Audit of the Remediation of the former Fruitgrowers Chemical Company Site, Mapua

Prepared for
Ministry for the Environment

June 2009

PATTLE DELAMORE PARTNERS LTD
Level 1, Perpetual Trust House
111 Customhouse Quay, Wellington
PO Box 6136, Wellington, New Zealand

Tel +4 **471 4130** Fax +4 **471 4131**
Web Site **http://www.pdp.co.nz**
Auckland **Wellington** Christchurch

solutions *for your environment*

Quality Control Sheet

TITLE	**Audit of the Remediation of the former Fruitgrowers Chemical Company Site, Mapua**
CLIENT	Ministry for the Environment
VERSION	Final
DATE	30 June 2009
JOB REFERENCE	W01738100
SOURCE FILE(S)	W01738100 R01 Final.doc

Prepared by

SIGNATURE

Mike Clyde / Graeme Proffitt

Directed, reviewed and approved by

SIGNATURE

Graeme Proffitt

Limitations:

The report has been prepared for the Ministry for the Environment, according to their instructions, for the particular objectives described in the report. The information contained in the report should not be used by anyone else or for any other purposes.

Executive Summary

Fruitgrowers Chemical Company (FCC) formerly operated an agrichemicals factory on a site in the small settlement of Mapua, 15 km west of Nelson. The site has the Mapua Channel and the Waimea Inlet on two boundaries. The former use of the land left a legacy of contaminated soil, marine sediment and groundwater on and adjacent to the site. Pattle Delamore Partners Limited (PDP) has been engaged by the Ministry for the Environment (MfE) to audit the recently completed remediation of the site.

The remediation

Environmental investigations and assessments carried out at the site in the past found elevated concentrations of contaminants in soil on the site and adjacent land, in groundwater, and in nearby marine sediments (thought to have been caused by run-off from the site). The major contaminants of concern were organochlorine pesticides (OCPs), which include DDT, DDD and DDE (collectively known as DDX), and aldrin, dieldrin and lindane (collectively known as ADL).

A decision was made to remediate the site to prevent further effects on the marine environment and to restore the site to a usable condition. Following initial trials, works commenced in October 2004 and were completed in early 2008. The remediation Validation Report was submitted to MfE in December 2008. The site has remained vacant since the remediation was completed.

The overall remediation site is made up of nine separate components each with different remediation targets: the western part of the former FCC site (FCC West), intended for residential use; the eastern part of the former FCC site (FCC East), intended for commercial use and open space; a former landfill area (FCC Landfill), intended to be recreational open space; two marine foreshore areas; and four privately owned residential properties to the south of the FCC sites. Site-specific soil acceptance criteria (SAC) were developed for each of the residential, commercial/open space and foreshore areas. The SACs were primarily aimed at protecting the marine environment, but by doing so, were also protective of human health.

Almost the complete site was excavated, with the soil tested as it was removed to determine its acceptability against the SACs. Soil was then assigned to stockpiles for later reuse as residential or commercial soil, or sent for treatment. Soil that exceeded commercial criteria for OCPs was treated to reduce concentrations to below the commercial criteria using a mechano-chemical dehalogenation (MCD) process.

The excavations were then backfilled with material that was considered suitable for the proposed land use for that area. The entire site was finally covered with half a metre of residential quality soil, the top third of which was imported topsoil.

Two areas of foreshore adjacent to the FCC site were included in the remediation. This consisted of excavating contaminated material broadly defined by previous investigation results and backfilling with imported clean gravel.

A number of groundwater monitoring wells and private groundwater bores were monitored prior to and during the remediation as a condition of resource consent.

The audit

An audit of the remediation has been carried out to assess whether the site complies with the SACs, is now fit for its intended purposes or whether any further steps are necessary to achieve this. During the audit a large number of documents relating to the site and remediation were reviewed, and key individuals involved in the remediation were consulted. This process has resulted in a good understanding of the remediation process, which provides confidence in the conclusions drawn.

The detailed and methodical approach by site staff gives confidence in the quality of the remediation works. The soil and marine sediment sampling carried out to assess the effectiveness of the remediation was undertaken in a professional manner, using methods consistent with accepted industry practice. The quality of the data used to validate the remediation was generally of an acceptable quality.

Overall, the site-specific SACs developed as targets for the remediation are appropriate for the future uses, and so where the relevant SACs are met for a particular part of the site, then that part of the site is fit for its intended purpose. An exception to this is exposure through drinking of groundwater, which is assumed to be controlled by other means. Also, no criteria were derived for nitrogenous compounds or phosphorus, which were used in significant quantities as additives in the soil treatment process.

Soil:

FCC West is fit for its intended purpose (residential) with respect to soil quality, subject to a minor uncertainty on whether concentrations of DDX always meet the residential SAC due to high detection limits used in the laboratory analysis. A programme of sampling or retesting of existing samples has been recommended to address this uncertainty. It is probable that the additional testing will confirm the current results.

Overall, the FCC East site is also considered fit for its intended purposes (commercial and open space) with respect to the soil remediation. Some uncertainty remains with respect to the potential for ammonia gas to be generated from MCD-treated soil (arising from the additives used in the treatment) and possible effects on human health, and the possibility of plant health effects on deep-rooted plant species used in future amenity planting. These issues can be readily managed with a site management plan (SMP). The proposed SMP will also ensure that excavation into commercial quality soil will be controlled so that it is not left on the ground surface where it could migrate to the marine environment in site runoff, or be disposed of to a more sensitive environment. Copper compounds, also used as a treatment additive, are not of concern.

FCC Landfill site is also considered fit for its intended purpose (open space) with respect to the soil remediation. However, there is again some uncertainty with respect to the possibility of ammonia generation and phytotoxicity of copper in treated fines. However

these are not human health issues for day to day use as open space and can also be readily managed with an SMP.

The soil quality at the four residential property sites is considered to be fit for residential purposes.

Marine Foreshore:

It is considered that "remediation to the extent practicable" has been broadly achieved in the marine foreshore areas. The benefits of further remediation are likely to be outweighed by the additional disruption and impacts to the environment. It is clear that the remediation in these areas has not been successful in meeting the SACs for DDX and ADL. However, re-deposition of non-complying sediment from the surrounding marine environment probably meant that compliance with the SACs could not be achieved within the foreshore surface sediments. In addition, re-contamination of the deeper backfill material has occurred during the remediation works. The mechanism(s) for this are not clear, but site runoff is probably a major contributor.

While contamination remains within the backfilled material, there is evidence that the surface sediment quality has been improving since completion of the remediation. A key aspect of the foreshore remediation is the removal of the site as a source of ongoing sediment contamination. This will allow natural attenuation processes to slowly improve the foreshore sediment quality over the coming years.

Apart from localised effects on the marine ecosystem, the effects of the residual sediment contamination on other receptors are not likely to be significant. In the case of risks to human health via seafood consumption, additional data is required to confirm this as the current dataset is limited.

Groundwater:

The groundwater under the site contains elevated concentrations of some contaminants, in particular DDX, dieldrin and nutrients. This will remain for an extended period, resulting in discharges to the marine environment. However, it is by no means clear that the groundwater contamination is creating an unacceptable risk, or risks that cannot be managed. The direction and rate of groundwater flow under the site are currently uncertain, which makes the potential risks arising from the groundwater contamination difficult to assess.

This contamination may pose a risk to potential groundwater users on the site. However, future groundwater use can be controlled to mitigate this risk. In addition, the presence of a reticulated water supply provides a disincentive for future installation of water bores. While there is some uncertainty as to whether groundwater is flowing from the site towards existing private bores in nearby Tahi Street, the current groundwater quality from these bores is suitable for irrigation use.

It is likely that there will be localised effects on the foreshore ecosystem at the point of discharge of the groundwater. Algal growth shows excess nutrients in the discharge.

However, the potential effects on the wider marine ecosystem are not expected to be significant due to dilution. Remediation of groundwater could be considered to deal with local effects, but such consideration is premature. Further monitoring is required to better assess the significance of the local effects. Remediation should only be considered if unacceptable effects are confirmed and such effects cannot be managed in some other way. Remediation of groundwater would be expensive, potentially uncertain and have to continue for many years.

Recommendations

Additional soil sampling should be undertaken on FCC West to increase confidence in the precision of the OCP soil analysis. This could also be achieved by re-analysing current samples held by the laboratory.

A programme of sampling and risk assessment should be carried out for ammonia gas in locations where treated soil exists. This could be carried out on a case-by-case basis when buildings are constructed on FCC East.

Additional groundwater monitoring wells should be installed and ongoing groundwater monitoring carried out. The groundwater monitoring data should be used to update the hydrogeological model for the site. This will contribute to assessing the importance of local effects from groundwater discharge on the foreshores and clarify whether there is a significant southerly groundwater flow towards private bores in Tahi Street.

Sediment and snail sampling should continue, following a review of the sampling design to ensure it is adequately quantifying the risk via seafood consumption and is properly representing the quality of the surface sediments.

The health and diversity of the foreshore ecosystems should be benchmarked relative to suitable control sites elsewhere in the Waimea Inlet. The information will contribute to assessing the significance of the residual contamination in the foreshore sediments and the local effects of contaminated groundwater discharge.

Table of Contents

Appendices:

1.0 Introduction

Pattle Delamore Partners Limited (PDP) has been engaged by the Ministry for the Environment (MfE) to audit the recently completed remediation of the former Fruitgrowers Chemical Company (FCC) site ('the site') in the small settlement of Mapua, 15 km west of Nelson.

From the 1930s until 1988, FCC operated a factory on the site which produced a range of agrichemicals. These historic activities left a legacy of contaminated soil, marine sediment and groundwater on and adjacent to the site. The major contaminants of concern were persistent organochlorine pesticides including DDT, DDD, DDE, aldrin, dieldrin and lindane.

By the late 1990s, the Tasman District Council (TDC) had inherited the site and, in conjunction with MfE, began to consider potential remediation options from that time. The intention was to render the site suitable for a range of uses including residential, commercial and recreational. Resource consent for the chosen remedial solution was granted in 2003. Site works commenced late 2004 and bulk earthworks were completed in January 2008 (MWH, 2009f). The remediation Validation Report was submitted to MfE in December 2008.

This report provides an independent audit of the remediation and an assessment of whether the site is now fit for its intended purposes.

1.1 Report Structure

The report is structured as follows:

- **Section 1** – provides an introduction to the project and set outs audit limitations;
- **Section 2** – sets out the objectives and scope of the audit;
- **Section 3** – provides a background to the project, including a brief site history and a summary of the remediation;
- **Section 4** – summarises the audit process;
- **Section 5** – outlines the results of the audit of the soil remediation for FCC East, FCC West, FCC Landfill and the four residential properties;
- **Section 6** – provides the audit results for the two marine foreshore sediment remediation areas;
- **Section 7** – summarises the current groundwater quality and provides the audit results relating to groundwater;
- **Section 8** – provides a summary of the audit results and conclusions; and
- **Section 9** – summarises the audit recommendations.

1.2 Report Limitations

This audit report has been prepared for the Ministry for the Environment for the objectives and to the scope set out in the report. Use by any other party or for any other purpose is at that party's risk.

The report has drawn on work performed and information provided by others, including as-built information, bore hole, test pit, surface water, sediment and biota sampling, laboratory analysis and similar work. The information has been accepted as provided. PDP has endeavoured to satisfy itself that the information is representative of the particular locations for which the information applies, but accepts no responsibility for its accuracy in representing conditions on site.

The report is based on information obtained from investigation locations and from the results of processing material in bulk. Actual conditions could vary and PDP offers no guarantees as to the actual conditions. Conditions could change with time, thus the opinions expressed relate to the time of the actual sampling

2.0 Objectives and Scope

2.1 Objectives

The overall objectives of this report are to provide an independent audit of the remediation works. The specific objectives, set out in the audit brief, were to assess:

1. the remediation of the persistent organochlorine pesticide contaminants present on the site;
2. compliance with the remediation soil acceptance criteria;
3. whether "clean-up to extent practicable" of the marine sediments has been achieved;
4. the adequacy of the draft Site Management Plan;
5. the current status of the groundwater;
6. whether the land is fit for purpose; and
7. the actual and potential environmental effects of the residual contamination on the site.

Further, the audit is to assess what, if any, monitoring (including from contaminants resulting from the remedial processes used e.g. copper and ammonia) is required to:

1. ensure the continued safe use of the site; and
2. determine the nature and effect of any on going discharges from the site.

Should the site not be fit for purpose, the Auditor shall determine the necessary steps to be taken to ensure the site is suitable for its intended use.

2.2 Scope

The scope is restricted to assessing the quality of soil, marine sediments and groundwater against various consent conditions, using the Site Validation Report, Groundwater and Sediment Monitoring Report, draft Site Management Plan and such other information as may be provided by MfE. The basis for the Auditor's[1] review was set out in the audit brief as follows:

[1] Note: A Site Auditor was appointed as a consent condition to provide overview and technical advice during the remediation process – see Section 3.4.1. This is not the same as the current audit function.

Medium	Assessment criteria	Scope of site auditor assessment
Soil	Compliance with the relevant soil acceptance criteria and an assessment of whether the land is fit for purpose.	Assessment of compliance with relevant SAC. Review of draft Site Management Plan prepared for MfE. Provision of comments and variations to the draft Site Management Plan, following review.
Marine sediments	Compliance with relevant soil acceptance criteria and an assessment of whether "clean-up to extent practicable" has been achieved.	Assessment of compliance with relevant SAC. If SAC have not been achieved, assessment of whether "clean-up to extent practicable" has been achieved. Review of draft Site Management Plan prepared for MfE. Provision of comments and variations to the draft Site Management Plan, following review.
Groundwater	Threshold values in the Resource Consents and applicable New Zealand Standards.	Review Groundwater Sediment Monitoring Report prepared for MfE and any additional material provided by MfE including the TDC groundwater and biota monitoring reports. Comment on the current status of the groundwater. Assessment of implications of groundwater on foreshore and marine environments and neighbouring properties. Recommendations of monitoring and management required for the site and neighbouring properties, if not covered in the draft Site Management Plan.
Ammonia and Copper	Human health and environmental effects.	Comment on information provided by the Ministry for the Environment. Recommendations of monitoring and management required for the site and neighbouring properties, if not covered in the draft Site Management Plan.

The review of the draft Site Management Plan will be reported separately. However, where relevant, the audit comments on aspects that need to be controlled by the SMP.

The scope does not include:

- consideration of air quality;
- assessment of material that was taken off site for disposal;
- assessing compliance with consent conditions that do not relate to achieving relevant site acceptance criteria (SAC) or threshold values for soil, water and sediment; or

- a review of the conduct of the remediation process. The audit focuses on the current site status rather than 'how it got there', except where the process itself could affect the interpretation of data or the suitability of the site for its intended use.

3.0 Background

The background information in the sections below is based on a site visit in February 2009 and information contained in the following references: SKM (2008); T&T (2003); and Woodward-Clyde (1996).

3.1 Site Description

The approximately five hectare site is located in the settlement of Mapua, 15 km west of Nelson (Figure 1). Mapua is located adjacent to the northern end of Waimea Inlet, a large tidal estuary between Rabbit Island and the mainland. The site is located at the base of a small peninsula known as Grossi Point which is bounded to the west by the Waimea Inlet and to the east by the Mapua Channel. The channel leads to the main entrance of Waimea Inlet, approximately 1 km to the north-east. Aranui Road forms the northern site boundary and Tahi Street bisects the site from north to south. Tahi Street itself was not included in the remediation site.

The overall remediation site is made up of nine separate components (see Figure 1):

- a former landfill area (FCC Landfill) – approximately 0.6 hectares;
- the western portion of the former FCC site (FCC West) – 1.7 hectares;
- the eastern portion of the former FCC site, on the other side of Tahi Street (FCC East) – 1.3 hectares;
- two marine foreshore areas - approximately 0.5 hectares in total; and
- four residential properties to the south of the FCC sites. These include 13, 15, 18 and 20 Tahi Street and make up a total area of approximately 0.8 hectares.

The adjacent site uses are:

- residential to the south along the peninsula;
- residential and undeveloped paddocks to the west; and
- a mixture of commercial and residential to the north beyond Aranui Road.

The former FCC site is currently vacant and almost entirely grassed. The exception to this is an area of compact gravel on FCC East adjacent to Tahi Street. The site is a mixture of flat areas and gentle contours, with the highest points built up about two metres above the general elevation of the surrounding land. An open drain ('the creek') runs along the north-west edge of FCC Landfill.

The beach along the southern boundary of FCC Landfill consists of coarse gravel, with tidal mudflats beyond. An engineered embankment covered with cobbles and boulders forms the eastern boundary of FCC East, adjacent to the Mapua Channel. Beyond the embankment the beach exposed at low tide consists of a mixture of gravel, sand and mud, sloping gently towards the adjacent channel.

The tidal range at Mapua is up to 3.3 m and there are strong currents close to the eastern foreshore during the ebb and flow of tides. Measurements show tidal velocities

of up to 1.55 m/s at the edge and 1.8 m/s in the centre of Mapua Channel. There is considerably less tidal energy in the mudflats to the south of FCC Landfill as it is protected from the main tidal flows by the position of Grossi Point.

3.2 Site History

3.2.1 General

FCC operated an agrichemical formulation plant on FCC East and West from 1932 until 1988, producing pesticides, herbicides and fungicides that were used throughout the country. The north-eastern portion of FCC East was operated by a subsidiary company, originally known as Lime and Marble Limited and later as Mintech Ltd. The Mintech site was generally used for processing non-toxic minerals but also included the FCC micronising plant[2] and some biocide preparation. Facilities used for agrichemical formulation and storage were operated on both FCC East and West.

From the 1950s, a number of areas were either in-filled or reclaimed, including: low lying areas of FCC East; the area now known as FCC Landfill, reclaimed from the Waimea Inlet; and the eastern portions of FCC East, reclaimed from the Mapua Channel. The fill material used contained waste material from site operations.

FCC ceased operations in 1988 and by 1996 TDC had either inherited or acquired the FCC portions of the site i.e. FCC Landfill, FCC West and FCC East. FCC Landfill was inherited first, in the early 1990s. In May 1992, TDC installed a clay cut-off wall along the southern edge of FCC Landfill to reduce leachate migration into the Waimea Inlet. From the early 1990s onwards, the site was the subject of a number of environmental investigations and assessments. It was clear from the investigation results that some form of remediation or management of residual contamination at the site was required. Elevated contaminant concentrations were detected in soil on and adjacent to the site, groundwater and in nearby marine sediments. The major contaminants of concern which drove the need for remediation were organochlorine pesticides. Other contaminants included heavy metals, organonitrogen pesticides, organophosphorous pesticides, petroleum hydrocarbons, acid herbicides and elemental sulphur.

The peak soil concentrations were typically found in the vicinity of historical process areas. Marine sediments appear to have been contaminated from site runoff and drainage, including from the landfill, to the nearby estuary and Mapua Channel – see next section.

A decision was made to remediate the site after initial plans for capping the site were set aside. Soil treatment trials to select an appropriate technology were carried out in 1999 – 2000. Resource consents for the remediation were granted in November 2003.

---

[2] The micronising plant produced 'wettable powders' by reducing the particle size of various compounds, mainly DDT, DDD and dieldrin.

The remediation works commenced in October 2004, after a proof of performance stage, and were completed in early 2008. The consents expired in November 2007, four years after they were granted. Since the remediation was completed, the site has remained vacant.

3.2.2 Historic Site Drainage

As noted in the previous section, marine sediments in the adjacent Waimea Inlet and Mapua Channel have been contaminated most likely from site runoff. Stormwater from the site historically discharged as follows:

- a portion of FCC East discharged to an outfall close to the north-east corner of the site;
- the remainder of FCC East and a portion of FCC West discharged to a cylindrical surge chamber located eastern foreshore, approximately halfway along the bund. An outlet from the surge chamber discharged into Mapua Channel below low tide level;
- the majority of FCC West drained to a pipe which discharged to Waimea Inlet; and
- leachate from the landfill was able to drain directly to the estuary.

3.3 Intended Site Uses

The intended site uses at the time of consent were as follows:

- FCC Landfill – recreational / open space. It is envisaged as a green area with benches, plantings and walkways rather than fields to be used for sports;
- FCC West – residential;
- FCC East – commercial and open space;
- the marine sediments adjacent to the site to support an aquatic ecosystem; and
- the four residential properties on Tahi Street continuing in residential use.

3.4 Remediation Overview

This section provides a brief overview of the remediation works. More detail on the various aspects of the works is described as required in the audit sections of this report.

3.4.1 Remediation Management Structure

Over the period of the remediation, a number of parties were involved in a range of roles. This section briefly summarises these roles.

TDC is the site owner and also the consenting authority. MfE initially provided funding for the proposed remediation, along with TDC. In 2001, TDC awarded the contract for the remediation to a joint bid comprising Thiess Services Pty Limited (Thiess) and

Environmental Decontamination Limited (EDL). Thiess is a specialist remediation contractor based in Australia. EDL was the supplier of the mechano-chemical dehalogenation (MCD) remediation technology chosen for the reduction of the organochlorine contamination.

Thiess withdrew from the project mid-2004. At that point, MfE took over the management of the remediation and contracted EDL to complete the remediation works. MfE subsequently contracted Effective Management Systems (EMS) as Site Manager. MWH New Zealand Limited (MWH) was appointed by MfE as Site Engineer for the remediation project. MWH subsequently retained EMS as Engineer's Representative. The main earthworks contractor was initially Hiway Stabilisers Environmental Limited (HSE). However, they were replaced by Taylor's Contracting Limited (TCL) in October 2006.

Separately, Peter Nadebaum of GHD Pty Ltd (GHD) was appointed for the duration of the remediation works by MfE and TDC as the Site Auditor to provide independent technical advice. As required by a consent condition, a peer review panel of experts was also appointed by TDC. The panel was to meet regularly and advise on progress, monitoring results and other issues as they arose. This panel included the Site Auditor. The appointments of the auditor and peer review panel lapsed with the expiry of the consents in November 2007.

3.4.2 Remediation Preliminaries

As part of the resource consent application for the remediation, a remediation action plan (RAP) was written (Thiess, 2004) and an assessment of potential environmental effects completed (T&T, 2003). A second version of the RAP (MfE, 2005a) and a summary of changes to the RAP (MfE, 2007) were produced during the remediation. The RAP as a whole was never approved by TDC, the consenting authority, despite being condition of the remediation consent. While significant portions of the document were approved by TDC and the peer review panel during the remediation works, overall approval was not given as some sections of the RAP were never finalised.

