013



REPORT OF ANALYSIS

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Report No. RN0981494

Client : AUCKLAND UNIVERSITY OF TECHNOLOGY
55 WELLESLEY ST EAST
AUCKLAND NZ 1010
NEW ZEALAND
Attention : DR KAY C VOPEL
Project Name :
Your Client Services Manager : RICHARD COGHLAN

Job No. : AUCK06/130708
Quote No. : QT-01735
Order No. :
Date Sampled :
Date Received : 8-JUL-2013
Sampled By : CLIENT
Phone : (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03541	BL-F5	SEAWATER ELUTRIATION
NQ13/03542	BL-R1	SEAWATER ELUTRIATION
NQ13/03543	BL-R2	SEAWATER ELUTRIATION
NQ13/03544	BL-R3	SEAWATER ELUTRIATION

Lab Reg No.		NQ13/03541	NQ13/03542	NQ13/03543	NQ13/03544	
Sample Reference	Units	BL-F5	BL-R1	BL-R2	BL-R3	Method
Trace Elements						
Cadmium Total	ug/L	< 0.1	< 0.1	< 0.1	< 0.1	NT2_47
Chromium Total	ug/L	2.7	< 1	< 1	< 1	NT2_47
Copper Total	ug/L	8	1.4	< 1	< 1	NT2_47
Lead Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Nickel Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Zinc Total	ug/L	3	4.1	3.8	5.6	NT2_47

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Lab Reg No.		NQ13/03541	NQ13/03542	NQ13/03543	NQ13/03544	
Sample Reference	Units	BL-F5	BL-R1	BL-R2	BL-R3	Method
TCLP						
Volume of Elutriate water	ml	80	80	80	80	NW_SL17
Volume of Elutriate water plus sample	ml	100	100	100	100	NW_SL17
Elutriate water used		2.5% NaCl	2.5% NaCl	2.5% NaCl	2.5% NaCl	NW_SL17

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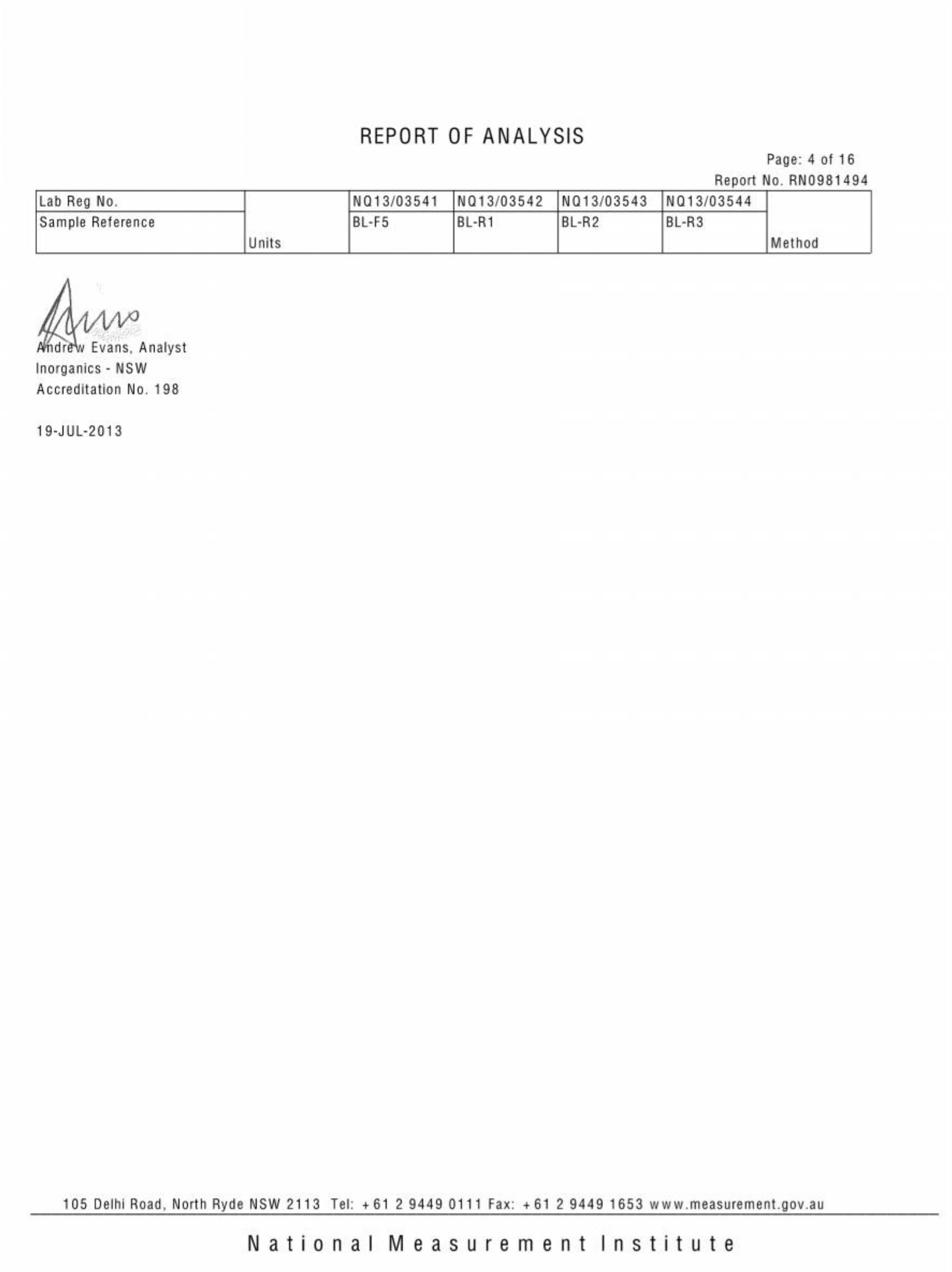

REPORT OF ANALYSIS

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Report No. RN0981494

Lab Reg No.		NQ13/03541	NQ13/03542	NQ13/03543	NQ13/03544	
Sample Reference	Units	BL-F5	BL-R1	BL-R2	BL-R3	Method

