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Waiwhetu Stream 2012

Broad and Fine Scale Baseline Monitoring in the Tidal Reaches

Prepared for Greater Wellington Regional Council

July 2012

Cover Photo: Intertidal sampling in the lower reach of Waiwhetu Stream, February 2012.

Sampling in the very narrow and steep intertidal zone at Site B-02, Waiwhetu Stream, February 2012.

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By

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All photos by Wriggle except where noted otherwise.

WAIWHETU STREAM - EXECUTIVE SUMMARY

This report summarises baseline monitoring of Waiwhetu Stream undertaken in January 2009, and repeat monitoring undertaken in February 2012 following the completion of extensive flood control work and the removal of 88,665 tonnes (43,481m^3) of sediment by Greater Wellington Regional Council (GWRC) and Hutt City Council (HCC) as a first stage of ongoing rehabilitation efforts.

Sampling methods were based on the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002), and recent extensions (Robertson and Stevens 2006, 2007, 2008, 2009), with results (summarised below) compared to broad and fine scale indicators of chemical and biological condition to help relate estuary condition to the key issues of eutrophication, sedimentation, toxicity, and habitat loss.

INDICATOR	Condition Rating		2009-2012 Change	RESULT
	2009	2012		
SALTMARSH	LOW	LOW	VERY GOOD (Improved)	Saltmarsh habitat scarce, with margins extensively reclaimed, steepened, straightened and reinforced to mitigate flood flows. Flood channelling has reduced area of intertidal flats and increased subtidal area. Restoration planting has doubled saltmarsh area, but bank erosion and plant loss is evident throughout the estuary.
VEGETATED TERRESTRIAL MARGIN	POOR	POOR	POOR (Degraded)	Most (80%) highly modified e.g. industrial, commercial, residential, or roading. Remaining 18% in grassland with only 2% densely vegetated. Many mature trees and dense plantings lost since 2009, but new plantings established along banks.
MACROALGAE	FAIR	FAIR	Degraded	Cover low but widespread. Indicates excess of nutrients in the estuary.
SEAGRASS	POOR	POOR	No change	No seagrass present in the estuary.
SOFT MUD	POOR	VERY GOOD	VERY GOOD (Improved)	Muds characterised by high anoxia (a lack of oxygen), and the presence of sulphides. Significant reduction of intertidal muds, but extensive subtidally.
RPD Depth	POOR	POOR-GOOD	Variable but generally improved	Significantly improved at some intertidal sites (substrate change from mud to gravel) but generally very shallow (~1mm deep) indicating poor sediment oxygenation.
Nutrients	ENRICHED	ENRICHED		TN and TP, indicators of nutrient enrichment, remain elevated.
Organic Content	ENRICHED	ENRICHED		TOC, the indicator of organic enrichment, remains elevated.
METALS	POOR to GOOD			Variable pattern of increases and decreases from 2009-2012. In 2012, Site B-02 was worse following remediation, particularly for lead and zinc. Mercury remained between ANZECC ISQG-Low and High at 3 of 4 sites following remediation. Sites upstream of remediation in 2012 show elevated nickel, lead and zinc.
PESTICIDES	POOR	POOR		4,4′-DDD and -DDE present at Site B-02 above ANZECC ISQG-High trigger values following remediation. Reduced pesticides (only aldrin) detected in shellfish in 2012.
PAHs	GOOD	FAIR		PAHs exceed ANZECC ISQG-Low trigger values at 2 of 4 sites following remediation. Site B-02 substantially worse than others. PAHs exceed ISQG-Low upstream of site.
PETROLEUM HYDROCARBONS	GOOD	POOR		Total petroleum hydrocarbons above ANZECC ISQG-High trigger value at Site B-02 following remediation. Other sites low with highest concentrations in subtidal mud.
Benthic Community	Community reflects species that tolerate moderate organic enrichment (i.e. omnivorous surface deposit feeding species) and which live predominantly in a relatively clean layer of oxygenated surface mud present above the underlying anoxic sediments. Overall a slight improvement in macroinvertebrate life from 2009 to 2012.			

The monitoring results show significant changes to the lower Waiwhetu Estuary following flood control work and sediment remediation. Extensive saltmarsh and terrestrial vegetation plantings have expanded this important habitat, although the total area remains low. In addition, much of the densely vegetated margin and many shade trees were lost from the upper estuary during remediation. Along the estuary margins, extensive areas of saltmarsh plantings and bank sediment are being eroded.

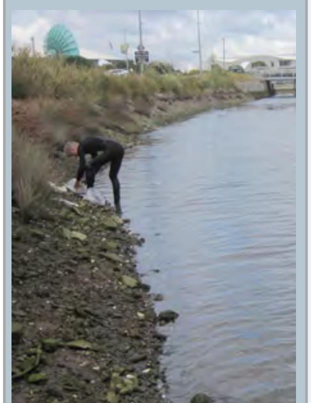
56,331 tonnes (27,314m^3) of contaminated sediments were removed and replaced by clean gravel, sand and cobble. Despite this very significant improvement, sediments retained high nutrient and organic concentrations and were eutrophic, although they supported a slightly improved benthic invertebrate community. Very high concentrations of some heavy metals, pesticides, and hydrocarbons at intertidal site B2 highlighted a seam of capped contaminated material in the stream bank that was subsequently re-exposed by erosion.

In the lower estuary, vertical flood channelling has replaced previously sloping intertidal concrete riprap. This has resulted in the loss of already greatly under-represented intertidal flats and now presents habitat unsuitable for virtually all estuarine species.

In conclusion, past stream modification has been significant with the loss of most saltmarsh and the vegetated terrestrial buffer. While remediation and flood control works have resulted in some improvements to this habitat, and a very significant removal of contaminated sediment, overall there has been limited improvement to the ecological quality of the estuary which continues to be rated poorly in terms of eutrophication, sedimentation, toxicity and habitat loss.

1. INTRODUCTION

OVERVIEW



A project to remove contaminated sediments from the lower Waiwhetu Stream, and to widen and deepen it for flood control purposes, was undertaken between November 2009 and May 2010 by Greater Wellington Regional Council (GWRC) and Hutt City Council (HCC). As part of this programme, Wriggle Coastal Management was contracted by GWRC to establish an ecological baseline in the transitional (seawater influenced) waters in the lower stream in February 2009 prior to work commencing (reported in Stevens and Robertson 2009), followed by another assessment after the works had been completed to assess change. This second survey was undertaken on 21 February 2012 following project completion.

As the lower streamway is estuarine in character, the sampling approach is based on the methods described in the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions (e.g. Robertson and Stevens 2006, 2007, 2008, 2009). It consists of two key components (see below) to provide a defensible, but cost effective, overview of the existing ecological health of Waiwhetu Stream, recognising that extensive sampling and analysis of sediment contaminants has been undertaken as part of the wider remediation programme. This report describes:

1. **Broad scale habitat mapping**. This component is used to characterise the dominant surface substrate and vegetation, including the adjoining terrestrial margin (~100m either side of the estuary) using a combination of aerial photos, ground truthing, and GIS based digital mapping. Results detail the location and area of saltmarsh, unvegetated substrates, and dominant terrestrial features.
2. **Fine scale physical, chemical and biological monitoring**. This component provides detailed information on sediment chemistry and biota at both intertidal and subtidal sites within the remediation zone. Results are compared to condition ratings for key indicators of stream/estuary condition (e.g. metals, organic matter), and to baseline conditions to assess changes. Shellfish were also sampled at the mouth of the Waiwhetu Stream to assess contaminant accumulation in shellfish flesh downstream of the remediation works.

For the fine scale monitoring, three sampling sites were established in 2009 downstream of Bell Road in the lower Waiwhetu Stream (Figure 1). This 1,500m long tidally influenced area is where remediation of the most contaminated sediments was undertaken. Sites A and B (Figures 2 and 3), each with an intertidal and subtidal site, were located in representative unvegetated soft mud areas to identify the sediment dwelling animals and contaminant concentrations present. Site C (Figure 1), downstream of the proposed works, was included to assess the accumulation of contaminants in shellfish. In 2012, all these sites were resampled, along with an additional site, D located just upstream of the remediation works, to gauge the extent of upstream contamination that could potentially mobilise into downstream sites.

This comparative design has been used because the large number of stormwater/surface water discharges entering the lower Waiwhetu Stream, coupled with the transition from fresh to estuarine waters, precluded the meaningful inclusion of upstream and downstream biological reference sites.

This report describes the methods used, and the ecological condition of the selected sites before and after the remediation work. The monitoring also provides information on four of the major issues affecting most NZ estuaries (Table 1): sedimentation, eutrophication, toxins and habitat loss. Disease risk has not been included as it is reported on separately by GWRC through its freshwater state of the environment monitoring programme. In evaluating these aspects we use the relevant indicators of each issue which are detailed in Table 2. Specific condition ratings for each are presented in the Methods (Section 2) of this report, and the results are presented and discussed in relation to each of the key issues in Section 3.

1. Introduction (Continued)

Table 1. Summary of the major issues affecting most New Zealand estuaries.

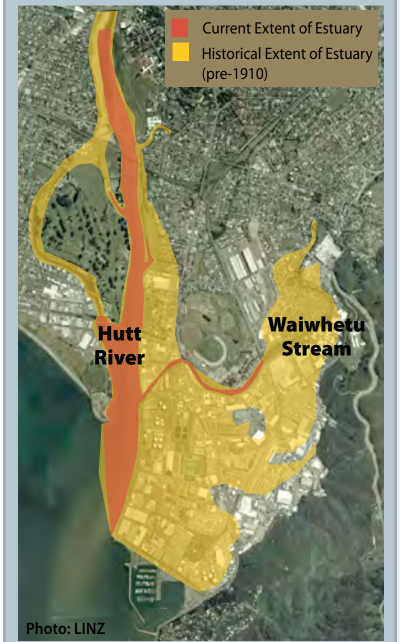
Major Estuary Issues	
Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there.
Disease Risk	Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time. Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds. Diseases linked to pathogens include gastroenteritis, salmonellosis, hepatitis A, and noroviruses.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to estuaries through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Loss	Estuaries have many different types of habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes cited as sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff and wastewater discharges.

Table 2. Summary of the broad and fine scale EMP indicators.

Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Eutrophication	Nuisance Macroalgal Cover	Broad scale mapping - estimates the change in the area of nuisance macroalgal growth (e.g. sea lettuce (*Ulva*), *Gracilaria*) over time.
Eutrophication	Organic and Nutrient Enrichment	Chemical analysis of total nitrogen, total phosphorus, and total organic carbon in replicate samples from the upper 2cm of sediment.
Eutrophication	Redox Profile	Measurement of depth of redox potential discontinuity profile (RPD) in sediment estimates likely presence of deoxygenated, reducing conditions.
Toxins	Contamination in Bottom Sediments	Chemical analysis of indicator metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) in replicate samples from the upper 2cm of sediment.
Toxins, Eutrophication, Sedimentation	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Habitat Loss	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
Habitat Loss	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.

1. Introduction (Continued)

BACKGROUND



Hutt Estuary - 1909 historical extent (from Bell 1910), and present day.

Waiwhetu Stream flows from the bush covered Eastern Hutt hills, through the suburban areas of Lower Hutt, before combining with the lower Hutt River Estuary. Historically it was situated within a much wider area of saltmarsh and low-lying wetland at the Hutt River mouth (see inset figure left), although, as is typical for most tidal river mouth estuaries, it would have had only relatively small areas of intertidal flats and saltmarsh.

Over the past 60 years the stream has received an extensive range of contaminant inputs from sewage overflows, stormwater and, in particular, industrial discharges. This has left a legacy of heavy metals and other chemical pollutants in the sediments of the streambed, particularly near Gracefield and Seaview (e.g. Sheppard 2001, Sheppard and Goff 2001, 2002, Tremblay et al. 2005). The stream corridor itself has also been extensively modified by flood protection works, reclamation, and removal of the natural vegetated margin. Particularly in the lower reaches, public access to the stream is restricted by fencing of industrial sites. Because of extensive hard surfacing and channelling, the area responds quickly in terms of flow, and is subject to flooding. The estuary itself is well-flushed with a very short residence time.

As a direct consequence of impacts from past reclamation of saltmarsh and intertidal flats, loss of vegetated margins, increased muddiness, litter, sediment contamination, and disease risk, the stream is in a poor condition. Despite this, it remains valued for activities such as walking, jogging, dog exercising, and whitebaiting/fishing (near the mouth) and the remediation work is intended to improve the existing ecological and amenity value of the estuary.

Site	NZTM East	NZTM North
A	1759579	5433387
B	1760128	5433230
C	1759326	5433135
D	1760485	5433549

Figure 1. Location of monitoring sites in Waiwhetu Stream (sampled January 2009 and February 2012).

Site	NZTM East	NZTM North
WwhA1 01	1759575	5433393
WwhA1 02	1759579	5433394
WwhA1 03	1759579	5433394
WwhA2 01	1759575	5433387
WwhA2 02	1759579	5433387
WwhA2 03	1759582	5433390

Figure 2. Location of Waiwhetu Stream monitoring site A (downstream of the Seaview Road bridge).

Site	NZTM East	NZTM North
WwhB1 01	1760126	5433227
WwhB1 02	1760128	5433229
WwhB1 03	1760130	5433230
WwhB2 01	1760128	5433224
WwhB2 02	1760130	5433226
WwhB2 03	1760132	5433228

Figure 3. Location of Waiwhetu Stream monitoring site B (downstream of the Bell Road bridge).

2. METHODS

BROAD SCALE HABITAT MAPPING

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland, etc). It follows the EMP approach originally described for use in NZ estuaries by Robertson et al. (2002) with a combination of aerial photography, detailed ground-truthing, and GIS-based digital mapping used to record the primary habitat features present. Very simply, the method involves three key steps:

- Obtaining laminated aerial photos for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing).
- Digitising the field data into GIS layers (e.g. ArcMap 9.3).

For the 2009 and 2012 studies, GWRC supplied rectified ~10cm/pixel resolution colour aerial photos. Photos covering the lower streamway/estuary at a scale of 1:2,500 were laminated, and two scientists ground-truthed the spatial extent of dominant habitat and substrate types by walking the area, and recording features directly on the laminated aerial photos.

Sampling positions and photographs were georeferenced and the information collected was used to produce GIS-based habitat maps showing the following:

- Dominant intertidal substrate.
- Dominant saltmarsh vegetation.
- 100m wide terrestrial margin vegetation/landuse.

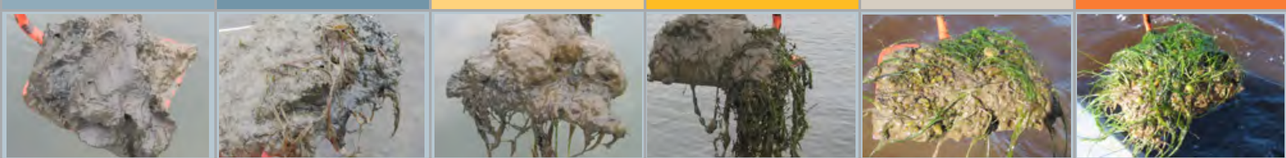
Appendix 1 lists the class definitions used to classify substrate and vegetation.

