

Technical Report 16

NIWA – Marine Sediments and Contaminants (Lyall Bay)

Wellington Airport Runway Extension: Marine sediments and contaminants (Lyall Bay)



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Prepared by:

Craig Depree
Scott Nodder
Lisa Northcote
Greg Olsen

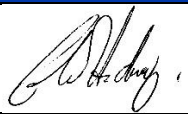

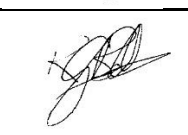
For any information regarding this report please contact:

Craig Depree
Environmental Chemist - Group Manager
Environmental Chemistry and Ecotoxicology
+64-7-856 1750
craig.depree@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

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	Reviewed by:	Chris Hickey
	Formatting checked by:	Alison Bartley
	Approved for release by:	Rob Bell

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Executive summary

In August-October 2014, surface sediments (i.e., upper 50 mm) were collected in Lyall Bay (Hue te para) over water depths ranging from 5-15 m as part of a baseline survey to characterise grain-size and contaminant concentrations in the vicinity of the proposed Wellington International Airport runway extension and in the wider bay.

Lyall Bay receives stormwater from a 283 ha (4% of total), fully developed, urban catchment that discharges an estimated 5% of Wellington's stormwater contaminant loads through a series of outfall at Lyall Bay Beach, Moa Point, and near the breakwater at the south end of the airport runway.

The outer bay receives treated wastewater (and occasional partially-treated overflows) from the Moa Point wastewater treatment plant. Despite sources of stormwater and wastewater (i.e., overflows), water quality is generally very good with respect to aesthetics and human health (WCC 2014). Chemical contaminants have not been previously assessed, but because of the high dilution and dispersion of the area, contaminants are not considered to have any significant effects on marine organisms (WCC 2014).

At the time of developing the sediment sampling strategy, there was no available information regarding construction methods. In the absence of any guidance on the nature of sediment disturbances likely to be encountered during construction, it was assumed that sediment from depths of between 0.5 and 1 m could be displaced (i.e., suspended) and deposited at near- or far-field locations.

Thirteen sites were selected and sampled for sediment physical properties, with a subset of seven sites sampled for contaminants (i.e., heavy metals, organochloride pesticides (DDT and analogues) and polycyclic aromatic hydrocarbons (PAH)). Two of the sites in the area of proposed runway extension were also sampled for elutriates, including heavy metals, nutrients and sulfide, to a depth of 0.2 m. Unfortunately the sand/gravel substrate type prevented sampling sediment to the preferred depth of 1 m.

As expected from the high-energy nature of the area and previous studies, Lyall Bay is not a depositional environment, and is characterised by uniformly moderately to well sorted, fine sandy sediments with very low mud content (~2-5%; mean 2.5%) and clay content (0%). The low fines content in the Lyall Bay sediments suggest that these sediments are less contaminated than muddy sediments from inner and outer Wellington Harbour.

In terms of contaminants in the surficial sediments of Lyall Bay:

- Total extractable heavy metals (and arsenic) concentrations were consistent with background soil/rock for the Wellington region, with no measurable anthropogenic 'foot print' observed in the Lyall Bay surficial sediments.
- Total extractable heavy metal concentrations of arsenic, cadmium, chromium, copper, nickel, lead, zinc and mercury in Lyall Bay sediments (<2 mm fraction) were all well below ANZECC interim sediment quality guideline (ISQG) trigger ('low') values. With respect to the major urban-derived heavy metals:
 - copper: average concentration (± 1 s.d.) 3.0 ± 0.3 mg/kg was 21-times lower than the ANZECC trigger value of 65 mg/kg

- lead: average concentration (± 1 s.d.) 7.6 ± 0.3 mg/kg was at least 6-times lower than the ANZECC trigger value of 50 mg/kg
- zinc: average concentration (± 1 s.d.) 31 ± 2 mg/kg was at least 6-times lower than the ANZECC trigger value of 200 mg/kg.
- Weak acid extractable heavy metal concentrations (copper, lead and zinc) in the mud-size sediment fraction (as an estimate of bioavailable concentrations) were not relevant for assessing bioavailability of heavy metals because of the non-depositional nature of Lyall Bay (<2% mud). If the proposed construction activities, associated with seabed disturbance, did result in mud accumulation, albeit highly unlikely, concentrations present indicate there would be no likely toxic effects on marine biota.
- Heavy metal concentrations at sites 10 and 11 within the proposed runway extension area appear to be homogeneously distributed to at least a depth of 0.2 m. Over this depth range, it is assumed that organic concentrations, similarly do not change (i.e., increase) markedly.
- DDT and associated analogues were the main organochlorine pesticides present in the surficial sediments of Lyall Bay. The average concentration (± 1 s.d) of 0.24 ± 0.15 $\mu\text{g/kg}$ is 6-times lower than the current ANZECC ISQG 'low' trigger value of 1.6 $\mu\text{g/kg}$. Organic-normalised (1%-OC) total DDT concentrations ranged between 0.3 and 1.1 $\mu\text{g/kg}$, with an average concentration of 0.49 ± 0.30 $\mu\text{g/kg}$, which is 3-times lower than the current ANZECC ISQG value (1.6 $\mu\text{g/kg}$).
- PAH concentrations (mass normalised) ranged from 45 to 155 $\mu\text{g/kg}$ in Lyall Bay sediments, with an average (± 1 s.d) of 94 ± 38 $\mu\text{g/kg}$, which was approximately 40-times lower than the ANZECC ISQG 'low' trigger value of 4,000 $\mu\text{g/kg}$ (note that the recommended revised 'low' guideline value for total PAH is 10,000 $\mu\text{g/kg}$). Organic-normalised (1%-OC) PAH concentrations ranged between 90 and 330 $\mu\text{g/kg}$, with an average concentration of 187 ± 77 $\mu\text{g/kg}$ that is approximately 20-times lower than current ANZECC ISQG value.

Contaminant concentrations in Lyall Bay surficial sediments are very low and uniformly distributed across the study area, including at sites most likely to be disturbed by construction activities, namely, sites 10 and 11 in the area to be reclaimed. Mobilisation of sediment from 0-0.2 m depths from within the area of the proposed runway extension is not expected to result in any significant increase in sediment contaminant concentrations in surrounding areas.

From a contaminant perspective, the risk of adverse effects on the water column from transient sediment suspension/disturbance events during construction is very low given that water column concentrations, even after allowing for reasonable mixing, are estimated to be at least two-orders of magnitude lower than default ANZECC water quality trigger values.

1 Introduction

1.1 Background

Wellington International Airport Ltd (WIAL) issued a Request For Proposals to provide environmental baselines for the planned extension of the present runway to the north and south into Evans Bay (Akau tangi) and/or Lyall Bay (Hue te para), respectively (WIAL 2014). In late April 2014, WIAL selected the option of lengthening the existing runway from approximately 1950 m to at least 2300 m to the south into Lyall Bay (Hue te para) only.

In late May 2014, the National Institute of Water & Atmospheric Research Ltd (NIWA) submitted a tender to undertake a range of activities (i.e., sediment characterisation and contaminants, marine ecology and hydrodynamic modelling) as part of establishing environmental baselines in Lyall Bay (Hue te para), Wellington, prior to runway construction work being undertaken.

1.2 Study area description

Lyall Bay is a semi-circular, open bay on the Wellington south coast between the rocky headlands of Te Raekaihu to the east and Hue te taka (Moa Point) to the west that is exposed to southerly swell from the Cook Strait (Raukawa moana) (Beca Carter-Caldwell Connell, 1980; WQC-WRC, 1989). The bathymetry of the bay shoals progressively from about 18-20 m in outer Lyall Bay, with steep slopes close to the headlands and around the reclamation and breakwater associated with the present-day Wellington airport runway (e.g., Lewis and Carter, 1976; Pickrill, 1979; Wright et al. 2006).

Lyall Bay receives stormwater from the Lyall Bay catchment, the southern parts of the Miramar Golf Course and Wellington Airport and part of Moa Point Wastewater Treatment Plant. The approximately 280 ha catchment comprises 5 urban subcatchments, namely (WCC 2014):

- Lyall Bay West (118 ha), fully developed and outer residential, 4 major stormwater outfalls and one constructed overflow (sewage).
- Lyall Bay East (29 ha), fully developed and outer residential, 2 major stormwater outfalls.
- Airport South (57 ha), airport land, 1 major stormwater outfall.
- Strathmore Park South (57 ha), fully developed and outer residential, 1 major stormwater outfall.
- Moa Point (16 ha), fully developed and outer residential, wastewater treatment discharge.

The approximate locations of stormwater outlets (including some non-major outfalls) are provided in Appendix A. The catchments discharge through a series of outfalls at Lyall Bay Beach, Moa Point, and near the breakwater at the south end of the airport runway. The discharge zone is therefore spread along a large exposed beach, break water and rocky coast, all of which are subject to relatively high energy from waves. Stormwater loads of contaminants (zinc, copper, lead and PAHs) are estimated to be around 5% of the total load from Wellington City (catchment comprises 4% of the total area). Despite some sources of waste water (i.e., occasional partially-treated overflows), water quality is generally very good with respect to aesthetics and human health (WCC 2014). Chemical contaminants have not been previously assessed, but because of the high dilution and dispersion of the area, contaminants are not considered to have any significant effects in the Bay (WCC 2014).

Surface sediments in Lyall Bay are predominantly well sorted, fine sands overlying coarser gravels that can form exposed aprons of mega-ripples, especially in the vicinity of the rocky substrates (greywacke bedrock) that form the headlands (e.g., Arron and Lewis, 1993; Carter and Lewis, 1995). The upper sandy deposits are mobile under fair- and storm-wave activity, with pebble gravels also able to be transported under extreme wave conditions, even at water depths of 60 m (Nodder, 1991, 1994; Carter and Lewis, 1995). Offshore, in the vicinity of Hue te taka (Moa Point), greywacke basement or boulder-sized materials associated with the basement lithologies may be within about 2 m of the sea-floor, although there are localised incidences of the upper sandy and gravel deposits being at least 7-10 m below the sediment surface (Nodder and Smits, 1994). In outer Lyall Bay, the depth to greywacke basement might be as much as 70-80 m (Davey, 1971; Grant-Taylor et al. 1974).

1.3 Objectives

The objectives of this study of sediment physical and contaminant properties are to establish sediment baseline conditions prior to the runway extension and to characterise the wider environs in Lyall Bay in order to evaluate potential impacts of the proposed engineering development on the seafloor environment.

Based on previous knowledge of the homogenous nature of seafloor sediments in Lyall Bay (Lewis and Carter, 1976; Pickrill, 1979; Arron and Lewis, 1993; Carter and Lewis, 1995; Wright et al. 2006), and utilising historical and new multi-beam backscatter and bathymetry data collected as part of the WIAL project (Mackay and Mitchell, 2014), a gridded pattern of sampling was planned to characterise the surficial sediments in the bay. In the NIWA tender proposal (NIWA, 2014), it was also planned to collect samples to determine historical sedimentation rates in Lyall Bay using radio-isotopes, however this was dependent on the nature of sediments in the bay. Field observations subsequently confirmed that the sandy nature of the sediments were unsuitable for determining historical sedimentation rates.

Surficial and subsurface sediments at a subset of sites were also characterised in terms of their contaminant content (e.g., heavy metals, organic pesticides). Therefore, sediment contaminant risk assessment of the proposed runway extension into Lyall Bay comprised two main components:

- 1) *Establish baseline conditions:* Characterisation of contaminants in proximity to and within the runway extension area to determine the current 'contaminant status' of the surrounding benthos. Existing status was assessed by comparing whole sediment (i.e., <2 mm sediment fraction) concentrations with ANZECC interim sediment quality guideline (ISQG) values for a range of inorganic and organic contaminants based on the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (known as "ANZECC"). For completeness (and to be consistent with other Greater Wellington Regional Council sediment monitoring programmes, e.g., GWRC (2014)), concentrations of weak acid-extractable metals were determined on the fine mud-sized (<0.063 mm) material to provide a measure of the potential bioavailability of heavy metals. Although it is noted that this method is normally only relevant to depositional receiving environments.
- 2) *Potential for contaminant release/mobilisation from construction activities:* Potential Contaminant characterisation (including mobility) of sediment within the proposed runway extension area. Although no engineering/construction details about the extension were available prior to designing the sediment sampling programme, the assumption was that sediment material at depths of between 0.5 and 1 m could be displaced (i.e., suspended) and

be deposited on the adjacent seafloor in Lyall Bay. To assess for potential risks from water column and/or benthic effects from suspension and subsequent deposition of mobilised sediments, contaminant concentrations in subsurface layers, and elutriates were tested. Initially it was planned to sample to depths of 1 m or more; however, sediment sampling depths were limited to a maximum of 0.2 m due to the coarse nature of the seafloor substrates in Lyall Bay.

The second component of the risk assessment is based around the assessment framework ('decision tree') for contaminants outlined in New Zealand (MSANZ, 1999; Figure B-1, Appendix B) and Australian (Figure B-2, Appendix B) guidelines for sea disposal of waste (e.g., dredged material). The use of dredge disposal frameworks in this context was considered relevant because runway construction could potentially involve suspension of anoxic/suboxic subsurface sediment, which has the potential to have adverse transient effects on water column quality. This was assessed by undertaking elutriate testing of sediments using standard US-EPA methods. Subsurface sediments were analysed at sites likely to incur maximum disturbance (i.e., within the proposed runway extension area) to determine whether these sediment pose a risk when deposited on the surface of adjacent seafloor areas.