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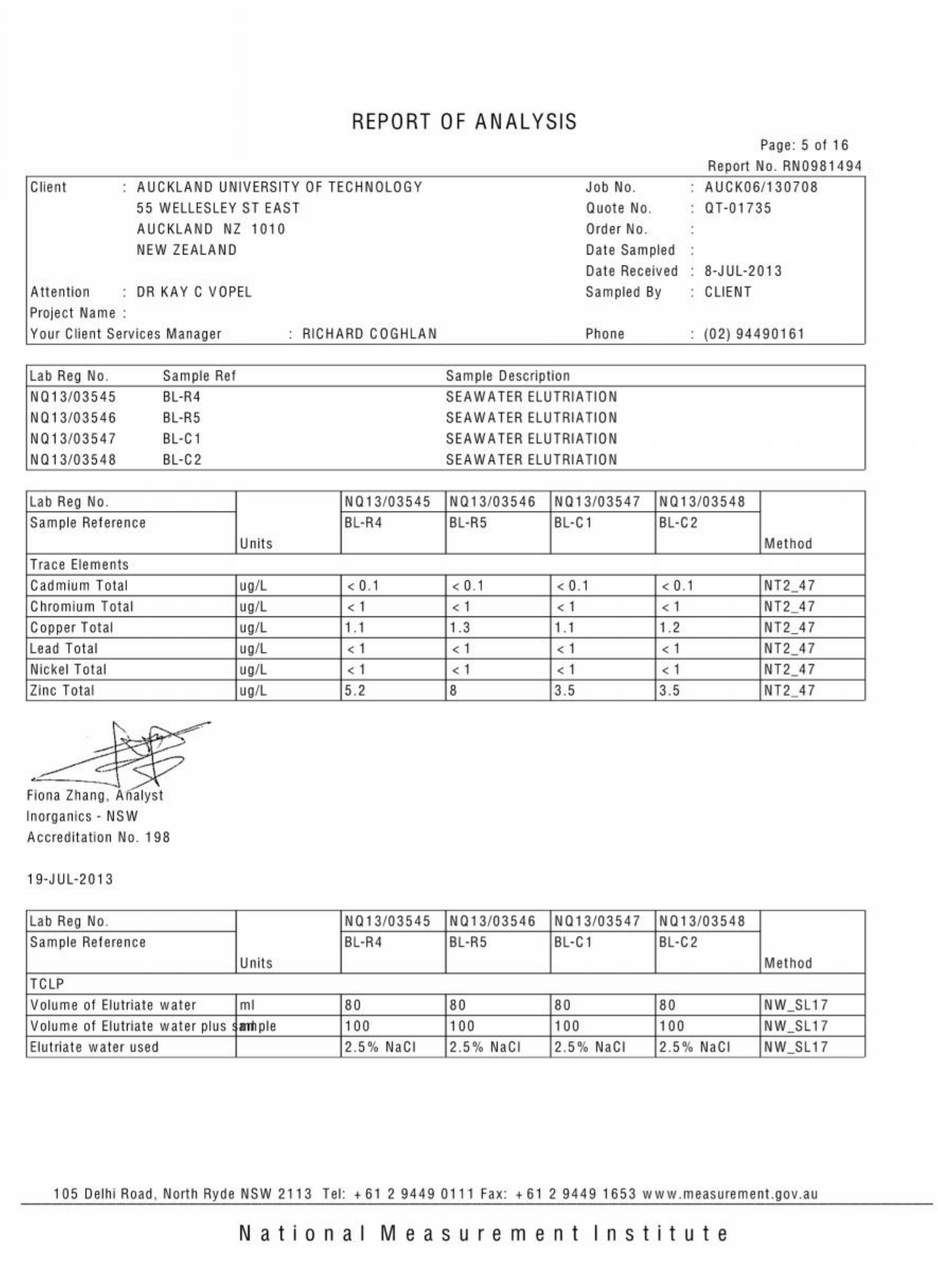

REPORT OF ANALYSIS

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Report No. RN0981494

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No.	: AUCK06/130708
		Quote No.	: QT-01735
		Order No.	:
		Date Sampled	:
		Date Received	: 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03545	BL-R4	SEAWATER ELUTRIATION
NQ13/03546	BL-R5	SEAWATER ELUTRIATION
NQ13/03547	BL-C1	SEAWATER ELUTRIATION
NQ13/03548	BL-C2	SEAWATER ELUTRIATION

Lab Reg No.		NQ13/03545	NQ13/03546	NQ13/03547	NQ13/03548	
Sample Reference	Units	BL-R4	BL-R5	BL-C1	BL-C2	Method
Trace Elements						
Cadmium Total	ug/L	< 0.1	< 0.1	< 0.1	< 0.1	NT2_47
Chromium Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Copper Total	ug/L	1.1	1.3	1.1	1.2	NT2_47
Lead Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Nickel Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Zinc Total	ug/L	5.2	8	3.5	3.5	NT2_47

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Lab Reg No.		NQ13/03545	NQ13/03546	NQ13/03547	NQ13/03548	
Sample Reference	Units	BL-R4	BL-R5	BL-C1	BL-C2	Method
TCLP						
Volume of Elutriate water	ml	80	80	80	80	NW_SL17
Volume of Elutriate water plus sample	ml	100	100	100	100	NW_SL17
Elutriate water used		2.5% NaCl	2.5% NaCl	2.5% NaCl	2.5% NaCl	NW_SL17

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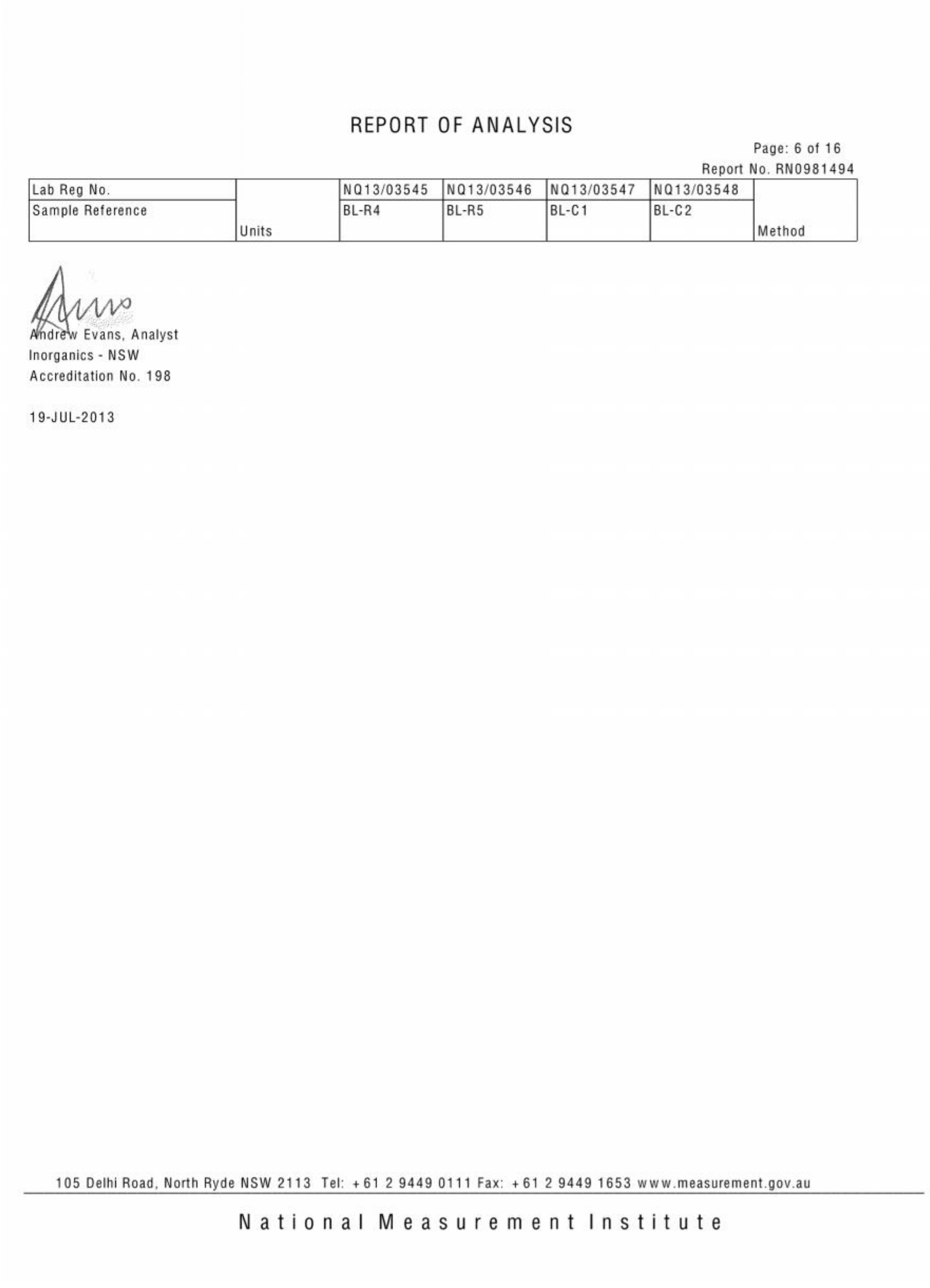