Digital mapping results were entered by digitising features directly off aerial photos in the GIS using a Wacom Intuos3 electronic drawing tablet within ArcMap 9.3. The spatial location, size, and type of broad scale habitat features in the estuary are provided as ArcMap 9.3 GIS shapefiles on a separate CD. Georeferenced digital field photos are also provided. The broad scale results are summarised in the current report in Section 3, with the supporting GIS files providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions.

When present, macroalgae and macrophyte percentage cover was classified using a seven category visual rating scale (see macrophyte example below) to describe macroalgae and macrophyte density and distribution.

Visual rating scale for percentage cover estimates of macrophytes

0-5%	5-10 %	10-20 %	20-50 %	50-80 %	80-100 %



2. Methods (Continued)

FINE SCALE MONITORING

Fine scale monitoring was based on the methods described in the EMP (Robertson et al. 2002) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type present. Two representative sampling sites selected in 2009 in unvegetated intertidal soft mud at low-mid water, and from two adjacent subtidal sites at the edge of the stream channel (Figures 1, 2 and 3) were resampled and analysed for:

- Oxygenation (Redox Potential Discontinuity - RPD depth).
- Organic Matter: (Total organic carbon - TOC).
- Nutrients: Total nitrogen (TN), Total phosphorus (TP).
- Heavy metals: Total recoverable Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn).
- Semi volatile organic compounds (SVOCs), including organochlorine pesticides (OCPs), and polycyclic aromatic hydrocarbons (PAHs).
- Macroinvertebrate abundance and diversity (infauna and epifauna).

The following sampling was undertaken:

Physical and chemical analyses: (Sites A, B and D)

- Within each sampling location, one core was collected to a depth of at least 100mm and photographed alongside a ruler and a corresponding label. Colour and texture were described and average redox potential discontinuity (RPD) depth recorded.
- A composite sample of the top 20mm of sediment (each approx. 250gms) was collected adjacent to the three sediment cores.
- All samples were kept in a chillybin in the field or stored as appropriate.
- Chilled samples were sent to R.J. Hill Laboratories for analysis (details in Appendix 2). To allow direct comparison with ANZECC guidelines, metal and nutrient analyses were based on whole sample fractions, while PAH results were normalised to 1% carbon.
- Samples were tracked using standard Chain of Custody (COC) forms and results checked and transferred electronically to avoid transcription errors.
- Photographs were taken to record the general site appearance.

Epifauna (surface-dwelling animals): (Sites A and B)

- Epifauna were assessed from three random 0.25m^2 quadrats at each intertidal site. All animals visible on the sediment surface were identified and counted, and any microalgal mat development noted. The species, abundance and related descriptive information were recorded on waterproof field sheets containing a checklist of expected species. Photographs of quadrats were taken and archived for future reference.

Infauna (animals within sediments): (Sites A and B)

- Three randomly placed sediment cores were taken from each site using a 130mm diameter (area = 0.0133m^2) PVC tube.
- The core tube was manually driven 150mm into the sediments, removed with the core intact and inverted into a labelled plastic bag.
- Once all replicates had been collected at a site, each core was washed through a 0.5mm nylon mesh bag, with the infauna retained and preserved in 90% isopropyl alcohol.
- Samples were then sent to a commercial laboratory (Gary Stephenson, Coastal Marine Ecology Consultants) for sieving, counting and identification.

Shellfish flesh: (Site C, beneath the Port Road bridge)

- Approximately 20 blue mussels (*Mytilus galloprovincialis*) were collected from the intertidal zone, wrapped in aluminium foil and sealed in a plastic bag. The sample was sent chilled to R.J. Hill Laboratories for shucking and analysis for metals, PAHs and OCPs (details in Appendix 2).

2. Methods (Continued)

CONDITION RATINGS

A series of interim broad and fine scale estuary "condition ratings" (presented below) have been proposed for estuaries in the Wellington region (based on the ratings developed for New Zealand estuaries - Robertson & Stevens 2006, 2007, 2008, 2009). The ratings are based on a review of estuary monitoring data, guideline criteria, and expert opinion. They are designed to be used in combination with each other (usually involving expert input) when evaluating overall estuary condition and deciding on appropriate management. The condition ratings include an "early warning trigger" to highlight rapid or unexpected change, and each rating has a recommended monitoring and management response. In most cases initial management is to further assess an issue and consider what response actions may be appropriate (e.g. develop an Evaluation and Response Plan - ERP). Only condition ratings appropriate for use in the lower reaches of the Waiwhetu Stream have been applied. In particular, the macrofauna biotic index, used in other estuaries in the Wellington region (e.g. Robertson and Stevens 2009), has not been used as the physical stressors in the lower Waiwhetu (e.g. high freshwater dilution and varying salinity) favour a community of tolerant species with generally low diversity. Consequently the index does not provide a suitable rating of ecological condition.

SALTMARSH (PERCENT COVER)

A variety of saltmarsh species (commonly dominated by rushland but including scrub, sedge, tussock, grass, reed, and herb fields) grow in the upper margins of most NZ estuaries where vegetation stabilises fine sediment transported by tidal flows. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth and have strong aesthetic appeal. Where saltmarsh cover is limited, these values are decreased.

SALTMARSH PERCENT COVER CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very High	>20% of estuary area is saltmarsh	Monitor at 5 year intervals after baseline established
High	10%-20% of estuary area is saltmarsh	Monitor at 5 year intervals after baseline established
Moderate	5%-10% of estuary area is saltmarsh	Monitor at 5 year intervals after baseline established
Low	2%-5% of estuary area is saltmarsh	Post baseline, monitor 5 yearly. Initiate ERP
Very Low	<2% of estuary area is saltmarsh	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	<5% of estuary area is saltmarsh	Initiate ERP (Evaluation and Response Plan)

SALTMARSH (AREA)

Saltmarshes are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Decreases in saltmarsh extent is likely to indicate an increase in these types of pressures.

SALTMARSH AREA CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Area of cover (ha) stable or increasing	Monitor at 5 year intervals after baseline established
Good	Decline in area of cover (ha) <5% from baseline	Monitor at 5 year intervals after baseline established
Fair	Decline in area of cover (ha) 5-20% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Poor	Decline in area of cover (ha) >20% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	Trend of decrease in area of cover (ha)	Initiate ERP (Evaluation and Response Plan)

2. Methods (Continued)

TERRESTRIAL VEGETATED MARGIN BUFFER (PERCENT COVER)

The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the saltmarsh and estuary. This buffer protects against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat.

TERRESTRIAL VEGETATED BUFFER PERCENT COVER CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very High	80%-100% cover of terrestrial vegetated buffer	Monitor at 5 year intervals after baseline established
High	50%-80% cover of terrestrial vegetated buffer	Monitor at 5 year intervals after baseline established
Fair	25%-50% cover of terrestrial vegetated buffer	Post baseline, monitor 5 yearly. Initiate ERP
Poor	5%-25% cover of terrestrial vegetated buffer	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	<50% cover of terrestrial vegetated buffer	Initiate ERP (Evaluation and Response Plan)

TERRESTRIAL VEGETATED MARGIN BUFFER (AREA)

Estuaries are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Reduction in the vegetated buffer around the estuary is likely to result in a decline in estuary quality.

TERRESTRIAL VEGETATED BUFFER AREA CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Terrestrial buffer is 100% dense vegetation	Monitor at 5 year intervals after baseline established
Good	Decline in vegetated buffer (ha) <5% from baseline	Monitor at 5 year intervals after baseline established
Fair	Decline in vegetated buffer (ha) 5-10% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Poor	Decline in vegetated buffer (ha) >10% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	Trend of decrease in area of vegetated buffer (ha)	Initiate ERP (Evaluation and Response Plan)

MACROALGAE INDEX

Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota. A continuous index (the macroalgae coefficient - MC) has been developed to rate macroalgal condition based on the percentage cover of macroalgae in defined categories using the following equation: ***MC=((0 x %macroalgal cover <1%)+(0.5 x %cover 1-5%)+(1 x %cover 5-10%)+(3 x %cover 10-20%)+(4.5 x %cover 20-50%)+(6 x %cover 50-80%)+(7.5 x %cover >80%))/100.*** Overriding the MC is the presence of either nuisance conditions within the estuary, or where >5% of the intertidal area has macroalgal cover >50%. In these situations the estuary has a minimum rating of FAIR, should be monitored annually, and an Evaluation & Response Plan initiated.

MACROALGAE CONDITION RATING

RATING	DEFINITION (+Macroalgae Coefficient)	RECOMMENDED RESPONSE
Over-riding rating: Fair	Nuisance conditions exist, or >50% cover over >5% of estuary	Monitor yearly. Initiate Evaluation & Response Plan
Very Good	Very Low (0.0 - 0.2)	Monitor at 5 year intervals after baseline established
Good	Low (0.2 - 0.8)	Monitor at 5 year intervals after baseline established
	Low Low-Moderate (0.8 - 1.5)	Monitor at 5 year intervals after baseline established
Fair	Low-Moderate (1.5 - 2.2)	Monitor yearly. Initiate ERP
	Moderate (2.2 - 4.5)	Monitor yearly. Initiate ERP
Poor	High (4.5 - 7.0)	Monitor yearly. Initiate ERP
	Very High (>7.0)	Monitor yearly. Initiate ERP
Early Warning Trigger	Trend of increasing Macroalgae Coefficient	Initiate ERP (Evaluation and Response Plan)

2. Methods (Continued)

SOFT MUD (PERCENT COVER)

Estuaries are a sink for sediments. Where large areas of soft mud are present, they are likely to lead to major and detrimental ecological changes that could be very difficult to reverse, and indicate where changes in land use management may be needed.

SOFT MUD PERCENT COVER CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<2% of estuary substrate is soft mud	Monitor at 5 year intervals after baseline established
Good	2%-5% of estuary substrate is soft mud	Monitor at 5 year intervals after baseline established
Fair	5%-15% of estuary substrate is soft mud	Post baseline, monitor 5 yearly. Initiate ERP
Poor	>15% of estuary substrate is soft mud	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	>5% of estuary substrate is soft mud	Initiate ERP (Evaluation and Response Plan)

SOFT MUD (AREA)

Soft mud in estuaries decreases water clarity, lowers biodiversity and affects aesthetics and access. Increases in the area of soft mud indicate where changes in catchment land use management may be needed.

SOFT MUD AREA CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	Area of cover (ha) not increasing	Monitor at 5 year intervals after baseline established
Good	Increase in area of cover (ha) <5% from baseline	Monitor at 5 year intervals after baseline established
Fair	Increase in area of cover (ha) 5-15% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Poor	Increase in area of cover (ha) >15% from baseline	Post baseline, monitor 5 yearly. Initiate ERP
Early Warning Trigger	Trend of increase in area of cover (ha)	Initiate ERP (Evaluation and Response Plan)

REDOX POTENTIAL DISCONTINUITY (RPD)

The RPD is the grey layer between the oxygenated yellow-brown sediments near the surface and the deeper anoxic black sediments. The RPD marks the transition between oxygenated and reduced conditions and is an effective ecological barrier for most but not all sediment-dwelling species. A rising RPD will force most macrofauna towards the sediment surface to where oxygen is available. In addition, nutrient availability in estuaries is generally much greater where sediments are anoxic, with consequent exacerbation of the eutrophication process.

RPD CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	>10cm depth below surface	Monitor at 5 year intervals after baseline established
Good	3-10cm depth below sediment surface	Monitor at 5 year intervals after baseline established
Fair	1-3cm depth below sediment surface	Post baseline, monitor 2 yearly. Initiate ERP
Poor	<1cm depth below sediment surface	Post baseline, monitor 2 yearly. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate ERP (Evaluation and Response Plan)

TOTAL ORGANIC CARBON

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, release of excessive nutrients and adverse impacts to biota - all symptoms of eutrophication.

TOTAL ORGANIC CARBON CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<1%	Monitor at 5 year intervals after baseline established
Low-Mod Enrichment	1-2%	Monitor at 5 year intervals after baseline established
Enriched	2-5%	Monitor at 2 year intervals and manage source
Very Enriched	>5%	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

2. Methods (Continued)

TOTAL PHOSPHORUS

In shallow estuaries the lower Waiwhetu, the sediment compartment is often the largest nutrient pool in the system, and phosphorus exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL PHOSPHORUS CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<200mg/kg	Monitor at 5 year intervals after baseline established
Low-Mod Enrichment	200-500mg/kg	Monitor at 5 year intervals after baseline established
Enriched	500-1000mg/kg	Monitor at 2 year intervals and manage source
Very Enriched	>1000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

TOTAL NITROGEN

In shallow estuaries like the lower Waiwhetu, the sediment compartment is often the largest nutrient pool in the system, and nitrogen exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL NITROGEN CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<500mg/kg	Monitor at 5 year intervals after baseline established
Low-Mod Enrichment	500-2000mg/kg	Monitor at 5 year intervals after baseline established
Enriched	2000-4000mg/kg	Monitor at 2 year intervals and manage source
Very Enriched	>4000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

METALS

Heavy metals provide a low cost preliminary assessment of toxic contamination in sediments and are a starting point for contamination throughout the food chain. Sediments polluted with heavy metals (poor condition rating) should also be screened for the presence of other major contaminant classes: pesticides, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

METALS CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<0.2 x ISQG-Low	Monitor at 5 year intervals after baseline established
Good	<ISQG-Low	Monitor at 5 year intervals after baseline established
Fair	<ISQG-High but >ISQG-Low	Monitor at 2 year intervals and manage source
Poor	>ISQG-High	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

SEMI-VOLATILE ORGANIC COMPOUNDS (SVOCS)

Semi-volatile organic compounds, including organochlorine pesticides (OCPs), and polycyclic aromatic hydrocarbons (PAHs) provide a more in depth assessment of toxic contamination in sediments. A broad screen of contaminants requires a range of guideline criteria to be used. Here, a condition rating is provided for PAHs as indicative of wider contamination issues which are discussed in the text where relevant.

PAH CONDITION RATING		
RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<0.2 x ISQG-Low	Monitor at 5 year intervals after baseline established
Good	<ISQG-Low	Monitor at 5 year intervals after baseline established
Fair	<ISQG-High but >ISQG-Low	Monitor at 2 year intervals and manage source
Poor	>ISQG-High	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

3. RESULTS AND DISCUSSION

BROAD SCALE MAPPING

Saltmarsh planted in 2011 in the lower estuary following sediment remediation. Photo Feb 2012.

Saltmarsh in Jan 2009 (above) and Feb 2012 (below) before and after sediment remediation.