The selection of potential contaminants of concern was directed by previous sampling (GWRC, 2014) and relevant New Zealand and Australian guideline documents for sea disposal of waste (MSANZ 1999; Commonwealth of Australia 2009; refer to Table B-1). The final list of contaminants factored in the aforementioned documents, and the availability of commercial (and certified) analytical testing methodologies. Contaminants included in the assessment are described in the methods section below.

2 Methods

2.1 Sediment sampling sites

The gridded survey plan included a total of 13 sampling sites in Lyall Bay (Figure 2-1) from which surficial sediments (0-5 cm depth) and subsurface sediments (typically less than 20 cm depth) were collected. Water depths of the sites ranged from approximately 5 to 15 m. These sites were identical to the sites also sampled for benthic biological communities (MacDiarmid et al. 2015).

Sediment samples were collected using a HAPS corer (KC Denmark), which has a base frame of 80 x 80 cm, is 156 cm high and weighs 170 kg. The corer was deployed by winch off the stern of NIWA's 14 m inshore coastal research vessel, *Ikateri*. The HAPS corer has a single 13 cm diameter sediment core that can penetrate the seabed to a maximum depth of 300 mm, collecting an undisturbed surficial sediment sample.

Originally we had planned to use a 'mini' multi-corer (KC Denmark) that would have enabled deeper sediment sampling (approximately 400 mm), however, this was not used because of poor penetration when tested in Lyall Bay. Similarly, long cores, collected using a gravity corer, for sedimentation rate analyses using radiogenic elements (^{210}Pb , ^{137}Cs , ^7Be , ^{14}C) were not able to be obtained due to the homogenous sandy nature of the seafloor sediments, which made penetration of the corer into the seabed impossible to achieve, despite best efforts in the field. Because of the short nature (<20 cm) of sediment cores collected using the HAPS corer, we decided it was unlikely that expensive radioisotope analyses would yield meaningful sedimentation rate estimates due to the highly active sedimentary regime and low mud content of surface sediments in Lyall Bay (A. Swales, NIWA, pers. comm., 2014).

Sediment samples were collected from 13 sites (Figure 2-1) on the 27th and 28th of August 2014. At all 13 sites the upper 5 cm of sediment was carefully removed (on-board) and placed in labelled zip-lock bags. Samples were stored in a cooler before being returned to the laboratory and frozen (-20°C) prior to grain-size analysis (refer to 2.2.1).

At seven of the 13 sites (sampled 27th and 28th August 2014), sediment was collected for contaminant analyses (red and blue marked sites, Figure 2-1). This included four sites adjacent to (sites 1, 3, 5 and 8) and three sites within (sites 10, 11 and 12) the proposed area of the runway extension. Cores from all seven sites were processed on-board, with the surface sediment (0-5 cm layer) removed and then double-bagged in labelled zip-lock plastic bags. Samples were stored in a cooler before being returned to the laboratory and frozen (-20°C) prior to shipping to the NIWA Water Quality Laboratory in Hamilton for further processing (see below). At sites 10 and 11 (blue marked sites, Figure 2-1), additional sediment samples were taken at 5-10 cm and >10 cm depth (total depth of sediment was approximately 14 cm). These sediments were, similarly, placed in zip lock plastic bags, frozen and freighted to the NIWA Water Quality Laboratory in Hamilton for further processing.

Additional sampling of sites 10 and 11 was undertaken on October 15th 2014 to obtain surface (0-10 cm) and sub-surface (10-20 cm) sediment for elutriate testing (blue marked sites, Figure 2-1). Sediment cores were collected and sliced on-board at 0-5, 5-10, 10-15 and 15-20 cm intervals. Samples were then double-bagged in labelled zip-lock plastic bags, chilled (not frozen) and shipped overnight to the NIWA Water Quality Laboratory in Hamilton for further processing (see below). Prior to elutriate testing and analyses, the sediment fractions were composited to give a single 0-10 cm surface sample and a single 10-20 cm sub-surface sample.

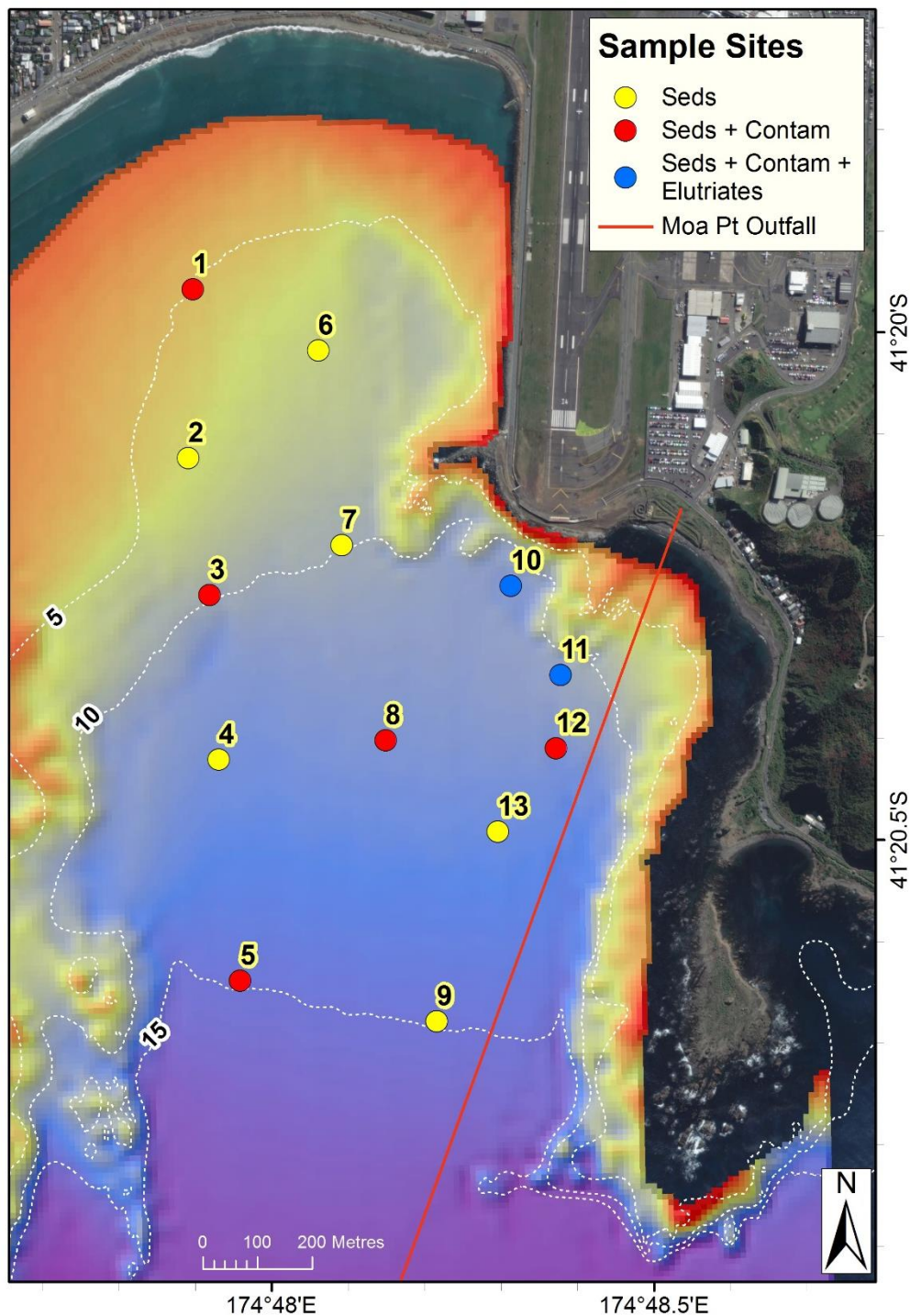


Figure 2-1: Sediment sampling sites in Lyall Bay, Wellington. Contaminant sampling sites were 1, 3, 5, 8, 10, 11 and 12. Other sampling sites shown were analysed for sediment grain-size. Seds = Sediment analyses, Contam = Contaminant analyses, Elutriates = Elutriation experiments (see text for details). The location of the Moa Point outfall is also shown as a red line. Bathymetric data are reprocessed at a 10 m grid cell-size from all data collected in the study area (e.g., Wright et al. 2006; Mackay and Mitchell, 2014).

At all seven contaminant sampling sites, sediments were analysed for a suite of contaminants in the surface layer (0-5 cm) in both whole (<2 mm size) and fine (<0.063 mm) sediment particle size-fractions. At sites 10 and 11, deeper cores were sampled in 5 cm increments to 20 cm, such that 0-10 cm and 10-20 cm composite samples could be used for elutriate testing, reflecting the mobilisation/solubilisation of contaminants from sediments to overlying water. These elutriate sediment depth fractions were also analysed for heavy metals. A summary of the contaminant analyses that were undertaken on the Lyall Bay samples is provided in Table 2-1.

Table 2-1: Summary of Lyall Bay sediment sampling sites and contaminant analyses. TOC = total organic carbon. PAH = polycyclic aromatic hydrocarbons. See Figure 2-1 for sample site locations.

Sample sites	Sediment depth (cm)	Size-fraction (mm)	Analyses
Sediments collected 27 th and 28 th August 2014			
1,3,5,8,10,11,12	0-5	<2	TOC, total heavy metals, organics (PAHs, organochlorines)
1,3,5,8,10,11,12	0-5	<0.063	TOC, extractable heavy metals (copper, lead and zinc)
Sediment collected 15 th October 2014			
10,11	0-10	whole ^a	TOC, total heavy metals, elutriate testing ^b
10,11	10-20	whole ^a	TOC, total heavy metals, elutriate testing ^b

^a Most of the sediment (i.e., close to 100%) would have been <2 mm; however to preserve core integrity, sediments were not sieved prior to elutriate testing or analysis. ^b elutriate extracts (i.e., water fraction) were analysed for heavy metals (As, Cd, Cr, Cu, Pb, Hg, Ni and Zn), nutrients (ammoniacal nitrogen NH₄-N, nitrate-N and nitrite-N) and total sulfide.

2.2 Sediment processing

2.2.1 Grain-size

Grain-size distributions in the sediment samples were measured using a Beckman Coulter LS13-320 dual-wavelength laser-particle sizer that measures grain-sizes in the 0.04-2000 µm size range with 1% reproducibility. Approximately 0.5 cm³ of sediment was re-suspended in distilled water in a 50 ml container, invigorated using ultrasound, and then washed through a 2 mm sieve into the laser-sizer where it was analysed for 90 seconds. Standard granulometric statistics (mean grain-size, sorting, skewness and kurtosis) were calculated for each core sample from the 'percent by volume' laser data using GRADISTAT (Blott and Pye, 2001) that also provides standard textural descriptions using the Folk and Ward (1957) classification scheme. Samples with gravel clasts over 2 mm from sites 8 and 13 were sieved at 2 mm, 0.500 mm, 0.250 mm, 0.125 mm and 0.063 mm size-fractions. Although continuous grain-size distributions are produced from the laser-particle sizer output, grain-sizes are presented primarily as percent gravel (over 2 mm diameter), sand (0.063–2 mm), mud (<0.063 mm), silt (0.002–0.063 mm) and clay (<0.002 mm).

Samples were run in triplicate to provide an estimate of the subsampling reproducibility and laser sizer precision.

2.2.2 Contaminants

As described above, sediments collected on August 27th and 28th 2014 were sectioned in the field and couriered overnight frozen (-20°C) to NIWA Hamilton where sediment samples were then freeze-dried and dry sieved to collect <2 mm 'whole sediment' and <0.063 mm fine (or mud-sized) sediment fractions. Subsamples of material were sent to Asure Quality (Lower Hutt) for organochlorines analyses and Hill Laboratories (Hamilton) for total heavy metals (<2 mm), weak extractable heavy metals (<0.063 mm) and total organic carbon (TOC).

Additional cores (0-20 cm sediment) from sites 10 and 11 were collected on 15th October 2014 for the purpose of elutriate testing and contaminant characterisation (i.e., heavy metals) of deeper sediments that will potentially be mobilised during construction of the runway extension. These sediments were shipped overnight to NIWA Hamilton by refrigerated freight (4°C).

2.3 Sediment contaminant analyses

Details of the methods used by Hill Laboratories and Asure Quality Ltd for the sediment contaminant analyses, including analytical detection limits, are provided in Appendix C.

2.3.1 Total organic carbon (TOC)

TOC content was determined using a non-accredited method by Hill Laboratories where sediment is acidified to remove inorganic carbonates, then neutralised. TOC content was then determined via an Elemental CHN combustion analyser with a detection limit of 0.05 g/100 g dry weight.

The total nitrogen (TN) content in the elutriate samples was also measured using the same CHN combustion analyser, but was below analytical detection limits (<0.02%). Consequently, the data are not reported here. This was consistent with very low concentrations (at or below 0.02%) in surficial sediments (0-5 cm) from all the sites sampled as part of the marine ecology study (Macdiarmid et al. 2015).

2.3.2 Heavy metals

Total recoverable heavy metals were analysed using accredited methodologies at Hill Laboratories, including nitric/hydrochloric acid digestion in accordance with US EPA method 200.2 and trace level detection using ICP-MS. Metals analysed for included arsenic (As, metalloid), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn) and mercury (Hg).