A total of seven resource consents were granted for the proposed remediation in October 2003. Included as a condition of consent were a set of soil acceptance criteria (SAC). The SAC provide target criteria for soil in residential, open space and commercial areas, and for marine sediments.

The SAC were derived taking into account a number of potential exposure pathways. For the key contaminants of concern (CoCs), the controlling pathway was generally not risk to human health i.e. if only human health was considered, the SAC would have been higher in most cases (Egis, 2001). For example, the residential criterion for one of the key CoCs, DDT (as the sum of DDT and it derivatives), is controlled by the risk to the marine environment of potential discharges of sediment from the site. For the equivalent commercial criteria, the controlling pathway is the effect on groundwater quality, and the risk that the discharge of the groundwater poses to the marine environment after dilution.

3.4.3 Soil Remediation

For the purposes of the remediation, the entire FCC site was divided into a 15 m grid of cells, each with a unique identification. Each cell was divided vertically into a series of layers. The layers were at 0.5 m intervals to 2 m depth and 1 m intervals below that point. This basic reference system was used to label and control the soil remediation.

For practical and logistical reasons, work was carried out in stages involving groups of cells. These groups of cells were called subgrades and were labelled sequentially. Figures 2 and 3 show subgrades for the FCC site overlaid on the main cell grid.

The soil remediation on the FCC sites involved initially characterising soil across the site by laboratory testing and visual assessment into the various categories relating to the SAC i.e. whether the material was compliant with the residential, open space or commercial criteria, or whether it required treatment to make it suitable for one of these categories. Pre-remediation sample results were used as an initial guide, backed up by more detailed sampling undertaken during the remediation. Decisions were then made on a cell by cell basis whether the material could be retained in-situ, used elsewhere on-site, treated and re-used on-site or had to be taken off-site for disposal. Soil was placed in temporary stockpiles relating to each category.

As noted above, the key contaminants of concern were considered to be organochlorine pesticides (OCP). Where OCP concentrations exceeded the commercial SAC and the soil was physically suitable for treatment, the soil was treated to reduce the concentrations below the commercial target criteria. The MCD soil remediation process involves the de-chlorination of organic compounds by the input of mechanical energy to the soil matrix in a ball mill. Additives such as iron, copper and nitrogen compounds were used in the process. Prior to treatment, the soil was screened to remove coarse fractions which were considered to be relatively free of contamination. These were generally recombined with the treated fine fractions prior to reinstatement.

Material removed from the excavation was characterised by laboratory testing, typically by pre-excavation testing of the in-situ soil. As soil was excavated, the extents of the excavation were tested to check for compliance with the relevant SAC. The excavations were then backfilled with material that was considered suitable for the proposed site use for that area i.e. based on the laboratory testing and geotechnical requirements. For example, FCC West was backfilled with soil that complied with the residential SAC. Material was imported to make up shortfalls in certain soil categories. The entire site was finally covered with at least 0.5m of residential quality soil (including the non-residential FCC Landfill and FCC East). The top 0.15 m of this layer consisted wholly of imported topsoil.

The approximate volumes of the various material categories generated or imported during the remediation were as follows (MWH, 2008):

- residential quality soil excavated and reused on site – 18,200 m^3;

- marine sediments excavated from the western and eastern foreshores and used as backfill on various parts of the site – 4,800 m^3;
- commercial quality soil excavated from site and used as backfill in FCC Landfill and FCC East – 27,500 m^3;
- soil treated using the MCD process and used as backfill in FCC Landfill and FCC East – 10,500 m^3;
- crushed concrete, buried on site – 2,000 m^3;
- imported gravels for backfill of marine sediment excavations – 5,000 m^3;
- imported residential soil – 5,800 m^3;
- imported topsoil – 5,300 m^3; and
- imported clay – 1,000 m^3.

As part of the treatment process, a number of reagents were added by EDL to the soil before it passed through the MCD plant. The reagents were made up variously of sand, diammonium phosphate, copper/iron based compounds and urea (PDP, 2007). It would appear that the discharge of the reagents to the site was not specifically covered in the consents granted for the remediation works.

3.4.4 Marine Sediment Remediation

Two areas of foreshore adjacent to the FCC site were included in the remediation (see Figure 1):

- the tidal beach of Mapua Channel, to the east of FCC East; and
- the tidal mudflats in the Waimea Inlet to the south of FCC Landfill, including a tidal channel that crossed the mudflats (the “swale”) . Also included was a section of the tidal creek along the north-west edge of FCC Landfill.

The extent of contamination at these locations was broadly defined by previous investigation results and additional sampling during the remediation works. Based on the pre-remediation results, a surface layer of contaminated sediment was excavated down to the low tide contour in FCC East. In the west, the creek (for most its length adjacent to the site), part of the foreshore and part of the tidal swale were excavated and backfilled. The removal of contaminated sediments was completed in a series of cells, each backfilled with imported gravels after validation sampling from the base of the excavation. The resource consent required that excavated cells were sampled and backfilled within one tide. Consequently, the excavations were backfilled before the validation test results were received.

3.4.5 Groundwater Monitoring

A number of groundwater monitoring wells along the southern and eastern boundary of the FCC site were monitored prior to and during the remediation as a condition of resource consent (see Figure 1). In addition, a number of private groundwater bores

located on residential properties to the south were also monitored. The samples collected from the wells were tested for a range of analytes to cover the potential contaminants of concern associated with the site.

4.0 Audit Process

4.1 Introduction

This audit has sought to:

(a) confirm the remediation was carried out as intended by the Remediation Action Plan (RAP);

(b) confirm that soil in the various areas complied with relevant SAC;

(c) confirm that groundwater complies with relevant SAC;

(d) confirm that the site (including the tidal areas of the Waimea Inlet and Channel) have been remediated to the extent practical and/or are fit for their future purposes; and

(e) confirm that the reporting (including the Validation Report and site management plan) contain adequate information for record and future management purposes.

In order to do this, the auditors must gain sufficient confidence that the actual condition of the site is essentially as claimed by the various reports and records. In order to gain such confidence, sufficient records must be examined to determine that:

- the remediation work was actually carried out as proposed and/or reported;
- validation sampling and testing was carried out in accordance with appropriate protocols and at an appropriate frequency (density) of testing for the various parts of the site. This is to determine both that the sample result can be trusted and that the sample is sufficiently representative of what is being tested;
- the results have been appropriately interpreted, including the use of statistical analyses;
- systems were in place to detect non-compliant results, that appropriate remedial action was taken in the event of non-compliance and that such action was recorded; and finally
- that proposed future management is appropriate to the site's condition and intended use

In the event that confidence was not gained on any aspects, the audit then sought to identify any deficiencies or gaps in information, assess the effect of those deficiencies or gaps on the final outcome and make recommendations for additional work to fill the gaps if appropriate.

The primary sources of information to guide the audit process were expected to be:

- the resource consent conditions relevant to the soil and water quality;

- the RAP[3], which should reflect the resource consent conditions and set out the detail of the remediation to ensure the remediation will achieve its intent. This would typically include monitoring of the remediation, validation testing and means of interpreting the testing;
- the Validation Report (a consent requirement) which should describe the actual remediation (or at least reference other documents that do this), summarise the results of testing, interpret the results relative to the requirements set out in the consent and RAP and determine whether the requirements were achieved, or not. The Validation Report should also record any variations from the RAP and non-compliance with mandatory requirements;
- a random sample of primary records such as daily site records, laboratory results and weekly or monthly reports;
- additional reports and other information to assess the condition of the groundwater and consider the impact of the various reagents used in the MCD process, as these were beyond the scope of the Validation Report; and
- various guideline documents, including MfE's Contaminated Land Management Guidelines No.1 – Reporting (which sets out recommendations for the contents of a validation report) and No.5 - Site Investigation.

4.2 Audit Progression

The audit commenced with an initial review of the following documents to gain a preliminary understanding of the remediation, and to determine the adequacy of the information presented for audit:

- the Assessment of Environmental Effects (AEE) for the remediation (T&T, 2003);
- the various resource consents covering the remediation works;
- the two basic versions of the RAP (Thiess, 2004 and MfE, 2005a) and a summary of changes to the RAP (MfE 2007). The 2005 version of the RAP contained various work plans, which themselves had also been revised several times in some cases; and
- the Validation Report (SKM, 2008)

It was immediately apparent that there was not a TDC (as the consent authority) approved RAP against which to judge the remediation. There were conflicts between the RAPs, and between different versions of work plans appended to the MfE RAP (particularly different versions of Work Plan 13 – Validation Sampling and Analysis, which set out the SACs and where and how samples were to be taken and the results interpreted). It was

[3] The consent required a RAP and Site Specific Project Management Plan containing subsidiary plans and procedures, but these were prepared as a single RAP document with various management plans and procedures in the body or appended.

not clear which RAP or work plan should be referred to. This makes it difficult for the Validation Report to do one of its jobs, which is to compare actual methods employed with the intention, and report any variation that might have significance for the success of the remediation.

In addition, it became apparent that the Validation Report did not contain a sufficiently complete description of the methods employed for the various aspects of the remediation to gain confidence that what was supposed to have been done had in fact been done. If it is not clear how sampling was carried out or whether the proposed remediation method was actually followed, there is a loss of confidence in the subsequent validation of the remediation. That was the case on first examination of the above reports.

It therefore became necessary to review a large volume of site records and consult individuals involved in various parts of the remediation. The additional information was sought to: clarify what was actually done; to determine whether what was done complied with the intentions as defined by the RAPs or, in the absence of an approved RAP, some other agreed document (e.g. record of acceptance of an approach recommended by the Site Auditor or Peer Review Panel); and to arrive at a judgement that what was actually done was satisfactory.

The key sources of additional information utilised were:

- a site visit and meeting with Jenny Easton of Tasman District Council (TDC);
- a meeting with Paul Russell and Juliet Westbury of MWH (the Site Engineer). Additional information was subsequently supplied by MWH as a result of the initial meeting;
- a meeting with Chris Purchas, Bruce Clarke and Philip Outram of SKM (the authors of the Validation Report). Additional information was subsequently supplied by SKM as a result of the initial meeting;
- a review of correspondence between the remediation Site Auditor (Peter Nadebaum of GHD, Melbourne) and MfE during the remediation works
- telephone contact with the Site Auditor;
- a review of a partially completed QA / QC document by EMS which was discovered in MfE records (EMS, 2007). This document sets out most of the actual methods employed during the remediation and provides discussion where the methods vary from the original Thiess RAP;
- a review of all monthly remediation summary reports prepared by EMS for MfE;
- a review of selected site records by EMS; and
- a review of additional monitoring of sediment, groundwater and biota undertaken by or for TDC at various times.

The audit conclusions have been arrived at by assessing the entire set of information reviewed. Where relevant, the specific source of information relating to a particular aspect of the audit is cited if the information is not contained in the Validation Report.

Key components for which extra detail was sought included:

- the adequacy of the sampling and analytical suites;
- the various validation sampling methods used;
- the tracking and control of the various material categories during the remediation;
- the quality assurance and quality control methods employed;
- the marine sediment remediation methods; and
- the validity of the various datasets and the statistical methods used to assess them in the validation analysis.

Instances where a perceived information gap could not be addressed are discussed in the section of the report relating to the missing information. Overall, the level of information finally reviewed was sufficient to support the audit conclusions. A list of documents reviewed is provided in Appendix B.

4.3 RAP Status

As noted above, it would appear that the RAP (and associated management plans) was not approved by the consenting authority, as required by Condition 9 of the various consents, due to parts of the RAP never being finalised. However, Condition 12 states:

> *To ensure flexibility in achieving the results for avoiding remedying or mitigating any adverse effects the provisions of the plans and work procedures submitted in accordance with Condition 9 shall not be conditions of this Consent provided however the Consent Holder shall not depart from the provisions of any plans submitted and approved in accordance with Condition 9 in a manner that any adverse effect caused by departure will be more than minor.*

In addition, Condition 13 states with respect to reporting to the TDC's Compliance Coordinator, the Site Auditor and the Peer Review Panel:

> *Where necessary, each of these parties can request a meeting of all the parties to discuss the activities of the remedial works and their compliance with consent conditions and to make recommendations for amendments of the Plans cited in Condition 9 to the Consent Holder.*

It would appear that the RAP was a "living document" that was updated from time to time. However, EMS (2007) in managing the site stated that MfE indicated in November 2006 that, until such time that a new RAP was approved, EMS was to follow the Thiess RAP dated July 2004 for validation. As noted below, this was not always the case as subsequent variations to the work plans were implemented by EMS on-site. SKM appears to have followed the Thiess RAP in preparing the Validation Report.

It is clear, however, that TDC approved variations from the original SACs, which were reflected in later versions of the RAP, including changes to the SACs for manganese and

nickel. There was also discussion between the Site Auditor and MfE on acceptance or otherwise of treated soil where the test result was within 2.5 times the SAC (as set out in the Thiess RAP). The conclusion was that it was appropriate to accept results up to 1.5 times the SAC for the treated soil, rather then 2.5 times the SAC, to ensure the average (calculated as the 95% upper confidence limit of the mean, or 95% UCL) remained within the SAC.

Given the changes throughout the remediation, for the purpose of this audit it has been assumed that the latest version of the RAP (MfE, 2005 and Work Plan 13, v3 dated 30 April 2007) provides the relevant criteria against which to judge the remediation. It is apparent from reviewing the various documents on the progress of the remediation, including the Site Auditor's recommendations, that at least with respect to most issues of importance to this audit (but not necessarily all issues), there was essential agreement by all parties.

There is an important exception; that of the requirement on the original RAP to split a percentage of samples for analysis in both the primary laboratory and an independent second laboratory. This was never carried out. The last version of the Work Plan 13 appears to have been written as a record of what occurred, i.e. post remediation sampling of FCC East, rather than what should have been a pre-determined programme of checks. This is considered in greater detail in Section 5.3.4.

5.0 Soil Remediation

5.1 Soil Acceptance Criteria

The original soil acceptance criteria (SAC) are set out in Attachment 1 of resource consent RM030521. During the course of the remediation, the SACs were altered slightly through reissue by TDC as follows:

- the manganese criterion for residential site use was increased from 500 mg/kg to 1,500 mg/kg to take into account high naturally occurring concentrations of this element in the region;
- for similar reasons, the nickel criterion was increased from 60 mg/kg to 600 mg/kg for residential site use and from 21 mg/kg to 70 mg/kg for marine sediments (TDC letter to MfE of 13 April 2007); and
- an additional category of 'topsoil' was added for the final 0.15 m of the capping layer. The only difference between the residential criteria and the topsoil criteria is the nickel criterion: 60 mg/kg for the topsoil category versus the revised 600 mg/kg for the residential category.

The final SAC associated with the resource consent were issued by TDC on 13 April 2007 and are set out in Table 1 below.

Table 1: Soil Acceptance Criteria as Applied

Substance	Residential[1] (mg/kg)	Topsoil[2] (mg/kg)	Open space[3] (mg/kg)	Commercial[3] (mg/kg)	Marine sediments (mg/kg)
Arsenic	30	30	200	500	20
Boron	3 (sol)	3 (sol)	6,000	15,000	
Cadmium	3	3	40	100	1.5
Chromium (III)	600	600	24%	60%	
Chromium (VI)	9	9	200	500	80
Copper	300	300	2,000	5,000	65
Cyanide (complexed)	20	20	1,000	2,500	
Cyanide (free)	50	50	500	1250	
Lead	300	300	600	1500	50
Manganese	1,500	1,500	3,000	7,500	
Methyl Mercury	10	10	20	50	
Mercury (inorganic)	1	1	30	75	0.15
Nickel	600	60	600	3,000	70
Sulphur	600	600	600	600	

Table 1: Soil Acceptance Criteria as Applied

Substance	Residential[1] (mg/kg)	Topsoil[2] (mg/kg)	Open space[3] (mg/kg)	Commercial[3] (mg/kg)	Marine sediments (mg/kg)
Zinc	200	200	14,000	35,000	200
Aldrin + dieldrin+10% lindane[5]	3	3	60	60	0.01
Chlordane	50	50	100	250	0.0005
DDT[4]	5	5	200	200	0.01
Heptachlor	10	10	20	50	
PAHs	20	20	40	100	
Benzo(a)pyrene	0.27	0.27	25	25	0.430
Phenol	40	40	17,000	42,500	
PCBs (total)	10	10	20	50	0.023
TPH C7-C9 C10-C14 C15-C36	 500 510 NA[6]	 500 510 NA[6]	 500 2,200 NA[6]	 500 2,200 NA[6]	

Notes:
1. Residential criteria do not apply to the top 0.15 m which should comply with the topsoil category.
2. Applies to the top 0.15 m of imported topsoil.
3. The commercial and open space criteria apply only to soil below 0.5 m depth. Surface soil should comply with topsoil and soil from 0.15 m to 0.5 m depth should comply with residential values regardless of end use/location.
4. Applied as the sum of DDT and its derivatives DDD and DDE (referred to as 'DDX').
5. The sum of aldrin, dieldrin and 10% of lindane is referred to as 'ADL'
6. NA indicates the criterion exceeds 20,000 mg/kg at which point residual separate phase is expected to have formed in soil matrix. Some aesthetic impact may be noted.

An additional set of criteria were also specified for DDX and ADL where soil was to be placed close to the foreshore areas, with the intention of creating a buffer zone. The criteria as set out in Condition 10(j) of the resource consent are set out in Table 2:

Table 2: Buffer Zone Criteria for Soil Below 0.5 m Depth (FCC East and Landfill)

Distance From Shoreline	Maximum DDX Concentration	Maximum ADL Concentration
3	40	12
10	120	40
15	200	60

5.1.1 Basis of the Site Acceptance Criteria

It is not the purpose of this audit to question the site acceptance criteria. The SACs were considered as part of the consenting process and deemed appropriate at that time. However, it is appropriate to give the background to derivation of soil guidelines in general, and the SACs in particular, as this affects later consideration of the long-term fitness for purpose of the land.

As noted earlier, risk arises through a receptor (e.g. a person, a marine organism, or a plant) being exposed to a contaminant through some exposure mechanism or pathway (e.g. direct contact or ingestion of soil, or through leaching of contaminants from soil and transport of that leachate to the marine environment). Different receptors have different susceptibility to effects of exposure and different exposure pathways have differing efficiencies in conveying the contaminant to where it may cause an effect. In selecting existing published values or deriving site-specific values to become the SACS, the most conservative combination of receptor and exposure pathway was chosen for what were considered to be relevant receptors (Egis, 2001).

This process is based on the site conceptual model, which is a summary of contaminants, receptors and mechanism of exposure. For Mapua, a number of receptors/exposure combinations were considered for soil, including (Egis, 2001):

- people using the site directly exposed to soil through dermal contact, inhalation of dust or vapour, soil ingestion and indirectly through consumption of produce grown in contaminated soil, where relevant. Exposure was considered for residential, commercial and parklands uses;
- transport of soil in stormwater runoff to the adjacent marine environment, with consideration of direct effects on marine organisms (principally mud snails), sensitive higher trophic groups within the estuarine food chain (birds) and people eating shell fish;
- leaching of soil contaminants to groundwater and subsequent exposure of marine organisms following discharge of the groundwater to the marine environment after dilution.

The SACs for the key OCP contaminants were derived specifically for the site (Egis, 2001). It should be noted that the “critical” or most sensitive exposure pathway/receptor combination for these SACs varies for DDX and ADL and between end use categories.

For DDX, the controlling pathway for the residential site use (SAC of 5 mg/kg) was determined to be sediment runoff effects on the marine aquatic ecosystem. The guideline value derived for protection of human health in a residential setting was over 20 times higher, at 110 mg/kg. It should be noted that a lower generic New Zealand guideline for DDX for the residential scenario use for DDX was derived some years after the site-specific derivation for Mapua (MfE, 2006). The value, 28 mg/kg, is about a quarter of the residential value derived by Egis (2001), but the value protecting marine

sediments is lower again and therefore protective of human health even if the lower residential value is applied. The more recent generic guideline has been used in this audit when fitness for purpose needs to be considered.

The controlling pathway for DDX for a commercial use (SAC of 200 mg/kg) was determined to be effects on groundwater (noting that the 0.5 m of capping surface soil in the commercial area still had to meet residential criteria to guard against sediment runoff effects). Again, the value derived for protection of human health was much higher at 650 mg/kg.

For ADL for the residential site use (SAC of 3 mg/kg), the human health and sediment runoff exposure pathways had similar derived values, with the value protective of human health being slightly lower and therefore the critical value. Similarly, for the commercial site use (SAC of 60 mg/kg), the human health and groundwater discharge to the marine environment exposure pathways produced very similar target criteria for ADL.

It should also be noted that the DDX and ADL criteria were derived by making a number of assumptions about dilution, infiltration and other factors. The Egis (2201) report noted the potential uncertainty in these assumptions by selecting a range where appropriate. Consequently, the SACs themselves were selected from within a range of potential estimates. They should not be viewed as precise numbers.

It should also be remembered that soil guideline values, and the SACs are no exception, are intended to be protective for chronic or long-term exposure. Short-term, or occasional, exposure at several-fold greater concentrations will not normally be of concern.

5.1.2 SACs and their Relationship to Fitness for Purpose

The basic conceptual model used in the derivation of the SACs and the approach to the derivation is appropriate. Consequently, in general, if the relevant SACs are complied with for a particular part of the site, then that part of the site is fit for its intended purpose. However, compliance with the SACs will not necessarily be protective of all potential site receptors. Exceptions are:

- direct ingestion of groundwater, as the derivation of the SACs for DDX and ADL do not appear to have taken this pathway into account (and effects on groundwater are greater than expected); and
- effects of groundwater discharge on the marine ecosystem, again because of greater than expected effects on groundwater, and uncertainties with respect to the hydrogeology.

The groundwater aspects are discussed separately in Section 7.0.

SACs were not derived for all the potential contaminants arising from use of reagents in the MCD treatment process. A problem was that there was no appreciation at the time of consenting that large quantities of copper (as copper sulphate) and diammonium

phosphate would be used in the MCD process. An SAC for copper was fortuitously included as part of a general heavy metal suite, but there were no SACs for nitrogenous compounds or phosphorus.