Broad scale habitat mapping uses measures of the areas of saltmarsh, densely vegetated terrestrial margin, macroalgal cover, and soft mud to apply condition ratings to assess key estuary issues of habitat modification, eutrophication, and sedimentation. The results of the broad scale assessments undertaken in 2009 and 2012 are presented below, followed by the fine scale results.

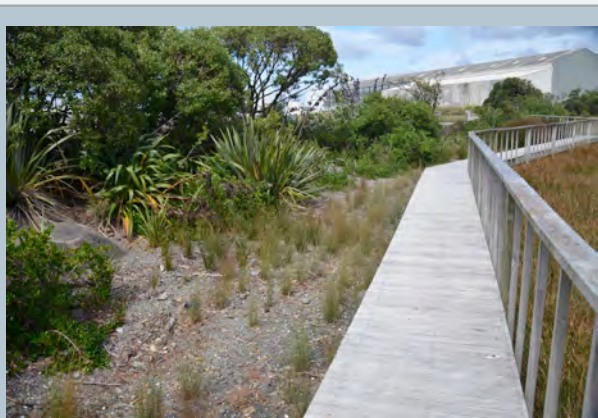
SALTMARSH: Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, and provides an important habitat for a variety of species including fish and birds.

While historically the lower Waiwhetu Stream estuary was surrounded by saltmarsh and wetland, in 2009 the stream was confined within narrow banks, often steepened, straightened, and reinforced to mitigate flood flows. Due to this modification, combined with extensive historical reclamation and draining of surrounding land, the only significant saltmarsh habitat remaining in 2009 was a very small remnant (0.06ha, 2.1% of the estuary) downstream of the Seaview Road bridge (Figure 4, photos this page). It had a condition rating of "low" based on the low percentage cover within Waiwhetu Estuary.

When mapped in 2012 (Figure 5), restoration planting as part of the stream remediation work had doubled the total area of saltmarsh in the estuary (0.14ha, 4.5%) - (Table 3), although the total area remained small and the condition rating was still in the "low" category. However the increase in saltmarsh from 2009 to 2012, was rated "very good".

Table 3. Summary of dominant estuary features downstream of the Bell Road Bridge, January 2009 and February 2012.

Feature		2009 Area - Ha (%)	2012 Area - Ha (%)
Saltmarsh Class	Dominant saltmarsh species	0.06 (2.1)	0.14 (4.5)
Rushland	*Juncus kraussii* (searush) *Apodasima similis* (jointed wire rush)	0.01 (0.4) 0.02 (0.7)	0.10 (3.1) 0.04 (1.4)
Reedland	*Spartina anglica* (cord grass)	0.01 (0.2)	0 (0)
Herbfield	*Sarcocornia quinqueflora* (glasswort)	0.02 (0.8)	0 (0)
Unvegetated intertidal flats		1.14 (40.2)	0.32 (10.3)
Water		1.64 (57.7)	2.63 (85.2)
TOTAL		**2.8 (100)**	**3.1 (100)**



Saltmarsh in 2009 (above left) and 2012 (above right) before and after sediment remediation adjacent to the Seaview Road boardwalk.

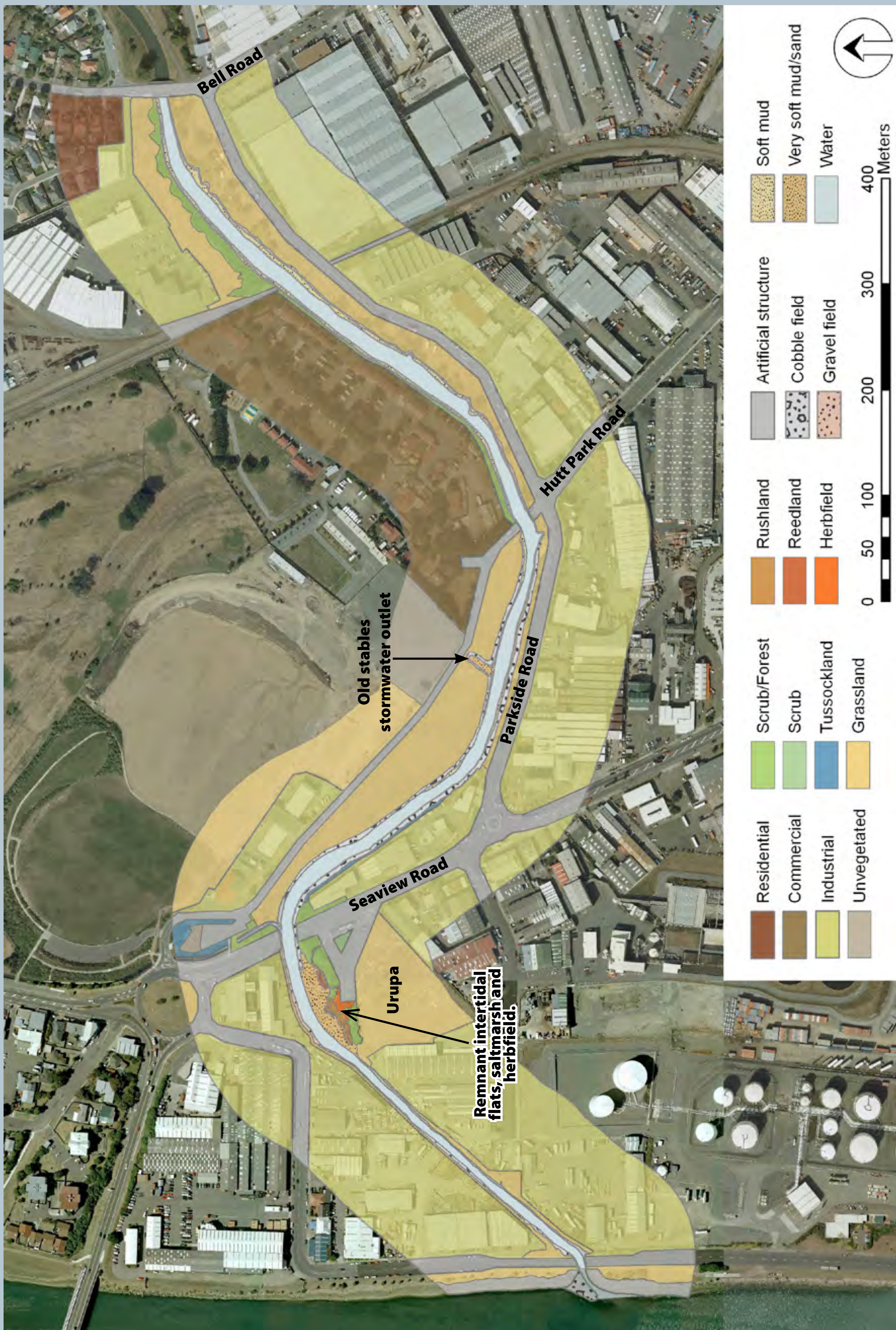
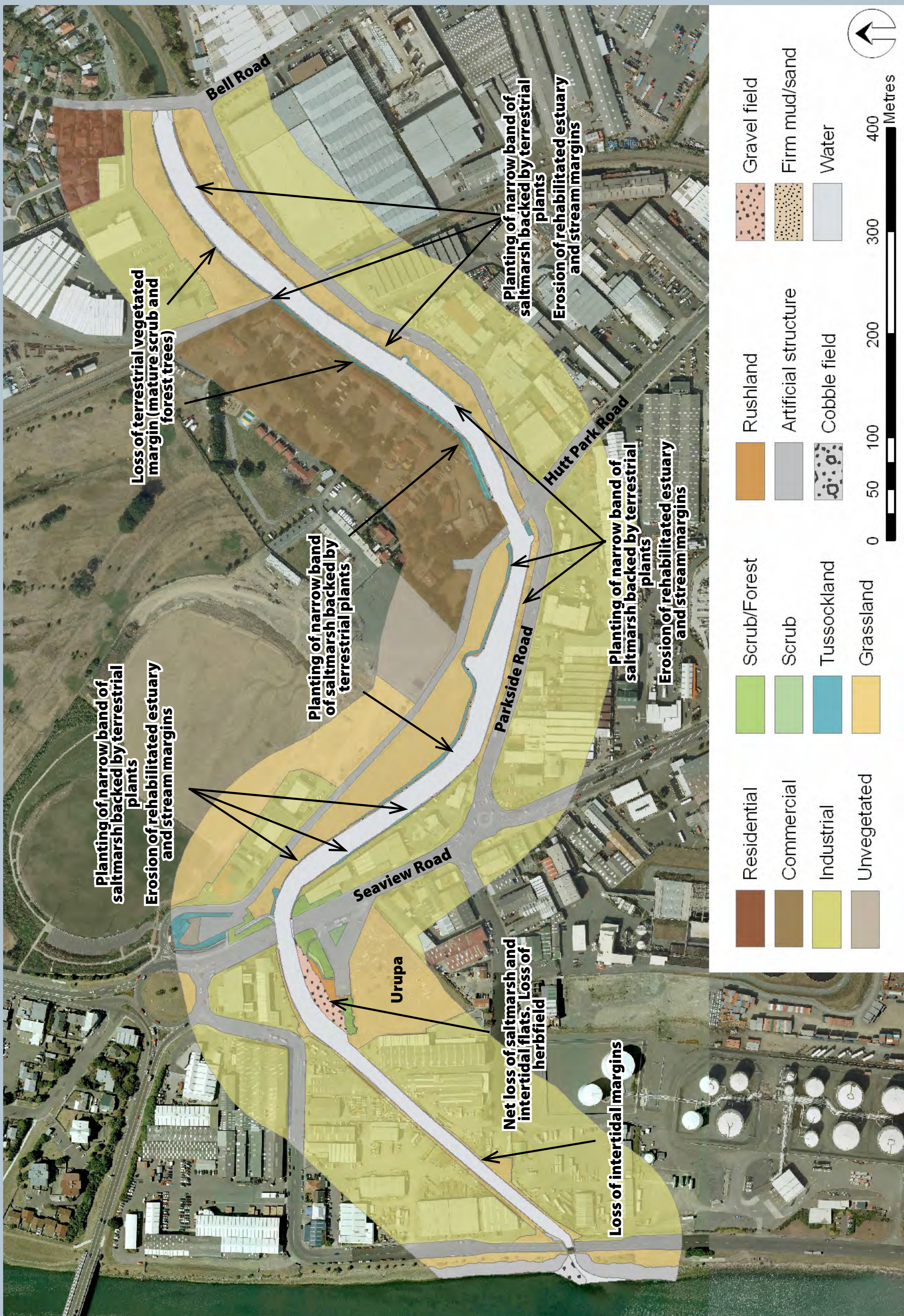


Figure 4. Broad scale features of the lower Waiwhetu Stream, January 2009.

Figure 5. Broad scale features of the lower Waiwhetu Stream, February 2012.

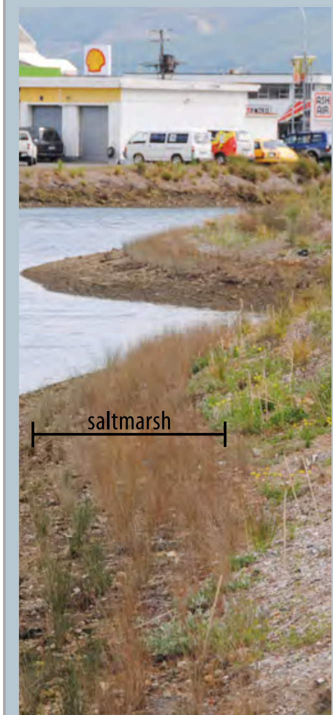


3. Results and Discussion (Continued)

BROAD SCALE MAPPING (CONT.)

SALTMARSH % COVER CONDITION RATING
2009 LOW
2012 LOW

SALTMARSH CHANGE (AREA) CONDITION RATING
2009-2012 VERY GOOD



0.5-2m wide band of saltmarsh planted in the lower Waiwhetu Estuary following remediation. Photo Feb, 2012.

Changes to the saltmarsh remnant present in 2009 included removal of the invasive cord grass *Spartina,* the loss of *Sarcocornia* dominated herbfields, and a minor reduction in the cover of rushland. This localised loss was offset by new plantings along the estuary margins between the Seaview and Bells Road bridges where rushland (predominantly searush *Juncus kraussii*, and jointed wire rush *Apodasima similis*) has been planted in a narrow (0.5-2m wide) band along the upper tidal range of the estuary (see sidebar photo).

Unfortunately, because past reclamation and modification has narrowed the flow channel, the majority of the estuary now has steep intertidal margins which greatly limit the area where saltmarsh is able to grow. In addition, as a consequence of the narrowed flow channel, flow velocities are relatively high and the planted margins have been subject to erosion that has washed away many plants, undercut banks, and eroded sediments used to cap the remediation works (see photos below). In several locations where capping had been eroded, there was clear evidence of underlying (historical) contaminant sources in the exposed sediments (e.g. landfill debris, and leachate and hydrocarbons seeps).

Bank erosion in the lower Waiwhetu Estuary showing the loss of remediation capping and plantings.

Another significant change associated with the margin redevelopment has been a 65% reduction in intertidal flats in the estuary. This already greatly under-represented and important estuarine habitat has been lost throughout the estuary by channel deepening and bank steepening, the extreme being the construction of vertical concrete flood channelling that has made the lower estuary entirely subtidal. The vertical concrete walls offer habitat unsuitable for virtually all estuarine species.

Sloping intertidal margins in the lower Waiwhetu Estuary in 2009 (left photos), replaced by vertical concrete walls and subtidal habitat in 2012 (right photos).

3. Results and Discussion (Continued)

BROAD SCALE MAPPING (CONT.)

TERRESTRIAL MARGIN % COVER CONDITION RATING
2009 POOR
2012 POOR

TERRESTRIAL MARGIN CHANGE (AREA) CONDITION RATING
2009-2012 POOR

TERRESTRIAL MARGIN VEGETATION: Like saltmarsh, a densely vegetated terrestrial margin naturally filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade helping to moderate stream temperature fluctuations, and improves estuary biodiversity.

Figures 4 and 5 and Table 4 summarise the dominant features present in a 100m buffer strip around the lower estuary. There was very little change from 2009 to 2012. In 2009, 80% of the buffer had little vegetation and was highly modified for industrial, commercial, residential, or roading purposes, ~18% was open grassland, with just 2.2% densely vegetated - a condition rating of "poor". In 2012, 98% of the estuary still lacked a densely vegetated terrestrial margin, although the grassland adjacent to industrial sites, which previously was largely un-maintained and dominated by introduced weeds and rubbish, had been tidied up.

Of the small vegetated margin area present, there had been a tripling of the cover of native tussockland from 2009 to 2012 (which included small native trees which will establish over time), but a halving of scrub/forest cover - mainly of established trees flanking the streamway downstream of the Bell Road bridge (see photos below). The net decrease in the densely vegetated terrestrial margin from 2009 to 2012, was rated "poor".