2.3.3 Polycyclic aromatic hydrocarbons (PAHs)

Using an accredited methodology by Hill Laboratories, PAH concentrations were determined using a sequential method involving ultrasonication solvent extraction, solid phase extraction (SPE) clean-up, followed by gas chromatography mass spectrometry (GC-MS) and selected ion analysis (SIM) in accordance with US EPA method 8270C. Detection limits for individual PAHs range from 0.002 to 0.01 mg/kg dry weight. Results are for the summed total of the 16 priority US EPA PAHs, namely naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b+k]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno(1,2,3-c,d)pyrene, dibenzo[a,h]anthracene and benzo[g,h,i]perylene. For compounds that were below the limits of detection, concentrations equal to half the detection limit value was used to calculate total (sum of 16) PAH sediment concentration.

Using an accredited methodology, Hill Laboratories determined total extractable heavy metal concentrations on whole sediments (<2 mm fraction), including copper (Cu), zinc (Zn), lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and mercury (Hg). Note that arsenic is not a true metal and usually referred to as a metalloid. Sediment samples were extracted using nitric and hydrochloric acids in accordance with US EPA Method 200.2. Heavy metals were then quantified by trace level analysis using inductively coupled plasma mass spectrometry (ICP-MS). Detection limits range from 0.01 to 0.4 mg/kg dry weight.

Following the non-accredited method developed by Auckland Regional Council (ARC, 1994), concentrations of “bioavailable” copper (Cu), lead (Pb) and zinc (Zn) were estimated in <0.063 mm sediment fractions using dilute (2 M) hydrochloric acid, following by trace level analysis by ICP-MS. Default detection limits for copper, lead and zinc were 1, 0.2 and 2 mg/kg (dry weight), respectively. Extractions and analyses were carried out by Hill Laboratories.

The use of dilute extraction metals as a proxy for bioavailable metals is also consistent with Australian dredge guidelines (Commonwealth of Australia, 2009). The guidelines state that the weak acid extractable concentrations are a closer approximation to the bioavailable fraction than total recoverable heavy metal concentrations, and, as such, are a guide to bioavailability, particularly to sediment-ingesting organisms.

2.3.4 Organochlorine pesticides (e.g., dieldrin and DDTs)

Organochlorine compounds were analysed byASURE Quality using IANZ certified methodology (based on US EPA 1699 method). For DDT analogues and dieldrin, the detection limits were between 0.01 and 0.1 mg/kg, respectively. A complete list of analytes and detection limits is provided in Table C-1 (Appendix C).

2.3.5 Organotin antifouling compounds

Organotin antifouling compounds are environmentally persistent, but are generally associated with areas where boat maintenance (removal and application of antifouling paint) occurs, such as marinas and boat slipways. Such sources are not-applicable to Lyall Bay, and therefore antifouling organotin compounds were not included in the initial risk assessment. Sediment samples have been archived should the analysis of organotin compounds be required as part of the consent process. Tributyltin compounds were generally found to be below the ANZECC ‘low’ value of 5 µg Sn/kg in Wellington Harbour sediments (GWRC, 2008).

2.4 Elutriate testing

Elutriation testing is used to investigate what happens when anaerobic sediments are removed from the seabed and exposed to aerated seawater, as happens during dredging operations. Sediment cores (20 cm deep) were collected from sites 10 and 11, and sliced at 5 cm intervals before being sealed in zip-lock bags and couriered refrigerated overnight to NIWA Hamilton. In the NIWA Hamilton laboratory, the 0-5 and 5-10 cm depth sections were composited to give a ‘surface’ composite sediment (i.e., 0-10 cm depth) and the 10-15 and 15-20 cm section were composited to give a ‘subsurface’ composite sample (i.e., 10-20 cm depth). The composite samples (two for each site) were sent to Hill Laboratories for elutriate extraction and analysis of the elutriate fluid for heavy metals, nutrients and sulfide. The surface and subsurface composite sediment samples were also analysed for heavy metals (section 2.3.2) and TOC (section 2.3.1).

Sediments elutriate tests were conducted in accordance with US EPA method 503/8-91/001 “Evaluation of dredged material for ocean disposal”. Briefly, 30 g of sediment was added to 120 ml of oceanic water collected from the Alderman Islands, 20 km east of Tairua and Pauanui, Coromandel Peninsula (i.e., mixed in a 1:4 ratio) and mixed for 30 min and allowed to settle for 1 hour, prior to filtration and analysis of dissolved analytes (i.e., heavy metals, nutrients and sulfide). Methodological information and associated limits of detection for target analytes are provided in Table C-3 (Appendix C).

3 Results and discussion

3.1 Grain-size distributions in Lyall Bay sediments

Except for two subsamples from sites 8 and 12, all the surficial sediment samples from Lyall Bay were moderately to well-sorted, very fine to fine sands (Appendix F). Across all sites, the average sand content was 97.4% (± 0.7 , 1 standard deviation), with 0.1 (± 0.3) % gravel, 2.5 (± 0.7) % silt and 0% clay. The median grain-size (D_{50}) for all sand samples was 0.154 (± 0.013) mm diameter (fine sand). The two subsamples that contained gravel were from site 8 (replicate #3) and site 12 (replicate #1), with both designated as very fine gravelly sands (1.1 and 1.8% gravel, respectively), comprising 96-97% sand and ~2% silt. In essence, however, all of the samples can be regarded as moderately to well-sorted fine sands.

These grain-size data confirm previous work undertaken in Lyall Bay and along the Wellington south coast, with well-sorted fine sands forming a uniform sandy veneer that overlies pebbly gravels, which are often characterised by mega-ripples (e.g., Lewis and Carter, 1976; Arron and Lewis, 1993; Carter and Lewis, 1995). These coarser gravelly substrates can be exposed as aprons around many of the submerged rocky reefs along the Wellington south coast (e.g., Arron and Lewis, 1993; Carter and Lewis, 1995; Wright et al. 2006), and are represented in Lyall Bay by areas of high back-scatter reflectivity in the multi-beam data recently collected and compiled for Lyall Bay (e.g., Mackay and Mitchell, 2014). These very gravelly sediment substrates were not sampled by the present study, since the focus was on the sandy substrates and their association with potential contaminants and infauna that might be affected by the planned runway extension.

Since long cores were unable to be obtained as part of the present study (refer to Section 2.1), the thickness of the uppermost fine sandy sediment is not known precisely in Lyall Bay. Previous studies suggest that the fine sand veneer might be in the order of 1-2 m thick (Nodder, 1991, 1994; pers. obs.; Nodder and Smits, 1994), thinning closer to the coast where coarse-grained gravels and rocky outcrops are exposed eventually (e.g., Arron and Lewis, 1993).

In terms of sediment mobility, Carter and Lewis (1995) have showed that fine sand (less than 0.25 mm diameter) will be typically stirred by wave activity at water depths less than 30 m for almost 50% of the time, especially in autumn through to spring, based on wave data from Lyall Bay by Pickrill (1979). Furthermore, under extreme swell wave conditions, even pebble-sized gravels (greater than 4 mm diameter) will be mobilised over water depths up to 60 m (Nodder, 1994).

3.2 Contaminant concentrations in Lyall Bay sediments

3.2.1 Heavy metals and arsenic in surficial sediments (0-5 cm)

Concentrations of heavy metals in Lyall Bay sediments were low (Table 3-1) and relatively homogenous across the seven sample sites, with relative standard deviations of less than 10%. Sediment concentrations were all well below the corresponding ANZECC interim sediment quality guideline (ISQG) 'low' value, which is based on a 10% effects probability (as opposed to 'high', which is a 50% effects probability). With respect to percentage of the ANZECC 'low' value, concentrations in the Lyall Bay sediments ranged from 1% for cadmium to 39% for nickel.

Table 3-1: Heavy metal (and arsenic) concentrations in surficial sediments (0-5 cm) from Lyall Bay. All concentrations are in mg/kg dry weight. Std dev = standard deviation.

Site	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
1	6.0	0.02	8.2	2.4	7.8	0.03	7.0	30
3	5.8	0.02	9.4	3.2	7.9	0.04	7.7	30
5	5.5	< 0.02	10.5	3.2	6.9	0.04	8.6	31
8	6.1	< 0.02	11.1	3.0	7.8	< 0.02	8.9	32
10	5.3	< 0.02	9.6	3.1	7.6	0.04	7.7	32
11	4.8	< 0.02	10	3.5	7.7	0.05	8.6	34
12	4.7	< 0.02	10.6	2.9	7.4	0.09	8.4	31
Mean	5.5	0.013	10	3.0	7.6	0.04	8.1	31
Std dev	0.6	0.005	1	0.3	0.3	0.02	0.7	2
ANZECC Low ^a	20	1.5	80	65	50	0.15	21	200
ANZECC High ^a	70	10	370	270	220	1	52	410

^a ANZECC (2000) trigger values for sediments.

Heavy metal concentrations in Lyall Bay sediments showed little, if any, indication of anthropogenic enrichment of heavy metals since concentrations were within the normal ranges for background soil concentrations for the Wellington region (Table 3-2; values taken from GWRC, 2005). This is not unexpected given the relatively minor amounts of stormwater discharged into Lyall Bay (compared with, for example, the inner Wellington Harbour), combined with the high energy and dispersive nature of the receiving marine environment. Anthropogenic contaminants, in particular heavy metals, tend to be associated with fine particulate materials (i.e., <0.063 mm), which dominate the suspended sediment load in stormwater. Accordingly, high energy environments (i.e., non-depositional) typically have relative coarse sediments and low concentrations of anthropogenic contaminants. Lyall Bay sediments are dominated by sand-sized particles (~97%), with silt content (less than 0.063 mm) on average being only 2.5% by mass with no clay fraction (see section 4.1).

Table 3-2: Comparison of mean concentrations of heavy metals in Lyall Bay surficial sediment with typical background concentrations for Wellington soils. All concentrations in mg/kg dry weight.

	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
Lyall Bay sediment mean	5.5	0.013	10	3.0	7.6	0.04	8.1	31
Main soil type 1 (sand) ^a	<2-7	<0.1-0.1	7-12	4-10	5-15	<0.1-0.1	4-9	28-79
Main soil type 2 (greywacke) ^a	<2-7	<0.1-0.1	6-16	3-25	6-79	<0.1-0.1	4-13	24-105

^a GWRC (2005).

As part of a comprehensive stormwater consent to discharge directly to Wellington Harbour, Greater Wellington Regional Council and Wellington City Council undertake sediment monitoring at a number of sites within Wellington Harbour at 5-yearly intervals, the most recent being in 2011 (GWRC, 2014). Inner Wellington Harbour sites (refer to Appendix D for sediment sampling sites) contained elevated concentrations (relative to background) of heavy metals, in particular, mercury (0.5-0.7 mg/kg), lead (50-70 mg/kg), copper (15-40 mg/kg) and zinc (100-130 mg/kg), although only mercury exceeded the ANZECC 'low' guideline value. In contrast, Lyall Bay sediments showed no of accumulation of anthropogenic heavy metals (relative to background).

3.2.2 Organic material content in surficial sediments (0-5 cm)

Total organic carbon (TOC) content is measured in sediments so that the concentrations of organic contaminants can be normalised to 1% OC and compared with ANZECC ISQG values. The rationale behind this is that persistent organic contaminants have higher (i.e., stronger) binding affinities for organic matter than for mineral surfaces. Accordingly, sediment with high amounts of organic matter (measured in the present report as TOC) can be expected to have lower bioavailability of an organic contaminant because of additional carbon binding sites that provide strong binding potential and reduce bioavailability. An ANZECC sediment quality guidelines revision document by the CSIRO (Simpson et al. 2013), provide guidelines values for organic contaminants normalised to 1% organic carbon (OC) content, and the authors recommend this be applied within OC limits of 0.2 to 10% OC. It is emphasised, however, that this revision document is not a revised (i.e., official) version of the ANZECC guidelines. Given the uncertainty of normalising against very low organic carbon concentrations, for the purpose of this assessment, we implemented the recommendations of Batley et al. (2002) and used a lower normalisation limit of 0.5% OC. The following explanation regarding the use of a lower 0.5% OC threshold was provided by Batley et al. (2002).

"It should be noted that organic carbon normalization is most appropriate for non-polar organics. We recommend that normalization be applied over the range 0.5 to 10% organic carbon. For very high organic carbon concentrations, the carbon may be as oil or tar rather than metal binding substrates such as humic materials, and normalization fails. At lower organic values, other physical and chemical factor influence the partitioning process (Kadeg et al. 1986), the normalised sediment quality values become extremely low, and the uncertainties in the commonly used un-normalised values (for many effect data carbon is not report), these are difficult to justify. For less than 0.5% carbon, considering the carbon as 0.5% is probably acceptable."

Organic carbon content in Lyall Bay sediments ranged from 0.22 to 0.39% (refer to Table E-5, Appendix D), and were consistent with the OC content values (c. 0.1 to 0.3%) reported in the Lyall Bay benthic study (Macdiarmid et al. 2015). In the benthic report, the highest OC values of 0.2-0.3% were found in sediments on the shallow (~10 m depth), easternmost side of the bay off the southern end of the present runway in the area of the proposed extension (sites 10, 11 and 12). Organic carbon content generally decreased offshore, with the possibility of a mid-bay “high” in the inner part of Lyall Bay between water depths of 5-10 m, although this observation would need to be confirmed with further sampling and analysis (Macdiarmid et al. 2015).