5.2 Chemical Analysis Requirements

The chemical analysis requirements for validation testing of soil were not specified in the resource consent, other than indirectly through defining the various SACs. It is normal that the RAP would specify the detail of analytical requirements, including analytical suites, sampling frequency/density and sampling methods. The analytical requirements in the original RAP (Thiess, 2004), and that set out in the Validation Report (SKM, 2008) were:

- 100% of samples for OCPs, including DDT and its derivatives and aldrin, dieldrin and lindane;
- 50% of samples for total petroleum hydrocarbons (TPH), volatile chlorinated hydrocarbons (VCH) and selected heavy metals (arsenic, cadmium, chromium, copper, cyanide, lead, manganese, mercury, nickel, selenium and zinc); and
- 10% of all samples for a suite specified in a New South Wales guideline (NSWEPA, 1998).

However, in late 2004 a revised analytical suite was agreed between TDC, the Site Auditor and MfE. The change was based on the results of an additional investigation (T&T, 2004) which provided greater confidence that the CoCs were DDT and its derivatives, aldrin, dieldrin and lindane. The altered suite was referred to in the monthly site report for December 2004 (MfE, 2004b) and it appears that it was implemented from this point forward. The suite was also confirmed in a memo from the Site Auditor to MfE in January 2005 (GHD, 2005a) and is referred to in the second version of the RAP (MfE, 2005a).

The remediation site managers (EMS) recognised the initial lack of clarity in specification of analytical suites and created a series of summary tables outlining the suites that were actually applied (EMS, 2007). The set of four tables summarise the testing requirements for commercial soil, residential soil, marine sediments and treated soil. The final analytical suites were:

- 100% of samples for OCPs;
- 50% of samples additionally analysed for total petroleum hydrocarbons (TPH), organophosphorous (OPP) and organonitrogen (ONP) pesticides;
- 50% of samples from selected areas, based on observations of hydrocarbon contamination, analysed for volatile organic compounds (VOC);
- 10% of samples analysed for VOC, a heavy metal suite (arsenic, cadmium, chromium (III and VI), copper, lead, manganese, mercury, nickel, selenium and zinc), hot water soluble boron, total cyanide, free cyanide, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and chlorobenzene.

A slightly different analytical suite was implemented for the treated soil in mid-2005 i.e. only applying to soil that had passed through the MCD treatment process. The suite was altered to take into account reagent use in the remediation process (as potential contaminants) and the processing rate. The suite was formally set out in an attachment to an email from the Site Auditor to MfE dated 25 July 2005 (GHD, 2005d). However, the suite was applied to the treated soil from 1 April 2005, as set out in a revised version of the RAP (MfE, 2005). The analytical suite for treated soil was then:

- a sample from every day's production and at least every 25 m^3 for DDX, aldrin, dieldrin and lindane;
- a sample from every third production day (or two per week) also analysed for copper, leachable nitrogen (using the synthetic precipitation leaching procedure – SPLP). This was reduced to a sample every second week after October 2006 (EMS, 2007);
- for every 200 m^3 (or every second week) a sample analysed for manganese, selenium and TPH; and
- for every 1,000 m^3 (or every 10 weeks) a sample analysed for VOCs, OPP, ONP, PCBs, PAHs and a suite of heavy metals (arsenic, cadmium, total chromium, copper, lead, manganese, mercury, nickel, selenium and zinc). PCBs were removed from this suite from 4 July 2005 onwards.

For some of the contaminants, the analytical method used does not directly match the corresponding SAC, and a direct comparison of the results against the criteria could not be made. In addition, analysis was not completed for a number of contaminants with SAC values. The following discrepancies were identified in the Validation Report (SKM, 2008):

- there are SACs for methyl mercury and inorganic mercury. However, the validation samples were tested for total mercury. This is not significant as almost all total mercury results were below both the individual methyl mercury and inorganic mercury SAC for the various end use categories. Thus, even if the 'total' result was made up entirely of either methyl mercury or inorganic mercury, it still would have complied with the relevant SAC. The only exception to this was a single result from the marine sediment excavation in the west. This is discussed separately in Section 5.4.6 below;
- there are SACs for free and complexed cyanide, the lower value being for complexed cyanide[4]. However, total cyanide was analysed rather than complexed cyanide. Comparison of the total value against the complexed guideline for

[4] It should be noted that the residential SAC for free and complexed cyanide in the consent are the reverse of the values in the source document (RIVM, 2001). This apparent error had no effect on result interpretation as the cyanide concentrations were sufficiently low.

residential use is conservative. In any case, the maximum total cyanide concentration detected in all samples of 6.4 mg/kg was well below the complexed cyanide SAC of 20 mg/kg;

- no validation samples were analysed for sulphur or phenol, both of which are included in the SAC list. This is not a significant information gap as the previous investigations indicate that neither of these contaminants are likely to be of concern on the site; and
- many of the marine sediment SAC are based on the ANZECC 'ISQC-Low' marine sediment values (ANZECC/ARMCANZ 2000). This document requires the analytical results to be normalised to 1% total organic carbon (TOC). However, this could not be completed as TOC was not included in the analytical suite. This is conservative as the likely high organic content of the marine sediment would result in higher target criteria.

Based on the history of chemical usage on the site and the results of the various investigations undertaken to characterise the site, we consider that the analytical suites implemented were generally suitable for the purpose of validating the remediation. The use of an analytical regime with a variable sampling frequency depending on how likely it is that a particular analyte will be encountered at elevated concentrations is appropriate.

There is no doubt that the OCPs were the primary contaminants of concern and warranted frequent analysis. However, the decision to reduce the frequency of heavy metal analysis warrants some scrutiny.

The site history prepared by Woodward-Clyde (1996) mentioned production of organo-mercury compounds and storage of lead arsenate. It is not known (or at least not recorded in the documents reviewed) where these activities occurred. The main concern for heavy metals is in near surface soils in a residential setting (i.e. FCC West). The less intense exposure in an open space setting and the ability to manage exposure in a commercial setting means heavy metals are less of a concern for those uses. While every site is different, heavy metals typically bind to soil and are frequently not of great concern for groundwater contamination and subsequent discharge to the marine environment.

Residential quality soil was sourced from both FCC East, where much of the former manufacturing and storage historically occurred, and from FCC West, where less intense manufacturing and storage occurred but still had potential for spillages to occur. As a manufacturing and bulk storage site for concentrated chemicals, spillage could result in very high localised contamination. The issue then is whether sufficient investigation was initially carried out to have a good chance of detecting heavy metal contamination and whether the subsequent follow-up validation was at a sufficient frequency to confirm the decisions made from the initial sampling. The following sampling was carried out:

- 65 samples were analysed in the Woodward-Clyde 1992/3 investigations (Woodward-Clyde; 1992, 1993), including six from the Mintech part of the site. The samples were collected as five sub-samples from each location, which were

then composited and analysed. The samples represented a depth range of 0 to 500 mm.

The results generally showed an absence of high metal concentrations. However, the sampling was fairly limited at some of the locations where spills might be expected to occur, i.e. manufacturing and storage locations.

- 21 samples were analysed in the T&T baseline study (T&T). Again the results showed only low to moderate contamination from heavy metals.

The relatively sparse level of sampling means that hotspots could have been missed. If the hotspot had high enough concentrations it would not be guaranteed to receive sufficient mixing during material handling to ensure that it would be below residential guidelines[5] after backfilling. However, mitigating factors are as follows:

- during the remediation, the majority of the surface around former process areas, which are the most likely areas for heavy metal contamination, was removed to or remained on FCC East, either as commercial quality soil or following treatment for OCP contamination. In many cases, this surface stripping was to a depth of 1 m;
- a relatively small proportion of the residential quality soil mined and then used as backfill was used as capping soil on FCC West. Most was either used as capping material on FCC East or buried more deeply in FCC West, reducing the likelihood of any excessive contamination being near the surface;
- the residential soil is capped with clean topsoil, reducing the exposure to deeper soil;
- the validation sampling (see Section 5.6.2), found at most only slightly elevated metal concentrations, although the sampling frequency was only 3% of the primary samples; and
- additional test data for 25 post-remediation samples of residential backfill on FCC West showed low concentrations of arsenic, lead and mercury (see Section 5.6.2.1). These samples increase the frequency for these contaminants (the most likely metals to be of concern) to 9% of the primary samples for the residential backfill.

In summary, the decision to reduce the frequency of heavy metal analyse to only 10% of all samples increased the risk of missing a hotspot. However, the subsequent execution suggests that the risk of excessive concentrations of heavy metals in near surface soil is low, although the absence of such a hotspot cannot be absolutely guaranteed. No further work is required.

[5] Incidental mixing during mining, stockpiling and backfilling might reasonably be expected to achieve up to two or three-fold dilution, but beyond that would require deliberate mixing.

The information reviewed otherwise confirms that the actual analyses are broadly in line with the intentions. Other exceptions are discussed further against individual material types in subsequent sections.

5.3 Confidence in Data Quality/Laboratory Analyses

5.3.1 Introduction

The reporting on data quality provided in the Validation Report is limited. In addition, some of the procedures implemented during the project have not always been ideal. The aspect of the remediation that is most sensitive to this is the compliance of residential soil with the DDX and ADL criteria. While there is sufficient confidence in the data quality to conclude that the conclusions arrived at in the Validation Report are probably valid, there are specific instances where confidence in the data quality is reduced. Other information has been relied on to provide additional confidence. Instances where the methods employed have the potential to influence the quality of the specific datasets are discussed in Section 5.4. General aspects of the data quality are discussed below.

5.3.2 Sampling Techniques

Overall, we have confidence that the soil and marine sediment sampling was undertaken in a professional manner, using methods consistent with accepted industry practice. The RAP (regardless of version) and the EMS quality assurance document (EMS, 2007) specified appropriate sampling techniques. The RAP (regardless of version) required that the sampling be carried out in accordance with AS 4482.1-1997 *Guide to the Sampling and Investigation of Potentially Contaminated Soil* (SA, 1997). The EMS quality assurance document (EMS, 2007), confirms the methodical and consistent approach employed for the validation sampling. A review of a sample of site documents suggests the methods set out in the EMS document were in fact followed.

A factor providing additional confidence were the people involved. The two principals of the company that supervised the remediation and carried out the sampling (EMS) were very experienced environmental professionals. One had over 25 years experience with remediation projects, including eight years managing a field operations team at the United States Environmental Protection Agency (USEPA). This role included training staff in sampling techniques, field analysis, environmental monitoring and remediation technology. The other EMS principal had a similar length experience in environmental clean-up projects. Site Auditor notes and anecdotal reports suggest that the field practice typically exceeded the written requirements.

In terms of the number of samples taken, there seems to have been a philosophy on the part on the part of the EMS team of taking extra samples (at least for OCPs) to build confidence in the validation, rather than trying to keep sampling to a minimum. An example of this is the decision by EMS to validate the extent of the FCC East at a higher

density than the original RAP intention. Thus, the general scope of sampling is adequate for the validation purposes. Any exceptions to this have been discussed in Section 5.4.

5.3.3 Laboratory Analyses

In general, the analytical methods used during the remediation are suitable for characterising the site.

The key exception to this relates to the detection limits for DDX and ADL analyses, which are relatively close to the residential SACs in some cases. This is not discussed in the Validation Report. It appears that different detection limits were applied to different parts of the site for the DDX and ADL analyses as follows:

- for testing on FCC East a laboratory detection limit of 1 mg/kg for each individual OCP was typically employed;
- for FCC Landfill a mixture of 0.5 mg/kg and 1 mg/kg detection limits were employed; and
- for FCC West a detection limit of 0.5 mg/kg was employed.

The result of this is the effective detection limit for ADL is 2.1 mg/kg for the samples with a 1 mg/kg base detection limit (i.e. the sum of the detection limits for aldrin and dieldrin and 10% of the lindane detection limit). Similarly, an effective detection limit of 6 mg/kg results for the DDX summation (i.e. a sum of the 1 mg/kg detection limits for the six individual isomers). For the commercial SACs for ADL and DDX of 60 mg/kg and 200 mg/kg, this is acceptable as the detection limits are well below the target criteria. However, these effective detection limits are close to or slightly above the corresponding residential SACs for ADL and DDX of 3 mg/kg and 5 mg/kg respectively. Consequently, in some circumstances, there could be a significant uncertainty as to whether samples with ADL and DDX concentrations below the detection limit actually comply with the residential SAC.

This uncertainty applies when material remaining on FCC West has been classified using the coarser detection limit of 1 mg/kg for the DDX and ADL analyses. This appears to have occurred only for residential material that was sourced from FCC East and the FCC Landfill. Consequently, the only dataset affected by the high laboratory detection limits is that for the validation results for the residential backfill material. While the use of laboratory detection limits of a similar magnitude to the SAC is not good practice, there are the following mitigating factors in this case:

- Of the approximately 400 samples representing residential soil mined from FCC East and FCC Landfill, only about 15% were analysed at the 1 mg/kg detection limit. The remainder were analysed at a detection limit of 0.5 mg/kg or lower. A detection limit of 0.5 mg/kg is acceptable, although not ideal;
- for the samples analysed with the lower detection limit of 0.5 mg/kg, approximately only 5% of the samples had aldrin, dieldrin or lindane concentrations above the lower detection limit of 0.5 mg/kg. This gives greater confidence that samples that

were analysed with the 1 mg/kg detection limit are also likely to be below the 0.5 mg/kg limit, resulting in ADL concentrations below the SAC of 3 mg/kg. This also gives reasonable confidence that the average concentration of this dataset will be below the SAC;

- there appears to be a reasonably consistent ratio between the six different isomers making up the DDX sum, for concentrations close to the residential SAC. The 4,4 DDT isomer consistently makes up the greatest proportion of the DDX total. The isomers 2,4 DDT, 4,4 DDE and 4,4 DDD are typically each a third or less of the 4,4 DDT concentration. The concentrations of the 2,4 DDE and 2,4 DDD isomers are consistently less than a tenth of the 4,4 DDT concentration. Consequently, if the concentration of the 4,4 DDT isomer is less than 1 mg/kg, there will be reasonable confidence that the DDX sum will also be below the residential SAC of 5 mg/kg;
- the residential SAC of 5 mg/kg for DDX is based on sediment runoff effects. However, this exposure pathway is less relevant for the residential soil with the expectation that the future site will be paved, covered in buildings or well vegetated, with the additional barrier of 0.15 m of imported topsoil. As discussed in Section 5.1.1, a potentially relevant human health value of 28 mg/kg (MfE, 2006) is much higher and the higher than desirable detection limit is of less concern.

Overall, while the use of detection limits close to the target criteria is not good practice, it is acceptable in this case.

5.3.4 Quality Assurance and Quality Control

The general level of quality assurance and quality control procedures implemented during the remediation is considered to be good, if not always well documented. The main exception to this relates to the analytical QA/QC. The level of documentation of the QA/QC procedures provided in the Validation Report is limited:

- no details are provided in the Validation Report on the compilation of the datasets and what checks were made to ensure they are both complete and do not have results that do not belong in the particular dataset. The latter is particularly important for sample results for excavated material, as at the time of sampling it was not known which dataset of various potential material types the results would belong to;
- no statement is made in the Validation Report that the data has been transcribed correctly into the tables and the spreadsheets or formulas used have been independently checked; and
- no comment is provided on the process to identify invalid data, or details of any data that have been rejected.

Additional documentation would have increased confidence in the conclusions.

5.3.4.1 General Site QA/QC

The Mapua remediation project was complex and involved generating and handling a large amount of data. Similarly, the project required accurate tracking of the various categories of material generated during the works. The general QA/QC procedures employed during the remediation are outlined in the EMS QA/QC document (EMS, 2007). A review of site documents indicates that the intended procedures appear to have been implemented as intended. The detailed and methodical approach gives confidence in quality of the remediation works.

5.3.4.2 Analytical QA/QC

The resource consent did not require soil samples to be analysed by an accredited laboratory but required all water samples to be analysed by an IANZ (International Accreditation New Zealand) accredited laboratory. All versions of the RAP required IANZ accreditation for all samples.

EMS (2007) reports that MfE initially planned to use the EDL site laboratory in Mapua to analyse the soil samples (and may have been used for early samples). However, following a comparison of split samples carried out by EMS in November/December 2004, Hill Laboratories, an IANZ accredited laboratory based in Hamilton, was engaged by MfE to analyse the soil samples (EMS, 2007).

The resource consents and the RAPS were silent on the analytical methods to be used. We have examined a sample of laboratory reports and are of the view that the analytical techniques employed by the laboratory were appropriate (subject to the comments on detection limits in Section 5.3.3).

No summary of the internal laboratory QA/QC procedures is provided in the Validation Report. The Ministry for the Environment's Guideline No 1 recommends reporting of these in a validation report, with an analysis of the data. However, the laboratory reports provide no information on internal laboratory QA/QC, such as results for laboratory duplicates, spikes and blanks, with associated percent recoveries, to allow such reporting. This is not unusual for New Zealand laboratories, which will often only provide internal QA/QC on specific request (at an additional cost). It is understood the laboratory followed the usual internal QA/QC for an IANZ accredited laboratory.

There is reference to QA/QC requirements for the laboratory analyses in Site Auditor correspondence during the remediation works. An early recommendation was made to analyse 10% of samples as split duplicates at a separate laboratory to check on data precision for the main laboratory. In the Thiess RAP (Thiess, 2004) QA/QC samples were to be taken in accordance with the AS 4482.1-1997. AS 4482.1-1997 recommends testing of split samples at a second laboratory at a rate of 5% of the primary samples. However, early versions of the MfE RAP (in Work Plan 13) refer to samples being taken at some unspecified rate less than 5%. This was not carried out.

To retrospectively address the lack of analytical QA/QC data, a set of soil samples was collected from the reinstated FCC East in April 2007 for testing for OCPs, TPH, various forms of nitrogen and a suite of ten heavy metals. This is presumably reflected in the April 2007 update of Work Plan 13 of the MfE RAP, which states:

> *QA/QC requirements under the standard AS4482.1, including duplicate laboratory comparisons, will be met through a dedicated sampling program designed and approved by the Site Auditor.*

This type of single-event QA/QC sampling was not undertaken regularly during the project and no similar sampling has been undertaken for the residential soil on FCC West.

The sample splits for the inter-laboratory comparison were prepared in the field by EMS. This is not the recommended practice, with sample splits normally being prepared by the primary laboratory. EMS homogenised the samples in the field by mixing with a trowel on a board and then using the trowel to split the sample. Samples for TPH analysis were not mixed before splitting.

The samples were sent to the laboratory of MGT Environmental Consulting in Victoria, Australia, a NATA (National Association of Testing Authorities) accredited laboratory. NATA is the Australian equivalent of IANZ and there is mutual recognition between the two accreditation schemes.

The details of this sampling programme are set out in the Validation Report (SKM, 2008). The main aims of the additional sampling were to:

- the confirm that the contaminant concentrations in the different categories of material used as backfill in FCC East were in line with the expected concentrations i.e. based on the original validation data; and
- to check the reliability of Hill Laboratories by analysing a number of split duplicate samples at a separate laboratory.

The Validation Report provided an analysis of the QA/QC sampling but did not arrive at a conclusion as to whether the results were satisfactory. Unfortunately, the Validation Report comparison of the results from the two laboratories for ADL was incorrect as an error was made by SKM in calculating aldrin+dieldrin+10% lindane for the primary samples (SKM, 2008). This error resulted in an apparent systematic under-reporting of ADL concentrations by Hill Laboratories i.e. non-conservative.

It is debatable whether in fact such a calculation should have been made for ADL and DDX, rather than comparing each compound separately, as the laboratories reported the individual compounds. Regardless, we have examined the DDX and ADL results from the two laboratories and are satisfied that for these particular samples the correspondence was satisfactory for soil samples.

An equivalent sampling programme has not been undertaken for the residential quality soil. This is not such a concern for the ADL compounds as many of the results in the FCC QA/QC samples were of a similar magnitude to the residential SAC for ADL.

Consequently, the conclusions drawn are likely to also apply for residential quality soil. This is not the case for DDX where the concentrations in the split duplicate samples were much higher than the residential SAC of 5 mg/kg, thus there is limited data at lower concentrations.

There are five inter-laboratory data points in the range of 25 to 35 mg/kg, which is close to a relevant human health guideline of 28 mg/kg for DDX (MfE, 2006). These show a reasonable correlation between the laboratories for this concentration range, although the secondary laboratory returned a concentration twice the primary laboratory for one sample. This could be a result of less than ideal preparation of the split samples. The other four samples showed much closer correlation. Overall, the dataset at these concentrations is too limited to draw firm conclusions.

The laboratory results from the primary laboratory did not have any results below the detection limit. However, there are results for individual ADL components of less than 0.2 mg/kg (and non-detects of other than DDX or ADL compounds at <0.01 mg/kg). This suggests that the screening method used throughout the project (with a detection limit of either 0.5 or 1 mg/kg) was not used by the primary lab for the inter-laboratory comparison. The inter-laboratory comparison was therefore not a good test of the precision of the DDX analysis actually employed to assess compliance with the residential SAC.

Greater confidence would be gained by repeating the QA/QC sampling on residential soil, with the primary laboratory using the same method (and detection limits) used for the routine testing.

5.3.5 Data Handling and Statistical Analysis

The information provided by SKM in the Validation Report on methods used for data handling and statistical analysis is limited. The following general comments are made:

- how non-detect results have been dealt with in calculations has not been discussed. From the spreadsheets it is apparent that a value of half the detection limit has been substituted for non-detect results. This is common practice where the proportion of non-detects is not too large. However, for a number of the datasets presented in the Validation Report, the percentage of non-detects is high, sometimes over 90%. In this case, a 95% UCL using values of half the detection limit is statistically meaningless. However, this is unlikely to change the conclusion i.e. the 'average' for the dataset is still likely to be below the SAC (assuming the detection limit is low enough relative to the criterion);
- there is no discussion on the various laboratory detection limits applied and how these relate to the SACs (see Section 5.3.3 above); and
- use of 95% UCL estimates for the mean is an accepted way of evaluating environmental data. However, SKM routinely assumed the datasets were log-normally distributed yet many, if not most, of the datasets are not log-normally distributed. The assumption of log-normal distribution is a common but often

incorrect assumption for left-skewed environmental datasets. No attempt was made to check whether the data followed particular distributions, by plotting histograms Q-Q plots or carrying out statistical goodness of fit tests. In addition, no identification of outliers is reported. Reanalysing some of the datasets[6] showed that nonparametric estimates for the 95% UCL was more appropriate than assuming a log-normal distribution, with the estimate being higher than if log-normality was assumed. However, the critical DDX and ADL datasets were often large and the differences in estimates are not so great as to arrive at a different conclusion. For example, goodness of fits test shows the 1798 member dataset for commercial soil does not follow normal, log-normal or gamma distributions and returned nonparametric 95% UCL estimates for ADL and DDX of 6 and 57 mg/kg, respectively. SKM calculated values of 5.4 and 79.3 mg/kg assuming log-normal distributions.