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Report No. RN0981494

Lab Reg No.		NQ13/03545	NQ13/03546	NQ13/03547	NQ13/03548	
Sample Reference	Units	BL-R4	BL-R5	BL-C1	BL-C2	Method

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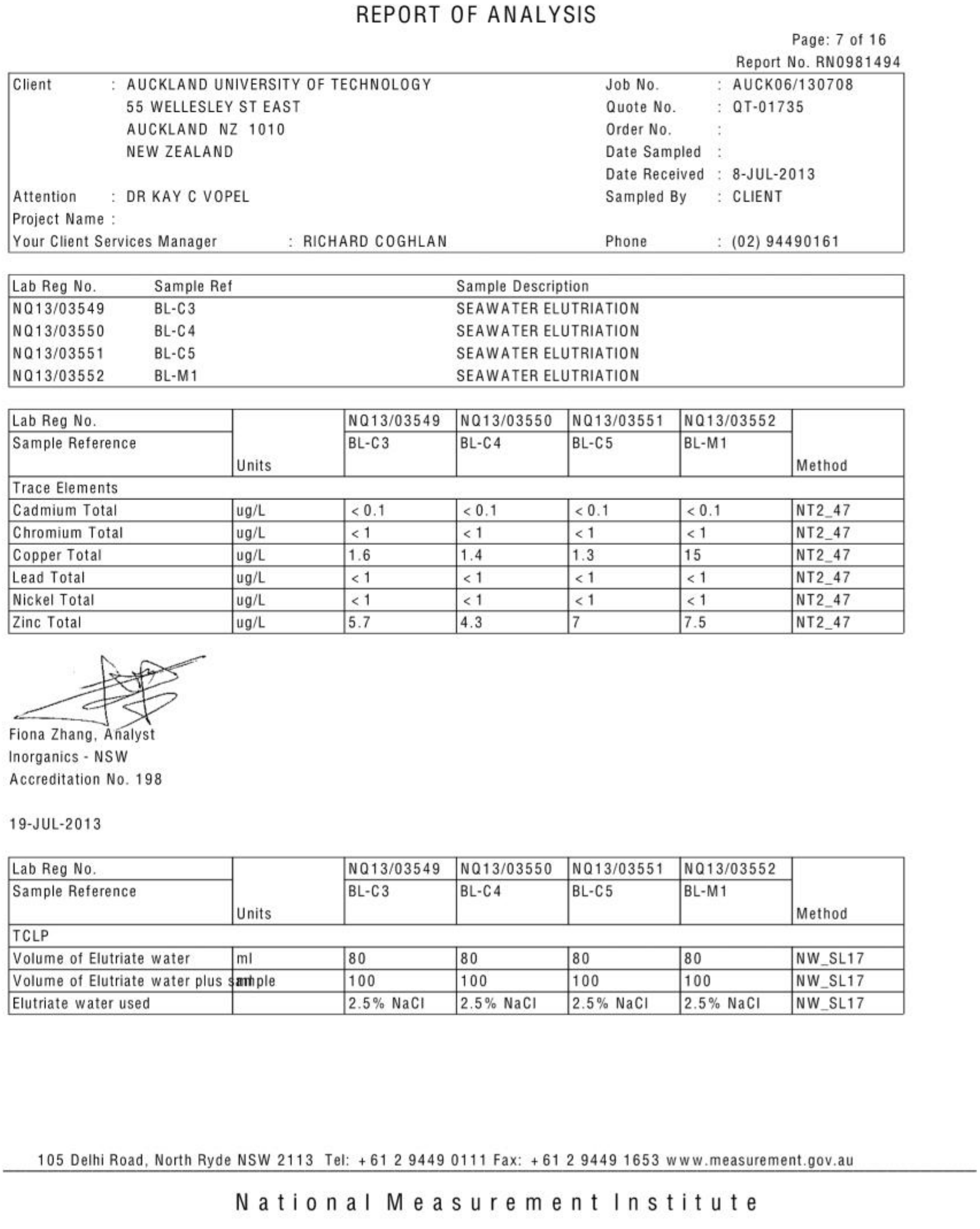

REPORT OF ANALYSIS

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Report No. RN0981494

Client : AUCKLAND UNIVERSITY OF TECHNOLOGY
55 WELLESLEY ST EAST
AUCKLAND NZ 1010
NEW ZEALAND

Job No. : AUCK06/130708
Quote No. : QT-01735
Order No. :
Date Sampled :
Date Received : 8-JUL-2013
Sampled By : CLIENT

Attention : DR KAY C VOPEL
Project Name :
Your Client Services Manager : RICHARD COGHLAN
Phone : (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03549	BL-C3	SEAWATER ELUTRIATION
NQ13/03550	BL-C4	SEAWATER ELUTRIATION
NQ13/03551	BL-C5	SEAWATER ELUTRIATION
NQ13/03552	BL-M1	SEAWATER ELUTRIATION

Lab Reg No.		NQ13/03549	NQ13/03550	NQ13/03551	NQ13/03552	
Sample Reference	Units	BL-C3	BL-C4	BL-C5	BL-M1	Method
Trace Elements						
Cadmium Total	ug/L	< 0.1	< 0.1	< 0.1	< 0.1	NT2_47
Chromium Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Copper Total	ug/L	1.6	1.4	1.3	15	NT2_47
Lead Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Nickel Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Zinc Total	ug/L	5.7	4.3	7	7.5	NT2_47

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Lab Reg No.		NQ13/03549	NQ13/03550	NQ13/03551	NQ13/03552	
Sample Reference	Units	BL-C3	BL-C4	BL-C5	BL-M1	Method
TCLP						
Volume of Elutriate water	ml	80	80	80	80	NW_SL17
Volume of Elutriate water plus sample	ml	100	100	100	100	NW_SL17
Elutriate water used		2.5% NaCl	2.5% NaCl	2.5% NaCl	2.5% NaCl	NW_SL17