Established terrestrial margin shrub/forest vegetation viewed downstream from the Bell Road bridge in 2009 (left photo), and the same area planted in saltmarsh and tussockland in 2012 (right photo).


Established terrestrial margin shrub/forest vegetation downstream of Hutt Park Road in 2009 (left photo), and the same area planted in saltmarsh and tussockland species in 2012 (right photo). Note the loss of shade trees, loss of intertidal flats/expansion of subtidal area, and steepening of intertidal margins.


Grassland opposite Parkside Road looking toward Seaview Road Bridge in 2009 (left photo), and the same area planted in saltmarsh and tussockland in 2012 (right photo).

3. Results and Discussion (Continued)

BROAD SCALE MAPPING (CONT.)

Table 4. Summary of dominant terrestrial margin features, 2009 and 2012.

Dominant Feature	Jan 2009 Area - Ha (%)	Feb 2012 Area - Ha (%)
Scrub/Forest	0.5 (1.8)	0.2 (0.7)
	Mostly plantings of pohutukawa, ngaio, willow, taupata, karo, and flax. Saltmarsh ribbonwood, five finger and manuka also present adjacent to the saltmarsh by Seaview Road bridge.	Established pohutukawa remaining within grassland. Most, ngaio, willow, taupata, karo, and flax upstream of Hutt Park Road removed. Ribbonwood, five finger and manuka remain by Seaview Road bridge.
Tussockland	0.1 (0.4)	0.35 (1.2)
	Predominantly flax, often mixed with introduced weeds.	Almost exclusively recent plantings of toetoe, flax, carex and umbrella sedge.
Grassland	5.5 (18.4)	5.5 (18.2)
	Mainly grass amenity areas (with occasional trees) and small overgrown areas of tall fescue and introduced weeds.	Mainly grass amenity areas (many with 2009 trees removed). Areas overgrown with tall fescue and introduced weeds reduced.
Artificial Structures	4.7 (15.7)	4.8 (15.9)
Railway Road Rock field Boulder field Cobble field Unvegetated	0.15 (0.5) 3.6 (12.0) 0.03 (0.1) 0.28 (0.9) 0.04 (0.1) 0.60 (2.0)	0.15 (0.5) 3.6 (12.1) 0.02 (0.1) 0.28 (0.9) 0.04 (0.1) 0.64 (2.1)
Residential	0.5 (1.6)	0.5 (1.6)
Commercial	3.5 (11.6)	3.5 (11.6)
Industrial	15.3 (50.7)	15.3 (50.8)
TOTAL	**30.1 (100)**	**30.1 (100)**

50-80% cover of macroalgae over lower estuary intertidal flats.

MACROALGAL MAPPING: Macroalgal blooms are a symptom of estuary eutrophication. These can deprive seagrass areas of light causing their eventual decline, while decaying macroalgae can accumulate subtidally and on shorelines causing oxygen depletion and nuisance odours. Macroalgae was not widespread in 2009 and the Macroalgae Coefficient (MC) was "very low" (0.1), a condition rating of "very good". However, the presence of nuisance conditions of anoxic muds and sulphide odours, meant macroalgae was given a condition rating of "fair".

In 2012, growths were more widespread with short growths (1-10mm long) of *Ulva intestinalis* present over the vast majority of the intertidal area within Waiwhetu Estuary - 0.38ha (84.4%) had greater than 5% cover, and 0.09ha (20% of the intertidal area) exceeded 50% cover (e.g. photo left). Despite the relatively high cover, nuisance conditions (e.g. rotting macroalgae and poorly oxygenated and sulphide rich sediments) were not evident in intertidal areas, possibly due to macroalgae being regularly washed out to sea. The extent of macroalgal growth in the Waiwhetu and adjacent Hutt Estuary, while currently below nuisance conditions, indicates an excess of available nutrients within the estuary (this issue is discussed further in the fine scale results on page 19).

MACROALGAL COVER CONDITION RATING
2009 FAIR
2012 FAIR

Year	Rating	MC	Macroalgal Result
2009	FAIR	0.1	Localised high cover (80-100%) of *U. intestinalis*, and nuisance conditions (anoxic muds and sulphide odours).
2012	FAIR	2.5	Increase in *U. intestinalis* in the lower estuary compared to 2009. Greater percentage of intertidal area impacted because of reduced intertidal zone.

SEAGRASS COVER CONDITION RATING
2009 POOR
2012 POOR

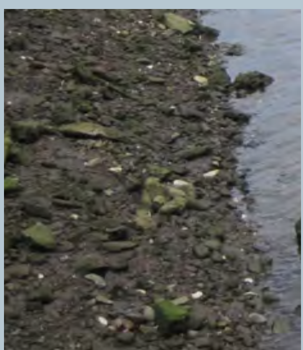
No seagrass was present in either 2009 or 2012, a condition rating of "poor".

3. Results and Discussion (Continued)

BROAD SCALE MAPPING (CONT.)

SOFT MUD % COVER CONDITION RATING
2009 POOR
2012 VERY GOOD

SOFT MUD CHANGE (AREA) CONDITION RATING
2009-2012 VERY GOOD



SUBSTRATE MAPPING: Increases in fine sediment, a common problem resulting from soil erosion from catchment development, can cause impacts such as increased muddiness and turbidity, shallowing, increased nutrients, changes in saltmarsh and seagrass habitats, less oxygen, increased organic matter degradation by anoxic processes (e.g. sulphide production) and alterations to fish and invertebrate communities. Also, because contaminants are most commonly associated with finer sediment particles, extensive areas of fine soft muds provide a sink which concentrate catchment contaminants.

Overall, in 2009 soft muds (45% - Table 5) were the dominant feature of unvegetated intertidal flats in the lower Waiwhetu Estuary, and were characterised by high levels of anoxia (a lack of oxygen), and the presence of sulphides. Even in areas where cobble (33%) and gravel (9%) were visually dominant surface features, these overlaid deposits of a very thick, black sulphide-rich ooze of mud - a key target in the proposed sediment remediation. The 2009 percentage cover condition rating for intertidal soft mud was "poor".

In stark contrast, soft mud was not a dominant intertidal feature in 2012 (Table 5). Sediments in 2012 were dominated by a mix of cobble, gravel, and sand, most being new material introduced following site remediation. There was also a significant reduction in the area of cobble and boulder habitat linked to the above where it had been removed and replaced. The increase in man-made rockfield from 2009 to 2012 is predominantly due to the flood channel constructed in the lower estuary.

Consequently the condition ratings for percentage cover of soft mud in 2012, and the change from 2009-2012 were both rated "very good". However, early indications that problems with increased muddiness are likely in the future were apparent with soft muds present subtidally. These muds were anoxic and organically enriched and appear to have settled in the estuary since the remediation work was completed.

Soft muds are most likely to be entering the estuary from the upstream Waiwhetu catchment. Erosion of remediated stream banks, mentioned previously, is also a likely source, as are inputs from the Hutt River on the incoming tide. Without identifying and managing sediment sources entering the estuary, muddiness is likely to continue to increase and degrade the estuary.

Table 5. Summary of dominant intertidal substrate, 2009 and 2012.

Dominant Feature	2009 Area - Ha (%)	2012 Area - Ha (%)	Comments
Rock field (man made)	0.01 (1.2)	0.04 (11.0)	2009 - Mostly rock along the lower estuary margin. 2012 - Rock replaced by concrete flood channel.
Boulder field (man made)	0.08 (6.7)	0.003 (0.9)	2009 - Mostly along the lower estuary margin. 2012 - Largely removed (replaced by flood channel).
Cobble field	0.39 (32.6)	0.07 (16.2)	2009 and 2012 - Mostly along the upper intertidal area.
Gravel field	0.11 (9.4)	0.15 (33.6)	2009 and 2012 - Dominant across most of the intertidal.
Firm Sand	0.16 (5.2)	0.17 (38.3)	2009 - Within rushland, reedland and herbfields. 2012 - As above and intertidally in middle estuary.
Soft mud	0.36 (30.4)	0 (0)	2009 - Predominantly in the middle intertidal reaches. 2012 - Not present intertidally (but present subtidally).
Very soft mud	0.17 (14.5)	0 (0)	2009 - Narrow band in the lower intertidal area. 2012 - Not present intertidally (but present subtidally).
TOTAL	**1.28 (100)**	**0.46 (100)**	

3. Results and Discussion (Continued)

FINE SCALE MONITORING

EUTROPHICATION: Excessive organic input, either from external sources or from algae growing within the estuary in response to high nutrient loads, is a principal cause of faunal change and physical and chemical degradation in estuarine benthic environments. In river mouth estuaries like the Waiwhetu, an oversupply of nutrients often promotes nuisance algal growth, and related sediment deoxygenation. As a consequence, the number of suspension-feeders (e.g. bivalves and certain polychaetes) declines, and deposit-feeders (e.g. opportunistic polychaetes) increase in response to increased organic input to the sediment (Pearson and Rosenberg 1978).

The primary fine scale indicators of eutrophication are grain size, RPD boundary, sediment organic matter, total nitrogen and phosphorus concentrations (TN and TP), and the structure of the sediment dwelling animal community. Broad scale indicators are the cover of macroalgae and soft mud.

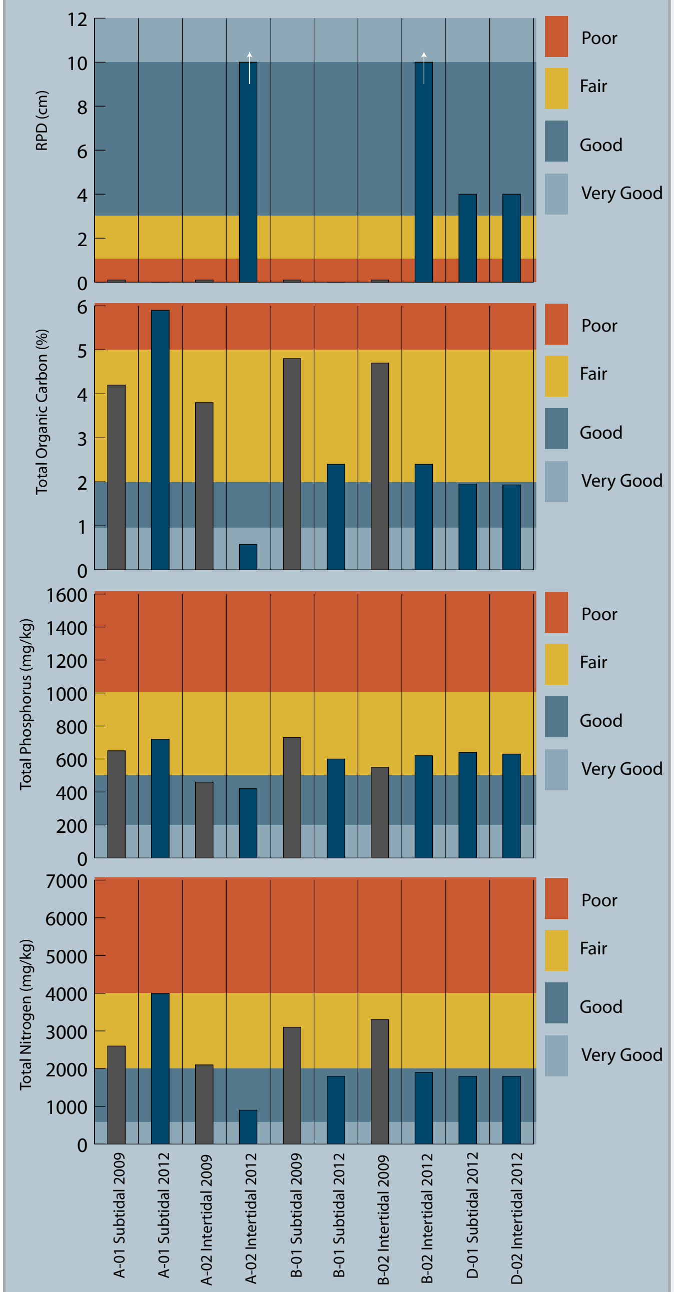


Figure 6. RPD depth, total organic carbon, total phosphorus, and total nitrogen, 2009 and 2012.

Redox Potential Discontinuity (RPD)

Figure 6 (top) and Table 6 show the RPD depth for sites sampled in 2009 and 2012. The results indicate a significant improvement in the remediated intertidal zone (from RPD at the surface in 2009 to >10cm in 2012), but little change subtidally (both years with surface RPD). Upstream, the RPD at Site D in 2012 was moderately deep (4cm). The results indicate a "poor" condition rating for subtidal sediments, and a benthic invertebrate community likely to be degraded. The "good-very good" rating for intertidal sediments reflects the coarse gravels present at the time of sampling and indicates that the intertidal benthic invertebrate community is likely to be in a recovery state.

Total Organic Carbon and Nutrients

Sediment nutrient concentrations (TN and TP) and organic matter (total organic carbon - TOC) also provide valuable trophic state information. In particular, if eutrophication symptoms are present (i.e. shallow RPD, excessive algal growth, low biotic index), then elevated TN, TP, and TOC concentrations provide a good indication that loadings are exceeding the assimilative capacity of the estuary. However, low TOC, TN or TP concentrations alone do not automatically indicate good conditions as an estuary, or part of an estuary, that has reached a eutrophic condition may have simply exhausted the available nutrient supply. Obviously, the latter case is likely to better respond to input load reduction than the former.

In relation to the intertidal and subtidal sites (Sites A, B and D), the results (Figure 6) indicate TOC, TP and TN concentrations are elevated at all sites. From 2009 to 2012, TOC, TP and TN concentrations all increased at subtidal site A-01, with other sites (A-02, B-01 and B-02) generally showing improved TOC and TN, but variable TP.

These results, combined with the 2012 macroalgal cover and the shallow subtidal RPD depths, show excessive organic matter and nutrients associated with eutrophic conditions in key parts of the estuary. The presence of such conditions following site remediation indicates ongoing sources to the estuary are likely, and that estuary condition will continue to decline if they are not managed appropriately.

CONDITION RATINGS	RPD	TOC	TP	TN
2009	POOR	ENRICHED	ENRICHED	ENRICHED
2012	POOR-GOOD	ENRICHED	ENRICHED	ENRICHED

3. Results and Discussion (Continued)

FINE SCALE MONITORING (CONTINUED)

METALS: If potentially toxic contaminant inputs (e.g. heavy metals) are excessive, estuary biodiversity is threatened and shellfish and fish may be unsuitable for eating. Heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn) and the metalloid arsenic (As) were used as indicators of sediment toxicants.