Total nitrogen (TN) content in the elutriate samples was below analytical detection limits (<0.02%) and consequently, the data are not reported here. For comparison, surficial sediments (0-5 cm) from all the benthic sites sampled in Lyall Bay, collected as part of the marine ecology study (Macdiarmid et al. 2015), also indicated very low and invariant TN values of or below 0.02%, resulting in molar C:N ratios that ranged from 5 to 17. The highest C:N ratios (14 to 17) were found at sites 10, 11 and 12 in the area of the proposed runway extension on the eastern side of Lyall Bay. At other sites, C:N ratios typically ranged from 5 to 8, with no obvious spatially coherent patterns (Macdiarmid et al. 2015).

3.2.3 Organic contaminants in surficial sediments (0-5 cm)

Based on the recommended OC-normalisation threshold of 0.5% OC (Batley et al. 2002), we derived organic-normalised values using this threshold value (since all OC values in Lyall Bay sediments were <9.5 %), resulting in doubling of the measured concentrations. We consider this approach a more realistic assessment of risks posed by contaminants in Lyall Bay sediments (i.e., sandy, low OC content), compared with that proposed by Simpson et al. (2013). Given the uncertainty around OC-normalising organic contaminant data for sediments with low OC content, we consider more emphasis should be placed on ‘un-normalised’ concentrations (i.e., not adjusted for OC content).

Organochlorines

Previous sediment monitoring in Wellington Harbour in 2006 and 2011 (GWRC, 2008, 2014, respectively) have shown that of the many organochlorine pesticides, it is only DDT (and related analogues) that are routinely measured above detection limits, and in some cases, above ANZECC ISQG values. Ultra-trace organochlorine pesticide analysis was undertaken byASURE Quality Ltd, and as part of the QA/QC process, they analysed a laboratory blank (Figure D-8, Appendix E) which was shown to contain 0.05 µg/kg pentachlorobenzene (PCB), 0.06 µg/kg hexachlorobenzene (HCB), 0.03 µg/kg δ-BHC (lindane), and 0.06 µg/kg of dieldrin. Comparable levels to those in the blank sample of these pesticides were detected in Lyall Bay sediments (Tables D-1 to D-7, Appendix E), and therefore it was assumed that these four compounds were background contamination artefacts. On the small chance that these pesticide concentrations in sediments were real, the concentrations are well below proposed ANZECC guideline revisions (Simpson et al. 2013). For example, the revised ISQG ‘low’ values for dieldrin and lindane are 2.8 and 0.9 µg/kg, respectively, which are 50 and 30-fold higher than concentrations in the Lyall Bay sediments and the laboratory blank sample analysed as part of the present study.

The only organochlorine compounds present in Lyall Bay sediments that were above detection limits were dichlorodiphenyltrichloroethane (DDT), and associated analogues (i.e., the breakdown products DDD and DDE), which are reported together as total DDT (Table 3-3). Total DDT concentrations (un-normalised) ranged from 0.15 to 0.54 µg/kg, with a mean and median concentration of 0.24 and 0.19 µg/kg, respectively. The median concentration across the 6 sites was 8- and 6-times lower than the current interim and proposed ANZECC ‘low’ guideline values of 1.6 (ANZECC 2000) and 1.2 µg/kg

(Simpson et al. 2013), respectively. As discussed, using 0.5% TOC as the low threshold for OC normalisation, total DDT concentrations for all sites were divided by 0.5 to produce estimated 1% OC normalised total concentrations (Table 3-3) OC-normalised concentrations ranged between 0.29 and 1.09 µg/kg, with a mean and median concentration of 0.49 and 0.38 µg/kg, respectively. The median total OC-normalised DDT concentration in Lyall Bay sediments was 4- and 3-times lower than the interim ANZECC and proposed guideline values, respectively.

Table 3-3: Organic contaminants (total PAH and DDT) in Lyall Bay surficial sediments (0-5 cm).

Concentrations in µg/kg dry weight (dw). Where compounds were not detected, a concentration equal to 50% of the detection limit was used to calculate total concentrations.

Site	Total DDT ^a (µg/kg)		Total PAH ^b (µg/kg)	
	un-normalised	1% OC normalised ^c	un-normalised	1% OC normalised ^c
1	0.17	0.33	108	216
3	0.54	1.09	97	194
5	0.21	0.41	45	90
8	0.15	0.29	87	174
10	0.18	0.35	115	230
11	0.22	0.44	155	310
12	na	na	49	98
mean	0.24	0.49	94	187
median	0.19	0.38	97	194
Current ANZECC ISQG (ANZECC, 2000)				
Low (trigger)	1.6	1.6	4,000	4,000
High	46	46	45,000	45,000
Recommended ANZECC ISQG (Simpson et al. 2013)				
Low (trigger)	1	1.2	10,000	10,000
High	5	5	50,000	50,000

^a Sum of the following 6 compounds: 2,4-DDE, 2,4-DDD, 2,4-DDT, 4,4-DDE, 4,4-DDD and 4,4-DDT, and includes estimated maximum possible concentrations (EMPCs) and half the detection limit value for those compounds not quantified.

^b Includes the 16 US EPA priority PAH compounds: naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b+k]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno(1,2,3-c,d)pyrene, dibenzo[a,h]anthracene and benzo[g,h,i]perylene and half the detection limit value for those compounds not quantified. ^c normalised by dividing concentration by 0.5% OC, which is the OC content threshold recommended by Batley et al. (2002).

na = not analysed.

Excluding site 3, the OC-normalised concentrations ranged from 0.29 to 0.44 µg/kg (un-normalised), indicating the homogenous nature of the surficial sediments. Site 3 contained around 3-times higher concentrations (1.1 µg/kg), but this was still less than both the current ANZECC ISQG and proposed guideline values (Table 3-3). Surficial sediments that are most likely to be displaced during the construction phase (i.e., sites 10 and 11), contained similar contaminant concentrations to adjacent sites. Accordingly, disturbance of these sediments, and subsequent deposition on adjacent areas, is unlikely to result in any measurable changes in the concentration of total DDT, which are approximately 4-times lower than the current ANZECC trigger value.

Total DDT concentrations within Wellington Harbour are significantly higher than Lyall Bay, with inner (closer to city) and outer harbour sites exhibiting average concentrations of approximately 7.8 and 2.5 µg/kg, respectively. Sediment from Lambton Harbour contained average total DDT concentrations of up to 17 µg/kg (n=3) (GWRC, 2014). Unlike Lyall Bay sediments that consisted of <2% mud-sized particles, Wellington Harbour sediments typically contained between 30 and 90% mud (i.e., <0.063 mm grain-size diameter), highlighting the energetic and low depositional environment of Lyall Bay.

Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous in aquatic receiving environments and are associated with the use and combustion of petroleum products, and the combustion of other fuels, such as coal and wood. PAHs, like metals and other contaminants, are often associated with finer particulate materials and therefore tend to be enriched in sediments that are dominated by mud-sized particles (i.e., <0.063 mm diameter), that is, low energy depositional environments.

Total PAH concentrations in Lyall Bay surficial sediments ranged from 45 to 155 µg/kg with a median concentration of 97 µg/kg. Organic carbon-normalised (i.e., 1% OC) PAH concentrations (using the lower threshold value of 0.5%; Batley 2002) ranged from 90 to 310 µg/kg, with a mean and median concentration of 187 and 194 µg/kg, respectively. The median OC-normalised total PAH concentration was approximately 20- and 50-times lower than the current (4,000 µg/kg) and recommended (10,000 µg/kg) ANZECC ISQG trigger ('low') values, respectively.

Concentrations of total PAHs across the seven sites varied approximately 4-fold, with the two highest concentrations corresponding to the area within the proposed extension (sites 10 and 11). The highest concentration of 155 µg/kg (sediment) at site 11 was 25-times lower than the current ANZECC ISQG trigger value, and 64-times lower than the recommended ANZECC guideline value of 10,000 µg/kg (Simpson et al. 2013). Using the OC-normalised concentration of 310 µg/kg for site 11, PAH concentrations were 13- and 32-times lower than the respective current and proposed ANZECC 'low' guideline values. Accordingly, with respect to contaminant risk, the potential for adverse effects arising from sediment mobilisation (disturbance) within the extension area, and subsequent transportation and deposition to other areas within Lyall Bay is unlikely. If modelling suggests increased accumulation of fine sediment in Lyall Bay (i.e., post construction), the analysis of PAHs (and other contaminants) in the fine sediment fraction (<0.063 mm) could be useful to confirm that this would be unlikely to result in environmentally significant increases in whole sediment concentrations.

As with heavy metals and organochlorine pesticides, and consistent with the higher ambient mud content, sediments within Wellington Harbour contain significantly higher concentrations of these contaminants. For example, total PAH concentrations (un-normalised) at inner harbour sites ranged from 800 to 2000 µg/kg, and from around 300 to 900 µg/kg at the outer harbour sites (GWRC, 2014).

3.2.4 Sediment contaminants in 0-10 cm and 10-20 cm depths

Within the area anticipated to have greatest potential for sediment disturbance (i.e., the area within the proposed runway extension, corresponding to sites 10 and 11), the intention was to characterise the contaminants (both sediment phase and solubilisation via elutriation testing – see section 3.3) in subsurface sediments down to a depth of approximately 1 m or more if possible. This was to determine the potential contaminant risk associated with the mobilisation of sediment from within the anticipated disturbance area, and settling of this sediment outside the disturbance area.

Because of the nature of the sediments, and the inability of the coring equipment to penetrate these well sorted sandy sediments, the maximum sediment depth was limited to 0.2 m, and therefore the subsurface analysis was limited to two depth fractions – 0 to 10 cm and 10 to 20 cm. Accordingly, the assessment of risk for redistribution of deeper sediment layers from within the disturbance area is limited to a relatively shallow depth of 0.2 m. If sediment is likely to be disturbed (i.e., mobilised) from depths significantly greater than this and discharged, then it is recommended that additional longer cores be collected and the relevant subsurface sediment layers analysed for contaminants. From the outset (i.e., proposal stage), the intention had been to evaluate sediment contaminant concentrations down to a depth of at least 1 m. To minimise analytical costs, subsurface contaminant analyses were limited to heavy metals; with the proviso that if these showed elevated concentrations (relative to surface sediments) it would be beneficial to analyse these sediments for organic contaminants.

Heavy metal contaminant concentrations were homogeneously distributed to at least a depth of 20 cm, with similar concentrations in 0-10 cm and 10-20 cm depth fractions (Table 3-4). These data indicate that from a contaminant risk perspective, the deposition of sediment from within the sediment disturbance zone (down to a depth of 20 cm) is unlikely to have adverse effects on the benthos outside the disturbance area.

Table 3-4: Heavy metal concentrations in 0-10 and 10-20 cm depth fractions at sites 10 and 11 (within the proposed runway extension area). All concentrations in mg/kg dry weight. See Figure 2-1 for sampling site locations.

	Site 10		Site 11	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Arsenic	5.3	5.5	5.3	5.3
Cadmium	0.018	0.033	0.019	0.016
Chromium	8.5	7.8	9.8	9.5
Copper	2.9	2.9	3.3	3.3
Lead	7.5	7.9	7.9	8.1
Mercury	0.046	0.056	0.051	0.046

	Site 10		Site 11	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Nickel	7.6	7.5	8.2	8.1
Zinc	30	27	31	31

Although coring limitations prevented us from determining typical contaminant concentrations at greater depth, based on the receiving environment characteristics and catchment history (i.e., current versus historic discharges via stormwater), it is unlikely that deeper sediments would contain significantly higher contaminant concentrations. This is consistent with the Stage 1 ICMP Development document (WCC 2014) which concluded for Lyall Bay that the potential for legacy contamination, present day stormwater contamination, and future stormwater contamination are all classified as low.

3.2.5 Weak-acid extractable metals from mud (<0.063 mm) fraction of surficial sediments

Generally, totally extractable metals concentrations are used to compare with sediment guideline values because this was the same method used to characterise sediments used in toxicity data sets to derive the guideline values, including the ANZECC ISQGs. Methods to determine total extractable metals use very aggressive and concentrated acids, and as such tend to over-estimate the bioavailable (and hence potentially toxic) concentration of heavy metals. Auckland Regional Council (ARC, 2004) developed a weak-acid extractable method that is considered more representative of the bioavailable fraction and was applicable to metals in muddy depositional (“settling zone”) environments. The ARC management framework included Environmental Response Criteria (ERC) for copper, lead and zinc to provide an indication of the potential effects of heavy metals on benthic ecology. While this approach provides an assessment and management approach for Auckland’s depositional sediments, it is not considered suitable for effects assessment relative to the low mud content (2%) present in Lyall Bay sediments.

The standard approach for assessing the potential risk from sediment contaminant concentrations is a tiered risk assessment (i.e., ANZECC 2000). This involves analysing the total extractable metals in whole sediments (operationally defined as <2 mm fraction), and if these exceed ANZECC trigger values, then a weak acid extraction could be used to estimate the ‘bioavailable fraction’. Note that this extraction is carried out on the whole sediment (<2 mm), and not the mud fraction that is specified by ARC protocols. The estimated ‘bioavailable’ concentrations of heavy metals would then be compared to the ANZECC ISQG trigger values, as opposed to ERC values (ARC 2004).

Weak acid extractable heavy metal concentrations on fine fractions from Lyall Bay sediments were included in this study (Table 3-5) because the ARC protocol has been used for other sediment monitoring in the greater Wellington region.