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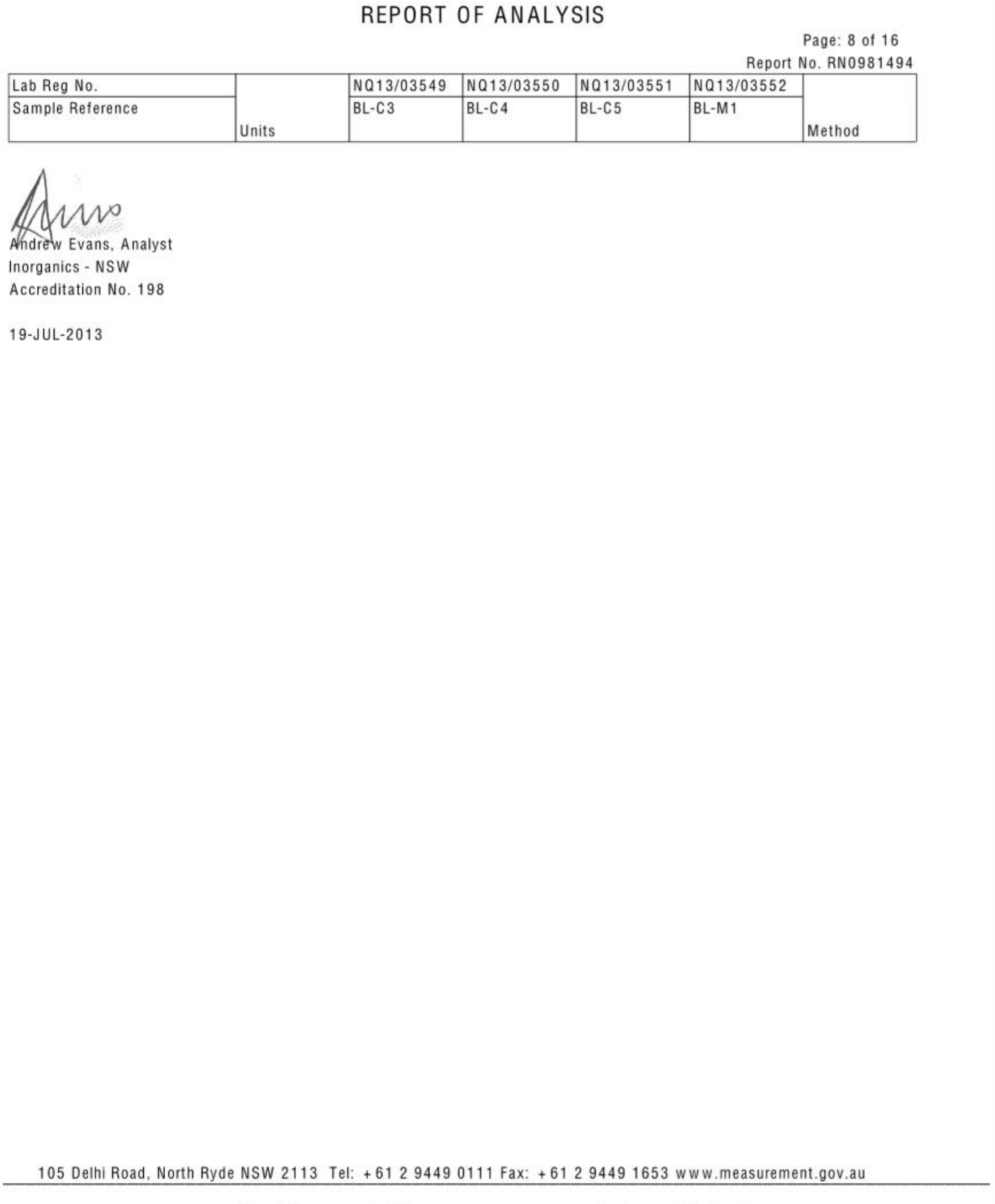

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Report No. RN0981494

Lab Reg No.		NQ13/03549	NQ13/03550	NQ13/03551	NQ13/03552	
Sample Reference	Units	BL-C3	BL-C4	BL-C5	BL-M1	Method

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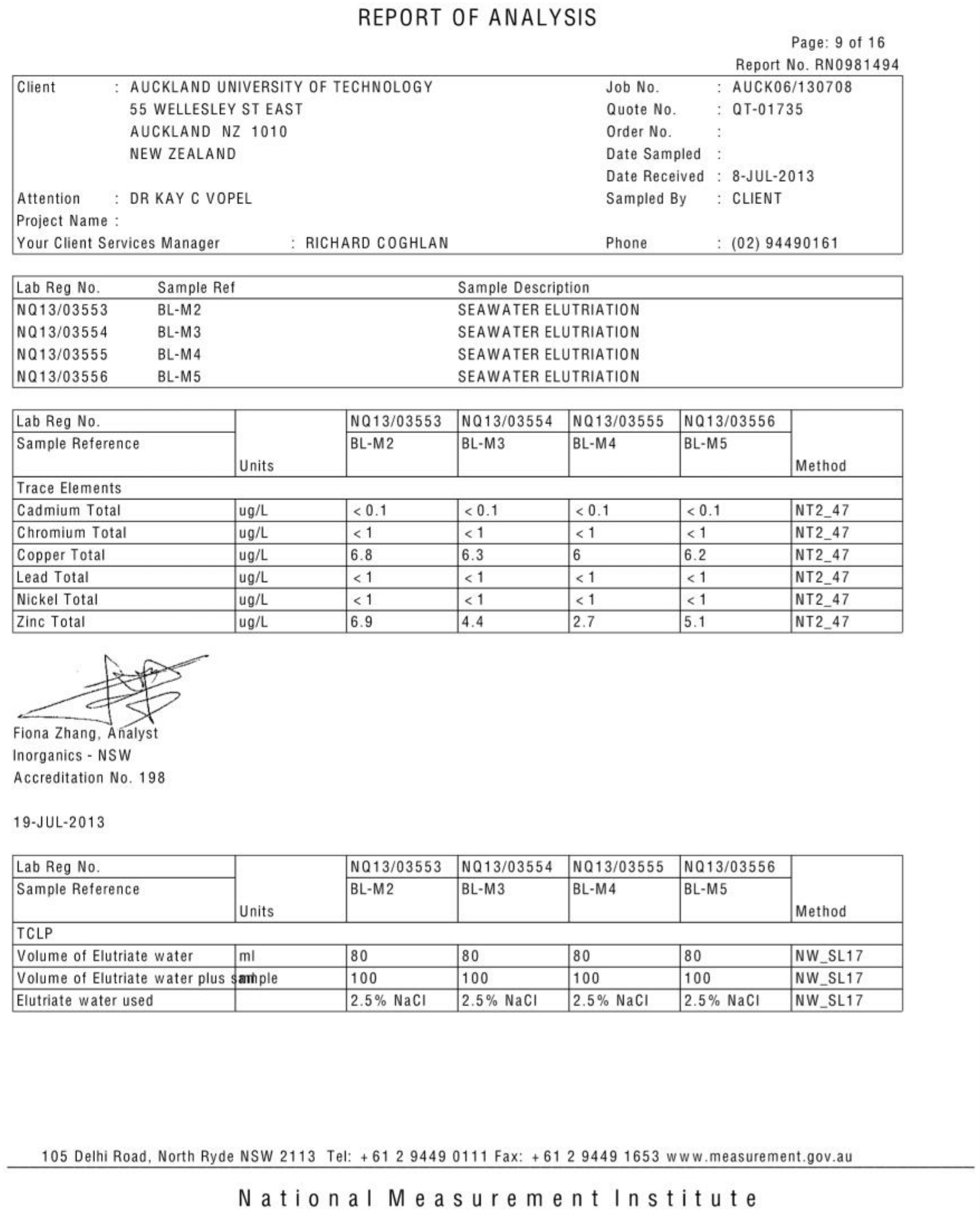

REPORT OF ANALYSIS

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Report No. RN0981494

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No.	: AUCK06/130708
		Quote No.	: QT-01735
		Order No.	:
		Date Sampled	:
		Date Received	: 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03553	BL-M2	SEAWATER ELUTRIATION
NQ13/03554	BL-M3	SEAWATER ELUTRIATION
NQ13/03555	BL-M4	SEAWATER ELUTRIATION
NQ13/03556	BL-M5	SEAWATER ELUTRIATION

Lab Reg No.		NQ13/03553	NQ13/03554	NQ13/03555	NQ13/03556	
Sample Reference	Units	BL-M2	BL-M3	BL-M4	BL-M5	Method
Trace Elements						
Cadmium Total	ug/L	< 0.1	< 0.1	< 0.1	< 0.1	NT2_47
Chromium Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Copper Total	ug/L	6.8	6.3	6	6.2	NT2_47
Lead Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Nickel Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Zinc Total	ug/L	6.9	4.4	2.7	5.1	NT2_47