In considering the various datasets, the statistical analyses in the Validation Report are only referred to in some cases. Where data summaries from the Validation Report have been used, comment on the applicability of these is provided as required.

5.4 Management and Validation Sampling Procedures

There were two main types of sampling undertaken on the site:

- site management sampling; and
- validation sampling.

Site management soil samples were collected to enable decisions on how a particular batch of soil was to be handled e.g. if it required treatment or could be reused on site as commercial or residential soil.

The purpose of the validation samples was to demonstrate that the site/material complied with the SACs. In many cases samples originally taken as site management samples became validation samples. This was the case for all soil that was defined as either commercial or residential soil on the basis of the management samples. Soil placed in stockpiles was not generally tested again before being used as backfill unless there was concern about a particular batch of soil placed in a stockpile. Soil taken from stockpile and placed as backfill was also not generally tested in-situ after placement. Thus, the original site management samples taken during excavation of soil that was later placed as backfill without further treatment are, in effect, validation samples.

Because the stockpiles were large, it is not possible to track the soil that a particular sample represented to its final resting place. In the absence of post-placement testing, the stockpile being generally compliant must therefore be relied on. The best that is

[6] using ProUCL4, software developed by the US EPA specifically to test and analyse environmental data sets (US EPA,

known is that soil of a particular type at a particular location should have concentrations somewhere in the range of concentrations of the samples representing the soil placed in the stockpile. This is an acceptable approach provided the frequency of sampling during excavation is adequate to properly represent the soil in the stockpiles. This was the case in general, as is described further below. Additional confidence arises because mixing of soil occurs during the process of original excavation, stockpiling, re-excavation from the stockpile and placing as backfill, resulting in an averaging of concentrations (and in theory a narrower range about the average, if good mixing has occurred). However, this incidental mixing will not be sufficient to average out extreme hotspots, but could result in up to two to three-fold reduction of high concentrations (and similarly raise the minimum concentrations towards the mean).

Where the sampling showed that the base or sides of the excavation complied with SACs, meaning that no further excavation was required at the location, then these samples also became validation samples for the base and sides of the excavation in the particular location.

Samples that showed the particular material could not be reused without treatment are not validation samples, but simply management samples. Such samples should not be part of the validation dataset.

For each different category of material, a different sampling strategy was employed to determine the frequency and type of sampling for that material. The results of that sampling generated a representative dataset for each material category. Those datasets were then compared by EMS with the SACs to determine compliance.

5.4.1 Sampling of Excavated Materials

In almost all cases soil was categorised by in-situ testing (site management sampling). As discussed earlier, the site was divided into 15 m by 15 m cells, which were further divided into vertical layers (Section 3.4.3). Testing was carried out for each individual layer from each cell to enable categorisation. Testing of excavated stockpiles was generally only undertaken to confirm the in-situ testing or if there was some uncertainty about the classification of soil.

For FCC East and the Landfill, the original RAP intention was that at least one composite sample be taken from each 15 by 15 m cell layer. However, based on professional judgement, EMS typically took four composite samples per cell layer, i.e. the RAP requirement was exceeded. The cell was divided into four 7.5 x 7.5 m ‘quadrants’, with one composite sample collected per quadrant Each composite was made by further dividing the quadrant into four sub-quadrants and taking a sub-sample from the centre of the sub-quadrant (EMS, 2007). Where the cell also contained a wall, at least one composite sample was taken from each layer of each wall of the cell. Each wall composite sample consisted of four sub samples approximately equally distributed along the wall.

For the more sensitive residential end use of FCC West, a 7.5 m grid was applied from the start and a composite sample made up of four sub-samples collected from the base of each 7.5 by 7.5 m cell. For walls in FCC West the same general sampling philosophy as that adopted for FCC East and Landfill was applied to the decreased grid size.

Based on the in-situ results, a decision was then made on whether that cell layer required treatment or could be re-used on site as commercial or residential quality soil.

For various materials generated during the remediation and re-used on the site, the frequency of validation sampling was specified in the RAP on a volume basis. In almost every case, more samples were taken than the original intention. However, in some cases the sampling frequency that was actually applied is not clear.

The intended sampling frequencies for the various materials are understood to be:

- residential soil – to be sampled every 100 m^3 for the main analytical suite and correspondingly greater volumes for the 50% and 10% suites. There was also a requirement in the original RAP (Thiess, 2004) that the soil be sampled every 25 m^3 if sourced from a cell adjacent to a cell that exceeded residential criteria. The latter sampling frequency appears to have been implemented by default for residential soil sourced in FCC East and Landfill by the EMS decision to take four samples per cell layer (EMS, 2007);
- commercial soil – to be sampled every 100 m^3 for the main analytical suite;
- crushed concrete – a 'representative' sample;
- oversize (>10 mm) – a representative sample of the fine material adhering to oversize material, analysed for OCPs.

5.4.2 Sampling of Treated Soil

The soil to be treated was screened prior to treatment to remove coarse fractions. An initial screening removed material above 10 mm, with a second screening to separate the 5 – 10 mm fraction after the soil had passed through a drier. The fraction less than 5 mm was then treated (EDL, 2007). The resultant treated fines (which were ground to dust during the treatment) were sampled on a daily basis and analysed for the suite of contaminants set out in Section 5.2 above. The daily production volumes were lower than anticipated so the sampling frequency was much greater than the minimum of 1 per 25 m^3 specified in the analytical protocol. Average daily production was approximately 12 m^3 (TDC, 2009a).

Nine samples were collected from the 5 – 10 mm component created during the treatment process, although no testing frequency was specified in the RAP documentation.

At the outset of the remediation, there was some difficulty in finding a suitable method to determine whether the treated soil complied with the SACs. Initially, the basis for acceptance was that the 95% upper confidence limit (UCL) of the mean for a particular

analyte should be less than the relevant SAC, with no individual result being more than 2.5 times the SAC. However, there were not enough sample results initially to create a meaningful 95% UCL. Consequently, on the recommendation of the Site Auditor, the compliance assessment was altered to a rolling six day average, with no single result allowed to exceed 1.5 times the relevant SAC (GHD, 2005d). This was expected to result in a 95% UCL less than the SAC, whereas a rolling average with the 2.5 factor risked not achieving the necessary standard. The approach was a pragmatic solution and appears to have worked well. The compliance of the treated soil with the SACs is discussed further in Section 5.7.3.3.

5.4.3 Sampling of Imported Materials

During the course of the remediation, significant quantities of material were imported to site for use as backfill in different parts of the site. The following materials were imported (approximate volumes are taken from the volume balance diagram (MWH, 2008):

- 5,300 m^3 of topsoil to complete the 0.15 m capping layer across the entire site;
- 5,800 m^3 of residential quality soil to make up a shortfall of this material;
- 5,000 m^3 of sand/gravel used as backfill for the marine sediment excavations;
- 1,000 m^3 of clay for the bund and surge chamber backfill; and
- 430 m^3 of sand/gravel that was imported as backfill for the marine excavations which was subsequently used as residential soil due to unacceptably high test results.

Overall, the test results that are available indicated that the various materials imported during the remediation are likely to comply with the relevant SAC. However, the level of information presented in the Validation Report (SKM, 2008) is limited, with sources and volumes from each source not generally given. Ideally the information for each source of imported material would include:

- a brief description of the source and type of material, and the historic potential for contamination at the source site;
- the total volume used;
- the type and number of validation samples taken for the material, with a summary of the results; and
- the final destination of the material.

A more detailed level of information on the imported soil would have enabled greater confidence to be placed on the conclusions that the material is suitable for its intended uses. The data presented in the Validation Report has been grouped into material categories and is not specific to each source. In this case the omission is not significant.

5.5 Test for Compliance with SACs

The resource consent does not state how compliance with the SACs is to be determined in a statistical sense. The different versions of the RAP and Work Plan 13 attempt to define compliance requirements. The original RAP (Thiess, 2004) stated that cell results comply if the cell mean is below the relevant SAC and no individual result exceeds the SAC by a factor of 2.5. It appears that the factor of 2.5 was also intended to apply to batches of commercial and residential material won on-site, although this is not clear. The subsequent MfE (2005) RAP reduced the exceedance factor to 1.5 and applied this to all material categories. It is unclear what was actually applied on site for cell results.

The basic approach of using an average and maximum when assessing compliance with target criteria is common in contaminated site work and is appropriate. The average concentration is used to determine general compliance with the target, and the maximum concentration is imposed to ensure that localised hotspots of contamination are not likely to cause adverse effects. It appears that the original factor of 2.5 was taken from an Australian guideline (NEPC, 1999b) which requires that no single value exceeds 250% of the health-based target criteria. As discussed in the previous section, the factor of 1.5 was initially introduced as a means of ensuring the 95% UCL for treated fines complied with the treated fines SACs.

In most cases, no definition of 'average' was given and it is assumed that the average was to be the arithmetic mean of whatever dataset was being assessed e.g. individual cell or the six day average for treated fines.

The Validation Report (SKM, 2008) used the original Thiess (2004) RAP factor of 2.5 when assessing compliance of the maximum values of each dataset with the SAC and a 95% UCL to determine overall compliance. The use of a 95% UCL is accepted industry practice to provide a conservative estimate of the average concentration of a dataset.

For the purposes of this audit, while the SKM analysis using the 2.5 factor has been considered, the factors of 1.5 and/or 2.5 have not been rigorously applied when assessing compliance. These factors were originally intended for 'site management' purposes when assessing individual cells or other small datasets and do not necessarily apply when assessing the larger combined datasets. Instead a case-by-case judgement has been applied to SAC exceedance depending on the relevant receptors and exposure pathways. For example, the basis of the original 2.5 factor relates to human health effects and assumes direct exposure to the contamination. Many of the SAC are not based on human health exposure and individual exceedances are typically less critical for other exposure routes, as the exposure mechanism (transport in groundwater or runoff of sediment) has an averaging effect. Similarly, if human health is relevant, but the material is buried and not immediately available for contact, then occasional large exceedances may not be significant.

In auditing compliance, the data have been compared directly with the SAC to determine initial compliance. The significance of any exceedances is then discussed in the context of that particular dataset and relevant receptors. The statistical analyses of the datasets

provided in the Validation Report have been used to assist in this assessment (SKM, 2008), taking into accounts the limitation of using log-normal distributions where relevant. Where most results are non-detects and the detection limit is suitably low, compliance can generally be judged by direct examination, rather than resorting to statistics (which may be meaningless if there are large number of non-detects) as compliance is obvious.

5.6 FCC West Remediation

5.6.1 Validation of FCC West Excavation

Soil within the FCC West area was required to comply with the residential/topsoil SACs. During the course of the remediation, all of the approximately 17,000 m^2 of FCC West was excavated. The cell and subgrade arrangement is shown in Figure 3.

5.6.1.1 Frequency of Excavation Analyses

Overall, the density of sampling for the FCC West excavation validation is adequate. A total of 652 samples were taken from the extents of the FCC West excavation. This number of samples is enough to fulfil the RAP intention of one sample from each cell floor and wall layer, assuming the distribution of samples is even between cells. SKM undertook a check of records to ensure that at least one OCP sample had been collected from each cell floor and wall layer.

All 652 samples were analysed for DDX and ADL, with 264 of these (40%) also analysed for the full OCP suite. Approximately 286 samples (44%) were analysed for TPH and 270 (41%) for ONP, OPP and VOCs. A total of approximately 55 samples (8%) were analysed for heavy metals PAHs, and PCBs.

The frequency of analysis of secondary contaminants is less than required by the RAP. This is not significant in this case as sufficient confidence exists that the other contaminants are not generally of concern. The concern expressed in Section 5.2 regarding sufficient numbers of metals analyses is less relevant for the base of excavations, as people do not typically have frequent exposure to sub-surface soil, particular for depths greater than 0.5 m.

5.6.1.2 Excavation Compliance with SACs

The Validation Report states that 56 of the 652 samples taken from the FCC West excavation extent had concentrations above the SAC (SKM, 2008). However, none of these exceedances are significant, as discussed below. The Validation Report also stated that 95% UCL values for all contaminant were below their respective SACs. As noted earlier, some of the 95% UCL calculations will be of dubious statistical validity. However, in this case the overall conclusions are not affected and it is accepted that mean values will be below the various SACs.

The highest DDX and ADL results were all from samples taken along the western edge of Tahi Street. This area is actually outside the proposed residential area and it is not appropriate to compare the results with the residential criteria as it will form the road verge. If the 17 samples elevated results from beneath the road verge are compared with the more appropriate commercial SAC, only one sample exceeds the criteria.

Sample 8474 was taken from the wall of cell L16 and had an ADL concentration of 137 mg/kg, above the SAC of 60 mg/kg. However, additional information from MWH indicates that six validation samples from the eastern wall in L16 all returned concentrations below the SAC, with a maximum ADL concentration of 14 mg/kg (MWH, 2009d). It appears likely that this sample represents material that was removed and should not be included in the validation dataset. TDC gave its approval to leave the soil beneath the road reserve in a letter dated 10 September 2007 (TDC, 2007b).

Removing the elevated results beneath the Tahi Street verge from the dataset for the FCC West excavation leaves 39 samples exceeding the SAC. Of these, 33 of the exceedances related to DDX failures, with a maximum concentration of 41 mg/kg. Most of the elevated concentrations were below 10 mg/kg DDX. Many of the exceedances relate to samples which were retested, returning different concentrations to the original test results. However, even assuming that all the peak results represent actual residual concentrations, the exceedances are not significant.

The DDX criterion of 5 mg/kg for residential site use relates to the sediment runoff exposure pathway. This pathway is not relevant for the excavation extents as the entire area is covered in at least 0.5 m of residential soil. The next most sensitive pathway is human health. All results comply with the SAC for human health and most results comply with the lower more recently derived generic value (MfE, 2006). Exceedances of the generic value at depths greater than 0.5 m are acceptable.

None of the remaining six SAC exceedances are significant. These were:

- a single cadmium result (22 mg/kg) exceeded the residential SAC of 3 mg/kg. However, this SAC is not significant as it is based on potential phytotoxic effects and the sample represents soil currently over 1 m bgl where effects on plant growth are unlikely. The criterion is based on the Australian National Environmental Protection Council values (NEPC, 1999a). The equivalent NEPC human health-based value for residential site use is 20 mg/kg[7].
- two results exceeded the SAC for C_{10}-C_{14} TPH of 510 mg/kg, with results ranging from 570 – 660 mg/kg. This criterion is from the Hydrocarbon Guidelines (MfE, 1999) and is a surrogate for PAH contamination associated with diesel. The

[7] Other jurisdictions have lower human health values but such values include consideration of home-grown produce consumption. This is not relevant for sample at 1 m depth.

directly measured PAH concentrations for both these samples were below the relevant criteria;

- the single ADL result (excluding the Tahi Street verge samples) above the SAC of 3 mg/kg is not significant (3.7 mg/kg); and
- two samples exceeded the hot-water soluble boron SAC of 3 mg/kg for a residential site use. The maximum concentration was 70 mg/kg, with the next highest result 5 mg/kg. The criterion is from the Timber Treatment Guidelines (MfE/MoH, 1997) and relates to phytotoxic effects. Both samples represent soil currently over 1 m bgl where significant effects on plant growth are unlikely. The equivalent human-health criterion from MfE/MoH (1997) is dominated by the home-grown produce consumption pathway, which is not relevant. Without produce consumption the guideline is several thousand mg/kg.

Overall, the FCC West excavation has been adequately validated.

5.6.2 FCC West Backfill Compliance with SACs

Backfill material used as residential soil on FCC West was derived from the following sources:

- soil excavated from FCC Landfill, FCC West and FCC East;
- excavated marine sediments from the West and East Marine remedial sites;
- a batch of soil imported as backfill for the marine remedial excavations that failed to meet the marine SAC;
- imported residential soil; and
- imported topsoil.

Each of these material categories is discussed separately below. The discussion is also relevant to residential soil and topsoil used to create the 0.5 m capping layer on FCC East and FCC Landfill.

5.6.2.1 Soil Excavated from Site

A total of approximately 18,200 m^3 of residential soil was excavated from the site during the remediation, the breakdown in source locations being:

- FCC East – 13,900 m^3
- FCC West – 2,150 m^3
- FCC Landfill – 2,150

A total of 356 and 41 samples were taken from the FCC East and FCC Landfill material, respectively. For DDX and ADL this is the equivalent of one sample per 39 m^3 and 52 m^3, respectively. The sampling density and distribution is adequate for these two areas. An additional 32 samples were collected from the residential stockpile for quality assurance purposes.

Only 19 validation samples have been reported in the Validation Report (SKM, 2008) as representative of the material excavated from FCC West. It is apparent from the data spreadsheet that these samples were in fact from two separate stockpiles representing only two of the 21 subgrades making up that area. There are no data presented for any of the residential soil excavated from the remaining 19 subgrades. Additional information was sought and it appears that a summary spreadsheet was not completed for this material. However, as with other material categories, it is expected that a significant number of site management samples were collected and used to determine the destination of that material. There is no reason to suspect a different decision making process was applied for the residential material sourced from FCC West.

To test this supposition, five cells from FCC West with missing data were selected and individual test results sought from site data held by MfE. In each case, site management samples were found confirming the expected decision making process and compliance with the residential criteria for soil classified as such. A total of approximately 30 samples that were relevant as validation samples were found for the five cells that were randomly selected. It is expected that a similar level of data would be available for other cells with missing data. Based on the additional information obtained, the missing data for residential soil sourced from FCC West is not a significant gap. On average, it is expected that the residential soil excavated from FCC West will comply with the SAC.

The data presented in the Validation Report for site-derived residential soil is discussed below.

Of the 448 samples in the dataset, all were analysed for DDX and ADL, with 109 (24%) of these also analysed for the full OCP suite. Approximately 50 samples (11%) were analysed for TPH, ONP, OPP and VOCs. A total of approximately 15 samples (3%) were analysed for heavy metals, and five for PAHs and PCBs.

Individual batches of soil have not been tracked to their final resting places, as the soil was temporarily stored in stockpiles. Consequently, using the average concentration and assessing variability is the only way to assess compliance with the SACs. This relies on peak concentrations not being so high that localised effects become significant. Confidence in the soil complying with SACs and being suitable for its purpose must additionally be gained from:

- a sufficient number of samples being taken to assess variability
- the average of the results being well below the relevant SACs, with many non-detects giving greater confidence
- excursions above the SACs being few and small
- most of the residential soil being below 0.5 m depth meaning the likelihood of a result being close to the surface where it has the potential to be washed to the marine environment is reduced
- incidental mixing during excavation, stockpiling and backfilling tending to reduce the likelihood of localised hotspots remaining, although such mixing would not be

sufficient if a batch had unidentified high concentrations of a contaminant (for example metals, which were only measured infrequently)

- the 0.15 m layer of clean topsoil provides and extra level of protection against non-complying residential soil being washed to the marine environment

In this case, the relatively large number of samples for DDX and ADL gives confidence that the material has been adequately characterised with respect to these contaminants. Of the 448 sample results, 43 exceeded the DDX SAC of 5 mg/kg, with two of those results also exceeding the SAC for ADL of 3 mg/kg. However, the majority of the samples were below laboratory detection limits and, despite the high laboratory detection limits employed (see Section 5.3.3), the average concentrations for the DDX and ADL datasets are expected to be below the SACs.

The DDX exceedances are not of concern. The exceedances are spread across the west site and represent isolated areas. Averaging will have occurred during soil handling and the actual concentrations will be lower. The main concern is for the highest of the exceedances which, if they occurred within the capping layer, could present a minor risk.

The maximum DDX concentration detected was 23 mg/kg. Information presented by SKM in the Validation Report and also independently obtained from MWH indicates that most of the peak results do not belong in the residential stockpile dataset, and therefore do not require further consideration. Regardless, there is no human health concern as the maximum DDX concentration is below a generic New Zealand guideline for residential use of 28 mg/kg (MfE, 2006). There would be a minor risk for the runoff pathway if these samples were near the surface within the capping layer[8], but the risk is reduced by the 0.15 m layer of topsoil.

The maximum ADL concentration of 4 mg/kg is not significant relative to the SAC of 3 mg/kg.

A number of other SAC exceedances were indentified in the Validation Report (SKM, 2008) as follows:

- one of the 14 samples analysed for manganese (725 mg/kg) was identified as exceeding the corresponding SAC. However, SKM used the value of 500 mg/kg rather than the revised value of 1,500 mg/kg and the result actually complies;
- four of the 15 samples analysed for nickel were identified as exceeding the corresponding SAC. However, SKM used the value of 60 mg/kg rather than the revised value of 600 mg/kg. The maximum detected nickel concentration of 109 mg/kg is below the SAC.

[8] An average chance of 27% as the residential capping material makes up 6000 m^3 of the total 13,400 m^3 of residential backfill in FCC West and only 61 % of the residential stockpile was used on FCC West.

The heavy metals analysis was well short of the RAP requirement at only 3 % of the primary analyses. The need for metals analysis and the mitigating factors is discussed in Section 5.2. The main metals of concern are mercury, arsenic and lead, from past manufacturing or storage of pesticides.

The 15 validation samples reported in SKM (2008) had mercury and lead concentrations typical of background. Arsenic for most samples also appears to be at background (around 1 – 5 mg/kg) although the maximum concentration of 17 mg/kg may be slightly elevated. The baseline pre-remediation testing (T&T, 2004) in which 21 surface samples were collected found arsenic generally at background concentrations, but one sample at 48 mg/kg (from a random location in FCC East that was in the vicinity of one of the original pesticide manufacturing buildings) is clearly elevated above background and three other samples showed a possible minor degree of contamination (11 – 16 mg/kg). Lead also showed minor elevation above background in some samples. Mercury was at concentrations typical of background. Early sampling by Woodward-Clyde (1993), while not reported in full, found significantly elevated lead in one sample (1290 mg/kg) in the vicinity of the same building at which elevated arsenic was found in the baseline sampling. Neither arsenic nor mercury was found to be elevated in the Woodward-Clyde sampling.