Table 3-5: Weak-acid extractable concentrations of copper, lead and zinc from mud-size fraction (<0.063 mm) from Lyall Bay surficial sediments. All metal concentrations in mg/kg dry weight. TOC = total organic carbon in percent of dry weight.

Site	TOC (% DW)	Copper	Lead	Zinc
1	na	8	22	59
3	1.3	8	20	45
5	0.6	6	11	33
8	1.1	9	17	45
10	1.0	6	16	43
11	0.8	7	18	44
12	na	8	24	58

na = not analysed.

3.3 Elutriate testing of sediments from site 10 and 11 (anticipated areas of sediment disturbance)

Elutriate testing is typically carried out on dredge spoil to evaluate the water column risks of anoxic dredged sediments becoming exposed to oxic water. The change in oxic status of sediments can have a significant effect on the mobilisation/solubilisation of different heavy metals that are associated with reduced phases (e.g., sulfide). Because of this effect, elutriate extracts from Lyall Bay were analysed for heavy metals and not organic contaminants. The mobility of hydrophobic organic contaminants is determined by partitioning to various organic carbon phases, and these interactions are largely independent of the oxic status of the sediments. Ammonia and sulfide concentrations were also analysed in elutriate fluids because porewater concentrations of these toxic compounds generally increase with increasing sediment depth.

Elutriate extracts were prepared by mixing sediment with water in a 1:4 ratio. Concentrations of analytes in the elutriate fluids from two sites in Lyall Bay are presented in Table 3-6. Without taking into account substantial water column dilution (see below), elutriate concentrations of all heavy metals (and arsenic) were below the method detection limit. For copper, the method detection limit of 0.001 g/m³ was above the ANZECC 99% protection trigger value of 0.0003 g/m³, but below the default 95% protection value of 0.0013 g/m³.

Table 3-6: Concentrations of heavy metals, ammonia and sulfide from elutriate extracts of different sediment depth fractions from sites 10 and 11 in Lyall Bay. Concentrations in g/m³; all analyte concentrations, as measured in Alderman Island seawater, and used for the elutriate tests, were below method detection limits.

analyte	site 10		site 11		elutriate seawater blank	ANZECC (2000) marine ^a	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	Alderman Is.	99%	95%
arsenic	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	-	-
cadmium	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0.0007	0.0055
chromium	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	0.0077	0.0274
copper	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	0.0003	0.0013
lead	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	0.0022	0.0044

	site 10		site 11		elutriate seawater blank	ANZECC (2000) marine ^a	
analyte	0-10 cm	10-20 cm	0-10 cm	10-20 cm	Alderman Is.	99%	95%
mercury	< 0.00008	< 0.00008	< 0.00008	< 0.00008	< 0.00008	0.0001	0.0004
nickel	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	0.007	0.07
zinc	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.007	0.015
NH ₄ -N	< 0.010	< 0.010	0.08	0.137	< 0.010	0.5	0.91
total sulfide ^b	< 0.010	< 0.010	0.011	0.013	< 0.010	-	0.002 ^c

^a 99% and 95% refer to the level of protection (i.e., % of aquatic species that are not affected by the trigger value). The default ANZECC trigger value is for a 95% level of protection. ^b Hydrogen sulfide is the toxic component and the percentage of total sulfide that is present as hydrogen sulfide is dependent of temperature, conductivity, but mainly pH; for example, at a pH of 8 (seawater) the amount of hydrogen sulfide is <10% of the total sulfide. ^c The current ANZECC (2000) water quality guidelines do not include trigger values for hydrogen sulfide in marine water, but earlier revisions (ANZECC, 1992) suggested a value of 0.002 g/m³. The ANZECC (2000) 99% and 95% trigger values for unionised hydrogen sulfide in freshwater systems are 0.0005 and 0.001 g/m³, respectively.

Based on the concentrations of ammonia and sulfide, site 11 showed signs of being more anoxic (or at least suboxic) than site 10 (where sulfide and ammonia were below detection limits), although this did not result in any measurable differences in heavy metal mobility between the two inshore sites. Elutriate concentrations of ammoniacal-nitrogen at site 11 were below the ANZECC trigger values (without applying additional water column dilution). Elutriate concentrations of total sulfide from site 11 sediments were up to 0.013 g/m³. Based on the pH of seawater, this corresponded to an estimated free hydrogen sulfide concentrations of 0.0009 g/m³ (i.e., 7% of total sulfide; Twining and Nowak, 1996), which is less than the default (95% protection) ANZECC trigger value prior to applying any receiving environment dilution factor.

The elutriate test was developed to determine the suitability of dredge material for sea disposal by assessing the potential for transient impacts on water column quality. The test uses a high sediment-to-water extraction ratio of 1:4, resulting in concentrated elutriates that greatly over-estimate receiving water concentrations. Accordingly, elutriate concentrations should not be compared directly with ANZECC water quality trigger values without first allowing for adequate receiving environment dilution. For dredge disposal guidelines (MSANZ, 1999; Commonwealth of Australia, 2009), this is defined as the amount of dilution that occurs within a four hour period of releasing dredged material into the water column. Methods to calculate potential water column dilutions are provided in the guideline documents (beyond the scope of this assessment); however, dilutions after 4 hours are likely to be, at least, hundreds of times greater than that of the analysed elutriate fluid (MSANZ, 1999).

From a contaminant perspective, the risk of adverse effects on the water column from transient sediment suspension/disturbance events in Lyall Bay is very low given that water column concentrations, after allowing for reasonable mixing rates, are generally at least two-orders of magnitude lower than default ANZECC water quality trigger values (Table 3-6).

3.4 Summary

As expected from the high-energy nature of the area and previous studies, Lyall Bay is not a depositional environment, and is characterised by uniformly moderately to well sorted, fine sandy sediments with very low mud content (~2-5%; mean 2.5%) and clay content (0%). Anthropogenic

contaminants are generally enriched in fine particulates (i.e., suspended sediments in stormwater) are generally less than 0.1 mm in size, and therefore areas with low potential to accumulate fine particulates similarly have low potential to accumulate anthropogenic contaminants. In this respect, Lyall Bay sediments are markedly less contaminated than muddy sediments from the depositional environment of Wellington Harbour.

Focussing on the different contaminant classes examined in the surficial sediments of Lyall Bay:

- Total extractable heavy metals (and arsenic) concentrations were consistent with background soil/rock for the Wellington region, with no measurable anthropogenic 'foot print' observed in the Lyall Bay surficial sediments.
- Total extractable heavy metal concentrations of arsenic, cadmium, chromium, copper, nickel, lead, zinc and mercury in Lyall Bay sediments (<2 mm fraction) were all well below ANZECC interim sediment quality guideline (ISQG) trigger ('low') values. With respect to the major urban-derived heavy metals:
 - copper: average concentration (± 1 s.d.) 3.0 ± 0.3 mg/kg was 21-times lower than the ANZECC trigger value of 65 mg/kg
 - lead: average concentration (± 1 s.d.) 7.6 ± 0.3 mg/kg was at least 6-times lower than the ANZECC trigger value of 50 mg/kg
 - zinc: average concentration (± 1 s.d.) 31 ± 2 mg/kg was at least 6-times lower than the ANZECC trigger value of 200 mg/kg.
- Weak acid extractable heavy metal concentrations (copper, lead and zinc) in the mud-size sediment fraction (as an estimate of bioavailable concentrations) were not relevant for assessing bioavailability of heavy metals because of the non-depositional nature of Lyall Bay (<2% mud). If the proposed construction activities did result in mud accumulation, albeit highly unlikely, concentrations present indicate there would be no likely toxic effects on marine biota.
- Heavy metal concentrations at sites 10 and 11 within the proposed runway extension area appear to be homogeneously distributed to at least a depth of 0.2 m. Over this depth range, it is assumed that organic concentrations, similarly do not change (i.e., increase) markedly.
- Because of the very low OC content in Lyall Bay sediments (0.2-0.3%), a cautious approach was taken for normalising contaminant concentrations to 1% OC – instead of dividing by the measured OC content, the lower threshold OC value suggest by Batley et al. (2002) of 0.5% was used for OC-normalisation at all sites.
- DDT and associated analogues were the main organochlorine pesticides present in the surficial sediments of Lyall Bay. The average concentration (± 1 s.d) of 0.24 ± 0.15 $\mu\text{g/kg}$ was 6-times lower than the current ANZECC ISQG 'low' trigger value of 1.6 $\mu\text{g/kg}$ (note that the proposed revised ANZECC guideline trigger value for total DDT is 1.2 $\mu\text{g/kg}$ (Simpson et al. 2013)). Organic-normalised (1%-OC) total DDT concentrations ranged between 0.30 and 1.01 $\mu\text{g/kg}$, with an average concentration of 0.49 ± 0.30 $\mu\text{g/kg}$, which is around 3-times lower than the current ANZECC ISQG value. The highest single OC-normalised concentrations of 1.09 $\mu\text{g/kg}$ (site 11) was below both the current interim and proposed guideline values.

- PAH concentrations (mass normalised) ranged from 45 to 155 µg/kg in Lyall Bay sediments, with an average concentration (± 1 s.d) of 94 ± 38 µg/kg, which is around 40-times lower than the ANZECC ISQG 'low' trigger value of 4,000 µg/kg (note that the recommended revised 'low' guideline value for total PAH is 10,000 µg/kg). Organic-normalised (1%-OC) PAH concentrations ranged between 90 and 330 µg/kg, with an average concentration (± 1 standard deviation) of 187 ± 77 µg/kg, which is around 20-times lower than current ANZECC ISQG value.

Contaminant concentrations in Lyall Bay surficial sediments are very low and uniformly distributed across the study area, including at sites most likely to be disturbed by construction activities, namely, sites 10 and 11. Mobilisation of sediment (from 0-20 cm depth) from within the area of the proposed runway extension is not expected to result in any significant (i.e., measurable) increase in sediment contaminant concentrations in surrounding areas. Because sediment mobilisation would involve mainly fine material, however, if hydrodynamic modelling data indicates that some areas of Lyall Bay will have greater depositional tendencies (especially post-construction) (e.g., Pritchard et al. 2015), then it would be useful to characterise a greater range of contaminants in this fine grain-size fraction.

From a contaminant perspective, the risk of adverse effects on the water column from transient sediment suspension/disturbance events during construction is very low given that water column concentrations, even after allowing for reasonable mixing, are estimated to be at least two-orders of magnitude lower than default ANZECC water quality trigger values.

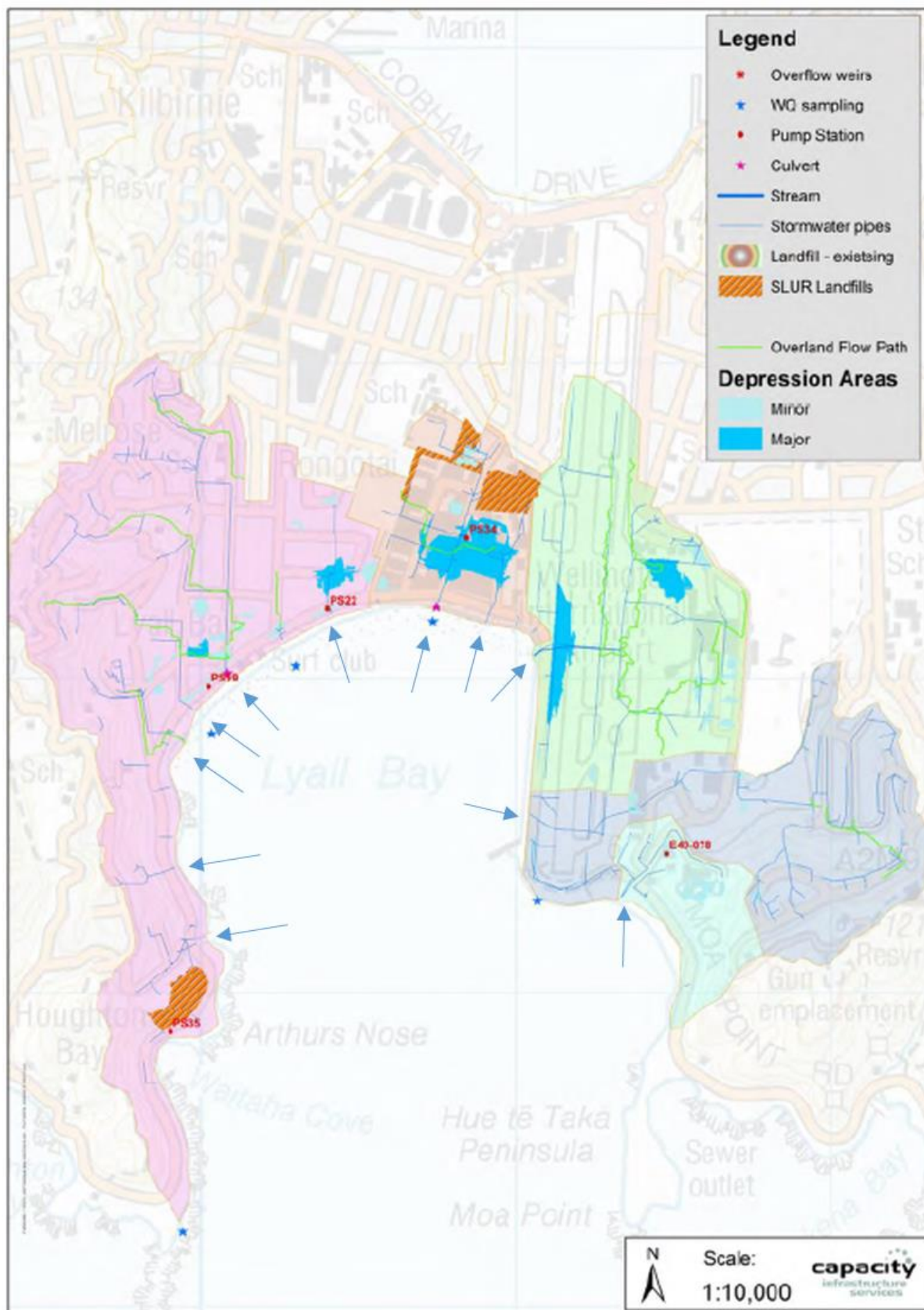
4 References

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Appendix A Approximate locations of outfalls in Lyall Bay stormwater catchments (from WCC2014, Figure 37)