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Lab Reg No.		NQ13/03553	NQ13/03554	NQ13/03555	NQ13/03556	
Sample Reference	Units	BL-M2	BL-M3	BL-M4	BL-M5	Method
TCLP						
Volume of Elutriate water	ml	80	80	80	80	NW_SL17
Volume of Elutriate water plus sample		100	100	100	100	NW_SL17
Elutriate water used		2.5% NaCl	2.5% NaCl	2.5% NaCl	2.5% NaCl	NW_SL17

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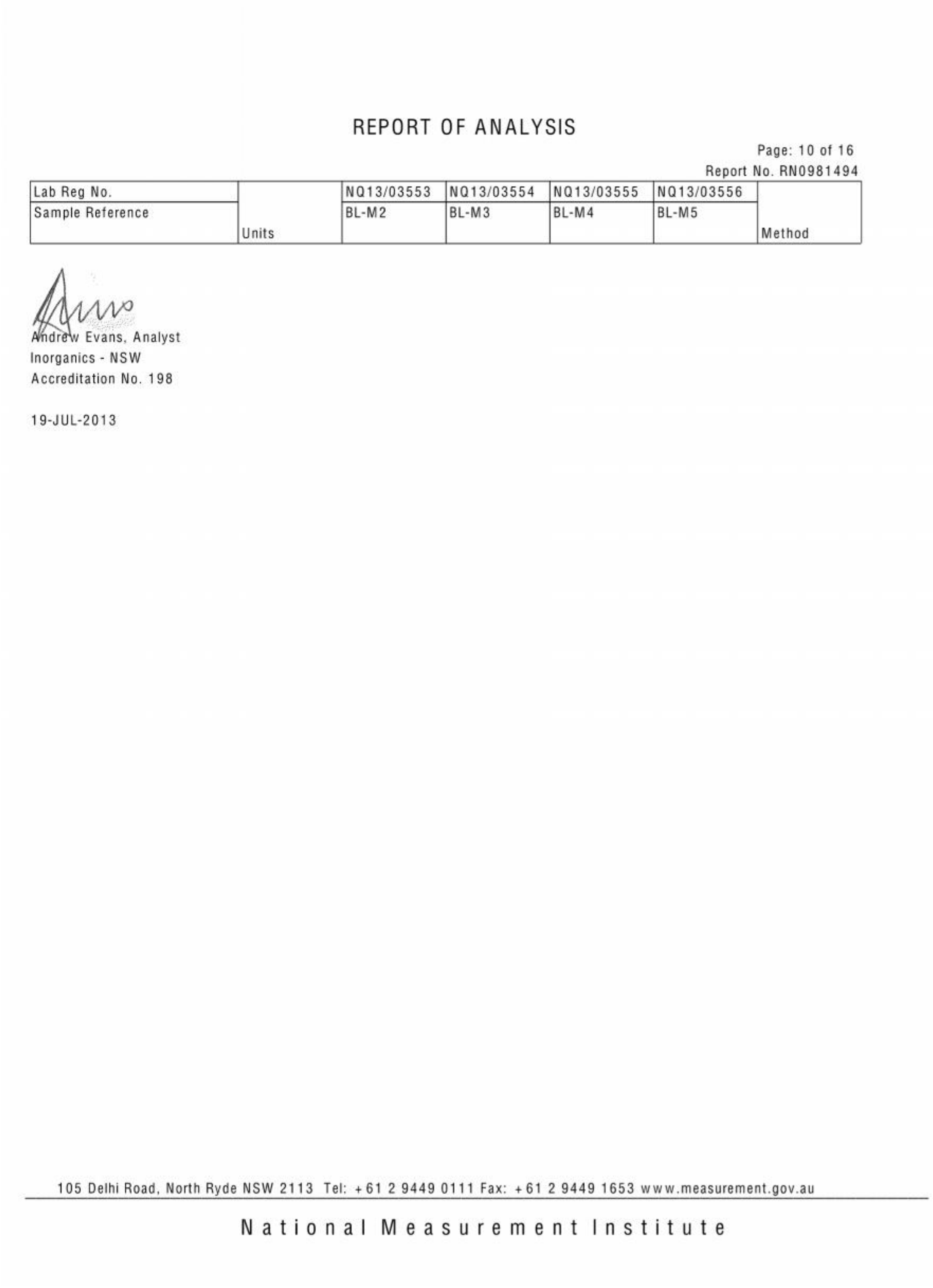

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Lab Reg No.		NQ13/03553	NQ13/03554	NQ13/03555	NQ13/03556	
Sample Reference	Units	BL-M2	BL-M3	BL-M4	BL-M5	Method

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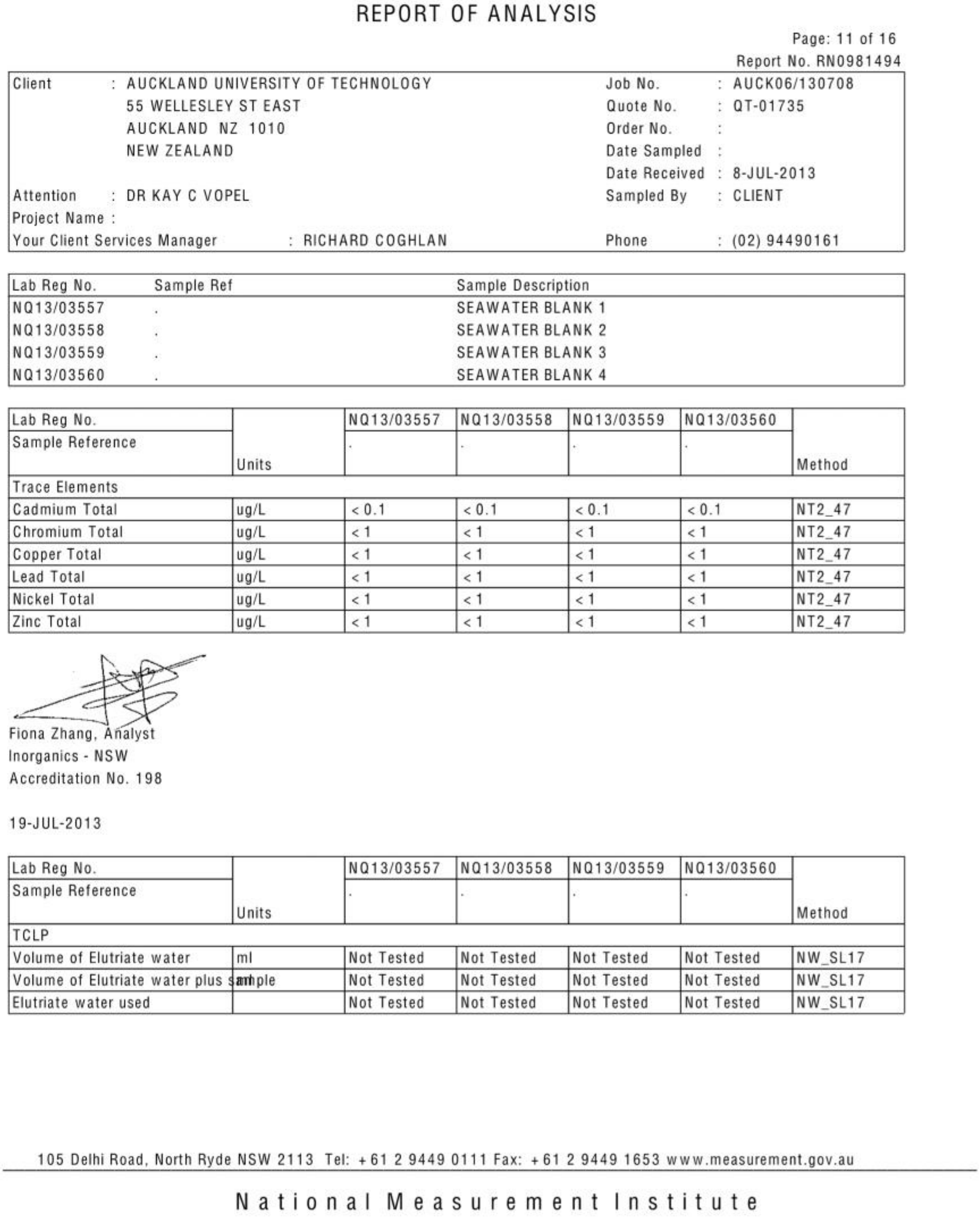
19-JUL-2013