Results, summarised in Table 6 and Figure 7, showed metal concentrations exhibited a consistent improvement at sites B1 and A2 from 2009 to 2012 following the remediation work, with variable increases and decreases at Site A1, and a significant decline at B2. Lead and zinc in particular remained elevated and exceeded ANZECC (2000) ISQG-High trigger values. They were much higher at Site B2 in 2012 after remediation, a condition rating of "poor". Mercury also remained above ANZECC (2000) ISQG-Low trigger values at 3 of the 4 remediated sites in 2012, a rating of "fair". Arsenic, cadmium, chromium, and nickel were all below ANZECC (2000) ISQG-Low trigger values in 2009, a condition rating of "good", but in 2012 the upstream intertidal site B2 As, Cd, and Ni exceeded this trigger, a condition rating of "fair". Copper exceeded the ISQG-Low trigger values at one site in 2012, down from 3 sites in 2009, a condition rating of "good to fair". The presence of Ni, Pb, and Zn above ISQG-Low trigger values at the upstream site indicates potential contaminant sources are also affecting this part of the streamway, and subsequent follow-up sampling undertaken by GWRC staff has confirmed the presence of sediment metals (particularly lead and zinc) at high levels in stream bank sediments in the vicinity of Site B2 (J. Milne, pers. comm. 2012). These sediments were identified as originating from a seam of contaminated stream bank material which was capped during completion of the remediation project, and subsequently re-exposed by erosion (A. Allan, pers. comm. 2012).

Table 6. Physical and chemical results for Waiwhetu Stream, 2009 and 2012.

	Site	RPD	TOC	TN	TP	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
	Waiwhetu	cm	%	mg/kg (dry weight)									
2009	A-01 Subtidal	0.1	4.2	2,600	650	10	1.2	32	65	0.27	15	440	860
2009	A-02 Intertidal	0.1	3.8	2,100	460	10	1.2	42	49	0.56	18	490	660
2009	B-01 Subtidal	0.1	4.8	3,100	730	11	1.3	34	76	0.44	16	1,900	920
2009	B-02 Intertidal	0.1	4.7	3,300	550	11	1.2	34	74	0.34	16	1,200	850
2012	A-01 Subtidal	0	5.9	4,000	720	12.9	0.63	32	66	0.26	19	193	490
2012	A-02 Intertidal	>10	0.6	900	420	3.0	0.07	16	8.4	0.11	12	400	89
2012	B-01 Subtidal	0	2.4	1,800	600	6.8	0.41	26	38	0.25	14	1,010	380
2012	B-02 Intertidal	>10	2.4	1,900	620	21.0	6.0	63	64	0.53	24	7,900	1,350
2012	D-01 Subtidal	4	2.0	1,800	640	6.3	0.75	47	40	0.11	27	142	290
2012	D-02 Intertidal	4	1.9	1,800	630	8.5	0.18	16	30	0.08	11	99	143
ANZECC ISQG-Low		-	-	-	-	20	1.5	80	65	0.15	21	50	200
ANZECC ISQG-High		-	-	-	-	70	10	370	270	1	52	220	410

KEY	
(dark orange)	Detected concentration exceeds ANZECC ISQG High Guideline
(yellow)	Detected concentration exceeds ANZECC ISQG Low Guideline
(light peach)	Below detection limit (DL) but 0.5xDL exceeds ANZECC ISQG High
(grey)	Concentration less than ANZECC ISQG Low Guideline

CONDITION RATINGS	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
2009	GOOD	GOOD	GOOD	FAIR-GOOD	POOR	FAIR	GOOD	POOR
2012	GOOD-FAIR	GOOD-FAIR	GOOD	GOOD-FAIR	POOR-FAIR	FAIR-GOOD	GOOD-FAIR	POOR-FAIR

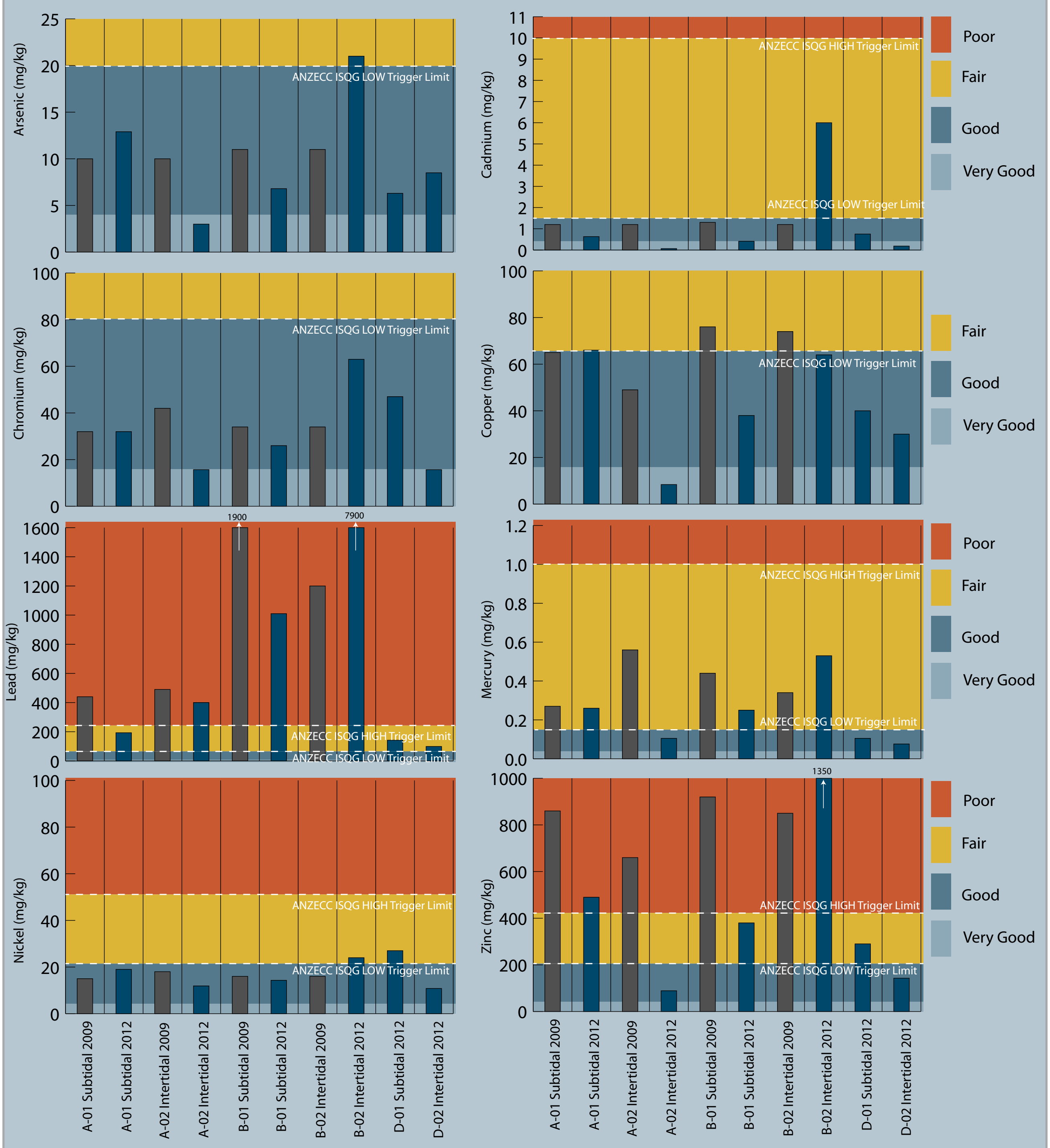


Figure 7. Total recoverable metal concentrations in the lower Waiwhetu Stream, 2009 and 2012.

SEMI-VOLATILE ORGANIC COMPOUNDS (SVOC'S): SVOCs were analysed to screen for key pollutants including organochlorine pesticides (OCPs), polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs) and pthalates (Table 7, Figure 8). Appendix 2 describes the analytical methods and Appendix 3 presents the results in full. The results show several OCP's, PAH's and TPH's remain present in concentrations that exceed the ANZECC (2000) ISQG Low or High Trigger Values. Overall, between 2009 and 2012 there was relatively little change in the subtidal Sites A1 and B1, a marked improvement at Site A2 (downstream intertidal), and a significant decline at Site B2 (intertidal upstream) where contamination was greater following remediation than prior to it. Key findings were:

3. Results and Discussion (Continued)

- Site B2 (intertidal upstream) was the most contaminated site in 2012, where the OCP's, 4,4'-DDD and 4,4'-DDE and TPHs were present above ANZECC ISQG-High trigger values, and a variety of PAH's were present above ANZECC ISQG-Low trigger values.
- Site D2 (intertidal site located immediately above the rehabilitation area) was the next most contaminated, where a variety of PAH's exceeded ANZECC ISQG-Low trigger values, then Site A1 (subtidal downstream) with a single PAH exceedence.
- There were no detected SVOC's at Site A2 (intertidal downstream) in 2012 (a very coarse gravel site with low organic content), and no exceedances for SVOC's at Sites B1 and D1 (subtidal sites).
- Because a "trace" level detection limit was used for OCP's as an initial screen, it is possible sites other than B2 also have OCP's present above ANZECC trigger levels. This is supported by applying the standard approach of assuming 50% of the detection level provides a conservative estimate of the potential concentration. Table 7 indicates that when this approach is used, all sites potentially exceed the guidelines for OCPs. Because of the generally high toxicity of OCP's to aquatic species, and their capacity to accumulate and bio-magnify up the food chain, repeat monitoring using "ultra-trace" analysis techniques is recommended to confirm the spatial extent and concentration of DDT contamination (and its breakdown metabolites).

When ANZECC ISQG-High triggers are exceeded, the next procedural step according to ANZECC (2000) is to undertake toxicity testing of the contaminated sediment. This will determine whether the concentrations present are bioavailable and likely to cause harm to biota. However, it is noted that the high organic carbon content is likely to reduce the bioavailability of OCP's (ANZECC 2000), consistent with TCLP leaching tests that showed contaminants tightly bound to stream sediments (A. Allan, pers. comm. 2012).

Table 7. Semi volatile organic compounds (SVOCs) normalised to 1% TOC in Waiwhetu Estuary, 2009 and 2012 (mg/kg dry wgt).

Data presented include 1% TOC normalised values for all compounds greater than the Detection Limit (DL). Where below DL, a value of 50% of the DL had been assumed. ANZECC criteria have been applied only to detected values, but OCP values are highlighted where 0.5xDL exceeds the ANZECC ISQG High guideline.

GROUP	Organic Chemical	*ISQG-Low*	*ISQG-High*	2009				2012					
				A1	A2	B1	B2	A1	A2	B1	B2	D1	D2
Organochlorine Pesticides (OCPs)	4,4'-DDD	0.002	0.02	0.09	0.12	0.14	0.14	0.20	0.07	0.09	3.83	0.09	0.07
	4,4'-DDE	0.002	0.027	0.09	0.12	0.14	0.14	0.20	0.07	0.09	0.21	0.09	0.07
	DDT	0.0016	0.046	0.28	0.27	0.17	0.24	0.35	0.15	0.20	0.20	0.20	0.15
Low molecular weight (LMW) PAHs	Naphthalene	0.16	2.1	0.05	0.06	0.07	0.07	0.09	0.05	0.05	0.05	0.05	0.05
	2-Methylnaphthalene	N/A	N/A	0.05	0.06	0.07	0.07	0.09	0.05	0.05	0.05	0.05	0.05
	Acenaphthene	0.044	0.64	0.05	0.06	0.07	0.07	0.09	0.05	0.05	0.05	0.05	0.05
	Acenaphthylene	0.016	0.5	0.05	0.06	0.07	0.07	0.09	0.05	0.05	0.24	0.05	0.09
	Fluorene	0.019	0.54	0.05	0.06	0.07	0.07	0.09	0.05	0.05	0.02	0.05	0.05
	Phenanthrene	0.24	1.5	0.07	0.11	0.05	0.05	0.04	0.05	0.08	0.10	0.08	0.45
	Anthracene	0.085	1.1	0.05	0.06	0.07	0.07	0.09	0.05	0.05	0.10	0.05	0.09
	TOTAL LMW PAHs	0.552	3.16	0.37	0.47	0.47	0.47	0.58	0.35	0.38	0.62	0.38	0.83
High molecular weight (HMW) PAHs	Fluoranthene	0.6	5.1	0.20	0.29	0.13	0.15	0.11	0.05	0.19	0.50	0.19	0.95
	Pyrene	0.665	2.6	0.16	0.29	0.14	0.16	0.12	0.05	0.20	0.58	0.21	0.95
	Benzo[a]anthracene	0.261	1.6	0.06	0.12	0.04	0.06	0.05	0.05	0.10	0.47	0.12	0.46
	Chrysene	0.384	2.8	0.06	0.12	0.06	0.06	0.05	0.05	0.10	0.47	0.11	0.43
	Benzo[a]pyrene (BAP)	0.43	1.6	0.06	0.15	0.07	0.07	0.07	0.07	0.12	0.73	0.13	0.52
	Dibenzo[a,h]anthracene	0.063	0.26	0.09	0.01	0.14	0.14	0.20	0.07	0.09	0.18	0.09	0.11
	TOTAL HMW PAHs	1.7	9.6	0.62	0.99	0.59	0.65	0.59	0.33	0.79	2.92	0.84	3.42
Other PAHs	Benzo[b]fluoranthene	N/A	N/A	0.07	0.19	0.11	0.14	0.10	0.07	0.16	0.82	0.17	0.62
	Benzo[g,h,i]perylene	N/A	N/A	0.04	0.14	0.07	0.10	0.08	0.07	0.12	0.58	0.11	0.38
	Benzo[k]fluoranthene	N/A	N/A	0.09	0.08	0.14	0.14	0.20	0.07	0.09	0.28	0.09	0.23
	2-Chloronaphthalene	N/A	N/A	0.05	0.06	0.07	0.07	0.09	0.05	0.05	0.05	0.05	0.05
	Indeno(1,2,3-c,d)pyrene	N/A	N/A	0.09	0.09	0.14	0.14	0.20	0.07	0.08	0.48	0.09	0.34
	TOTAL PAHs	4	45	1.32	2.02	1.58	1.70	1.85	0.99	1.66	5.75	1.72	5.88
Plasticisers	Bis(2-ethylhexyl)phthalate	N/A	N/A	0.40	2.53	1.65	2.77	1.61	0.25	1.25	0.33	0.51	0.30
	Butylbenzylphthalate	N/A	N/A	0.17	0.13	0.16	0.38	0.35	0.15	0.20	0.20	0.20	0.15
Total Petroleum Hydrocarbons	C15 - C36			69.0	107.9	87.5	61.7	45.8	0.2	47.1	766.7	47.2	0.2
	Total hydrocarbons (C7 - C36)	275	550	71.4	113.2	87.5	66.0	45.8	0.4	47.1	766.7	47.2	0.4

KEY			
	N/A = Not Available	Measurable concentration less than ANZECC ISQG Low Guideline	Below detection limit (DL) but 0.5xDL exceeds ANZECC ISQG High Guideline
		Detected concentration exceeds ANZECC ISQG Low Guideline	Detected concentration exceeds ANZECC ISQG High Guideline

3. Results and Discussion (Continued)

PAHs are a group of chemical compounds produced by the incomplete combustion of organic material. The most common sources in urban streams are vehicle emissions, roading materials (e.g. tar), and domestic wood and coal fires. Many PAH's are chronically and/or acutely toxic to a range of aquatic organisms, and pose a health risk if present in high concentrations (they are known carcinogens).