Appendix B Dredge spoil assessment

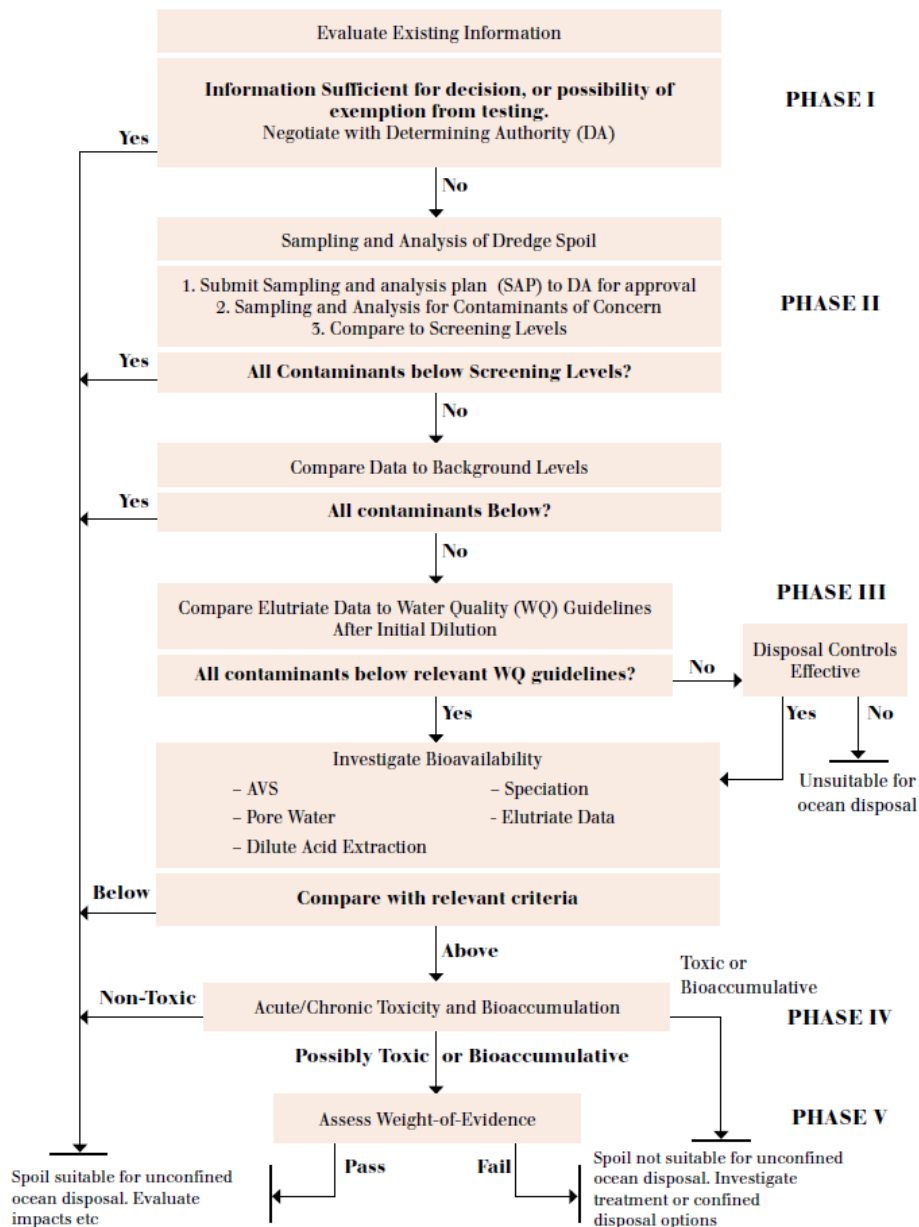


Figure B-1: Assessment of potential contaminants in dredge spoil (Figure 3, from the National Assessment Guidelines for Dredging; Commonwealth of Australia 2009).

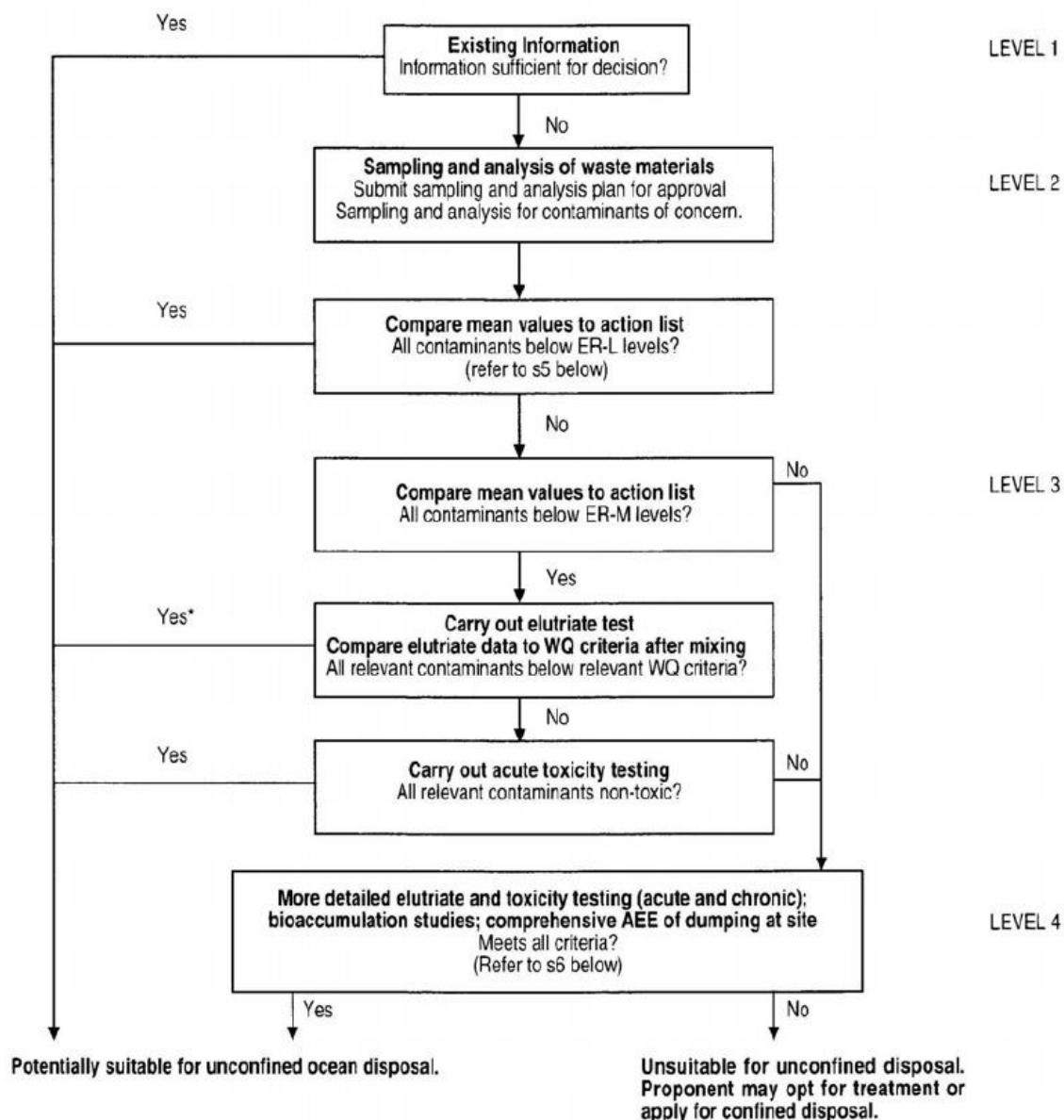


Figure B-2: Waste characterisation process for dredge spoil (Figure 4, New Zealand Guidelines for Sea Disposal of Waste; MSANZ 1999).

Table B-1: Screening levels (based on ANZECC ISQG 'low' values) for various contaminants to assess suitability for sea disposal. Table 2 from the National Assessment Guidelines for Dredging, Commonwealth of Australia, 2009).

Analytical Parameter	Screening Level (ISQG Trigger Value)
METALS & METALLOIDS[†]	(mg/kg=ppm)
Antimony	2
Arsenic	20 ^{**}
Cadmium	1.5
Chromium	80
Copper	65
Lead	50
Mercury	0.15
Nickel	21 ^{**}
Silver	1.0
Zinc	200
ORGANICS^{***}	(µg/kg=ppb)
Total PCBs	23
Pesticides	
DDD	2
DDE	2.2
Total DDT	1.6
Dieldrin	280
Chlordane	0.5 [@]
Lindane	0.52 [@]
Endrin	10
Total polycyclic aromatic hydrocarbons (PAHs)	10 000
Total petroleum hydrocarbons	550 mg/kg
Tributyltin (as Sn)	9 µg Sn/kg ^{@@}
RADIONUCLIDES^{**} (sum of gross alpha and gross beta)	35 Bq/g

Appendix C Analytical contaminant suites and methods

Table C-1: Organochlorine analytical suite - provided byASURE Quality Ltd.

	Soil
AQ Analysis Code	OCs-MAN
Sample Size	50 g
Turnaround Time (calendar days)	14 days for the first batch of 10 samples and an additional 7 days per batch of 10 samples thereafter
Accreditation Status	IANZ Accredited
Method	Based on USEPA 1699
Units	ng/g
Reporting Limits ¹	LOR
<i>alpha</i> -HCH	0.01-0.1
<i>beta</i> -HCH	0.01-0.1
<i>gamma</i> -HCH	0.01-0.1
hexachlorobenzene	0.01-0.1
aldrin	0.01-0.1
dieldrin	0.01-0.1
heptachlor	0.01-0.1
heptachlor epoxide	0.01-0.1
<i>alpha</i> -chlordanes	0.01-0.1
<i>gamma</i> -chlordanes	0.01-0.1
<i>p,p'</i> -DDE	0.01-0.1
<i>p,p'</i> -TDE (<i>p,p'</i> -DDD)	0.01-0.1
<i>o,p'</i> -DDT	0.01-0.1
<i>p,p'</i> -DDT	0.01-0.1
<i>o,p'</i> -DDE*	0.01-0.1
<i>o,p'</i> -TDE (<i>o,p'</i> -DDD)*	0.01-0.1
mirex*	0.01-0.1
<i>delta</i> -HCH*	0.01-0.1
methoxychlor*	0.01-0.1
endosulfan I *	0.01-0.1
endosulfan II *	0.01-0.1
endosulfan sulphate*	0.01-0.1
endrin*	0.01-0.1
endrin aldehyde*	0.1-1
endrin ketone*	0.1-1
pentachlorobenzene*	0.01-0.1

Table C-2: Summary of methods and associated detection limits for analytes in sediments (particulate-phase). Supplied by Hill Laboratories.

Sample Type: Sediment		
Test	Method Description	Default Detection Limit
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt
Polycyclic Aromatic Hydrocarbons Trace in Soil	Sonication extraction, SPE cleanup, GC-MS SIM analysis US EPA 8270C. Tested on dried sample	0.002 - 0.010 mg/kg dry wt
ARC 2M HCl Extraction*	<63µm Sieved Fraction, extracted with 2M HCl. Solid:Liquid 1:50 w/v. ARC Tech Publication No. 47, 1994.	-
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-
Extractable Copper*	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech Publication No. 47, 1994.	1.0 mg/kg dry wt
Extractable Lead*	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech Publication No. 47, 1994.	0.2 mg/kg dry wt
Extractable Zinc*	2M HCl extraction (<63µm fraction), ICP-MS. ARC Tech Publication No. 47, 1994.	2 mg/kg dry wt
Total Organic Carbon*	Acid pretreatment to remove carbonates if present, neutralisation, Elemental Combustion Analyser.	0.05 g/100g dry wt

Table C-3: Summary of methods and associated detection limits for analytes in elutriate fluids (dissolved phase). Supplied by Hill Laboratories

Sample Type: Saline		
Test	Method Description	Default Detection Limit
Filtration, Unpreserved*	Sample filtration through 0.45µm membrane filter.	-
Filtration for dissolved metals analysis*	Sample filtration through 0.45µm membrane filter and preservation with nitric acid. APHA 3030 B 22 nd ed. 2012.	-
Dissolved Arsenic*	Filtered sample, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 22 nd ed. 2012.	0.004 g/m ³
Dissolved Cadmium*	Filtered sample, ICP-MS, ultratrace level. APHA 3125 B 22 nd ed. 2012.	0.0002 g/m ³
Dissolved Chromium*	Filtered sample, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 22 nd ed. 2012.	0.0010 g/m ³
Dissolved Copper*	Filtered sample, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 22 nd ed. 2012.	0.0010 g/m ³
Dissolved Lead*	Filtered sample, ICP-MS, ultratrace level. APHA 3125 B 22 nd ed. 2012.	0.0010 g/m ³
Dissolved Mercury*	0.45µm filtration, bromine oxidation followed by atomic fluorescence. US EPA Method 245.7, Feb 2005.	0.00008 g/m ³
Dissolved Nickel*	Filtered sample, ICP-MS, ultratrace level. APHA 3125 B 22 nd ed. 2012.	0.006 g/m ³
Dissolved Zinc*	Filtered sample, ICP-MS with dynamic reaction cell, ultratrace. APHA 3125 B 22 nd ed. 2012.	0.004 g/m ³
Total Ammoniacal-N*	Saline, filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH ₄ -N = NH ₄ ⁺ -N + NH ₃ -N). APHA 4500-NH ₃ F (modified from manual analysis) 22 nd ed. 2012.	0.010 g/m ³
Nitrite-N	Saline sample. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO ₃ ⁻ I 22 nd ed. 2012.	0.002 g/m ³
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO ₂ N. In-House.	0.0010 g/m ³
Nitrate-N + Nitrite-N	Saline sample. Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO ₃ ⁻ I 22 nd ed. 2012.	0.002 g/m ³
Dissolved Reactive Phosphorus*	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22 nd ed. 2012.	0.004 g/m ³
Sulphide Distillation*	Acid distillation of sample into alkaline trapping solution using Simple Distillation system. APHA 4500-S ₂ ⁻ I 22 nd ed. 2012.	-
Total Sulphide*	Sulphide distillation. Automated methylene blue colorimetry, discrete analyser. APHA 4500-S ₂ ⁻ I (modified) 22 nd ed. 2012.	0.002 g/m ³

Appendix D GWRC Wellington Harbour sampling locations (2006, 2008 and 2011).