REPORT OF ANALYSIS

Page: 11 of 16
Report No. RN0981494

Client : AUCKLAND UNIVERSITY OF TECHNOLOGY
55 WELLESLEY ST EAST
AUCKLAND NZ 1010
NEW ZEALAND
Attention : DR KAY C VOPEL
Project Name :
Your Client Services Manager : RICHARD COGHLAN

Job No. : AUCK06/130708
Quote No. : QT-01735
Order No. :
Date Sampled :
Date Received : 8-JUL-2013
Sampled By : CLIENT
Phone : (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03557	.	SEAWATER BLANK 1
NQ13/03558	.	SEAWATER BLANK 2
NQ13/03559	.	SEAWATER BLANK 3
NQ13/03560	.	SEAWATER BLANK 4

Lab Reg No.		NQ13/03557	NQ13/03558	NQ13/03559	NQ13/03560	
Sample Reference	Units	.	.	.	.	Method
Trace Elements						
Cadmium Total	ug/L	< 0.1	< 0.1	< 0.1	< 0.1	NT2_47
Chromium Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Copper Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Lead Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Nickel Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Zinc Total	ug/L	< 1	< 1	< 1	< 1	NT2_47

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Lab Reg No.		NQ13/03557	NQ13/03558	NQ13/03559	NQ13/03560	
Sample Reference	Units	.	.	.	.	Method
TCLP						
Volume of Elutriate water	ml	Not Tested	Not Tested	Not Tested	Not Tested	NW_SL17
Volume of Elutriate water plus sample		Not Tested	Not Tested	Not Tested	Not Tested	NW_SL17
Elutriate water used		Not Tested	Not Tested	Not Tested	Not Tested	NW_SL17

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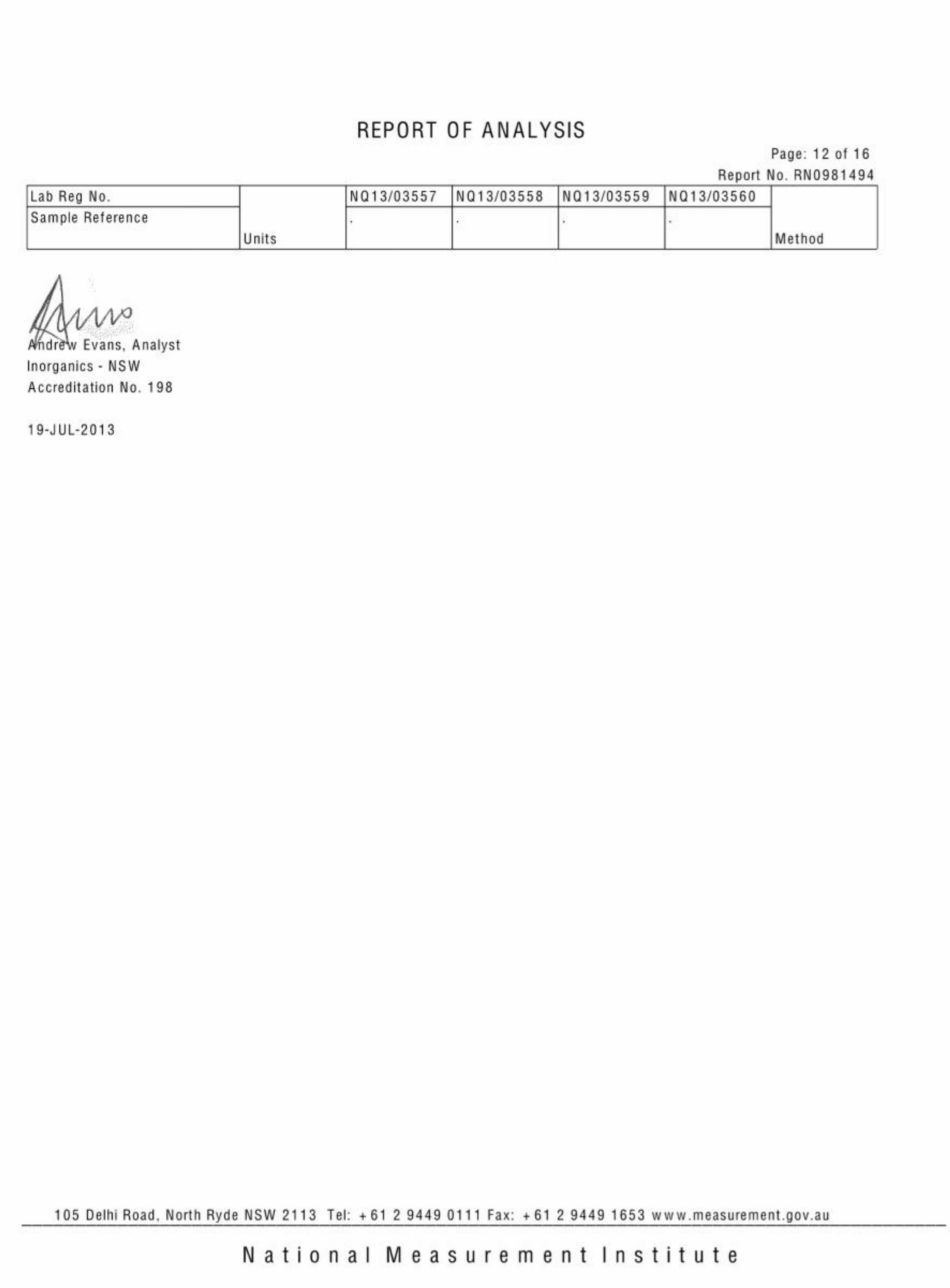

REPORT OF ANALYSIS

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Report No. RN0981494

Lab Reg No.		NQ13/03557	NQ13/03558	NQ13/03559	NQ13/03560	
Sample Reference	Units	.	.	.	.	Method