Additional sampling of the residential fill material for mercury was carried out by TDC in August 2008 (TDC, 2008b) in which 25 samples were collected on a grid, with clusters of four samples collected at each location. Subsequently, the laboratory provided arsenic and lead analysis results for these samples. This sampling found concentrations typical of background for all three metals. Including these as validation samples for the residential backfill on FCC West brings the number of samples analysed for these metals to approximately 9% of the total. The extra results have given sufficient additional assurance that significant undetected hotspots of arsenic, lead and mercury are unlikely to exist within the residential capping layer on FCC West.

5.6.2.2 Marine Sediments

The marine sediments used as residential backfill have not been well characterised by the data presented in the Validation Report (SKM, 2008) and there is therefore some uncertainty regarding strict compliance with the residential SAC. The majority of the potential exceedances were of the DDX criterion of 5 mg/kg. However, the average DDX concentration in the marine sediments is generally expected to be below the SAC (see further discussion below). In this case, the peak DDX concentrations detected were significantly above the SAC e.g. the two highest results were in the marine sediment samples were 125 and 82 mg/kg. Mixing during soil handling would be expected to reduce the significance of these peak exceedances to some extent. However, localised areas above 5 mg/kg are likely to remain given the initial concentrations. As noted above, the question then is whether such concentrations are likely to have ended up within the residential capping layer creating a minor risk for the sediment runoff pathway (noting the protection offered by the 0.15 m layer of topsoil) and a human health risk if

the concentrations are above the residential criterion. More detailed comments are provided below.

A total of approximately 4,800 m^3 of marine sediment was removed from the east and west marine remedial excavations. According to the volume balance diagram (MWH, 2008), approximately 850 m^3 of the east marine sediments was mixed with commercial material and backfilled in FCC East. However, it is not known which of the samples represent the remainder of the marine east material which was used as residential material. For the purposes of assessing the portion of the material used for residential backfill, SKM included all the data for the east marine sediment (SKM, 2008). This is a reasonable approach.

However, for both east and west, SKM combined the pre-excavation and excavation base validation test results into single datasets that it considered representative of the excavated marine sediment. This assumes that the validation samples from the excavation base are representative of the material removed, presumably for the lower part of the excavated material. This is of dubious validity unless specifically tested and shown to be reasonable.

Examination of the pre-excavation and excavation base datasets by PDP indicates that that there are statistical outliers substantially biasing the 95% UCL estimates. When the outliers are excluded, the excavation base dataset is similar to the data from the removed material, and therefore could be treated as single combined datasets for each of east and west (but that similarity also means that insufficient material had been removed to effect adequate remediation).

Recalculating 95% UCL estimates without SKM's assumption of log-normality, but using the complete datasets, found that both the east and west sediments had 95% UCL estimates substantially greater than the DDX residential criterion of 5 mg/kg. This would suggest the material should have been rejected as residential backfill. However, when one or two apparent statistical outliers were excluded from the datasets, the 95% UCL estimates complied with the DDX criterion for both the East and West sediments. The conclusion is that most of the sediment does in fact comply, but that there are isolated hotspots of many times the SAC within the sediment (up to 125 mg/kg for the east sediments and up to 82 mg/kg for the west sediments).

Such hotspots would not be completely eliminated by the incidental mixing during material handing and raises the possibility that some material within the residential capping layer could have DDX concentrations substantially above the SAC in isolated areas. The chance of this occurring can be roughly calculated.

The exact quantity of marine sediments used in FCC West as backfill is not known. Approximately 61% of the residential stockpile, of which the marine sediments made up 35%, was used in FCC West. If it assumed that the marine sediments were used in FCC West in the proportion in which they were in the stockpile, and knowing that the residential stockpile made up 84% of the 13,400 m^3 of total residential quality backfill in FCC West, the marine sediments theoretically amount to 18% of the backfill. If it is

further assumed that the marine sediments are evenly distributed through the 6000 m^3 of residential capping, then a marine sediment hotspot has an 8% chance of being in the capping layer. This is acceptable when combined with the factors, discussed earlier, that further reduce risks to either the marine environment or human health.

A number of other SAC exceedances were indentified in the Validation Report (SKM, 2008) as follows:

- seven of 31 samples analysed for hot water soluble boron exceeded the SAC of 3 mg/kg, with a maximum concentration detected of 10.8 mg/kg. These exceedances are not significant as this criterion relates to phytotoxic effects and the maximum concentration is not significantly above the SAC. The 95% UCL concentration (SKM's log-normal distribution assumption) was approximately 4 mg/kg;
- four of the 31 samples analysed for nickel were identified as exceeding the corresponding SAC. However, SKM used the value of 60 mg/kg rather than the revised value of 600 mg/kg. The maximum detected nickel concentration of 80 mg/kg is below the SAC.

In summary, while the various datasets for the marine sediments may not strictly represent the excavated material, the large number of samples analysed for the key OCP contaminants gives reasonable confidence that the actual concentrations fall somewhere within the overall dataset. Consequently, there is reasonable confidence that the material is suitable as residential backfill and the few DDX hotspots will not create an unacceptable risk.

5.6.2.3 Failed Imported Marine Backfill

A total of 430 m^3 of material imported to site as backfill for the marine excavations was found to exceed the marine SAC of 0.01 mg/kg for DDX and used in FCC West as residential backfill[9]. However, the material complied with the less stringent residential SAC and was therefore appropriate for that purpose.

A total of 13 samples were taken to confirm the material was suitable as residential material. All 13 samples were analysed for the full OCP suite. Four samples were analysed for TPH, three samples were analysed for a metals suite and one sample was analysed for hot water soluble boron, total/free cyanide, PAHs and PCBs. The sampling rates are reasonable given the source of the material and the fact that OCPs were the reason the material could not be used in the marine environment.

[9] There is a discrepancy between the volume of failed imported marine backfill shown in Table 27 of the Validation Report (SKM, 2008) and that shown in Table 40. Table 27 shows 1,355 m^3 of failed marine sediments were used in FCC West. Table 40 has been used for this report, which is also consistent with the volume balance diagram (MWH, 2008).

The Validation Report identified minor exceedances of the nickel and manganese SACs in all three samples analysed for those contaminants. However, the SAC values used by SKM have been superseded and when the results are compared with the actual SACs, they easily comply. No other SAC exceedances were identified.

5.6.2.4 Imported Residential Soil

The test results for the approximately 5,830 m^3 [10] of clean material imported as residential have been assessed as a whole in the Validation Report, rather than on a source by source basis. Whilst not ideal for the reasons outlined previously, conclusions can be drawn on the general quality of the material as a whole. It is difficult to determine exactly where the imported soil was used on the site and the dataset also represents soil used in the 0.15 m surface layer on FCC East and Landfill. Approximately 1,760 m^3 or 30% of the total imported material was used on FCC West.

A total of 30 samples were analysed for DDX and ADL, with 23 of these also analysed for the full OCP suite. Approximately 16 samples were analysed for a metals suite, nine were analysed for TPH, and eight were analysed for PAHs and PCBs. The frequency of sampling was adequate.

The only result to exceed the SAC was a manganese concentration of 1,960 mg/kg, above the corresponding SAC of 1,500 mg/kg. This exceedance is not significant as the original data spreadsheet indicates that the destination of this material was subgrade 19A on FCC Landfill. The detected concentration is not significant for the recreational/open space site use for this part of the site.

Overall, the imported residential soil complies with the relevant SAC.

5.6.2.5 Imported Topsoil

A total of about 5,560 m^3 of topsoil was reported to have been imported from several sources (SKM, 2008)[11]. A total of 22 samples were taken at an average rate of one per 250 m^3 for OCP analysis. This rate is satisfactory. The Validation Report statistically

---

[10] This total comes from adding the amount reported in tables 31 and 40 of the Validation Report and is consistent with the volume balance diagram (MWH, 2008). This is at variance with the destinations of imported clean material shown in Table 27. Table 27 does not show any imported clean material as being used as residential backfill in FCC East or West except for failed marine sediment backfill. The volumes in Tables 31 and 40 have been used in this report when considering FCC East and West backfill quality.

[11] Calculated from the sum of imported topsoil reported in tables 31, 35, 40 and 49 of the Validation Report. Once again, this is at variance with Table 27, which shows 5,100 m^3 of imported topsoil.

analysed the topsoil results together with imported residential material. The assumption is that results from the two types of imported materials and the various sources are from the same statistical populations, which is not necessarily the case (and was not reported as being tested). However, the generally low results makes this unimportant. Individual exceedances were identified against material types.

The topsoil SACs are identical to the residential SACs except for a lower nickel criterion of 60 mg/kg, compared with 600 mg/kg for the residential soil. Much of the soil in the Mapua area has naturally elevated nickel concentrations and there was some difficulty sourcing material that complied with the lower nickel value. As with the imported residential soil, it is difficult to determine exactly where the imported topsoil was used on the site. The dataset also represents soil used in FCC East, the Landfill and the private properties.

All test results were below the topsoil SAC except for a zinc concentration of 211 mg/kg in one of the samples which slightly exceeded the SAC of 200 mg/kg. The marginal exceedance is not significant, particularly as the criterion is based on plant health (NEPC, 1999a) and the equivalent human-health guideline value is several thousand mg/kg (NEPC, 1999b).

Overall, the imported topsoil complies with the relevant SAC.

5.6.3 The Remediation Treatment Area

The vicinity of the MCD plant and the locations of stockpiles of treated material have the potential for contamination by reagent chemicals, particularly copper, ammonia and nitrate (with consequent potential effects on groundwater). The Validation Report did not consider this possibility.

The MCD plant was decommissioned in August 2007. The slab was removed in the same month and the area beneath tested. This is Subgrade 40. Only the standard validation test were done, that is no testing was carried out for nutrients and only two metals test appear to have been done (both $<$10 mg/kg for copper). This subgrade was excavated to about 0.5 m and placed in the residential stockpile.

The area immediately to the south of the plant area (SG37) was tested around the same time as SG40. The top 0.25 – 0.5 m of this subgrade was sent to the commercial stockpile. The rest was excavated to about 1 m depth and placed in the residential stockpile. Again, only the standard validation suites were applied.

It is understood the treated material stockpiles were located in a variety of places. It is not known what testing was carried out post-decommissioning, but it is presumed that these areas were also stripped and tested in a manner typically of the rest of FCC-West.

In general, copper is not expected to penetrate much beyond the surface soil. Copper is not a health-concern but may be of concern for plant health. Copper may also be of concern for the aquatic environment but leaching of copper appears to be minimal (see

Section 7.8.2). It is understood that most of the soil from the stockpile areas was used as commercial backfill on FCC East. If so, copper will not be of concern.

Ammonia and phosphorus derived from the MCD process reagents are very much more soluble than copper and could have leached into the underlying soil. This is primarily of concern for groundwater, but excessive quantities of ammonia may also generate ammonia gas in the soil, affecting plant health and, in the extreme, be of concern for human health if the gas should gather in confined spaces (e.g. excavations). The likelihood of this occurring at former stockpile locations is low and no further testing is recommended at this stage. However, if sampling recommended in FCC East (Section 5.7.4) shows that generation of ammonia is a significant issue in the treated fines, the need for testing on FCC West should be reassessed.

5.6.4 Acceptability of FCC West Soil Remediation and Fitness for Purpose

Overall, we consider that FCC West will be fit for its intended purpose, subject to the minor uncertainties discussed below.

The Validation Report does not provide conclusions as to whether the remediation of FCC West met the RAP requirements for soil quality. However, on balance we consider that the soil quality will generally meet the SACs and in particular meet the ADL and DDX SACs. Local exceedances are not so great as to be unacceptable. As discussed in Section 5.1.2, compliance with the SACs for FCC West also indicates that FCC West will generally be fit for its intended purpose with respect to soil quality. Potential effects associated with groundwater are discussed separately in Section 7.0.

Some uncertainty remains from:

- the detection limits for DDX being close to the residential SAC; and
- a lack of inter-laboratory comparisons for DDX results at concentrations close to the residential SAC.

A programme of sampling to evaluate this is recommended (Section 5.3.4.2).

5.7 FCC East Remediation

5.7.1 General

Soil within the FCC East area was required to comply with the commercial SACs below 0.5 m depth and with the residential/topsoil SACs for the 0.5 m capping layer. All of the approximately 13,000 m^2 area of FCC East was excavated during the remediation works. The cell and subgrade arrangement is shown in Figure 2.

FCC East was backfilled with soil that was considered to have met the SACs when excavated and with treated material that was considered to have meet the SACs after treatment. Treated soil, was placed on its own, mixed with oversize material, commercial soil, or marine sediments from the East and West foreshores, or a combination of these.

5.7.2 Validation of FCC East Excavation

Overall, the density of sampling for the FCC East excavation validation is adequate. A total of 719 samples were taken from the extents of the FCC East excavation. This number of samples is enough to fulfil the RAP intention of one sample from each cell floor and wall layer, assuming the distribution of samples is even between cells. SKM undertook a check of records to ensure that at least one OCP sample had been collected from each cell floor and wall layer.

All 719 samples were analysed for DDX and ADL, with 499 (70%) of these also analysed for the full OCP suite. Approximately 280 samples (40%) were analysed for TPH, ONP, OPP and VOCs. A total of approximately 70 samples (10%) were analysed for heavy metals and approximately 50 samples were analysed for PAHs, PCBs.

The only results to exceed the SAC were four DDX concentrations ranging from 206 to 283 mg/kg. These exceedances are not significant relative to the SAC of 200 mg//kg. The isolated exceedances represent a small area of soil relative to the overall area of the FCC East excavation.

5.7.3 FCC East Backfill

5.7.3.1 Backfill Sources

Backfill material used on FCC East was derived from several sources:

- commercial soil excavated from FCC Landfill, FCC West and FCC East;
- treated soil;
- oversize material;
- crushed concrete;
- clay imported to repair the clay bund;
- marine sediments; and
- the 0.5 m capping layer consisting of site-derived and imported residential quality surface fill and imported topsoil[12]

Each of these material categories is discussed separately below.

[12] The Validation Report incorrectly states that the 0.5 m thickness of capping soil was all imported. This is true of the 0.15 m of topsoil, but not true of the underlying 0.35 m of residential quality soil. The residential soil was sourced from both the site-won residential stockpile and from imported soil. While some locations may be principally imported soil other locations will be principally site soil and other locations again will be some unknown mixture. It is not possible to identify what soil a particular location received.

5.7.3.2 Commercial Soil Excavated from Site

A total volume of approximately 27,500 m^3 of commercial quality soil was excavated from FCC Landfill, FCC West and FCC East during the remediation. This soil was used as backfill below 0.5 m depth in FCC East and FCC Landfill.

A total of approximately 1,700 samples were taken from the excavated commercial material. All samples were analysed for DDX and ADL (an average of one sample per 16 m^3, well within RAP requirements), with 73 also analysed for the full OCP suite (one sample per 380 m^3). A total of approximately 20 samples (one sample per 1,375 m^3, or 1% of all samples) were analysed for TPH, OPP, ONP and VOC. Approximately ten samples were also analysed for the metals suite, hot-water soluble boron and total/free cyanide (one sample per 2,750 m^3 or only 0.5% of all samples).

The sampling density and distribution for DDX and ADL is adequate for characterising the material. Analysis for other compounds fell short of the RAP requirements (well short in the case of metals), although this is not a significant information gap given the proposed use of FCC East.

The Validation Report reported that the 95% UCL for DDX concentrations was 79 mg/kg, well below the SAC of 200 mg/kg. Approximately 26% and 10% of samples were non-detects for ADL and DDX, respectively. Of the approximately 1,700 samples analysed, there were 53 exceedances of the DDX SAC (3% of the samples), with a maximum concentration of 765 mg/kg. Of the exceedances, most (43) were less than 1.5 times the DDX SAC. Given the large number of samples representing this material, there is a good degree of confidence that the peak results represent isolated SAC exceedances, noting that the mixing that will have occurred in the various excavation, stockpiling and backfilling processes will tend to “average out” exceedances in the final backfill.

The SAC of 200 mg/kg was based on leaching to groundwater and subsequent effects on the marine environment (via discharge of groundwater). Any remaining isolated SAC exceedances within the backfill are not significant in that context. Groundwater is an “integrating” medium meaning that effects of localised higher concentrations will be combined with effects from surrounding soil and averaged overall (but note the greater than expected effects on groundwater reported in Section 7.0).

The 95% UCL for ADL concentrations in the commercial soil reported in the Validation Report was 5 mg/kg (recalculated by PDP as 6 mg/kg), also well below the SAC of 60 mg/kg. Of the samples analysed, there were 6 exceedances of the ADL SAC, with a maximum concentration of 98 mg/kg. These individual exceedances are not significant for the reasons outlined above.

All other contaminant test results were below the respective SACs.

The commercial soil excavated from the site and used as backfill is compliant with the SACs. This also applies to the FCC Landfill backfill.

5.7.3.3 Treated Soil

Soil to be treated was initially screened to remove particle sizes greater than 10 mm (known as "oversize"). The 5 – 10 mm component was separated prior to treatment and stockpiled for later recombining with the treated soil during disposal. The validation of the 5 – 10 mm component is discussed separately below.

The less than 5 mm component, after treatment, became the "treated fines". As noted in Section 5.4.2, the validation criteria for the treated fines evolved during the works. In July 2005, a 6-day rolling average assessment was implemented, with no single sample to exceed 1.5 times the SAC. Similarly, the analytical suite and frequency of testing varied slightly during the remediation works (see Section 5.2), although the key changes were implemented early on in the project.

Overall, the scope and frequency of the validation testing for the treated fines is adequate to characterise the material and typically easily complied with various RAP requirements (SKM, 2008). The number of samples analysed for the various parameters is set out in tables 67 and 68 of the Validation Report (SKM, 2008). The approach in the Validation Report of analysing the pre and post-July 2005 datasets separately is reasonable.

Some of the early piles of treated fines went straight to stockpile without testing. Subsequent testing of these indicated slight exceedances of commercial SAC for DDX, with a maximum detected concentration of 231 mg/kg. These stockpiles were blended with other treated fines to reduce the concentrations and subsequently re-tested.

Pre-July 2005 Treated Fines

Approximately 1,400 m^3 of soil was treated prior to July 2005. Of the 118 samples analysed (average one sample per 12 m^3), 16 samples returned DDX concentrations above the SAC, with four of these samples also having ADL concentrations above the SAC. The two highest DDX results were just under 900 mg/kg, with the remainder of the exceedances only slightly over the SAC of 200 mg/kg. Although the two peak concentrations are significantly above the SAC, in the overall context, these exceedances are not significant.

The treated fines were handled several times and were either buried as treated fines or more commonly mixed with either commercial material or oversize before disposal (MWH, 2009e). The ratio of mixing was generally about one part treated fines to three parts commercial/oversize. The effect of this handling and mixing is to reduce the likelihood of significant hotspots remaining in the soil. The average concentration of DDX in the commercial soil was approximately 80 mg/kg. If a batch of treated fines is assumed to have the maximum detected DDX concentration of about 900 mg/kg, and this is combined with three parts commercial soil at the average concentration of 80 mg/kg, the average concentration for the combined material is about 285 mg/kg.

The 95% UCL calculated by SKM (2008) for DDX is 143 mg/kg for the pre-July 2005 treated fines, below the SAC of 200 mg/kg. This is acceptable.

For ADL, the Validation Report reported four exceedances (ranging from 70 to 84 mg/kg), only slightly above the SAC of 60 mg/kg. The exceedances are not significant. The 95% UCL calculated by SKM (2008) for ADL was approximately 16 mg/kg, well below the SAC of 60 mg/kg.

All other contaminant concentrations were below the corresponding SAC.

It should be noted that no SAC were derived for the various compounds containing nitrogen derived from the MCD process reagents. The significance of these results is discussed in the next section and with respect to groundwater in Section 7.3.

Post-July 2005 Treated Fines

Approximately 9,200 m^3 of soil was treated post-July 2005. Of the approximately 470 samples analysed (average of one sample per 20 m^3), 39 samples returned DDX concentrations above the SAC, with one of these samples also having ADL concentrations above the SAC.

The 95% UCL for DDX reported in the Validation Report was 114 mg/kg [13], well below the SAC of 200 mg/kg. The maximum DDX concentration of 300 mg/kg was 1.5 times the SAC and is not significant in the overall context, particular as mixing with commercial material is most likely to have reduced the concentration.

The 95% UCL for ADL was approximately 10 mg/kg, also well below the SAC of 60 mg/kg. The peak ADL concentration of 75 mg/kg was only 25% above the SAC.

Heavy metals were analysed on 136 occasions, or a frequency of 29% of the ADL and DDX analyses. This is greater than the required frequency of 10%. Two copper concentrations (out of 136 test results – one sample per 70 m^3) exceeded the SAC of 5,000 mg/kg, with a maximum concentration of 5,250 mg/kg detected. The 95% UCL for copper was approximately 1,900 mg/kg. The elevated concentrations of copper relate to copper compounds used as reagents in the treatment process. The significance of the copper concentrations in the treated fines in terms of groundwater is discussed in Section 7.3.

Leachable nitrogen compounds were analysed on 99 occasions (not 49 as reported in the Validation Report), or 20% of the rate of ADL and DDX analyses. These were analysed as synthetic precipitation leaching procedure (SPLP) tests and are reported as concentrations (mg/L) in the leachate. The Validation Report combined these results with the soil results with no reference to the difference in units (in fact no units are given in the various tables appended to the Validation Report or in the analysis spreadsheets). The equivalent total concentrations in the soil were apparently not analysed, which is unfortunate.

[13] Recalculation of the 95% UCL gave a result a little higher than the Validation Report calculation, but not enough to affect the conclusions. A similar result was found for the ADL 95% UCL.

Relationship between nitrogen soil concentrations and leaching test concentrations were later developed using the QA-QC samples (PDP, 2007). Using these relationships, the average Ammonia-N SPLP concentration from the treated fines validation sampling of 292 mg/L translates to a soil concentration of about 7300 mg/kg and the average Total-N SPLP concentration of 380 mg/L translates to a soil concentration of about 14,000 mg/kg (1.4%). While these relationships are based on a small number of samples, if they held true at the time of soil treatment they demonstrate that quite large quantities of potentially leachable nitrogenous compounds were being added to the treated fines. The significance of nitrogen in the groundwater is discussed further in Section 7.8.3.