OCPs are persistent chemicals that were used extensively in NZ before the 1980s. While now phased out with most banned from use, because they are slow to breakdown, they are still commonly found in agricultural catchments and industrial areas. They are generally of high toxicity to aquatic species, and are a concern because of their capacity to accumulate and bio-magnify up the food chain.

TPHs are a large family of several hundred chemical compounds that originally come from crude oil based products (for example, petrol, kerosene, fuel oil, mineral oil, and asphalt). TPHs have variable longevity and toxicity depending on what compounds are present. Certain TPH fractions will float in water and form thin surface films. Other heavier fractions will accumulate in the sediment at the bottom of the water, which may affect bottom-feeding fish and organisms.

The plasticisers are commonly used in manufacturing polyvinyl chloride (PVC) products like toys, vinyl upholstery, traffic cones, conveyor belts, shower curtains, adhesives and coatings, and in vinyl foams used as floor tiles. They are considered ecotoxic in the aquatic environment and are a potential endocrine disruptor in humans.

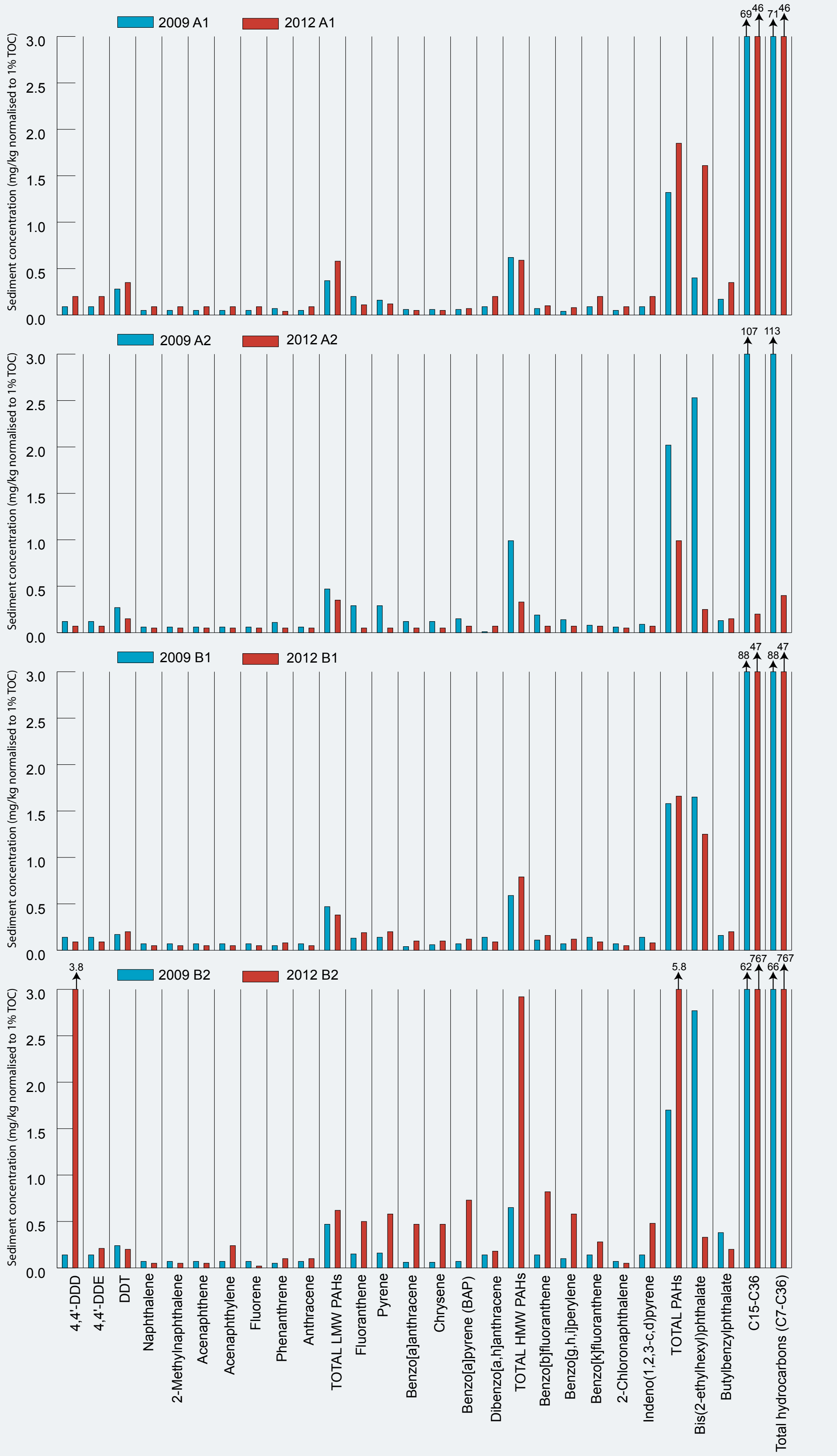


Figure 8. Semi volatile organic compounds (SVOCs) in Waiwhetu Stream, 2009, 2012.

3. Results and Discussion (Continued)

SHELLFISH FLESH TOXICITY: In addition to the sampling and results described above, shellfish (blue mussel, *Mytilus galloprovincialis*) were collected at the mouth of Waiwhetu Stream beneath the Port Road bridge (Figure 1) and the flesh analysed for metals, OCPs and PAHs. Appendix 3 shows that the chemical concentrations of metals, OCPs and PAHs present at Site C were all relatively low compared with available shellfish flesh toxicity criteria. Aldrin, DDD, DDE and dieldrin were all detected in 2009, but only aldrin was detected in 2012. All values were below the maximum permitted residue levels of agricultural compounds (NZFSA 2008).

There are no New Zealand guidelines for acceptable concentrations of chromium, copper, nickel or zinc in shellfish. In 2009 and 2012, arsenic, cadmium, lead and mercury were all below the NZFS 2002 (Australia New Zealand Food Standards Code) for trace metals in shellfish tissue.

There are no specified safe levels for polycyclic aromatic hydrocarbons in shellfish for human consumption in New Zealand.

Pathogens, the key limiting criteria for shellfish consumption, are periodically assessed separately by GWRC and were not measured as part of this project.

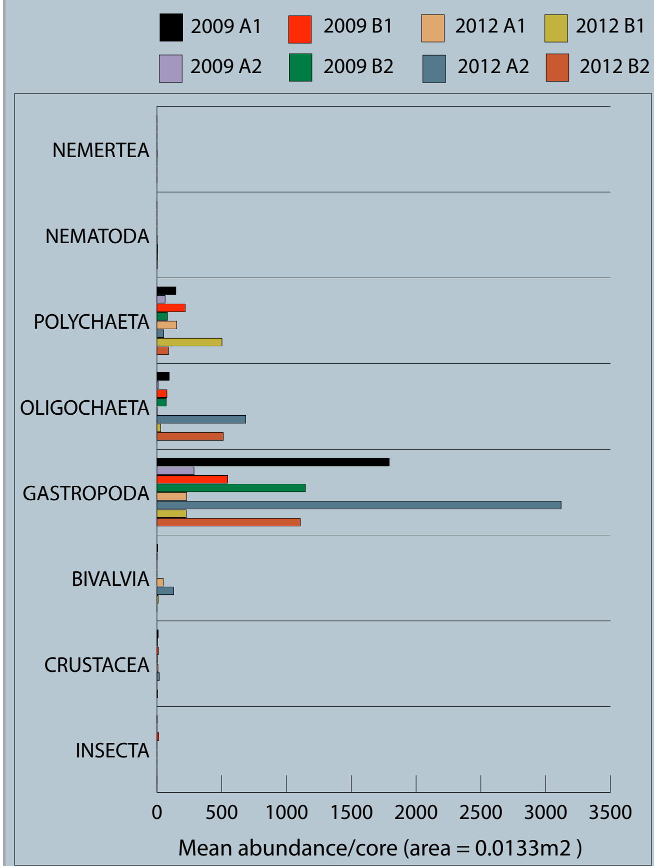


Figure 9. Mean abundance of macrofauna groups per core (area = 0.0133m^2), 2009 and 2012.

BENTHIC INVERTEBRATE COMMUNITY:

The invertebrate community living in and on the sediments at the four sites sampled, both in 2009 and in 2012, was dominated by "disturbance tolerant" gastropods, polychaetes and oligochaetes (Figure 9). Bivalves, crustacea, nemerteans, nematodes and fly larvae were also present, but in low numbers.

The relatively high diversity is most readily explained by the majority of the animals being sensitive juveniles or small immatures. This suggests they are mainly recent recruits, bred elsewhere, being washed into the area in low numbers, but not able to survive to adulthood. A statistical examination of the species composition at each site for 2009 and 2012, (NMDS plot, Figure 10) shows very little similarity between the species composition at each site in these years.

This is not surprising given the high degree of site disturbance during remediation, and the significant change in substrate from predominantly very soft deep muds in 2009 to coarse gravel/sand in 2012.

The main differences between 2009 and 2012 were:

- A large increase in pollution intolerant bivalves (pipis and cockles) at downstream Site A in 2012.
- A decline in pollution tolerant capitellid polychaetes in 2012, particularly at upstream Site B2 and B1 and downstream Site A2.
- An increase in pollution tolerant oligochaete worms at the intertidal sites A2 and B2 in 2012 and a decline at the subtidal sites A1 and B1.
- The presence of nematode worms in low numbers at all sites in 2012, from being absent at all sites in 2009.

Overall, these findings indicate a slight improvement in macroinvertebrate life at each of the sites in 2012.

3. Results and Discussion (Continued)

The results also indicate a dominance of species that tolerate moderate organic enrichment (i.e. omnivorous surface deposit feeding species) and which live predominantly in a relatively clean layer of oxygenated surface mud that was present above the underlying anoxic sediments. For example, the gastropod *Potamopyrgus* is intolerant of anoxic surface muds, but its presence in very high numbers indicates suitable surface conditions. The general absence of benthic invertebrates deeper in the sediments, and the few adults present, indicates that the underlying physical conditions are relatively harsh. This reflects both the physical extremes of being in the upper reaches of the estuary, as well as the enriched and toxic conditions present.

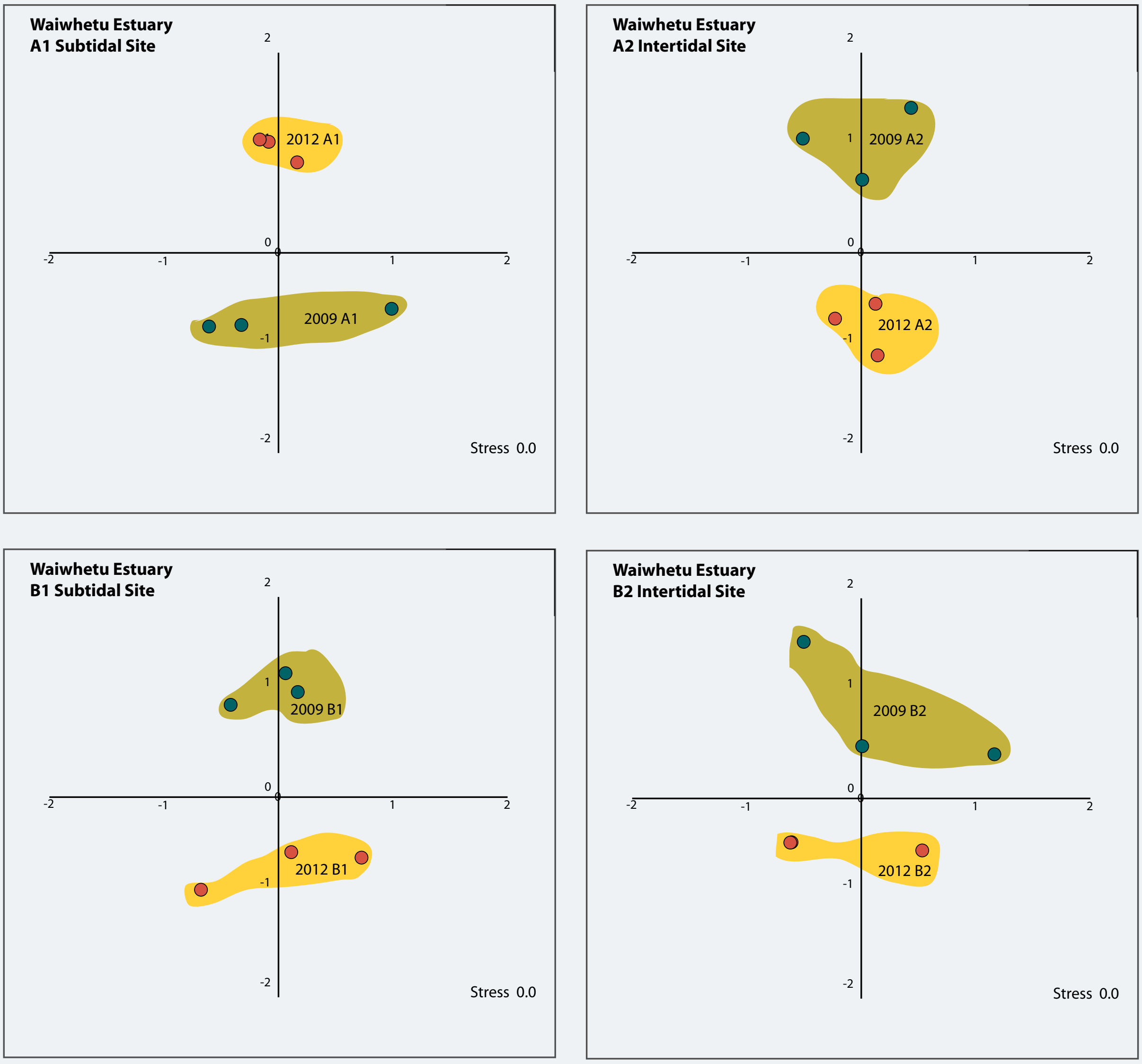
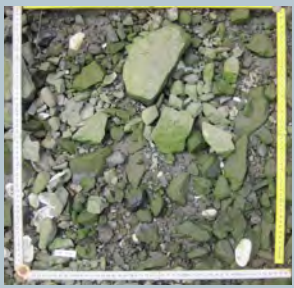


Figure 10. NMDS plot of sediment macrofauna groupings for Waiwhetu Estuary, 2009 and 2012.

Shows the relationship among samples in terms of similarity in macro-invertebrate community composition at Sites A and B for the two years of sampling (2009 and 2012). The plot shows the results for the 3 replicate samples for each tide level station and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves multivariate data analysis methods, in this case nonmetric multidimensional scaling (NMDS) using PRIMER vers. 6.1.10. The analysis basically plots the site and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities i.e. how low the calculated stress value is. Stress values greater than 0.3 indicate that the configuration is no better than arbitrary and we should not try and interpret configurations unless stress values are less than 0.2.