Figure 2.1: Map of Wellington Harbour showing the subtidal locations sampled in 2006 and 2011. Sample collection and analyses at sites EB1, WH1–5, LB1–2, AQ1–2 and WH10 were funded by Wellington City Council

Appendix E Analytical results

Table E-1: Concentrations of individual PAHs in Lyall Bay surficial sediments (0-5 cm). Concentrations in mg/kg dry weight.

PAH	Sediment sampling site						
	1	3	5	8	10	11	12
Naphthalene	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Acenaphthylene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Acenaphthene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Fluorene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Phenanthrene	0.004	0.006	< 0.002	0.004	0.004	0.006	< 0.002
Anthracene	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.002	< 0.002
Fluoranthene	0.013	0.012	0.004	0.011	0.014	0.018	0.004
Pyrene	0.014	0.014	0.005	0.012	0.015	0.022	0.005
Benzo[a]anthracene	0.01	0.009	0.003	0.007	0.011	0.013	0.004
Chrysene	0.01	0.009	0.004	0.008	0.01	0.013	0.004
Benzo[b]fluoranthene + Benzo[j]fluoranthene	0.014	0.011	0.005	0.01	0.015	0.02	0.006
Benzo[k]fluoranthene	0.006	0.005	0.003	0.005	0.007	0.009	0.003
Benzo[a]pyrene (BAP)	0.009	0.007	0.003	0.006	0.01	0.014	0.004
Indeno(1,2,3-c,d)pyrene	0.009	0.007	0.003	0.007	0.009	0.014	0.004
Dibenzo[a,h]anthracene	< 0.002	< 0.002	< 0.002	< 0.002	0.002	0.003	< 0.002
Benzo[g,h,i]perylene	0.009	0.007	0.004	0.007	0.009	0.014	0.004
TOTAL (mg/kg dw)	0.102	0.091	0.039	0.081	0.109	0.149	0.043

Table E-2: Sediment organochlorine concentrations for site 1 (0-5 cm). Asure Quality data

Results: Organochlorine Pesticides

Laboratory Reference: 164707-2

Sample Identification: OA179/2

Date Received: 25 September 2014			Date Analysed: 1 October 2014			
Date Extracted: 25 September 2014						
Analyte	Conc. ¹ (ng/g)	DL ²	EMPC ³	¹³ C %REC ⁴	LCL-UCL ⁵	Qualifiers
Pentachlorobenzene ⁶	0.0367			45	5 - 120	
HCB	0.0603			50	5 - 120	
Alpha-BHC	ND	0.0249		35	5 - 120	
Beta-BHC	ND	0.0258		40	32 - 130	
Gamma-BHC	ND	0.0193		55	11 - 120	
Delta-BHC ⁶	ND	0.0202		75	36 - 137	
Heptachlor	ND	0.00833		50	5 - 120	
Aldrin	ND	0.0247		30	5 - 120	
Heptachlor exo-epoxide	ND	0.0203		15	27 - 137	⌘
Oxychlordane ⁶	ND	0.104		10	23 - 135	⌘
Gamma-chlordane	0.0167			60	21 - 132	
Endosulfan-A ⁶	ND	0.0306		70	15 - 148	
Alpha-chlordane	0.0139					
Trans-nonachlor ⁶	ND	0.0548		70	14 - 136	
op-DDE ⁶	ND	0.0177		95	5 - 120	
pp-DDE	0.0430			100	47 - 160	
Dieldrin			0.0535	80	40 - 151	
Endrin ⁶	ND	0.0347		70	35 - 155	
Endosulfan-B ⁶	ND	0.0512		45	5 - 122	
Cis-nonachlor ⁶	ND	0.0367		70	36 - 139	
Endrin-aldehyde ⁶	ND	0.0369				
Kepone ⁶	NQ			NRE		
Endosulfan sulfate ⁶	ND	0.00387				
op-DDD ⁶			0.0187	110	5 - 120	
pp-DDD			0.0588	105	5 - 120	
op-DDT	ND	0.0335		50	5 - 199	
pp-DDT	ND	0.0378		40	5 - 120	
Endrin-ketone ⁶	ND	0.0442				
Methoxychlor ⁶	ND	0.0435				
Mirex ⁶	ND	0.00506		30	5 - 120	

Footnotes:
¹ Results are reported on a dry weight basis
² Sample specific estimated detection limit
³ Estimated Maximum Possible Concentration
⁴ Labelled compound recovery
⁵ Lower control limit - upper control limit
⁶ Results for these analytes are not accredited

Abbreviations:
ND: Not detected
NQ: Not Quantified
NRE: Recovery not calculable
⌘: Recovery outside LCL-UCL

Lab Analyst: CBA

Data Analyst: MA

Authorised: P C Bridgen

Table E-3: Sediment organochlorine concentrations for site 3 (0-5 cm). Asure Quality data

Results: Organochlorine Pesticides

Laboratory Reference: 164707-3

Sample Identification: OA179/3

Date Received: 25 September 2014			Date Analysed: 1 October 2014			
Date Extracted: 25 September 2014						
Analyte	Conc. ¹ (ng/g)	DL ²	EMPC ³	¹³ C %REC ⁴	LCL-UCL ⁵	Qualifiers
Pentachlorobenzene ⁶	0.0446			25	5 - 120	
HCB	0.0560			45	5 - 120	
Alpha-BHC	ND	0.0285		20	5 - 120	
Beta-BHC	ND	0.0213		40	32 - 130	
Gamma-BHC	0.0299			60	11 - 120	
Delta-BHC ⁶	ND	0.0248		35	36 - 137	⌘
Heptachlor			0.00639	65	5 - 120	
Aldrin	ND	0.0149		45	5 - 120	
Heptachlor exo-epoxide	0.00938			70	27 - 137	
Oxychlorane ⁶	ND	0.0196		60	23 - 135	
Gamma-chlordane	0.0216			55	21 - 132	
Endosulfan-A ⁶	ND	0.0439		80	15 - 148	
Alpha-chlordane	0.0152					
Trans-nonachlor ⁶	ND	0.0656		55	14 - 136	
op-DDE ⁶	ND	0.0158		100	5 - 120	
pp-DDE	0.0530			105	47 - 160	
Dieldrin	0.0625			85	40 - 151	
Endrin ⁶	NQ			NRE	35 - 155	
Endosulfan-B ⁶	ND	0.0491		55	5 - 122	
Cis-nonachlor ⁶	ND	0.0341		60	36 - 139	
Endrin-aldehyde ⁶	ND	0.0468				
Kepone ⁶	NQ			NRE		
Endosulfan sulfate ⁶	ND	0.00519				
op-DDD ⁶			0.0212	145	5 - 120	⌘
pp-DDD	0.113			140	5 - 120	⌘
op-DDT	ND	0.0348		40	5 - 199	
pp-DDT	0.331			25	5 - 120	
Endrin-ketone ⁶	ND	0.0492				
Methoxychlor ⁶	ND	0.0949				
Mirex ⁶	ND	0.00958		15	5 - 120	

Footnotes:

- ¹ Results are reported on a dry weight basis
- ² Sample specific estimated detection limit
- ³ Estimated Maximum Possible Concentration
- ⁴ Labelled compound recovery
- ⁵ Lower control limit - upper control limit
- ⁶ Results for these analytes are not accredited

Abbreviations:

- ND: Not detected
NQ: Not Quantified
NRE: Recovery not calculable
⌘: Recovery outside LCL-UCL

Lab Analyst: CBA

Data Analyst: MA

Authorised: P C Bridgen

Table E-4: Sediment organochlorine concentrations for site 5 (0-5 cm).Asure Quality data.

Results: Organochlorine Pesticides

Laboratory Reference: 164707-1

Sample Identification: OA179/1

Date Received: 25 September 2014			Date Analysed: 1 October 2014			
Date Extracted: 25 September 2014						
Analyte	Conc. ¹ (ng/g)	DL ²	EMPC ³	¹³ C %REC ⁴	LCL-UCL ⁵	Qualifiers
Pentachlorobenzene ⁶	0.0569			15	5 - 120	
HCB	0.0529			60	5 - 120	
Alpha-BHC	0.0199			55	5 - 120	
Beta-BHC	ND	0.0129		60	32 - 130	
Gamma-BHC	0.0288			65	11 - 120	
Delta-BHC ⁶	ND	0.0114		95	36 - 137	
Heptachlor	0.0119			70	5 - 120	
Aldrin	ND	0.0217		50	5 - 120	
Heptachlor exo-epoxide	ND	0.00550		50	27 - 137	
Oxychlordane ⁶	ND	0.0323		40	23 - 135	
Gamma-chlordane	0.0158			70	21 - 132	
Endosulfan-A ⁶	ND	0.0332		75	15 - 148	
Alpha-chlordane	0.00962					
Trans-nonachlor ⁶	ND	0.0457		80	14 - 136	
op-DDE ⁶	ND	0.0160		95	5 - 120	
pp-DDE	0.0595			100	47 - 160	
Dieldrin			0.0375	90	40 - 151	
Endrin ⁶	ND	0.0349		60	35 - 155	
Endosulfan-B ⁶	ND	0.0492		55	5 - 122	
Cis-nonachlor ⁶	ND	0.0297		75	36 - 139	
Endrin-aldehyde ⁶	ND	0.0358				
Kepon ⁶	NQ			NRE		
Endosulfan sulfate ⁶	ND	0.00461				
op-DDD ⁶			0.0261	115	5 - 120	
pp-DDD			0.0654	110	5 - 120	
op-DDT	ND	0.0218		70	5 - 199	
pp-DDT			0.0239	60	5 - 120	
Endrin-ketone ⁶	ND	0.0410				
Methoxychlor ⁶	ND	0.0344				
Mirex ⁶	ND	0.00275		50	5 - 120	

Footnotes:
¹ Results are reported on a dry weight basis
² Sample specific estimated detection limit
³ Estimated Maximum Possible Concentration
⁴ Labelled compound recovery
⁵ Lower control limit - upper control limit
⁶ Results for these analytes are not accredited

Abbreviations:
ND: Not detected
NQ: Not Quantified
NRE: Recovery not calculable
%: Recovery outside LCL-UCL

Lab Analyst: CBA
Data Analyst: MA
Authorised: P C Bridgen

Figure E-5: Sediment organochlorine concentrations for site 8 (0-5 cm).Asure Quality data.