Blended Stockpiles

Early batches of treated fines were found to have slightly exceeded the SAC for DDX (maximum DDX concentration of 231 mg/kg). Following discussions with the Site Auditor and MfE these were blended with other material under the supervision of EMS to bring the material into compliance, although the consent did not strictly allow treatment by dilution.

Eight samples were taken of the 1200 m^3 of blended material, a rate of one sample per 150 m^3. This rate is reasonable given the material was not far out of compliance in the first place. The Validation Report presents pre and post-mixing data which adequately demonstrates the material was brought into compliance.

5 – 10 mm component

Approximately 970 m^3 of the 5 – 10 mm component of the soil was produced during the remediation works (SKM, 2008). Nine samples of this material (one sample per 110 m^3, approximately) were analysed for DDX and ADL, and one sample was also analysed for the full OCP suite. The samples were analysed by using a solvent wash to remove fines adhered to the large particles (Graham Corban, Hill Laboratories, pers. comm.). The resultant contaminant weights were compared with the overall sample weight. The sampling scope and methods are reasonable.

The results were all below the SACs, with maximum DDX and ADL concentrations of 61 mg/kg and 14 mg/kg respectively.

5.7.3.4 Oversize Material

Approximately 3,800 m^3 of material greater than 10 mm material was estimated to have been generated by screening the contaminated soil to be treated (SKM, 2008). The screened material retained a certain amount of fine material which adhered to the larger particles. This fine material contained contamination at similar levels to the remainder of the fine soil that was subsequently treated. One of the original RAP requirements was that the oversize material should have no greater than 5% fines attached. In practice, this was difficult to achieve and oversize with up to 10% fines attached was accepted in some circumstances.

To estimate the level of contamination in the oversize, the contaminant concentrations in the fines was estimated or measured and factored by the estimated percentage of fines, assuming the greater than 10 mm components to be 'clean'. This is a reasonable approach.

In the first instance, the average DDX and ADL concentrations from the in-feed to the treatment plant were used as an estimate of the likely concentrations in the fines attached to the oversize. The DDX and ADL concentrations used were 1,012 mg/kg and 73 mg/kg respectively. However, the results of 24 samples of the oversize indicated that the actual concentration in the fines was likely to be somewhat lower, with average measured DDX and ADL concentrations of 457 mg/kg and 46 mg/kg.

Using the more conservative in-feed estimate, SKM estimated the DDX concentration of the total oversize to be approximately 40 mg/kg and the equivalent ADL concentration to be approximately 3 mg/kg. Both these values are well below the applicable SAC of 200 and 60 mg/kg for DDX and ADL respectively. The oversize material complies with the commercial SAC.

5.7.3.5 Crushed Concrete

A total of approximately 2,000 m^3 of crushed concrete was generated during the remediation works. During that time, 53 samples of concrete were analysed for DDX and ADL. The RAP required a representative sample. The frequency of testing is adequate.

The concrete samples were ground at the laboratory before analysis (Graham Corban, Hill Laboratories, pers. comm.). Any contaminated fines attached to the concrete would then effectively be 'diluted' by the mass of concrete. For similar reasons outlined for the oversize material in Section 5.4.8.4, this is a reasonable approach.

All 53 test results were below the commercial SAC, with maximum DDX and ADL concentrations of 177 mg/kg and 1.5 mg/kg respectively, demonstrating compliance.

5.7.3.6 Imported Clay

Approximately 1,000 m^3 of clay was imported to repair the bund and backfill the surge chamber excavation. A total of four samples of the imported clay were analysed for the full suite including OCPs, OPP, ONP, TPH, PAH, PCBs and a metals suite. All results were below the corresponding SAC, demonstrating compliance.

5.7.3.7 Marine Sediments

Approximately 850 m^3 of marine sediments were mixed with commercial material and used as backfill in FCC East. The sediments are discussed in detail in Section 5.6.2.2. All results were below the corresponding SAC, demonstrating compliance.

5.7.3.8 Surface soil

FCC East was covered with a half metre layer of residential quality material, including 0.15 m of imported topsoil. The sources and testing of this soil is covered in the analysis of results for FCC West – see Section 5.6.2. The 0.5 m capping layer is expected to meet the quality requirements for residential soil, subject to minor uncertainties discussed in Section 5.7.4.

5.7.3.9 Diesel Contamination

Correspondence from the Site Auditor refers to 'considerable diesel contamination' in the north-west portion of FCC East which was land-farmed to reduce concentrations (GHD, 2005b). However, there is no mention of this in the Validation Report or any other correspondence reviewed during the audit.

It is assumed that the material was subsequently tested and the results are part of the commercial material dataset. If so, the material complied.

5.7.4 Acceptability of FCC East Remediation

The Validation Report concludes that FCC East meets the SAC for an open space[14] and commercial use. We concur with this conclusion, subject to the comments below. As discussed in Section 5.1.2, compliance with the SACs for FCC East indicates that this part of the site will typically be fit for its intended purpose. However, we note six issues which are either potentially at variance with the SACs or may otherwise present a risk to the proposed site use:

1. the possibility of elevated concentrations of DDX within the residential soil in the 0.5 m capping layer;
2. the possibility of ammonia gas being generated from the nitrogen compounds in the treated fines;
3. the potential for the nitrogen compounds in the treated fines to cause adverse impacts on other receptors via groundwater;
4. the lack of buffer material adjacent to the marine environment of the Mapua Channel;
5. exceedance of the commercial copper guideline in treated fines material; and
6. the potential for copper concentrations in the mixed treated fine material to cause phytotoxic effects in some plant species.

[14] The conclusion in Section 17.6 of the Validation Report (SKM, 2008) in fact concludes that the FCC East site meets the SAC for *residential* and commercial use. We assume that this is a typographical error and should read 'open space and commercial'.

Items 3, 4 and 5 are related to risks to groundwater and are discussed in Section 7.0. The exceedances of copper referred to in Item 5 are not so great as to be a risk to human health.

Considering Item 1, this has been discussed with respect to FCC West and is acceptable, assuming a site management plan is put in place control future excavation. The same conclusion applies here.

Considering Item 2, the treated fines contain nitrogen compounds that were added during the remediation process. Some of the treated fines were mixed with typically three volumes of commercial soil and/or oversize during the backfilling operations (MWH, 2009e), reducing the effective concentration of nitrogen compounds in this material. However, the QA-QC sampling showed concentration of several hundred up to 5000 mg/kg of ammoniacal-N in mixed and unmixed treated material. Greater concentration could exist on the basis of the SPLP testing carried out during the remediation. There is an unknown potential for ammonia gas to be generated, that increases if the pH of the soil is elevated (alkaline).

Cement-stabilised marine sediment material was placed in subgrades SG5C, SG3, SG7, SG9, SG11 and SG14 (SKM, 2008). Cement is strongly alkaline and is likely to have increased the alkalinity of the soil in which it has been mixed. Mixed treated fines was also placed in subgrades SG3, SG7 and SG14. The location of the cement-stabilised material relative to the mixed treated fines is not known. However, it may be that there is an increased potential for generation of ammonia if infiltration made more alkaline by passing through cement-stabilised sediments then passes through mixed treated fines.

The key human-health effects of ammonia are acute and relate to the corrosive effects on skin, eyes and internal respiratory membranes. Ammonia gas has a distinctive sharp odour and would typically be smelt before concentrations reached harmful levels. The most likely exposure route would be maintenance or construction workers working in confined spaces such as trenches near or within treated fines. Any exposure is likely to be short-term and the ability to smell the gas at low concentrations may give an effective warning mechanism for workers. The risk may be more one of aesthetics (unpleasant odours) than a health risk.

Ammonia gas is also phytotoxic and will cause burning of root tips and leaves at sufficient concentrations. No sign of distressed grass suggestive of such effects was observed during PDP's site visit.

It is difficult to quantify the level of risk associated with ammonia gas given the available information. Additional information is required to better quantify the risk. It is recommended that a programme of soil gas sampling and analysis be carried out in locations where buried fines or mixed material exists. This should include subgrades SG3, SG7 and SG14 where cement- stabilised material and treated fines co-exist. If ammonia is found, interpretation should include consideration of migration to confined spaces.

If a potential risk is found, the risk can be managed by ensuring adequate procedures are in place for excavation workers. The site management plan should contain procedures for evaluating the atmosphere in confined spaces. If a significant risk is found by the sampling programme, the risk of gas penetration into future buildings will also need to be addressed in the Site Management Plan.

A buffer zone was required by Condition 10(j)(viii) of consent RM030521 to limit potential effects of leaching to groundwater and the adjacent marine ecosystem. The criteria are set out in Table 2. There is no information in either the Validation Report or other information reviewed to indicate that that a buffer zone was implemented adjacent to the Mapua Channel. However, the clay bund along the eastern foreshore provides a buffer of approximately 10 m between the commercial backfill and the shoreline (if the 'shoreline' is assumed to be the base of the sea-wall on the outside of the bund). The clay bund was tested and found to have low levels of contamination and imported clay to repair the bund complied with residential criteria. Additional information provided by MWH indicates that the majority of the fill immediately inside the clay bund is likely to generally comply with the '10 m' criteria of 120 mg/kg and 40 mg/kg for DDX and ADL respectively (MWH, 2009c). The as-built drawings (SKM, 2008) show the clay bund is underlain by clean gravel in subgrades SG10, SG11, SG13 and SG14 which will also comply with the buffer requirements. However, DDX concentrations of up to 174 mg/kg were present in backfill for subgrade SG14, but it is not known where in the subgrade the peak concentrations were placed.

In summary, the buffer zone requirements are likely to have been complied with to some extent on the eastern foreshore, but the full intent has probably not been realised. The potential implication is the effect on groundwater quality, which is discussed in greater detail in Section 7.0.

Considering Item 5, TDC intends using part of FCC East along the foreshore as open space (see Section 3.3). This raises the issue of phytotoxicity. Phytotoxicity is not generally an issue for commercial use but it may become a concern for amenity planting in an open space context.

The average concentration of copper in treated fines (95 % UCL of 1,606 mg/kg for pre-July 2005 and 1,924 mg/kg for post-July 2005) suggests a potential for phytotoxic effects for some deeper-rooted shrubs and trees. Treated fines material was placed in subgrade SG 7. Shallow-rooted plants within the surface 0.5 m of residential/topsoil material should not be at risk. Whether the copper is plant available depends on such things as the form of the copper, the pH of the soil and the soil mineralogy.

The as-built drawings show that no treated fines were placed in subgrades close to the foreshore (subgrades SG7, SG9, SG10, SG11 and SG14) although mixed treated fines were placed in SG3 and SG 7 at depths of 0.5 and 1 m respectively. Whether the mixed treated fines have sufficiently high copper concentration is not known. The issue is readily managed by precautionary replacement of the soil to a sufficient depth if deeper-rooted plants are planted where mixed treated fines are buried close to the surface.

5.7.5 FCC East Fitness for Purpose

Overall, with the exception the two uncertainties outlined below, the FCC East site is fit for its intended purpose with respect to the soil remediation (but see separate discussion on groundwater in Section 7.0). This is in the context of a Site Management Plan being implemented to control excavation into commercial quality material, so that this material is not allowed to migrate to the marine environment or be disposed of inappropriately off site (e.g. to a site with a more sensitive site use such as residential).

Issues that result in some uncertainty are:

- The potential for ammonia gas to be generated from treated fines material and possible effects on human health. A programme of soil gas testing is recommended. The site management plan should be amended to manage any risk found.
- The possibility of phytotoxic effects on deep-rooted plant species used in amenity planting. This is readily managed by soil replacement. The Site Management Plan should address this risk.

5.8 FCC Landfill Remediation

5.8.1 General

Soil within the FCC Landfill area was required to comply with the open space SACs below 0.5 m depth and with the residential/topsoil SAC for the 0.5 m capping layer. The intended end us is open space. The cell and subgrade arrangement is shown in Figure 3.

FCC Landfill was backfilled with soil that was considered to have met the SACs when excavated and with treated material that was considered to have meet the SACs after treatment.

5.8.2 Validation of FCC Landfill Excavation

The landfill covered an area of approximately 6000 m^2. Subgrade SG 18 formed the majority of the excavation in FCC Landfill (Figure 3). The north-west, south-west and south edges of SG 18 were approximately coincident with the extent of the waste i.e. the excavation was extended to ‘clean soil’.

The south-west tip of the former landfill area, beyond SG 18, is shown as un-excavated on the remediation as-built drawings (SKM, 2008). However, the initial characterisation investigation indicates that a 400 mm layer of waste was present at a depth of 1.4 m bgl in cell M3 (GES, 2002). The Site Engineer has advised (Paul Russell, pers. comm.) that this area was excavated to approximately 3 m deep to bury koiwi (human bones) and that any waste would have been removed at that time (MWH, 2009e). No records to confirm this have been sighted. We consider that this is unlikely to be a significant information gap, as it appears unlikely that any significant quantity of waste remains. In addition, the

area has been covered with at least 0.5 m of residential quality soil acting as a barrier to any waste that might remain.

A total of 361 samples were taken from the extents of the FCC Landfill excavation. This number of samples is enough to fulfil the RAP intention of one sample from each cell floor and wall layer, assuming the distribution of samples is even between cells. SKM undertook a check of records to ensure that at least one OCP sample had been collected from each cell floor and wall layer. The frequency of sampling for OCPs is acceptable.

All 361 samples were analysed for DDX and ADL, with 62 of these also analysed for the full OCP suite. This frequency is acceptable. Approximately 102 samples were analysed for TPH, ONP, OPP and VOCs, or only 28% of the primary analyses compared with the RAP requirement of 50%. A total of approximately 20 samples were analysed for heavy metals and approximately 19 samples were analysed for PAHs and PCBs. This is only 5.5% of the primary analyses compared with the requirement of 10%

The only results to exceed the SAC of the 361 samples taken were three ADL concentrations above the SAC of 60 mg/kg in samples taken from the floor of three separate cells (K7, K8 and N6). The concentrations ranged from 124 mg/kg (K8) to 170 mg/kg (N6). These exceedances are not significant as they appear to represent very localised hotspots and the average ADL concentrations in each of the cells with elevated results were all low. In each case, at least three other samples were taken from the cell floors, all returning concentrations well below the SAC of 60 mg/kg.

Examination of the secondary analytes (Table 77 of the Validation report) shows concentrations were at generally low levels. Examination of the validation spreadsheet showed many non-detects. Despite the less than required level of sampling, the results are sufficient to have confidence that the base of the excavation has been adequately validated. The lower than required testing frequency is therefore not significant.

5.8.3 FCC Landfill Backfill

The backfill for FCC Landfill was from the same sources as FCC East discussed in Section 5.7.3 above, that is:

- commercial soil excavated from FCC Landfill, FCC West and FCC East;
- treated fines;
- oversize material;
- crushed concrete; and
- the 0.5 m capping layer consisting of site-derived and imported residential quality surface fill and imported topsoil.

The as-built drawings show that, apart from layers of oversize or crushed concrete placed in the base of the excavation, all the commercial quality material was placed as treated fines alone or mixed treated fines. The commercial soil was always placed mixed with other material such as treated fines and oversize.

The discussion presented for FCC East and these sources (Section 5.7.3) also applies for FCC Landfill and is therefore not repeated.

5.8.4 Acceptability of FCC Landfill Remediation

The Validation Report concludes that FCC Landfill meets the SAC for an open space[15] use. Overall, we concur with this conclusion, with similar uncertainties to that discussed above for FCC East (see Section 5.7.4). Risks to groundwater are discussed in Section 7.10. The uncertainties with respect to soil quality are:

- Treated fines material was placed at depth in subgrades SG19A, SG19B and SH19C, while mixed treated fines material was placed in these and subgrade SG18 up to 0.5 m from the surface. There is an unknown potential for generation of ammonia gas. Currently the grass cover appears healthy. The potential for generation of ammonia in this area is not expected to create a particular human health risk for day-to-day use as open space. No buildings are planned for this area and excavation is expected to be infrequent. Testing for ammonia in soil gas is not required in this area, but confined space precautions should be taken if any excavation does take place in the area.
- The treated fines also have elevated concentrations of copper, which could cause phytotoxic effects for some deeper-rooted shrubs and trees. Shallow-rooted plants within the surface 0.5 m of residential / topsoil material should not be affected. The issue is readily managed by replacement of soil around deeper rooted plants where treated fines or mixed treated fines were buried close to the surface.
- There is only limited information on placement of backfill in the buffer zone on the western foreshore. There is a clay bund along the foreshore which will provide a natural buffer between the backfill and the shoreline. However, there is no information on the width of this bund. It appears probable that the buffer zone requirements were not complied with on the western foreshore. The significance of this is commented on in Section 7.3.

5.8.5 FCC Landfill Fitness for Purpose

Given the compliance with the SACs, with the exception of some uncertainty with respect to the possibility of ammonia generation and phytotoxicity of copper in treated fines, the FCC Landfill site is fit for its intended purpose with respect to the soil remediation (but see separate discussion on groundwater in Section 7.0). This is in the context of a Site Management Plan being implemented to control excavation into commercial quality

[15] The conclusion in Section 17.7 of the Validation Report (SKM, 2008) in fact reports that the FCC Landfill site meets the SAC for *residential* use. We assume that this is a typographical error

material, so that this material is not allowed to migrate to the marine environment or be disposed of inappropriately off site.

The uncertainty with respect to ammonia and copper are not human health issues for day to day use as open space. Carrying out further investigation to assess the risk from ammonia is not required. The potential risks from ammonia and copper during excavation or to plant health are readily managed by way of the Site Management Plan.

5.9 Residential Property Remediation

5.9.1 General

Four residential properties were remediated; 13, 15, 18 and 20 Tahi Street. The validation of the four residential properties was partly based on soil samples collected during the original characterisation investigation (GES, 2002). These soil samples were collected as vertical composites from the surface to 0.3 m depth and analysed for OCPs. The results were then compared directly with the SAC for compliance. Sampling over such a large depth range at the surface is not ideal as the peak concentrations are often found at the surface and the results could be 'diluted' by cleaner underlying soil. When assessing direct human exposure, a depth range of 0 – 0.075 is more commonly used in New Zealand (MfE, 2004a). For example, if it is conservatively assumed that all the contamination resided in the top 0.075 m of the characterisation (GES, 2002) samples, the actual surface samples could be up to 4 times higher than those reported i.e. by being diluted by the clean soil from 0.075 to 0.03 m depth. However, this potential flaw in sampling technique is not significant in terms of risk human health. Even if the reported concentrations are actually four times higher, the results will not be significantly elevated relative to human health criteria.

The SAC is based on potential effects on the local marine ecosystems via sediment runoff. However, even if the actual surface concentrations were slightly higher than indicated by the characterisation data, the overall effects are not likely to be significant. The potential for significant sediment runoff from the sites is relatively low as the properties make up a small proportion of the overall sediment 'catchment' for the local marine ecosystem.

5.9.2 13 Tahi Street

An area of DDX contamination along the northern boundary of 13 Tahi Street, adjacent to FCC East, was remediated and validated.

During the original characterisation (GES, 2002), 24 surface soil samples were collected from areas on this property not covered in building or hard-standing and analysed for OCPs. A further 13 samples were collected by TDC. Of the 37 samples, 17 had DDX concentrations exceeding the SAC of 5 mg/kg, ranging from just over 5 mg/kg up to

134 mg/kg. A single sample (6 mg/kg) had an ADL concentration above the SAC of 3 mg/kg. All other results were below the SACs.

The soil around the location with elevated OCP concentrations was excavated and the extents validated in line with the 'residential' protocol set out in Section 5.3. The excavation extended approximately 100 m along the northern boundary of the property and varied in width from about 12 m to 3 m. The depth of the excavation varied between about 1 and 1.5 m. A total of 48 validation samples were collected from the base and walls of the remedial excavation and analysed for OCPs. All samples returned OCP concentrations below the SACs.

A total of 22 samples were also analysed for TPH, ONP, OPP and VOCs. Four samples were analysed for 10% suite set out in Section 5.2 which included heavy metals, PAHs and PCBs. All non-OCP results were below the corresponding SAC. The only potential exceptions to this were two hot-water soluble boron results which that were unable to be interpreted due to a mistakenly high laboratory detection limit. The detection limit for these two samples was 30 mg/kg, ten times above the SAC of 3 mg/kg. The two other samples analysed for hot-water soluble boron had concentrations below 0.5 mg/kg. The potential information gap due to the high laboratory detection limit is not significant and the remaining two samples analysed for hot-water boron are considered representative.

The excavation was backfilled up to 0.15 m below surface with material from the residential stockpile and from 0.15 m depth to the surface with imported topsoil. The validation of these materials is discussed in Section 5.6.2.

Based on the information audited, we consider that the remediation has achieved compliance with the SACs at 13 Tahi Street.

5.9.3 15 Tahi Street

No remediation was required at 15 Tahi Street.

The validation of 15 Tahi Street is not reported in the Validation Report (SKM, 2008) as the characterisation sampling was completed in 2001, before the main remediation contract was awarded. The validation information relating to this property is contained in the characterisation report (GSE, 2002) and a report supplied by TDC (2002).

A total of seven surface soil samples were collected from areas not covered in building or hard-standing and analysed for OCPs. All samples complied with the relevant SAC. The DDX concentrations ranged from approximately 0.2 mg/kg to 4.3 mg/kg. No concentrations of ADL were measured above the laboratory detection limit of 0.1 mg/kg.

5.9.4 18 Tahi Street

A small area of DDX contamination was remediated and validated at the western end of 18 Tahi Street.

During the original characterisation (GSE, 2002), 18 surface soil samples were collected from areas not covered in building or hard-standing and analysed for OCPs. A sample close to the western property boundary returned a DDX concentration of 24 mg/kg, above the SAC of 5 mg/kg, but below the current human-health guideline of 28 mg/kg (MfE, 2006). All other results were below the relevant SACs.

According to the Validation Report (SKM, 2008), a total of nine validation samples were collected from the base and walls of the remedial excavation and analysed for OCPs. However, the extent of the excavation is not indicated in the report. The raw data in the validation spreadsheet indicates that the samples were from cells O9 and P9, in the south-west corner of property, that is adjacent to the initial exceedance. All samples returned concentrations below the SAC except for a single sample which returned a DDX concentration of 5.45 mg/kg, slightly above the SAC of 5 mg/kg. The ADL concentrations ranged from below laboratory detection limits up to 0.5 mg/kg. The slight exceedance of the 5 mg/kg SAC for DDX is not significant.