3. Results and Discussion (Continued)



EPIFAUNA: Limited information was able to be obtained from epifauna quadrats. In 2009, very soft muds obscured all but a few obvious adult estuarine snails (*Potamopyrgus*), and some of the many juveniles present. It was therefore not possible to accurately count or determine different species (*P. estuarinus, P. antipodarum* or *P. pupoides*) in the field. In 2012, the intertidal sites were dominated by coarse gravels, sand and cobble (see top inset photo). This substrate, because it provides areas where commonly present mobile species such as *Potamopyrgus* take refuge at low tide (primarily to minimise the effects of dessication), meant accurate counts were again not possible.

Overall, there were very few surface dwelling species present, and little obvious difference evident between 2009 and 2012, a reflection of the harsh physical conditions in the intertidal zone of a degraded river mouth estuary. Macrofauna core data indicate *Potamopyrgus* abundance increased at site A2 between 2009 and 2012. This is most likely in response to improved sediment conditions as it coincided with a decrease in muddy anoxic surface sediments, and a decrease in the rich growth of green benthic microalgae that was widespread in 2009.

While benthic microalgae was again present in 2012, it was mostly restricted to subtidal muds that had settled following remediation. Their presence usually indicates eutrophic (enriched) conditions, and there is clearly a ready supply of nutrients in the sediment in the Waiwhetu to support their growth. However, the very short residence time in the estuary and continual stream flushing is likely to limit extensive microalgal mat development and prevent algae growing to nuisance levels.

4. SUMMARY AND CONCLUSION

In conclusion, a range of physical, chemical and biological monitoring indicators of estuary condition in 2009 showed the lower part of the Waiwhetu Stream to be muddy, with organically enriched sediments that contained a range of industrial contaminants. It had poorly oxygenated soft sediment, an "unbalanced" benthic invertebrate community, high nutrient and organic concentrations, and was considered to be in a eutrophic state. Elevated concentrations of some heavy metals and the presence of other metals, pesticides, and industrial chemicals highlighted historical contaminant inputs, while past stream modification had resulted in the loss of most saltmarsh and most of the vegetated terrestrial buffer. Consequently the streamway rated poorly in terms of the key estuary issues of eutrophication, sedimentation, toxicity and habitat loss.

In 2012, reassessment of the same indicators showed significant changes to the lower part of the Waiwhetu Stream following flood control work and sediment remediation. Extensive saltmarsh and terrestrial vegetation plantings have expanded this important habitat, although the total area remains low. Any future expansion is greatly limited by the artificially steep sites of the estuary. In addition, much of the densely vegetated margin and many shade trees were lost from the upper estuary during remediation. Along the estuary margins, extensive areas of saltmarsh plantings and bank sediment are being eroded by stream flows.

56,331 tonnes (27,314m^3) of contaminated sediments were removed throughout the intertidal and subtidal zones and replaced with clean coarse sands, gravels and cobbles. Despite this very significant improvement, sediments retained high nutrient and organic concentrations and were eutrophic, although they supported a slightly improved benthic invertebrate community.

Very high concentrations of some heavy metals, pesticides, and hydrocarbons at

4. SUMMARY AND CONCLUSION (Continued)

intertidal site B2 highlighted a seam of capped contaminated material in the stream bank that was subsequently re-exposed by erosion.

In the lower estuary, vertical flood channelling has replaced previously sloping intertidal concrete riprap. This has resulted in the loss of already greatly under-represented intertidal flats and now presents habitat unsuitable for virtually all estuarine species.

In conclusion, past stream modification has been significant with the loss of most saltmarsh and the vegetated terrestrial buffer. While remediation and flood control works have resulted in some improvements to this habitat and a very significant removal of contaminated sediment, overall there has been limited improvement to the ecological quality of the estuary which continues to be rated poorly in terms of eutrophication, sedimentation, toxicity and habitat loss.

5. RECOMMENDATIONS

It is recommended that:

- Further targeted sampling and analysis be undertaken to determine the likely source, spatial extent, and concentration of sediment contaminants present in the lower estuary (commenced in March 2012 by GWRC).
- An appropriate management strategy be developed to determine how to best manage the residual sediment contaminants present, and to prevent ongoing contaminant inputs to the estuary.

  We understand that GWRC Flood Protection staff have such a strategy underway with HCC, and that GWRC's Take Charge industry education programme will be focusing on the Waiwhetu catchment in 2012/13.
- Continue to address issues of streambank and saltmarsh erosion, to reinstate areas of failed plantings, and to complete the environmental enhancement programme.
- In light of the sediment contaminant and streambank erosion problems identified, undertake a repeat survey in 3 years (Jan/Feb 2015) to confirm the status of sediment contaminants and saltmarsh/margin vegetation and the effect of any management initiatives.

6. ACKNOWLEDGEMENTS

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APPENDICES

APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

Vegetation was classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the two first letters of their Latin genus and species names e.g. marram grass, *Ammophila arenaria*, was coded as Amar. An indication of dominance is provided by the use of ( ) to distinguish subdominant species e.g. Amar(Caed) indicates that marram grass was dominant over ice plant (*Carpobrotus edulis*). The use of ( ) is not always based on percentage cover, but the subjective observation of which vegetation is the dominant or subdominant species within the patch. A measure of vegetation height can be derived from its structural class (e.g. rushland, scrub, forest).

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.
Treeland: Cover of trees in the canopy is 20-80%. Trees are woody plants >10cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.
Scrub: Cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.
Shrubland: Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.
Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of *Cortaderia, Gahnia,* and *Phormium*, and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla,* and *Celmisia*.
Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.
Grassland: Vegetation in which the cover of grass (excluding tussock-grasses) in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground.
Sedgeland: Vegetation in which the cover of sedges (excluding tussock-sedges and reed-forming sedges) in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. "Sedges have edges." Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it's probably a grass or a reed, if the stem is clearly triangular, it's a sedge. Sedges include many species of *Carex, Uncinia,* and *Scirpus*.
Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Leptocarpus*.
Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata*.
Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.
Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and where herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.
Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and where lichen cover exceeds that of any other growth form or bare ground.
Introduced weeds: Vegetation in which the cover of introduced weeds in the canopy is 20-100% and in which the weed cover exceeds that of any other growth form or bare ground.
Seagrass meadows: Seagrasses are the sole marine representatives of the Angiospermae. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries.
Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain cholorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope.
Cliff: A steep face of land which exceeds the area covered by any one class of plant growth-form. Cliffs are named from the dominant substrate type when unvegetated or the leading plant species when plant cover is ≥1%.
Rock field: Land in which the area of residual rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.
Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. Boulder fields are named from the leading plant species when plant cover is ≥1%.
Cobble field: Land in which the area of unconsolidated cobbles (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Cobble fields are named from the leading plant species when plant cover is ≥1%.
Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. Gravel fields are named from the leading plant species when plant cover is ≥1%.
Mobile sand: The substrate is clearly recognised by the granular beach sand appearance and the often rippled surface layer. Mobile sand is continually being moved by strong tidal or wind-generated currents and often forms bars and beaches. When walking on the substrate you'll sink <1 cm.
Firm sand: Firm sand flats may be mud-like in appearance but are granular when rubbed between the fingers, and solid enough to support an adult's weight without sinking more than 1-2 cm. Firm sand may have a thin layer of silt on the surface making identification from a distance difficult.
Soft sand: Substrate containing greater than 99% sand. When walking on the substrate you'll sink >2 cm.
Firm mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink 0-2 cm.
Soft mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When you'll sink 2-5 cm.
Very soft mud/sand: A mixture of mud and sand, the surface appears brown, and many have a black anaerobic layer below. When walking you'll sink >5 cm.
Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.
Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.
Shell bank: Area that is dominated by dead shells.
Artificial structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

APPENDIX 2. SUMMARY OF ANALYTICAL METHODS

Indicator (Sediment samples)	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Total organic carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	<3.8 g/100g dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg/kg dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg/kg dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg/kg dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg/kg dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg/kg dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg/kg dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05 g/100g dry wgt
Semivolatile Organic Compounds	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Haloethers	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Nitrogen containing compounds	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Organochlorine Pesticides	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Polycyclic Aromatic Hydrocarbons	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Phenols	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Plasticisers	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Other Halogenated compounds	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Other SVOCs	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
SMC Compounds	R.J. Hill	Sonication extraction, GPC cleanup, GC-MS FS analysis. US EPA 3540, 3550, 3640, 8270	
Total Petroleum Hydrocarbons	R.J. Hill	Sonication extraction, Silica cleanup, GC-FID analysis. US EPA 8015B/MfE Petroleum Industry Guidelines	
Total Recoverable digestion	R.J. Hill	Nitric / hydrochloric acid digestion. US EPA 200.2.	
Dry Matter (Env)	R.J. Hill	Dried at 103°C (removes 3-5% more water than air dry)	
Library Search on SVOC samples	A Library Search is conducted of the Mass Spectra for unidentified peaks against the NIST 2005 Mass Spectral Library containing 190,825 mass spectra of 163,198 different chemical compounds. Only peaks with a greater than 70% quality match are reported, along with their semi-quantitative concentrations, to a maximum of 50 peaks matched.		

* Coastal Marine Ecology Consultants (established in 1990) specialises in coastal soft-shore and inner continental shelf soft-bottom benthic ecology. Principal Gary Stephenson (BSc Zoology) has worked as a marine biologist for more than 25 years, including 13 years with the former New Zealand Oceanographic Institute, DSIR. Coastal Marine Ecology Consultants holds an extensive reference collection of macroinvertebrates from estuaries and soft-shores throughout New Zealand. New material is compared with these to maintain consistency in identifications, and where necessary specimens are referred to taxonomists in organisations such as NIWA and Te Papa Tongarewa Museum of New Zealand for identification or cross-checking.

Indicator (Shellfish samples)	Laboratory	Method	Detection Limit
Shucking of Shellfish	R.J. Hill*	Removal of tissue from shell.	
Homogenisation of Biological samples	R.J. Hill*	Mincing, chopping, or blending of sample to form homogenous sample fraction.	
Biological Materials Digestion	R.J. Hill*	Nitric and hydrochloric acid micro digestion, 85°C for 1 hour.	
Organochlorine Pesticides in Biomatter	R.J. Hill	Sonication extraction, GPC cleanup, dual column GC-ECD analysis.	
Polycyclic Aromatic Hydrocarbons in Biomatter	R.J. Hill		
Arsenic	R.J. Hill	Biological materials digestion, ICP-MS.	0.020 mg/kg as rcvd
Cadmium	R.J. Hill	Biological materials digestion, ICP-MS.	0.00040 mg/kg as rcvd
Chromium	R.J. Hill	Biological materials digestion, ICP-MS.	0.020 mg/kg as rcvd
Copper	R.J. Hill	Biological materials digestion, ICP-MS.	0.010 mg/kg as rcvd
Lead	R.J. Hill	Biological materials digestion, ICP-MS.	0.0020 mg/kg as rcvd
Mercury	R.J. Hill	Biological materials digestion, ICP-MS.	0.0020 mg/kg as rcvd
Nickel	R.J. Hill	Biological materials digestion, ICP-MS.	0.020 mg/kg as rcvd
Zinc	R.J. Hill	Biological materials digestion, ICP-MS.	0.010 mg/kg as rcvd
	*Analysis performed at Hill Laboratories - Food & Bioanalytical Division, Waikato Innovation Park, Ruakura Lane, Hamilton.		

APPENDIX 3. 2009 AND 2012 DETAILED ANALYTICAL RESULTS

Physical and chemical results for Waiwhetu Stream, 16 January 2009 and 21 February 2012.

	Site	RPD	TOC	TN	TP	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
	Waiwhetu	cm	%	mg/kg (dry weight)									
2009	A-01 Subtidal	0.1	4.2	2,600	650	10	1.2	32	65	0.27	15	440	860
2009	A-02 Intertidal	0.1	3.8	2,100	460	10	1.2	42	49	0.56	18	490	660
2009	B-01 Subtidal	0.1	4.8	3,100	730	11	1.3	34	76	0.44	16	1,900	920
2009	B-02 Intertidal	0.1	4.7	3,300	550	11	1.2	34	74	0.34	16	1,200	850
2012	A-01 Subtidal	0	5.9	4,000	720	12.9	0.63	32	66	0.26	19	193	490
2012	A-02 Intertidal	>10	0.6	900	420	3.0	0.07	16	8.4	0.11	12	400	89
2012	B-01 Subtidal	0	2.4	1,800	600	6.8	0.41	26	38	0.25	14	1,010	380
2012	B-02 Intertidal	>10	2.4	1,900	620	21.0	6.0	63	64	0.53	24	7,900	1,350
2012	D-01 Subtidal	4	2.0	1,800	640	6.3	0.75	47	40	0.11	27	142	290
2012	D-02 Intertidal	4	1.9	1,800	630	8.5	0.18	16	30	0.08	11	99	143
	ANZECC ISQG-Low	-	-	-	-	20	1.5	80	65	0.15	21	50	200
	ANZECC ISQG-High	-	-	-	-	70	10	370	270	1	52	220	410

Non-normalised semi volatile organic compounds (SVOCs) in Waiwhetu Stream, 2009 and 2012. (Only detected compounds are presented, all mg/kg d.w.).

GROUP	Organic Chemical	2009				2012					
		A1	A2	B1	B2	A1	A2	B1	B2	D1	D2
Organochlorine Pesticides	4,4'-DDD	0.36	0.45	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	9.2	< 0.17	< 0.14
	4,4'-DDE	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	0.51	< 0.17	< 0.14
Polycyclic Aromatic Hydrocarbons	Acenaphthylene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	0.58	< 0.10	0.18
	Anthracene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	0.25	< 0.10	0.18
	Benzo[a]anthracene	0.26	0.47	0.21	0.3	0.3	< 0.10	0.25	1.13	0.23	0.88
	Benzo[a]pyrene (BAP)	0.24	0.56	0.35	0.34	0.4	< 0.13	0.28	1.74	0.26	1.01
	Benzo[b]fluoranthene	0.31	0.73	0.51	0.67	0.6	< 0.13	0.38	1.96	0.33	1.2
	Benzo[g,h,i]perylene	0.18	0.55	0.34	0.46	0.5	< 0.13	0.28	1.38	0.21	0.73
	Benzo[k]fluoranthene	< 0.17	0.3	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	0.68	< 0.17	0.44
	2-Chloronaphthalene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
	Chrysene	0.26	0.47	0.28	0.29	0.31	< 0.10	0.23	1.13	0.21	0.83
	Dibenzo[a,h]anthracene	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	0.42	< 0.17	0.21
	Fluoranthene	0.82	1.1	0.62	0.72	0.64	< 0.10	0.46	1.21	0.38	1.84
	Indeno(1,2,3-c,d)pyrene	< 0.17	0.33	< 0.28	< 0.27	< 0.4	< 0.13	0.2	1.16	< 0.17	0.66
	Phenanthrene	0.29	0.43	0.22	0.23	0.24	< 0.10	0.18	0.25	0.15	0.86
	Pyrene	0.66	1.1	0.68	0.76	0.68	< 0.10	0.48	1.38	0.4	1.84
Plasticisers	Bis(2-ethylhexyl)phthalate	1.7	9.6	7.9	13.0	9.5	< 0.5	3.0	0.8	1.0	< 0.6
	Butylbenzylphthalate	< 0.33	0.51	0.75	1.8	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
Total Petroleum Hydrocarbons	C15- C36	290	410	420	290	270	< 40	113	1,840	92	< 40
	Total hydrocarbons (C7- C36)	300	430	420	310	270	< 70	113	1,840	92	< 70

Note: results are for a single composite sample for each site. The following section of Appendix 3 lists all the analyses undertaken, the vast majority for which no detectable results were obtained.