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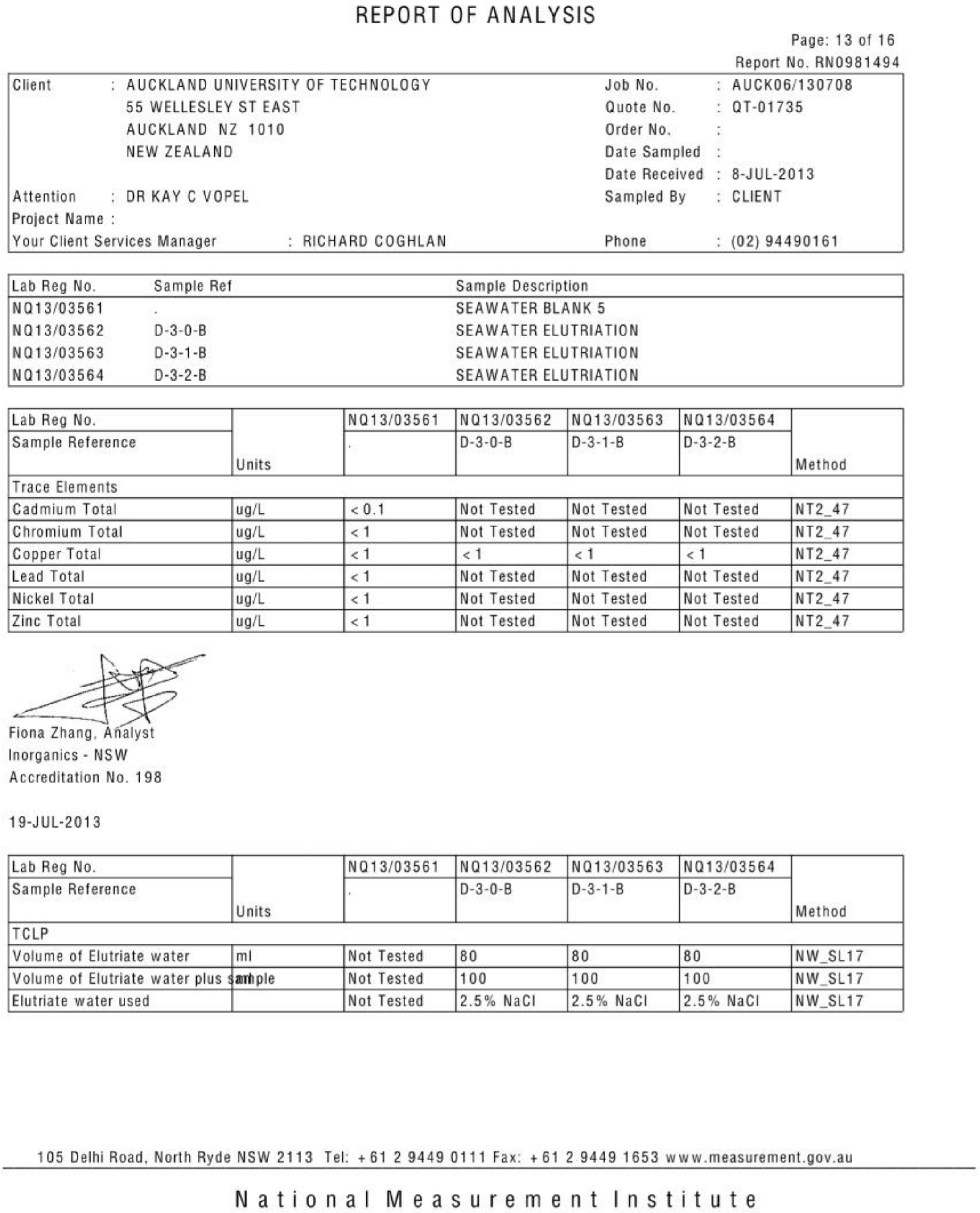

REPORT OF ANALYSIS

Client : AUCKLAND UNIVERSITY OF TECHNOLOGY
55 WELLESLEY ST EAST
AUCKLAND NZ 1010
NEW ZEALAND
Attention : DR KAY C VOPEL
Project Name :
Your Client Services Manager : RICHARD COGHLAN

Job No. : AUCK06/130708
Quote No. : QT-01735
Order No. :
Date Sampled :
Date Received : 8-JUL-2013
Sampled By : CLIENT
Phone : (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03561	.	SEAWATER BLANK 5
NQ13/03562	D-3-0-B	SEAWATER ELUTRIATION
NQ13/03563	D-3-1-B	SEAWATER ELUTRIATION
NQ13/03564	D-3-2-B	SEAWATER ELUTRIATION

Lab Reg No.		NQ13/03561	NQ13/03562	NQ13/03563	NQ13/03564	
Sample Reference	Units	.	D-3-0-B	D-3-1-B	D-3-2-B	Method
Trace Elements						
Cadmium Total	ug/L	< 0.1	Not Tested	Not Tested	Not Tested	NT2_47
Chromium Total	ug/L	< 1	Not Tested	Not Tested	Not Tested	NT2_47
Copper Total	ug/L	< 1	< 1	< 1	< 1	NT2_47
Lead Total	ug/L	< 1	Not Tested	Not Tested	Not Tested	NT2_47
Nickel Total	ug/L	< 1	Not Tested	Not Tested	Not Tested	NT2_47
Zinc Total	ug/L	< 1	Not Tested	Not Tested	Not Tested	NT2_47

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Accreditation No. 198

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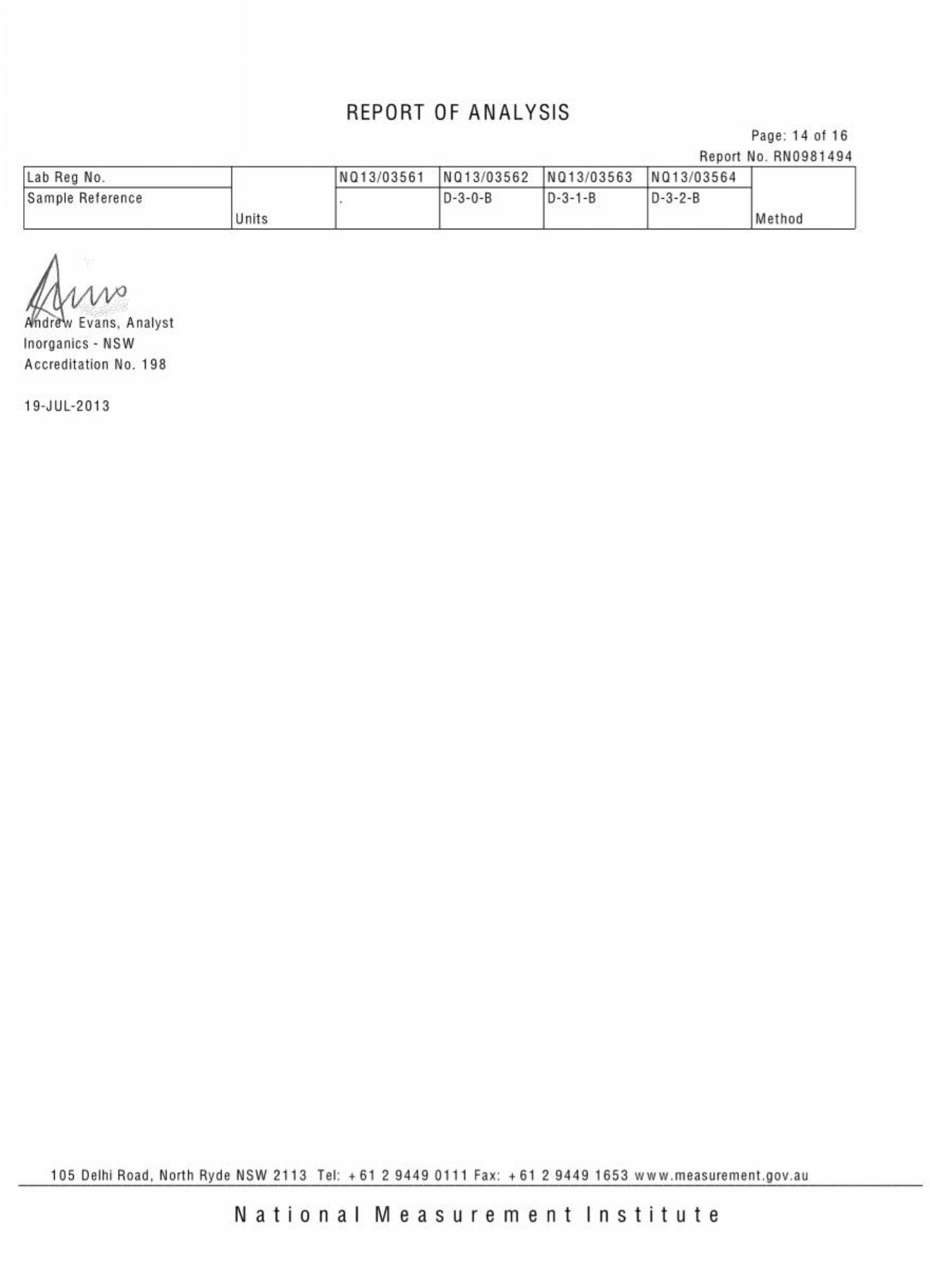
Lab Reg No.		NQ13/03561	NQ13/03562	NQ13/03563	NQ13/03564	
Sample Reference	Units	.	D-3-0-B	D-3-1-B	D-3-2-B	Method
TCLP						
Volume of Elutriate water	ml	Not Tested	80	80	80	NW_SL17
Volume of Elutriate water plus sample	ml	Not Tested	100	100	100	NW_SL17
Elutriate water used		Not Tested	2.5% NaCl	2.5% NaCl	2.5% NaCl	NW_SL17