The EMS site records were also reviewed and these show that further sampling was undertaken across the western end of 18 Tahi Street. The data show two additional samples with DDX concentrations above the SAC of 5 mg/kg, up to 10 m away from the area of original contamination in the south-west corner. Both samples recorded DDX concentrations of 8 mg/kg and were located towards the northern property boundary in cells O9 and O10. The results are not discussed in the Validation Report. A diagram in the EMS site file appears to indicate that the area encompassing the two elevated results was excavated, although this could not be confirmed and no validation data for any such excavation could be found.

No samples were analysed for any of the contaminants in the 50% and 10% suites. However, this lack of information is not significant as there is no reason to suspect contamination of this type at the base of the excavations on this site.

It is assumed that the excavations were backfilled according to the protocol used elsewhere on the site i.e. up to 0.15 m below surface with material from the residential stockpile and from 0.15 m depth to the surface with imported topsoil. The validation of these materials is discussed in Section 5.6.2.

Based on the information reviewed there is some uncertainty with respect to the extent of the remediation. It is possible that soil with DDX concentrations of up to 8 mg/kg remains on the property. These potential exceedances are not significant as the DDX criterion of 5 mg/kg for residential site use relates to the sediment runoff exposure pathway and the average concentration in the surface soil is likely to be below the 5 mg/kg target. The possible SAC exceedances are not relevant to the human-health pathway.

5.9.4.1 20 Tahi Street

A small area of DDX contamination was remediated and validated near the centre of 20 Tahi Street[16].

During the original characterisation (GSE, 2002), 10 surface soil samples were collected from areas not covered in building or hard-standing and analysed for OCPs. Three samples returned concentrations above the DDX SAC of 5 mg/kg, with concentrations of 5.1, 5.9 and 16.9 mg/kg. All other results were below the relevant SAC.

Additional sampling by TDC confirmed that the elevated concentrations were localised and an area of 5m by 2.3 m by 0.3 m depth was excavated to remove the contamination (TDC, 2002). Samples collected from the base and each wall of the remedial excavation had DDX concentrations ranging from 0.67 to 5.3 mg/kg. The slight exceedance of the 5 mg/kg SAC for DDX is not significant.

No samples were analysed for any of the contaminants in the 50% and 10% suites set out in Section 5.2. However, this lack of information is not significant as there is no reason to suspect a source for these contaminants on 20 Tahi Street.

Based on the information reviewed, we consider that the remediation has achieved compliance with the SACs at 20 Tahi Street.

5.9.5 Acceptability of Residential Property Remediation

The Validation Report concludes that the soil quality in the residential property sites meets the SACs. We concur with this conclusion.

[16] Note: since the remediation was completed, 20 Tahi Street has been subdivided into three separate lots

6.0 Marine Sediment Remediation

6.1 Remediation Requirements

The remediation of the marine sediments on the eastern and western foreshores adjacent to the Mapua Channel and FCC landfill, respectively, were intended to improve the habitat for the marine ecosystem and reduce risks to secondary feeders on that ecosystem. The site-specific SACs developed for the marine sediments (Egis, 2001) were based on protection of:

- sediment-dwelling organisms based on published data;
- human consumers of shell fish and fish which may bioaccumulate contaminants through the food chain; and
- species at higher trophic levels (seafood-eating birds) exposed at relatively high concentrations due to bioaccumulation within the food chain.

For DDT, the acceptable concentration in seafood food for human consumption was taken to be 0.1 mg/kg. A bioaccumulation factor (BCF) of 10 was assumed (Egis, 2001), based on measurement in mud snails (*amphibola crenata*), giving an SAC of 0.01 mg/kg. A check against higher trophic levels was made using literature bioaccumulation factors.

A similar approach was adopted for dieldrin. Again the starting point was the food standard of 0.1 mg/kg. The same BCF of 10 was used based on sediment and mud snail concentrations, resulting in the SAC of 0.01 mg/kg. A check that this would be protective of birds was carried out.

An SAC of 0.01 mg/kg for both DDT (applied as DDX) and dieldrin (applied to include aldrin and lindane) will be protective for recreational users of the foreshore, e.g. children playing. While children playing in mud can ingest larger quantities of sediment than for the residential situation and dermal exposure is expected to be greater (a child getting covered head to toe in mud), the frequency of exposure is expected to be less than the residential exposure frequency. The combination of these two factors will at worst be about even but probably favour a lower daily average sediment intake for the recreational scenario over the residential scenario. Given the marine SACs are at least two orders of magnitude lower than the corresponding human-health guidelines, a large margin of safety is provided for the recreational user.

The other SACs were the ISQG-Low marine sediment guidelines from ANZECC (2000). ANZECC (2000) recommends adjusting the guidelines for total organic carbon (TOC) as the guideline increases with increases in TOC. Measuring TOC is important for non-ionic organic compounds such as DDX and ADL, but the consent did not specify this and it was never carried out. Particle size distributions would also be helpful to give context to differences in contaminant concentrations between sample locations. The particle size distribution also affects the suitability of a sediment habitat for various biota.

The consents specified the remediation method in a relatively detailed way.

Condition 10(j) of both RM030521-General and RM030522-Coastal Marine required as part of a suite of procedures:

> *A coastal marine excavation works procedure specifying but not limited to:*
>
> *i. Excavation depth which shall not be limited to depth by distance but shall be such depth as is required to enable the Consent Holder to meet the validation standards required under the Soil Acceptance Criteria (Marine Sediments category);*
>
> *ii. Unless prevented by reason of practical considerations excavation in the Coastal Marine Area shall take place by way of long reach excavator;*
>
> *iii. As far as practicable, works will be completed in one tidal cycle, the area excavated covered with a layer of gravel to prevent the migration of fines onto the excavated surface. Works will recommence on the next low tide cycle and be carried out in the same manner;*
>
> *iv. In the event the validation samples do not establish that the criteria required by the Council has been achieved then the area shall be re-excavated to the depth that the remediation levels are met;*
>
> *v. A similar method will be adopted for removal of sediments up to 100m offshore adjacent to the FCC Landfill, with a gravel access being constructed to the limit of the works. The excavator will then, working on low tide, excavate the sediments and retreat toward the FCC landfill, recovering gravels as areas are completed;*

The coastal marine consent further required monitoring under Condition 19:

Monitoring

> *19. The Consent Holder shall undertake a programme of macro invertebrate and sediment quality sampling at selected sites within and distant to the area of sediment excavation. The monitoring programme shall be approved by the Council's Compliance Coordinator and shall be undertaken before works authorised under this consent commence, (unless Council holds sufficient prior sampling records) and at 12 months, 24 months and 36 months following completion of the works undertaken pursuant to this Consent.*

and imposed further constraints on the timing of the remediation in conditions 20 and 21, which specified:

Timing of Excavation

> *20. The marine sediment excavation process shall take place as late in the remediation process as practicable.*

21. Excavation of marine sediments shall not be carried out during rain or under water. The excavated area will be covered with clean fill appropriate for the marine environment prior to being submerged by the tide.

It is now a matter of record that the marine sediment remediation on both the east and western sides of the site failed to meet the SACs by a large margin, although there is some evidence to suggest that the situation has improved with time. The question is now whether the remediation was carried out to the extent practicable. This is a subjective test dependent on a number of factors.

The circumstances of the two marine sites are different and must be examined in turn, however, a common working definition of the extent practicable is required.

6.2 Working Definition of Remediation to the Extent Practicable

As noted, the extent practicable is a subjective test. It depends on such things as:

- constraints imposed by the immediate physical environment, not least, in this case, the tidal nature of the site imposing time constraints and the difficulty working in mud;
- constraints imposed by the amount of money available (with contractual arrangements presumably imposing additional constraints) – virtually anything is possible if enough time and money is available, but there never is;
- the condition of the wider environment – SACs will not be achievable if adjacent areas have higher concentration within sediment that is mobile;
- constraints imposed by the consent conditions in terms of methods and timing; and
- perceptions as to whether residual effects are acceptable or adverse, and if the latter, weighing up the potential benefits of further remediation against potential harm of the remediation itself (temporary destruction and/or permanent change to the habitat) and the cost.

For this assessment it is assumed that methods reasonably similar to those specified in the consent had to be used. More sophisticated (but not necessarily more effective given the circumstances) methods could have been adopted, but the cost would have been much greater.

It is also assumed that the remediation was to be limited to the low tide mark at the FCE East beach (to go into the channel increases the difficulty markedly).

It is further assumed that it was not physically or economically practical to remediate a considerable part of the western bay between Grossi Point and the FCC Landfill vicinity.

As with other aspects of the extent practicable definition, determining what effects on receptors are acceptable is a subjective decision. Essentially it is necessary to balance often intangible benefits against equally intangible perceptions of harm.

In making the final judgement it is necessary to have an understanding of why the remediation was not as successful as intended (which is the case). This is required in order to determine whether, for example, a better application of the method or a modest modification to the extent, might have achieved a better outcome, or alternatively, no matter what was done (within reason), the intended remediation was inherently flawed. If the reason for failure cannot be worked out, then this judgement cannot be arrived at.

6.3 East Marine Sediment Remediation

6.3.1 General

This section is based on information presented in the Validation Report (SKM, 2008) and a number of other sources as outlined in Section 4.0. A brief description of the remediation works has been included here as an understanding of this is required to interpret the validation data and a detailed description was not included in the Validation Report.

Figure 4 shows the approximate layout of the remediation excavation in relation to the bund / sea wall. This figure is based on Figure 41 in the Validation Report (SKM, 2008). No scale or lateral reference system was provided in the original figure making it difficult to determine what part of the bund the horizontal line at the top of the drawing represents (we have assumed it represents the historical 'top of bund' based on a review of site records). Consequently, the locations of the samples cannot be accurately determined from the information presented. The approximate scale shown on Figure 4 has been estimated from sample position information obtained separately.

6.3.2 Pre-excavation testing

In April 2005, a series of sediment samples were collected to attempt to characterise the contamination prior to remediation. The sample locations are shown in green on Figure 4. Samples were collected variously from 0.15, 0.5 and 1.0 m depths and analysed for DDX and ADL. The results indicated elevated concentrations of these contaminants, with only three of the 57 samples analysed for DDX returning concentrations below the marine SAC of 0.01 mg/kg. The maximum DDX concentration of approximately 8.5 mg/kg was detected at 0.5 m depth close to the toe of the former bund. There were approximately 19 samples with DDX concentrations above 1 mg/kg, with most of these located along the toe of the former bund. Concentrations above 1 mg/kg were detected at 0.5 m depth at six locations, with no analytical data from below that depth to show the vertical extent of the contamination.

The maximum ADL concentration detected was 0.65 mg/kg and 22 of the 57 samples returned ADL concentrations below the marine SAC of 0.01 mg/kg.

A number of other investigations have tested sediment samples from the wider vicinity along the eastern foreshore. These results are discussed further in Section 6.5.

6.3.3 Remediation Excavation

The removal of marine sediment occurred in early May 2005. The excavation was undertaken in a series of individual cells (FS1 – FS14 on Figure 4), extending into the channel by up to about 30 m from the toe of the bund. As required by the consent, each cell was excavated and backfilled within one tidal cycle i.e. above water. The depth of excavation ranged from approximately 0.25 m to 1.0 m below the original surface, with an average of about 0.5 m. This was greater than originally planned. The excavations were backfilled with an imported coarse river sand/gravel (see Section 6.3.6 for further detail).

The remediation of the area around the former stormwater surge chamber (see Section 3.2.2) was completed in July 2005, shortly after the marine sediment remediation. Figure 4 shows the approximate location of the surge chamber in relation to the sediment excavations.

From the information obtained, it is not clear whether the area represented by the pre-excavation samples 1072 – 1089 has been remediated (Figure 4). It would appear that these areas were not included in the marine sediment remediation works i.e. they are not within cells FS1 – FS14. However, it is likely that at least the central part of this strip of beach was remediated during the works to remove the surge chamber (subgrades SG10 and SG13 on Figure 2). In addition, the works to construct the sea wall are likely to have overlapped these sample locations to some extent. This is difficult to confirm as the position of the samples cannot be accurately determined from the location plan.

A review of site photos shows that the backfilled area was 'root-raked' in June 2005, the month after the remediation was completed. No other mention of this has been seen in any other documentation reviewed. It appears that the entire remedial excavation was dragged through with a comb-like bucket on the excavator. The tines on the bucket appear to be over 0.5 m in length. It is not known why this was undertaken, and whether the full depths of the tines were used in the process. If this was the case, it would have had the effect of mixing the backfill and potentially mixing in underlying in-situ material, given the length of bucket tines.

Although there are some uncertainties in the remediation work methods and the subsequent validation data, these do not significantly affect the overall conclusions regarding the marine sediment remediation.

6.3.4 Validation Sampling

Validation samples were collected from the base of each excavation immediately prior to backfilling. These samples are presented in black on Figure 4 and labelled as 'Layer 2 12th May 2005' on the legend. All 86 of these samples were analysed for the full OCP suite, including DDX and ADL. A further 31 samples were analysed for TPH, OPP, ONP and VOCs. Six samples were analysed for the 10% suite which includes heavy metals,

PAHs and PCBs. No samples were collected from the walls of the excavation, so the conditions at the edge of the excavation cannot be determined.

A subsequent set of 16 samples was collected about three months after the remediation works. These samples were collected from approximately 0.3 m depth in a line along the beach, as indicated by the red samples on Figure 4, and analysed for the full OCP suite. It is not stated what the target stratum was for this sampling, however, the sample depth would tend to imply that the samples were collected from within the remediation backfill material.

A further 15 samples were collected from the East beach by TDC and CH2M HILL in May 2007, approximately two years after the beach remediation was completed. Three of the samples were collected from 0.15 m below the surface and the remainder were collected between 0 and 0.05 m. The surface samples were collected over four three-part transects down the beach, spaced out along the beach. Two of the deeper samples were collected centrally on the beach and the other was collected opposite the first residential property south of the site. All samples were analysed for OCPs, ammonia and nitrate.

6.3.5 Compliance with SAC

The validation results indicate that the remediation of the eastern marine sediments did not achieve compliance with the SAC and sediment remaining in the area had concentrations significantly above the target values. The exceedances predominantly relate to DDX and ADL. In addition, the post remediation sampling of the backfill material indicated that the coarse sand and gravel backfill had been re-contaminated in the three months after the remediation had been completed. Details of the exceedances are discussed below and the significance of the exceedances is assessed in Section 6.7.

The Validation Report (SKM, 2008) combines the results from samples taken from the excavation base with post-remediation sampling of the backfill. This is not appropriate as the two datasets represent different situations and are likely to be from different populations. The datasets have been discussed separately below.

Initial Validation Sampling

Of the 86 samples taken from the excavation base, 69 had contaminant concentrations above the SAC. The majority of these exceedances related to elevated DDX concentrations, with 65 samples above the SAC of 0.01 mg/kg for DDX. The maximum DDX concentrations of 125 mg/kg and 58 mg/kg were detected in cell FS11, close to the surge chamber discharge point. All other DDX concentrations were below 3 mg/kg.

ADL concentrations above the SAC of 0.01 mg/kg were detected in 23 of the 86 samples, with a maximum concentration of 3.9 mg/kg (also in cell FS11).

As noted in the assessment of the marine sediments as residential backfill (Section 5.6.2.2), the Validation Report incorrectly assumed the dataset was log-normally distributed. However, given the 95% UCL estimates were well above the SACs (at least

five times for ADL and two orders of magnitude for DDX) regardless of method, this error is of no particular significance.

The Validation Report (SKM, 2008) stated that six nickel results were above the SAC, with a maximum concentration of 80 mg/kg. However, the report incorrectly used a superseded SAC of 21 mg/kg instead of the correct value of 70 mg/kg. The minor exceedance in nickel concentrations is not significant.

The detection limit for the PCB analysis (0.03 mg/kg) was not low enough to assess the data adequately against the SAC of 0.023 mg/kg. Five of the six samples analysed for PCB were below the detection limit, with a concentration of 0.07 mg/kg detected in a sample from FS10 (again, close to the surge chamber).

A similar situation exists for chlordane, where the laboratory detection limits (variable) were typically not low enough for comparison with the SAC of 0.0005 mg/kg. However, chlordane was detected above the laboratory detection limits in ten samples, with a maximum concentration of 0.16 mg/kg.

These discrepancies are not significant given the large non-compliance with the DDX SAC.

Post Remediation Sampling (May 2005)

Of the 16 samples post-remediation samples collected, 15 had DDX and ADL concentrations above the respective SAC. The DDX concentrations ranged between 0.4 and 6.4 mg/kg and the ADL concentrations between 0.02 and 0.28 mg/kg. As discussed above, it is not entirely clear what these samples represent. However, assuming that they were taken from within the sand/gravel backfill material, the samples are likely to represent fine sediment that has infiltrated the coarse backfill material. The potential source of this contamination and its significance are discussed in Section 6.7.

CH2M-HILL / TDC samples (May 2007)

All of the 12 surface (0 -0.05 m depth) samples had DDX concentrations above the SAC of 0.01 mg/kg, with concentrations ranging between 0.05 and 1 mg/kg. Four of the ADL concentrations in the same samples were above the SAC, with a maximum concentration of 0.05 mg/kg.

The three samples taken from 0.15 m depth had higher DDX and ADL concentrations. The DDX concentrations ranged from 3.2 to 27.5 mg/kg, with the maximum concentration detected in a sample from close to the base of the sea wall, at the top of the beach. The ADL concentrations in the same samples ranged from 0.10 to 0.66 mg/kg.

Ammonia and nitrate concentrations in all samples were below the corresponding laboratory detection limits of 5 and 1 mg/kg respectively.

6.3.6 East Marine Backfill

A total of approximately 5,000 m^3 of sand/gravel was imported for use as backfill for the marine excavations. Approximately 2,900 m^3 of this was used for the east marine

excavation and beneath the eastern bund / sea wall. The material was sourced from four different locations and at least two samples were taken from each location. The material was described a well-graded sandy gravel (MWH, 2009g), although no particle size distribution test data was available. The volume and final destination for each source is not known.

Ten samples were taken from the marine backfill material and analysed for the full OCP suite. This represents one sample per 500 m^3, which complies with the RAP requirements. Two of these samples (20%) were also analysed for a metals suite and a single sample was analysed for PAHs.

One of the 10 samples had a DDX concentration of 0.012 mg/kg, slightly above the marine SAC of 0.01 mg/kg. This exceedance is not significant, particularly as the result is well below the DDX concentrations remaining at the marine excavation extents. All other DDX and ADL concentrations were below the SAC.

One of the two samples analysed for nickel returned a concentration (165 mg/kg) above the SAC of 70 mg/kg for nickel. The average of the two samples was 102 mg/kg. It would have been desirable to have taken more samples for nickel to confirm the material as a whole complied with the SAC

The laboratory detection limit of 0.001 mg/kg for chlordane was not low enough to enable a comparison with the corresponding SAC.

Overall, the material imported as marine backfill sufficiently complies with the SACs.

6.4 West Marine Sediment Remediation

6.4.1 West Marine Excavation

This section is based on information presented in the Validation Report (SKM, 2008) and a number of other sources as outlined in Section 4.0. As with the east marine remediation, a brief description of the remediation works has been included here as an understanding of this is required to interpret the validation data. Figure 5 shows the approximate layout of the remediation excavation in relation to the 15 m characterisation grid. This figure is based on information supplied by MWH.

6.4.2 Pre-excavation Testing and Remediation Approach

Various investigations of the sediment quality in the creek and foreshore area had shown elevated concentrations of DDX and ADL compounds. The results indicated that elevated concentrations extended over 100 m from the site boundaries into the Waimea Inlet. DDX concentrations across the broader estuary appeared to range from 0.1 to 0.9 mg/kg (GHD, 2006), well above the SAC of 0.01 mg/kg. Based on the experience gained during the remediation of the eastern foreshore, the viability of achieving compliance with the SACs in the west marine remediation was discussed between the Site Auditor, TDC and

MfE. It was agreed that a more practical approach would be to attempt to remove the bulk of the contamination rather than adhering strictly to the SACs (GHD, 2006).

It is not clear how success was then to be judged as revised SACs were not developed. An initial suggestion of adopting a 1 mg/kg criterion for DDX was rejected by the Site Auditor on the basis that (GHD, 2006):

> *... it would appear that concentrations across the broader estuary typically range from 0.1 to 0.9 ppm. On this basis, it would be difficult to accept a revised criterion as high as 1 ppm.*

Presumably meaning that choosing a criterion similar to existing concentrations was hardly an improvement. The Site Auditor went on to say:

> *In addition, given the need to remove contaminated sediments, collect validation samples and backfill with clean material within one tidal cycle, it will not be confirmed (from the laboratory results) that the validation samples will meet the adopted criterion until well after the clean up works have been completed.*
>
> *A more practical approach would be to base the clean up on the principle of removing the bulk of the contamination sediments, and determining the extent of excavation on the basis of removing the highest concentration material. This would be consistent with the approach being taken for cleaning up the land at the site, where the objective has been to achieve a destruction efficiency of at least 90%, and would significantly reduce the time over which the target criterion will be reached through natural degradative processes. This would draw on the concept of "Clean Up to the Extent Practicable" ... where it is not practicable to comply with very stringent criteria and the risk associated with the residual contamination is not excessive.*

This is a sensible approach but inevitably relies on a somewhat subjective assessment in the absence of good information on the likely risks. The Site Auditor arrived at a preliminary estimate of the reduction in contaminant load for a revised excavation area that would achieve a 90% reduction in the contaminant load. It is not clear from the information reviewed whether this was to be a reduction in concentration (to, say, 0.06 – 0.09 mg/kg based on the measurements cited above) or a reduction in total mass within the area. It is also not clear over what total area the 90% reduction was being judged against, i.e. the immediate area of the beach or the complete bay bounded by Grossi Point.

6.4.2.1 Remediation Excavation

The initial remediation of the west foreshore area was completed at the beginning of May 2006. The excavation included three distinct areas: the creek; a swale from the end of

the creek extending out into the inlet; and the general foreshore area. The swale was a drainage pathway, cut through the marine sediments by the discharge from the creek.

The remediation excavation of the creek removed at least 200 mm of soil from the walls of the creek and up to 600 mm from the base (EMS, 2006). Prior to excavation, vegetation was removed from the edges of the creek. Where the vegetation was from areas of low contamination, this was put to one side for re-use. Alternatively, the vegetation was taken off-site for disposal. The excavation of the swale and the foreshore removed between 400 and 600 mm of sediment.