APPENDIX 3. 2009 AND 2012 DETAILED ANALYTICAL RESULTS (CONTINUED)

GROUP	Organic Chemical	2009 A1	2009 A2	2009 B1	2009 B2	2012 A1	2012 A2	2012 B1	2012 B2	2012 D1	2012 D2
Haloethers	*Bis(2-chloroethoxy) methane*	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	Bis(2-chloroethyl)ether	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	Bis(2-chloroisopropyl)ether	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	4-Bromophenyl phenyl ether	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	4-Chlorophenyl phenyl ether	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
Nitrogen containing SVOCs	*Aniline*	< 0.33	< 0.48	< 0.56	< 0.54	-	-	-	-	-	-
	3,3'-Dichlorobenzidine	< 0.83	< 1.2	< 1.4	< 1.4	< 1.8	< 0.7	< 0.9	< 1.0	< 0.9	< 0.7
	2,4-Dinitrotoluene	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	2,6-Dinitrotoluene	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Nitrobenzene	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	N-Nitrosodi-n-propylamine	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	N-Nitrosodiphenylamine	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
Organochlorine Pesticides	*Aldrin*	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	alpha-BHC	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	beta-BHC	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	delta-BHC	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	gamma-BHC (Lindane)	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	4,4'-DDD	0.36	0.45	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	9.2	< 0.17	< 0.14
	4,4'-DDE	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	0.51	< 0.17	< 0.14
	4,4'-DDT	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Dieldrin	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	Endosulfan I	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Endosulfan II	< 0.50	< 0.50	< 0.56	< 0.54	< 0.7	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
	Endosulfan sulphate	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Endrin	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Endrin Ketone	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Heptachlor	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	Heptachlor epoxide	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	Hexachlorobenzene	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
Polycyclic Aromatic Hydrocarbons	*Acenaphthene*	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
	Acenaphthylene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	0.58	< 0.10	0.18
	Anthracene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	0.25	< 0.10	0.18
	Benzo[a]anthracene	0.26	0.47	0.21	0.3	0.3	< 0.10	0.25	1.13	0.23	0.88
	Benzo[a]pyrene (BAP)	0.24	0.56	0.35	0.34	0.4	< 0.13	0.28	1.74	0.26	1.01
	Benzo[b]fluoranthene	0.31	0.73	0.51	0.67	0.6	< 0.13	0.38	1.96	0.33	1.2
	Benzo[g,h,i]perylene	0.18	0.55	0.34	0.46	0.5	< 0.13	0.28	1.38	0.21	0.73
	Benzo[k]fluoranthene	< 0.17	0.3	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	0.68	< 0.17	0.44
	2-Chloronaphthalene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
	Chrysene	0.26	0.47	0.28	0.29	0.31	< 0.10	0.23	1.13	0.21	0.83
	Dibenzo[a,h]anthracene	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	0.42	< 0.17	0.21
	Fluoranthene	0.82	1.1	0.62	0.72	0.64	< 0.10	0.46	1.21	0.38	1.84
	Fluorene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
	Indeno(1,2,3-c,d)pyrene	< 0.17	0.33	< 0.28	< 0.27	< 0.4	< 0.13	0.2	1.16	< 0.17	0.66
	2-Methylnaphthalene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
	Naphthalene	< 0.10	< 0.12	< 0.14	< 0.14	< 0.18	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
	Phenanthrene	0.29	0.43	0.22	0.23	0.24	< 0.10	0.18	0.25	0.15	0.86
	Pyrene	0.66	1.1	0.68	0.76	0.68	< 0.10	0.48	1.38	0.4	1.84

APPENDIX 3. 2009 AND 2012 DETAILED ANALYTICAL RESULTS (CONTINUED)

GROUP	Organic Chemical	2009 A1	2009 A2	2009 B1	2009 B2	2012 A1	2012 A2	2012 B1	2012 B2	2012 D1	2012 D2
Phenols	*4-Chloro-3-methylphenol*	< 0.50	< 0.50	< 0.56	< 0.54	< 0.7	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
	2-Chlorophenol	< 0.20	< 0.24	< 0.28	< 0.27	< 0.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
	2,4-Dichlorophenol	< 0.20	< 0.24	< 0.28	< 0.27	< 0.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
	2,4-Dimethylphenol	< 0.20	< 0.24	< 0.28	< 0.27	< 0.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
	2-Methyl-4,6-dinitrophenol	< 3.3	< 4.8	< 5.6	< 5.4	-	-	-	-	-	-
	3 & 4-Methylphenol (m- + p-cresol)	< 0.40	< 0.48	< 0.56	< 0.54	< 0.7	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
	2-Methylphenol (o-Cresol)	< 0.20	< 0.24	< 0.28	< 0.27	< 0.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
	2-Nitrophenol	< 0.40	< 0.48	< 0.56	< 0.54	< 0.7	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4
	4-Nitrophenol	< 0.50	< 0.50	< 0.56	< 0.54	-	-	-	-	-	-
	Pentachlorophenol (PCP)	< 6.0	< 6.0	< 6.0	< 6.0	< 7	< 6	< 6	< 6	< 6	< 6
	Phenol	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	2,4,5-Trichlorophenol	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	2,4,6-Trichlorophenol	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
Plasticisers	*Bis(2-ethylhexyl)phthalate*	1.7	9.6	7.9	13	9.5	< 0.5	3	0.8	1	< 0.6
	Butylbenzylphthalate	< 0.33	0.51	0.75	1.8	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Di(2-ethylhexyl)adipate	< 0.20	< 0.24	< 0.28	< 0.27	< 0.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
	Diethylphthalate	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Dimethylphthalate	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Di-n-butylphthalate	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Di-n-octylphthalate	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
Other Halogenated	*1,2-Dichlorobenzene*	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	1,3-Dichlorobenzene	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	1,4-Dichlorobenzene	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Hexachlorobutadiene	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	Hexachlorocyclopentadiene	< 0.83	< 1.2	< 1.4	< 1.4	< 1.8	< 0.7	< 0.9	< 1.0	< 0.9	< 0.7
	Hexachloroethane	< 0.33	< 0.48	< 0.56	< 0.54	< 0.7	< 0.3	< 0.4	< 0.4	< 0.4	< 0.3
	1,2,4-Trichlorobenzene	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
Other SVOC	*Benzyl alcohol*	< 1.7	< 2.4	< 2.8	< 2.7	< 4	< 1.3	< 1.7	< 1.9	< 1.7	< 1.4
	Carbazole	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	Dibenzofuran	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
	Isophorone	< 0.17	< 0.24	< 0.28	< 0.27	< 0.4	< 0.13	< 0.17	< 0.19	< 0.17	< 0.14
Total Petroleum Hydrocarbons	*C7-C9*	< 9.2	< 13	< 15	< 16	< 30	< 9	< 11	< 13	< 11	< 9
	C10-C14	< 20	< 20	< 21	< 22	< 50	< 20	< 30	< 30	< 30	< 20
	C15-C36	290	410	420	290	270	< 40	113	1,840	92	< 40
	Total hydrocarbons (C7-C36)	300	430	420	310	270	< 70	113	1,840	92	< 70

Metals and semi volatile organic compound results in shellfish tissue (mg/kg wet weight), Waiwhetu Stream, Site C, 16 January 2009 and 21 February 2012.

Shellfish Flesh Chemical Concentrations (Site C-01)			
Metals in Biomatter		2009	2012
	Limit*	(mg/kg)	
Arsenic (As)	1.0	0.73	0.88
Cadmium (Cd)	2.0	0.056	0.056
Chromium (Cr)	-	<0.098	< 0.10
Copper (Cu)	-	0.60	1.22
Mercury (Hg)	0.5	0.017	0.013
Nickel (Ni)	-	0.13	0.24
Lead (Pb)	2.0	0.77	0.51
Zinc (Zn)	-	15.0	16.2
Polycyclic Aromatic Hydrocarbons in Biomatter		(mg/kg)	
Acenaphthene	-	< 0.0005	< 0.0005
Acenaphthylene	-	< 0.0005	< 0.0005
Anthracene	-	< 0.0002	< 0.0002
Benzo[a]anthracene	-	0.00033	0.0006
Benzo[a]pyrene (BAP)	-	< 0.0002	0.0003
Benzo[b]fluoranthene + Benzo[j] fluoranthene	-	0.0014	0.0013
Benzo[g,h,i]perylene	-	< 0.0002	0.0005
Benzo[k]fluoranthene	-	< 0.0002	0.0004
Chrysene	-	0.00088	0.0006
Dibenzo[a,h]anthracene	-	< 0.0002	< 0.0002
Fluoranthene	-	< 0.0002	0.0019
Fluorene	-	< 0.0002	0.0002
Indeno(1,2,3-c,d)pyrene	-	< 0.0002	< 0.0002
Naphthalene	-	< 0.005	< 0.005
Phenanthrene	-	< 0.0004	0.0008
Pyrene	-	0.0015	0.0019

*NZFS (2002) The New Zealand (Australia New Zealand Food Standards Code) Food Standards (2002) PART 1.4 Contaminants and Residues, Standard 1.4.1 Contaminants and Natural Toxicants. Values mg/kg.

Shellfish Flesh Chemical Concentrations (Site C-01)			
Organochlorine Pesticides in Biomatter		2009	2012
	Limit*	(mg/kg)	
Aldrin	0.1	0.0012	0.0018
alpha-BHC		< 0.00050	< 0.0005
beta-BHC		< 0.00050	< 0.0005
delta-BHC		< 0.00050	< 0.0005
gamma-BHC (Lindane)		< 0.00050	< 0.0005
cis-chlordane		< 0.00050	< 0.0005
trans-chlordane		< 0.00050	< 0.0005
2,4'-DDD		0.0033	< 0.0005
4,4'-DDD		0.0049	< 0.0005
2,4'-DDE		< 0.00050	< 0.0005
4,4'-DDE		0.0022	< 0.0005
2,4'-DDT		< 0.00050	< 0.0005
4,4'-DDT		< 0.00050	< 0.0005
Sum of DDT	0.5	0.01	0.003
Dieldrin	0.1	0.0016	< 0.0005
Endosulfan I		< 0.0005	< 0.0005
Endosulfan II		< 0.0005	< 0.0005
Endosulfan sulfate		< 0.0005	< 0.0005
Endrin		< 0.0005	< 0.0005
Endrin aldehyde		< 0.0005	< 0.0005
Endrin ketone		< 0.0005	< 0.0005
Heptachlor		< 0.0005	< 0.0005
Heptachlor epoxide		< 0.0005	< 0.0005
Hexachlorobenzene		< 0.0005	< 0.0005
Methoxychlor		< 0.0005	< 0.0005
Total Chlordane [(cis+trans)*100/42]		< 0.002	< 0.002

*NZFSA (2008) New Zealand (Maximum Residue Limits of Agricultural Compounds) Food Standards 2008 Published by the New Zealand Food Safety Authority, PO Box 2835, Wellington. Values mg/kg -most conservative value selected.

APPENDIX 3. 2009 AND 2012 DETAILED ANALYTICAL RESULTS (CONTINUED)

Sediment macrofauna results for Waiwhetu Estuary Sites A and B, 2009 and 2012.

Group	Species	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012	2012
		A1	A1	A1	A2	A2	A2	B1	B1	B1	B2	B2	B2	A1	A1	A1	A2	A2	A2	B1	B1	B1	B2	B2	B2
		Rep 1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
NEMERTEA	*Nemertea sp.#1*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
NEMATODA	*Nematoda*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	5	0	2	3	1	0	1	2
POLYCHAETA	*Boccardiella magniovata*	0	0	0	0	0	0	27	21	11	0	0	0	0	0	0	3	2	13	0	0	0	0	13	4
	Capitella sp.#1	14	26	98	14	40	1	41	14	32	18	3	36	18	16	85	0	0	0	0	0	1	0	0	0
	Ceratonereis sp.#1	1	2	4	1	3	1	20	20	25	1	13	10	8	12	12	10	19	4	82	257	160	14	42	16
	Microspio maori	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
	Nicon aestuariensis	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Perinereis vallata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Spionidae sp.#1	1	0	0	0	0	0	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OLIGOCHAETA	*Oligochaeta*	21	4	69	0	8	1	33	33	11	1	52	18	0	0	2	222	246	217	1	27	1	266	99	147
GASTROPODA	*Potamopyrgus spp.*	1266	205	322	101	123	62	238	142	165	148	136	862	107	42	81	854	1270	995	58	62	106	196	152	759
BIVALVIA	*Arthritica sp.#1*	0	0	0	0	0	0	0	0	0	0	0	0	5	8	21	0	0	0	0	0	0	0	0	0
	Austrovenus stutchburyi	0	0	0	0	0	0	0	0	0	0	0	0	4	2	4	0	0	0	5	1	0	0	0	0
	Paphies australis	3	3	0	1	0	0	0	0	0	0	0	0	1	2	1	42	46	41	1	1	1	0	0	0
CRUSTACEA	*Amphipoda sp.#1*	0	0	2	3	1	1	7	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Amphipoda sp.#2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Austrohelice crassa	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3	4	0	0	0	0	1	5
	Exosphaeroma planulum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
	Halicarcinus whitei	0	2	3	0	0	0	0	0	0	0	0	0	1	0	1	1	3	1	0	0	0	0	0	0
	Helice crassa	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Macrophthalmus hirtipes	0	0	1	1	0	0	0	1	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0
	Paracorophium sp. or spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0
INSECTA	*Diptera sp.#1*	1	0	0	0	0	0	5	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diptera sp.#2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total number of species		**7**	**6**	**8**	**7**	**6**	**5**	**8**	**10**	**11**	**4**	**6**	**5**	**10**	**6**	**13**	**8**	**9**	**8**	**6**	**7**	**7**	**3**	**6**	**6**
Total number of specimens		**1307**	**242**	**500**	**123**	**176**	**66**	**372**	**240**	**253**	**168**	**206**	**927**	**147**	**82**	**215**	**1134**	**1597**	**1276**	**149**	**352**	**271**	**476**	**308**	**933**