REPORT OF ANALYSIS

Lab Reg No.		NQ13/03561	NQ13/03562	NQ13/03563	NQ13/03564	
Sample Reference	Units	.	D-3-0-B	D-3-1-B	D-3-2-B	Method

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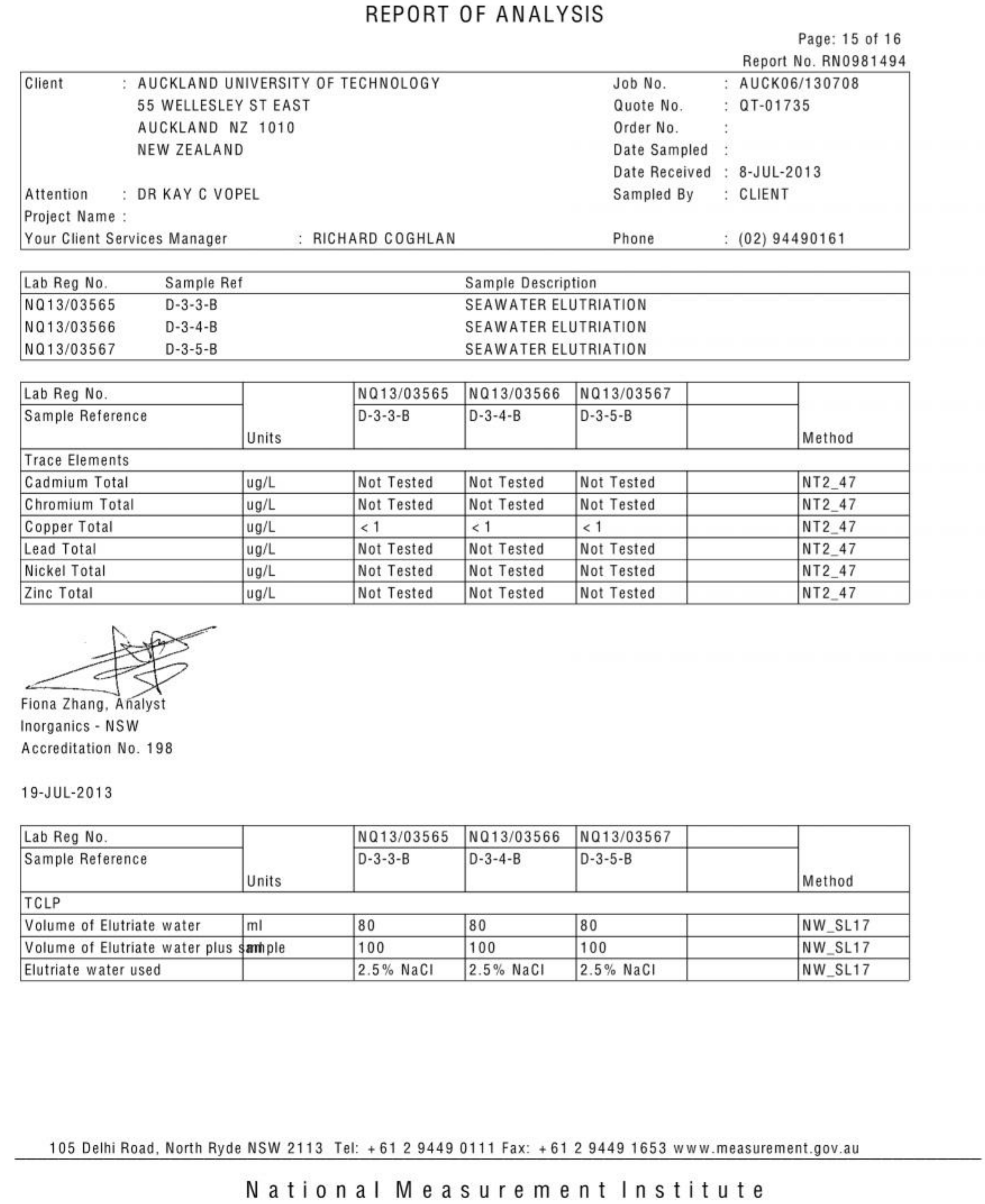
Accreditation No. 198

19-JUL-2013



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Report No. RN0981494

Client	: AUCKLAND UNIVERSITY OF TECHNOLOGY 55 WELLESLEY ST EAST AUCKLAND NZ 1010 NEW ZEALAND	Job No. Quote No. Order No. Date Sampled Date Received	: AUCK06/130708 : QT-01735 : : : 8-JUL-2013
Attention	: DR KAY C VOPEL	Sampled By	: CLIENT
Project Name :			
Your Client Services Manager	: RICHARD COGHLAN	Phone	: (02) 94490161

Lab Reg No.	Sample Ref	Sample Description
NQ13/03565	D-3-3-B	SEAWATER ELUTRIATION
NQ13/03566	D-3-4-B	SEAWATER ELUTRIATION
NQ13/03567	D-3-5-B	SEAWATER ELUTRIATION

Lab Reg No.		NQ13/03565	NQ13/03566	NQ13/03567		
Sample Reference	Units	D-3-3-B	D-3-4-B	D-3-5-B		Method
Trace Elements						
Cadmium Total	ug/L	Not Tested	Not Tested	Not Tested		NT2_47
Chromium Total	ug/L	Not Tested	Not Tested	Not Tested		NT2_47
Copper Total	ug/L	< 1	< 1	< 1		NT2_47
Lead Total	ug/L	Not Tested	Not Tested	Not Tested		NT2_47
Nickel Total	ug/L	Not Tested	Not Tested	Not Tested		NT2_47
Zinc Total	ug/L	Not Tested	Not Tested	Not Tested		NT2_47

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Lab Reg No.		NQ13/03565	NQ13/03566	NQ13/03567		
Sample Reference	Units	D-3-3-B	D-3-4-B	D-3-5-B		Method
TCLP						
Volume of Elutriate water	ml	80	80	80		NW_SL17
Volume of Elutriate water plus sample		100	100	100		NW_SL17
Elutriate water used		2.5% NaCl	2.5% NaCl	2.5% NaCl		NW_SL17

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Lab Reg No.	Units	NQ13/03565	NQ13/03566	NQ13/03567		Method
Sample Reference		D-3-3-B	D-3-4-B	D-3-5-B		

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Total = acid extractable elements.

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This Report supersedes reports: RN0981310 RN0981490