Results: Organochlorine Pesticides

Laboratory Reference: 164707-6

Sample Identification: OA179/7

Date Received: 25 September 2014

Date Analysed: 1 October 2014

Date Extracted: 25 September 2014

Analyte	Conc. ¹ (ng/g)	DL ²	EMPC ³	¹³ C %REC ⁴	LCL-UCL ⁵	Qualifiers
Pentachlorobenzene ⁶	0.0317			20	5 - 120	
HCB	0.0436			60	5 - 120	
Alpha-BHC	ND	0.0205		35	5 - 120	
Beta-BHC	ND	0.0206		35	32 - 130	
Gamma-BHC	0.0240			55	11 - 120	
Delta-BHC ⁶	ND	0.0234		45	36 - 137	
Heptachlor	ND	0.00351		80	5 - 120	
Aldrin	ND	0.0189		30	5 - 120	
Heptachlor exo-epoxide	0.0201			70	27 - 137	
Oxychlordane ⁶	ND	0.0160		60	23 - 135	
Gamma-chlordane	0.0648			70	21 - 132	
Endosulfan-A ⁶	ND	0.0247		85	15 - 148	
Alpha-chlordane	0.0163					
Trans-nonachlor ⁶	ND	0.0344		80	14 - 136	
op-DDE ⁶	ND	0.0121		100	5 - 120	
pp-DDE	0.0616			110	47 - 160	
Dieldrin	0.0694			100	40 - 151	
Endrin ⁶	ND	0.0372		50	35 - 155	
Endosulfan-B ⁶	ND	0.0536		60	5 - 122	
Cis-nonachlor ⁶	ND	0.0206		90	36 - 139	
Endrin-aldehyde ⁶	ND	0.0378				
Kepone ⁶	NQ			NRE		
Endosulfan sulfate ⁶	ND	0.00390				
op-DDD ⁶			0.0249	120	5 - 120	
pp-DDD	0.0983			120	5 - 120	
op-DDT	NQ			NRE	5 - 199	
pp-DDT			0.0307	70	5 - 120	
Endrin-ketone ⁶	ND	0.0428				
Methoxychlor ⁶	ND	0.0445				
Mirex ⁶	ND	0.00136		65	5 - 120	

Footnotes:

- ¹ Results are reported on a dry weight basis
- ² Sample specific estimated detection limit
- ³ Estimated Maximum Possible Concentration
- ⁴ Labelled compound recovery
- ⁵ Lower control limit - upper control limit
- ⁶ Results for these analytes are not accredited

Abbreviations:

- ND: Not detected
NQ: Not Quantified
NRE: Recovery not calculable
R: Recovery outside LCL-UCL

Lab Analyst: CBA

Data Analyst: MA

Authorised: P C Bridgen

Figure E-6: Sediment organochlorine concentrations for site 10 (0-5 cm).Asure Quality data

Results: Organochlorine Pesticides

Laboratory Reference: 164707-5

Sample Identification: OA179/6

Date Received: 25 September 2014

Date Analysed: 1 October 2014

Date Extracted: 25 September 2014

Analyte	Conc. ¹ (ng/g)	DL ²	EMPC ³	¹³ C %REC ⁴	LCL-UCL ⁵	Qualifiers
Pentachlorobenzene ⁶	0.0313			40	5 - 120	
HCB	0.0402			50	5 - 120	
Alpha-BHC	ND	0.0344		25	5 - 120	
Beta-BHC	ND	0.0251		30	32 - 130	⌘
Gamma-BHC	ND	0.0174		50	11 - 120	
Delta-BHC ⁶	ND	0.0289		40	36 - 137	
Heptachlor	ND	0.00323		65	5 - 120	
Aldrin	ND	0.0160		30	5 - 120	
Heptachlor exo-epoxide	ND	0.00548		45	27 - 137	
Oxychlordane ⁶	ND	0.0265		35	23 - 135	
Gamma-chlordane	0.0140			60	21 - 132	
Endosulfan-A ⁶	ND	0.0179		70	15 - 148	
Alpha-chlordane	0.00724					
Trans-nonachlor ⁶	ND	0.0414		70	14 - 136	
op-DDE ⁶	ND	0.0101		95	5 - 120	
pp-DDE			0.0346	105	47 - 160	
Dieldrin	0.0771			80	40 - 151	
Endrin ⁶	ND	0.0445		45	35 - 155	
Endosulfan-B ⁶	ND	0.0518		50	5 - 122	
Cis-nonachlor ⁶	ND	0.0291		70	36 - 139	
Endrin-aldehyde ⁶	ND	0.0502				
Kepone ⁶	NQ			NRE		
Endosulfan sulfate ⁶	ND	0.00401				
op-DDD ⁶			0.0193	115	5 - 120	
pp-DDD			0.0571	110	5 - 120	
op-DDT	ND	0.0231		65	5 - 199	
pp-DDT	ND	0.0377		30	5 - 120	
Endrin-ketone ⁶	ND	0.0366				
Methoxychlor ⁶	ND	0.0532				
Mirex ⁶	ND	0.00362		25	5 - 120	

Footnotes:

- ¹ Results are reported on a dry weight basis
- ² Sample specific estimated detection limit
- ³ Estimated Maximum Possible Concentration
- ⁴ Labelled compound recovery
- ⁵ Lower control limit - upper control limit
- ⁶ Results for these analytes are not accredited

Abbreviations:

- ND: Not detected
NQ: Not Quantified
NRE: Recovery not calculable
⌘: Recovery outside LCL-UCL

Lab Analyst: CBA

Data Analyst: MA

Authorised: P C Bridgen

Figure E-7: Sediment organochlorine concentrations for site 11 (0-5 cm).Asure Quality data.

Results: Organochlorine Pesticides

Laboratory Reference: 164707-Blank

Sample Identification: Laboratory Blank

Date Received: Not Applicable			Date Analysed: 1 October 2014			
Date Extracted: 25 September 2014						
Analyte	Conc. ¹ (ng/g)	DL ²	EMPC ³	¹³ C %REC ⁴	LCL-UCL ⁵	Qualifiers
Pentachlorobenzene ⁶	0.0498			55	5 - 120	
HCB	0.0605			50	5 - 120	
Alpha-BHC	ND	0.0286		45	5 - 120	
Beta-BHC	ND	0.0236		70	32 - 130	
Gamma-BHC	0.0263			70	11 - 120	
Delta-BHC ⁶	ND	0.0220		85	36 - 137	
Heptachlor	ND	0.00748		60	5 - 120	
Aldrin	ND	0.0106		85	5 - 120	
Heptachlor exo-epoxide	ND	0.00659		60	27 - 137	
Oxychlordane ⁶	ND	0.0282		60	23 - 135	
Gamma-chlordane	ND	0.0143		60	21 - 132	
Endosulfan-A ⁶	ND	0.0308		70	15 - 148	
Alpha-chlordane	ND	0.0155				
Trans-nonachlor ⁶	ND	0.0345		75	14 - 136	
op-DDE ⁶	ND	0.0197		100	5 - 120	
pp-DDE	ND	0.0147		100	47 - 160	
Dieldrin	0.0589			95	40 - 151	
Endrin ⁶	ND	0.0273		60	35 - 155	
Endosulfan-B ⁶	ND	0.0581		45	5 - 122	
Cis-nonachlor ⁶	ND	0.0329		75	36 - 139	
Endrin-aldehyde ⁶	ND	0.0369				
Kepone ⁶	NQ			NRE		
Endosulfan sulfate ⁶	ND	0.00571				
op-DDD ⁶	ND	0.0209		100	5 - 120	
pp-DDD	ND	0.0119		95	5 - 120	
op-DDT	ND	0.0243		60	5 - 199	
pp-DDT	ND	0.0320		45	5 - 120	
Endrin-ketone ⁶	ND	0.0379				
Methoxychlor ⁶	ND	0.0311				
Mirex ⁶	ND	0.00541		30	5 - 120	

Footnotes:

- ¹ Results are reported on an average weight of samples in this batch
- ² Sample specific estimated detection limit
- ³ Estimated Maximum Possible Concentration
- ⁴ Labelled compound recovery
- ⁵ Lower control limit - upper control limit
- ⁶ Results for these analytes are not accredited

Abbreviations:

- ND: Not detected
NQ: Not Quantified
NRE: Recovery not calculable
[R]: Recovery outside LCL-UCL

Lab Analyst: CBA

Data Analyst: MA

Authorised: P C Bridgen

Figure E-8: Organochlorine concentrations in laboratory blank. Asure Quality data.

Results: Organochlorine Pesticides						
Laboratory Reference: 164707-Blank						
Sample Identification: Laboratory Blank						
Date Received: Not Applicable			Date Analysed: 1 October 2014			
Date Extracted: 25 September 2014						
Analyte	Conc. ¹ (ng/g)	DL ²	EMPC ³	¹³ C %REC ⁴	LCL-UCL ⁵	Qualifiers
Pentachlorobenzene ⁶	0.0498			55	5 - 120	
HCB	0.0605			50	5 - 120	
Alpha-BHC	ND	0.0286		45	5 - 120	
Beta-BHC	ND	0.0236		70	32 - 130	
Gamma-BHC	0.0263			70	11 - 120	
Delta-BHC ⁶	ND	0.0220		85	36 - 137	
Heptachlor	ND	0.00748		60	5 - 120	
Aldrin	ND	0.0106		85	5 - 120	
Heptachlor exo-epoxide	ND	0.00659		60	27 - 137	
Oxychlordane ⁶	ND	0.0282		60	23 - 135	
Gamma-chlordane	ND	0.0143		60	21 - 132	
Endosulfan-A ⁶	ND	0.0308		70	15 - 148	
Alpha-chlordane	ND	0.0155				
Trans-nonachlor ⁶	ND	0.0345		75	14 - 136	
op-DDE ⁶	ND	0.0197		100	5 - 120	
pp-DDE	ND	0.0147		100	47 - 160	
Dieldrin	0.0589			95	40 - 151	
Endrin ⁶	ND	0.0273		60	35 - 155	
Endosulfan-B ⁶	ND	0.0581		45	5 - 122	
Cis-nonachlor ⁶	ND	0.0329		75	36 - 139	
Endrin-aldehyde ⁶	ND	0.0369				
Kepone ⁶	NQ			NRE		
Endosulfan sulfate ⁶	ND	0.00571				
op-DDD ⁶	ND	0.0209		100	5 - 120	
pp-DDD	ND	0.0119		95	5 - 120	
op-DDT	ND	0.0243		60	5 - 199	
pp-DDT	ND	0.0320		45	5 - 120	
Endrin-ketone ⁶	ND	0.0379				
Methoxychlor ⁶	ND	0.0311				
Mirex ⁶	ND	0.00541		30	5 - 120	
Footnotes:						
¹ Results are reported on an average weight of samples in this batch			ND: Not detected			
² Sample specific estimated detection limit			NQ: Not Quantified			
³ Estimated Maximum Possible Concentration			NRE: Recovery not calculable			
⁴ Labelled compound recovery			⊖: Recovery outside LCL-UCL			
⁵ Lower control limit - upper control limit						
⁶ Results for these analytes are not accredited						
Lab Analyst: CBA			Data Analyst: MA		Authorised: P C Bridgen	

Table E-5: Organic carbon content (%OC) of Lyall Bay sediments.

Depth (cm)	Sediment site number						
	1	3	5	8	10	11	12
0-5	0.30	0.26	0.39	0.29	0.29	0.32	0.22
5-10					0.36	0.34	
10-20					0.34	0.26	

Appendix F Sediment grain-size summary

Site/Replicate #	SAMPLE TYPE	TEXTURAL GROUP	SEDIMENT Description	% GRAVEL	% SAND	%SILT	% CLAY
Site 1/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.8%	2.2%	0.0%
Site 1/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.9%	2.1%	0.0%
Site 1/ rep 3	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.8%	2.2%	0.0%
Site 2/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	98.0%	2.0%	0.0%
Site 2/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	98.2%	1.8%	0.0%
Site 2/ rep 3	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	98.0%	2.0%	0.0%
Site3/ rep1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	96.8%	3.2%	0.0%
Site3/ rep 2	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Fine Sand	0.0%	97.3%	2.7%	0.0%
Site3/ rep 3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Fine Sand	0.0%	96.4%	3.6%	0.0%
Site4/ rep1,	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand	0.0%	98.2%	1.8%	0.0%
Site4/ rep 2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand	0.0%	98.2%	1.8%	0.0%
Site4/ rep 3	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand	0.0%	98.0%	2.0%	0.0%
Site5/ rep 1	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand	0.0%	96.6%	3.4%	0.0%
Site5/ rep 2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand	0.0%	96.4%	3.6%	0.0%
Site5/ rep 3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Fine Sand	0.0%	96.5%	3.5%	0.0%
Site6/ rep 1	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Fine Sand	0.0%	97.5%	2.5%	0.0%
Site6/ rep 2	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Fine Sand	0.0%	97.7%	2.3%	0.0%
Site6/ rep 3	Unimodal, Moderately Well Sorted	Sand	Moderately Well Sorted Fine Sand	0.0%	97.6%	2.4%	0.0%
Site7/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	98.1%	1.9%	0.0%
Site7/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	98.1%	1.9%	0.0%
Site7/ rep 3	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	98.1%	1.9%	0.0%

Site/Replicate #	SAMPLE TYPE	TEXTURAL GROUP	SEDIMENT Description	% GRAVEL	% SAND	%SILT	% CLAY
Site8/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	96.9%	3.1%	0.0%
Site8/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	96.8%	3.2%	0.0%
Site8/ rep 3 with gravel	Unimodal, Well Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	1.1%	97.3%	1.6%	0.0%
Site9/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.6%	2.4%	0.0%
Site9/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.8%	2.2%	0.0%
Site9/ rep 3	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.8%	2.2%	0.0%
Site10/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.6%	2.4%	0.0%
Site10/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.8%	2.2%	0.0%
Site10/ rep 3	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.6%	2.4%	0.0%
Site11/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.6%	2.4%	0.0%
Site11/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.5%	2.5%	0.0%
Site11/ rep 3	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.5%	2.5%	0.0%
Site12/ rep 1 with gravel	Unimodal, Moderately Sorted	Slightly Gravelly Sand	Slightly Very Fine Gravelly Fine Sand	1.8%	96.2%	2.0%	0.0%
Site12/ rep 2	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand	0.0%	95.4%	4.6%	0.0%
Site12/ rep 3	Unimodal, Moderately Sorted	Sand	Moderately Sorted Fine Sand	0.0%	95.5%	4.5%	0.0%
Site13/ rep 1	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.6%	2.4%	0.0%
Site13/ rep 2	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.4%	2.6%	0.0%
Site13/ rep 3	Unimodal, Well Sorted	Sand	Well Sorted Fine Sand	0.0%	97.8%	2.2%	0.0%