The excavation was completed in a series of cells, each within one tidal cycle i.e. above water. Imported sandy gravel was placed in the completed excavations.

In September and October of 2007, the surface 100 mm layer of sediment was removed across the approximate area of the original foreshore remediation excavation as a follow-up to finding excessive concentrations in sediment samples in May and July 2007 (TDC, 2007a, 2008a). This excavation created a shallow pond on the eastern half of the foreshore. Similarly, approximately 100 mm of sediment was removed from the stream bed in cells O1, N1 and M2 (see Figure 5).

In mid-October 2007, heavy rainfall caused a discharge of sediment from treated fines stored on the adjacent landfill site (TDC, 2008). The discharge was visually apparent. In November 2007, TDC sampled three locations across the beach to determine the effects of the discharge. The results indicated that eastern end of the beach had been impacted with DDX concentrations between 2 and 6 mg/kg.

A 100 mm layer of imported sand/gravel was placed across this area in November 2007. This occurred after FCC Landfill had been covered with the capping layer of residential quality soil. No further sediment was removed.

6.4.3 Validation Sampling and Compliance with SAC

Overall, the scope of validation sampling for the west marine sediment remediation is reasonable for characterising the quality of the remaining sediments. The separate datasets are discussed below.

The validation results indicate that the remediation of the western marine sediments did not achieve compliance with the SAC and sediment remaining in the area had concentrations significantly above the target values. As with the eastern foreshore, the exceedances predominantly relate to DDX and ADL. The most elevated concentrations were detected in samples from the creek excavation.

Initial Remediation

A total of 146 validation samples were collected from the base of the excavation immediately prior to backfilling. All of these samples were analysed for the full OCP suite, including DDX and ADL. A further 82 samples were analysed for TPH, OPP, ONP

and VOCs. Approximately 25 samples were analysed for the 10% suite (see Section 5.2) which includes heavy metals, PAHs and PCBs.

Of the 146 samples taken from the initial excavation extents, 94 had contaminant concentrations above the SAC. The majority of these exceedances related to elevated DDX concentrations, with 91 samples (97%) above the SAC of 0.01 mg/kg for DDX. The majority of the peak DDX concentrations were detected in samples from the creek excavation. Approximately 15 samples recorded DDX concentrations above 1 mg/kg (100 times the SAC) in this area, with a maximum concentration of 82 mg/kg detected in a sample from the north-west bank of the creek. The next highest DDX concentration in the creek area was 37 mg/kg. The only other DDX concentrations above 1 mg/kg were recorded in two samples at the eastern end of the beach, close to the high tide mark (9 – 15 mg/kg). It is understood that the sediment associated with these two elevated results was removed by EMS (Jenny Easton, TDC, pers. comm.), although no records have been located to confirm this.

The DDX concentrations in samples from the base of the foreshore excavation were typically below the SAC, indicating the full vertical extent of the contamination had been removed across the area. Samples from the edge of the foreshore excavation had DDX concentrations ranging from 0.01 to 0.13 mg/kg (excluding the hotspot at the eastern end of the beach). The samples from the base of the swale all returned DDX concentrations above the SAC of 0.01 mg/kg, with a maximum of 0.9 mg/kg.

ADL concentrations above the SAC of 0.01 mg/kg were detected in 19 of the 146 samples. Thirteen of the 19 exceedances were from the creek excavation, although the maximum concentration of 0.224 was detected at the eastern end of the beach (at the same location where elevated DDX concentrations were detected). As noted above, it is understood that the sediment associated with the peak concentration was removed.

The Validation Report (SKM, 2008) stated that nine nickel results were above the SAC, with a maximum concentration of 71 mg/kg. However, the report incorrectly used a superseded SAC of 21 mg/kg instead of the correct value of 70 mg/kg. The nickel concentrations are not significant.

The detection limit for the chlordane analysis (0.002 mg/kg) was not low enough to assess the data adequately against the SAC of 0.0005 mg/kg. Chlordane was detected above the laboratory detection limits (and the SAC) in a single sample, with a concentration of 0.083 mg/kg.

CH2M HILL / TDC Sampling

A total of 16 sediment samples were collected from the creek and western foreshore areas during the CH2M HILL and TDC sampling in May 2007 (see Section 6.3.4), approximately one year after the remediation. Fourteen of these samples were from the

surface (0 – 0.05 m), with the remaining two from 0.15 m depth. The surface sampling was likely to have been representative of fine sediment that had migrated into the remediated area over the period since the remediation was carried out.

The DDX concentrations in all 14 surface samples were above the SAC of 0.01 mg/kg, with concentrations ranging from 0.05 to 7.4 mg/kg. The concentrations in almost all samples were above 1 mg/kg. Similarly high concentrations were present in the row of samples at the top of the beach and the row 15 – 20 m off-shore, with no particular pattern. The exceptions to samples with concentrations above 1 mg/kg were the two upstream-most creek samples (0.05 and 0.09 mg/kg) and a single swale sample (0.4 mg/kg). The ADL concentrations in the 14 surface samples were also above the SAC, with concentrations ranging from just above the criterion of 0.01 mg/kg up to 0.15 mg/kg.

The DDX concentrations in the two deeper samples were above the SAC (0.2 – 0.4 mg/kg), albeit slightly lower than the typical surface concentrations. The ADL concentrations in these samples were 0.004 mg/kg (below the SAC) and 0.014 mg/kg.

Ammonia and nitrate concentrations in all samples were below the corresponding laboratory detection limits of 5 and 1 mg/kg respectively.

13 July 2007

Three samples of sediment were collected from the west beach foreshore on 13 July 2007 (approximately one year after the initial remediation), although the exact location of these is unknown. The samples were analysed for the full OCP suite and a reduced metals suite. It appears that these and the CH2M HILL samples were used as the basis for undertaking the additional (September/October 2007) remedial excavation, although this could not be confirmed from the information reviewed.

All three samples had DDX and ADL concentrations above the SAC. The DDX concentrations ranged from 5 mg/kg to 24 mg/kg and the ADL concentrations ranged from 0.09 mg/kg to 0.49 mg/kg. It is not known at what depth these samples were taken or whether the sediment they represent was subsequently removed by the additional excavation.

September / October 2007 Remediation

A total of 14 samples were collected to validate the additional sediment removal in September / October 2007 and analysed for DDX and ADL.

Of the 14 samples analysed, 11 had DDX concentrations above the SAC with concentrations ranging between just over 0.01 mg/kg and a maximum of 0.59 mg/kg. ADL concentrations slightly above the SAC were detected in five samples, with concentrations ranging between 0.01 mg/kg and 0.02 mg/kg. It is not entirely clear what these samples represent. However, it is assumed that they were taken from the surface of the sediment remaining at the base of the additional remedial excavation.

November 2007 TDC Sampling

Three samples of sediment were collected by TDC from the west beach foreshore on 6 November 2007 and analysed for OCPs.

The three samples across the beach contained DDX concentrations ranging from 0.72 mg/kg (at the western end of the beach) to 5.9 mg/kg. The ADL concentrations ranged from 0.019 to 0.18 mg/kg. This appeared to confirm the theory that the sediment quality had been impacted by site runoff. The eastern end of the beach, where the more elevated concentrations were detected, was covered with 100 mm of imported gravel on 29 November 2007 to prevent mobilisation of the contamination. No sediment was removed.

6.5 Additional Sediment and Biota Monitoring Data

Tasman District Council has carried out monitoring of sediment quality and snails since the marine sediment remediation was completed (TDC, 2009b) to fulfil the monitoring condition of the consent. A baseline monitoring was carried out prior to the remediation in 2005. The sampling was conducted to determine whether the remediation resulted in an improvement in the quality of the marine habitat with respect to contamination levels. An earlier study considered snails to be the most appropriate bio-indicator of the success of the remediation (Landcare Research, 2002). This study included measurement of OCP accumulation in other fauna such as cockles, crabs and oysters.

In February 2005, TDC obtained sediment samples and collected snails from a series of locations on the western and eastern foreshores to benchmark conditions before the marine sediment remediation works occurred. A control site to the west of the site was also sampled to assess likely background concentrations in the site vicinity. The sediment samples and snail flesh were analysed for DDX and dieldrin and lindane compounds.

Three annual monitoring rounds have been completed (at similar sampling locations) since the majority of the foreshore remediation works were finished in 2006. In the west, three sediment samples have been collected at 40 m intervals along the swale, from close to the south-west corner of FCC Landfill out into the Waimea Estuary. Snails were collected from a 10 m by 10 m area approximately 40 m from the high tide mark in the central portion of the western beach. A sample of sediment was also collected at this location.

In the east, sediment samples were collected along a transect from the base of the sea wall out into Mapua Channel. The ‘top’ sample was from adjacent to a seep at the base of the wall, with samples collected at 8 m and 15 m intervals from that point. The sediment samples were collected from the top 1-2 cm of the sediment surface.

The initial and three subsequent set of results for the eastern and western beaches are shown in Table 3 and Table 4, respectively.

The latest monitoring results (TDC, 2009b) indicate a decreasing trend in OCP concentrations in both sediment and snails, although the small sample size is not definitive. The DDX concentrations in snail flesh have reduced on both east and west sites (noting that the 2005 snail results for East were a different species of snail to that now being sampled, with the original snail bioaccumulating more). In the west, the DDX concentration in snail flesh has dropped from 51 mg/kg in 2007 to 3.5 mg/kg in February 2009. The corresponding dieldrin concentrations in the west have dropped from 2.2 mg/kg in 2007 to 0.2 mg/kg in February 2009, a ten fold decrease. In the east DDX concentrations in the snail flesh have dropped from 0.54 mg/kg to 0.03 mg/kg, an 18-fold decrease. The lesser bioaccumulation in the east versus the west is due to the different species of snail being tested (top shell versus mud snail).

Every sediment sample site has also shown a reduction in OCP concentrations when compared to the previous results For example, in the west, the DDX concentrations along the swale have reduced from between 0.4 and 3.9 mg/kg to between 0.1 and 0.6 mg/kg. The DDX concentration at the west snail sampling location has reduced from 16.6 mg/kg to 0.23 mg/kg over the three monitoring rounds. The dieldrin and lindane concentrations have also decreased at each site.

Bioaccumulation has possibly increased for both DDX and dieldrin since 2007, perhaps reflecting increased snail age, with bioaccumulation factors now higher than the 2005 samples, albeit at much reduced concentrations. This may be an effect of increased snail lifespan due to the lower concentrations than pre-remediation, allowing the snails to bioaccumulate relatively more.

In the east, the 'top' sediment sample is from adjacent to a groundwater seep. The DDX concentrations have decreased from 2.4 mg/kg to 0.03 mg/kg over the three monitoring rounds. In earlier monitoring rounds, there had been some algal growth on the beaches, particularly around the seepage area. In the latest monitoring round 'no excessive algal growth' was noted.

Table 3: Sediment and biota sampling Eastern Beach – 2005 – 2009 (mg/kg)

	DDX (mg/kg)				Dieldrin (mg/kg)				Lindane (mg/kg)			
Location	**2005[1]**	**2007**	**2008**	**2009**		**2007**	**2008**	**2009**		**2007**	**2008**	**2009**
Control: sediments (1 bay west of FCC west)	0.0056	ND	ND	0.005	-	ND	ND	ND	-	ND	ND	ND
East sediments from snail area, top of beach	0.63	2.12	0.187	0.130	0.12	0.071	0.026	0.006	-	0.68	ND	ND
East transect: central sediments at top of beach	273.5	2.4	0.477	0.30	77.13	0.58	0.078	0.054	0.36	ND	ND	ND
East transect: 10m, 5m, 4.8m, 8 m down beach in successive years	5.2	0.24	0.24	0.016	1.3	0.0108	0.28	0.005	0.004	ND	ND	ND
East transect: 22m, 15m, 10.5m, 15.0m down beach in successive years	0.34	0.023	0.044	0.013	0.15	0.0057	0.004	ND	0.004	ND	ND	ND
Control snails (same bay as control seds.)	0.11	-	-	-	0.007	-	-	-	-	-	-	-
Snails (top shells) from East Beach (results in mg/kg wet weight)	3.96	0.543	0.078	0.025	1.0	0.027	0.007	0.005	-	0.001	ND	ND

Notes Source: TDC (2009)

[1] Original snails were mud snails but change of habitat forced switch to mudflat top shell snails (*diloma subrostrata)*.
Top shell snails appear to bioaccumulate less because of different behaviour (do not burrow) and feeding habits.

ND = less than 0.0005mg/kg

- = no data given

Aldrin concentrations are not reported as they were typically below laboratory detection limits.

Table 4: Sediment and biota sampling Western Inlet – 2005 – 2009 (mg/kg)

	DDX (mg/kg)				**Dieldrin (mg/kg)**				**Lindane (mg/kg)**			
Location	**2005**	**2007**	**2008**	**2009**		**2007**	**2008**	**2009**		**2007**	**2008**	**2009**
Control: sediments (1 bay west of FCC west)	0.0056	ND	ND	0.005	-	ND	ND	ND	-	ND	ND	ND
West sediments transect = MHWS @concrete post bridge	12	3.9	1.8	0.129	0.0018	0.08	0.067	0.005	0.007	0.003	0.0057	ND
West sediment 40m down ditch from MHWS	0.26	1.43	2.0	0.62	0.129	0.08	0.06	0.02	-	0.004	0.0039	0.0016
West sediment 80m down ditch from MHWS	0.17	0.42	0.41	0.12	0.0035	0.013	0.013	0.004	0.0005	0.004	ND	ND
West sediments 10m x10m area 10m (2005,2007), 40m (2008), 45m (2009) from MHWS	1.64	16.6	0.987	0.23	0.022	0.19	0.025	0.009	0.003	0.008	0.003	ND
Control snails (same bay as control seds.)	0.11	-	-	-	0.007	-	-	-	-	-	-	-
West snails from 10mx10m area (results in mg/kg wet weight)	10.3	51.14	10.34	3.5	0.364	2.18	0.48	0.22	-	0.016	ND	ND
Bioaccumulation factor	6.2	3.1	10.5	15.2	16.5	11.5	19.2	24.4				

Notes Source: TDC (2009)
ND = less than 0.0005mg/kg
- = no data given
Aldrin concentrations are not reported as they were typically below laboratory detection limits.

6.6 Off-site Sediment Data

A number of investigations have involved testing sediment samples from locations away from the two main remediation areas.

On two occasions, sediment samples were collected from beneath the wharf approximately 40 m to the north-east of the site. The sampling events in 2005 and 2007 indicated that elevated OCP concentrations are present in the sediment beneath the wharf to depths of at least 0.4 m below the surface. For example, DDX concentrations ranging between about 1 mg/kg and 60 mg/kg were detected in samples from various depths. The ADL concentrations were much lower. The sediment at this location is covered by a layer of gravel armouring, a reflection of the high energy tidal environment which has removed the fine material leaving the larger stones.

A figure showing what appear to be DDX results from sediment samples in the wider site area was found during a review of the EMS site files. The date of sampling was not provided on the figure, although the document was tabled in a peer review panel meeting in December 2005 (Jenny Easton, TDC, pers. comm.). However, the results show sediment adjacent to the Mapua Channel beyond the wharf, approximately 100 m north north-east, also had elevated DDX concentrations (1 and 17 mg/kg). DDX concentrations in samples further along Mapua Channel appeared to decrease significantly. Concentrations were below the laboratory detection limit of 0.01 mg/kg in samples taken from approximately 500 and 800m to the north north-east of the site. A sample from the tip of Grossi Point, approximately 400 m to the south, returned a DDX concentration of 0.05 mg/kg. Two samples from 50 to 100 m west of the site returned DDX concentrations of approximately 0.01 mg/kg.

In October 2007, TDC collected a series of surface sediment samples from the Waimea Estuary in two transects. This included samples up to 250 m to the south of the western foreshore, within the tidal mud-flats (TDC, 2008a). The samples represented the top 0.1 m of the sediment.

The results are shown in Table 5. DDX concentrations ranged between 0.07 mg/kg and 0.24 mg/kg, with an average of about 0.15 mg/kg, not dissimilar to the most recent of the annual sediment samplings (Table 4). The sample collected at approximately 250 m from the foreshore had a DDX concentration of 0.13 mg/kg, showing how far from the shore similar to average concentrations can be. Dieldrin concentrations ranged from 0.0016 to 0.0061 mg/kg, with an average of 0.003.

Concentrations of DDX in snail flesh ranged from about 4 to 73 mg/kg, with the two highest concentrations occurring 85 and 167 m from the beach. These concentrations are much higher than that measured in TDC's annual snail surveys on the beach, although the highest snail concentrations are similar to the 2005 baseline measurements. Bioaccumulation factors are generally much higher than the annual samples, ranging from 30 to 400 for DDX and 70 to 950 for dieldrin. Again it might be

result of snails living longer at the lower concentrations and therefore bioaccumulating to similar concentrations as snails living on sediments with higher concentrations. Toxic effects causing mortality may be defining the upper limit of the concentration in the snails.

Table 5: Sediment sampling in Waimea Inlet October 2007

Sample	Location	DDX	dieldrin	aldrin	endrin
Sediment: mg/kg dry weight					
A	N-S Transect 65m from west beach	0.2396	0.0061	0.0009	<0.0005
B	N-S Transect 85 m from west beach	0.1829	0.0021	<0.0005	<0.0005
C	N-S Transect 105 m from west beach	0.1985	0.0019	<0.0005	<0.0005
D	Intersection of N-S and E-W Transects 147 m from west beach & 20 m from Grossi Point	0.0941	0.0020	<0.0005	<0.0005
E	N-S Transect 167 m from west beach	0.2001	0.0049	0.0009	<0.0005
F	N-S Transect 187 m from west beach	0.1094	0.0022	<0.0005	<0.0005
G	N-S Transect 237 m from west beach	0.0695	0.0015	<0.0005	<0.0005
H	E-W Transect 44 m from Grossi Pt	0.1045	0.0021	<0.0005	<0.0005
J	E-W Transect 72.5 m from Grossi Pt	0.1342	0.0031	<0.0005	<0.0005
Snails: mg/kg wet weight					
B	As above	73.26	1.99	0.00921	0.278
E	As above	65.52	2.18	0.0159	0.406
G	As above	12.36	0.59	0.0056	0.06
J	As above	4.14	0.213	0.00293	0.0208

Source: TDC (2008a)

A number of other earlier investigations collected sediment samples from the wider area of Mapua Channel and Waimea Inlet. These included a set of samples collected by TDC in 1996 which showed the following general patterns of contamination (T&T, 2003a);

- DDX contamination in shallow (0 – 0.25 m) sediment to the south of the eastern remedial excavation was variable but appeared to reduce with distance from the site. A concentration of 1.5 mg/kg was detected about 20 m south of the site, but concentrations were typically close to or below the SAC of 0.01 mg/kg beyond about 50 m from the site;
- in the Waimea Inlet, samples from up to 200 m south of the foreshore showed a similar pattern of contamination to that indicated in the 2007 TDC sampling discussed above. For example, a DDX concentration of 0.9 mg/kg was detected in shallow sediment (0 -0.25 m) approximately 100 m from the foreshore; and

- ADL concentrations in shallow sediment away from the site (for both east and west) were typically below the SAC of 0.01 mg/kg.

6.7 Significance of Residual Marine Sediment Contamination

6.7.1 Eastern Foreshore

6.7.1.1 Mass of contaminant removed

It is possible to estimate the total mass of DDX compounds removed by using the product of the approximate volume of sediment removed and an estimate of the average DDX concentrations of that material. Using the available data, it is estimated that the mass of DDX compounds removed was in the order of 8 kg. There is not enough data to estimate the mass of DDX contamination remaining in sediment outside the east marine excavation in the Mapua Channel. Consequently, it is not possible to estimate the proportional mass reduction achieved for the sediment remediation in the east.

6.7.1.2 East Current Status

The sediment quality on the eastern foreshore has not been fully characterised. However, it is clear that elevated concentrations of OCP compounds remain in sediment in the site vicinity. Post-remediation sampling has confirmed concentrations of DDX more than 100 times the SAC (i.e. above 1 mg/kg) remain at some locations in the vicinity of the remedial excavation (a maximum concentration of 125 mg/kg was detected in a sample from the base of the remedial excavation, although this was not typical). Elevated DDX concentrations are also present in shallow sediment up to 100 m to the north of the site (including beneath the adjacent wharf), with concentrations of between 1 and 60 mg/kg detected.

The ADL concentrations on the eastern foreshore are much lower than the DDX concentrations, but still elevated. The post remediation sampling showed that most ADL concentrations were below 1 mg/kg, but concentrations above 0.1 mg/kg were not uncommon.

Although there are high concentrations of nutrients in groundwater discharging from the site, concentrations of nitrogen compounds were measured in sediment and found to be below laboratory detection limits. This is expected as nitrogen based compounds would not typically adsorb to soil in significant quantities. Localised effects due to the nutrients in groundwater discharges (e.g. algal growth at seepage points) are discussed in Section 7.0.

The sandy gravel that replaced the excavated material should have been clean immediately after being placed. It is apparent that this material has been re-contaminated as samples from within the backfill had DDX concentrations of between 0.4 and 6.4 mg/kg (average of 1.7 mg/kg).

When considering the overall contaminant mass removal, it should be noted that these concentrations are not necessarily representative of backfill mass as a whole. This is because the laboratory results are based on the passing 2 mm fraction and do not take into account the mass of material above 2 mm. The analytical results are therefore likely to be more representative of fine sediment that has migrated into the coarse fill material from outside the excavation. Without a particle size distribution for the sandy gravel that was used as backfill, it is difficult to quantify this effect. However, based on the description and appearance of the fill material, a reasonable estimate of the percentage of material less than 2 mm might be 10%.

If this was the case, the effective DDX concentrations in the fill material are actually lower by a factor of 10 (i.e. with an average of about 0.2 mg/kg). How this might be compared with earlier sediment samples is not known. However, where previous samples were predominantly of mud, rather than of sandy gravel, the complete particle size range of the sample would have been analysed and therefore the sample would be more closely representing the whole sediment.

The current beach, mainly gravel with sediment between larger particles on the surface, provides a different habitat to the original foreshore. This is evidenced by the change from the mud snail to the top shell as the dominant snail species. The change in biota may mean that the residual contamination is less important for the new species, being surface dwellers rather than burrowers, but more study would be required to ascertain this.

6.7.1.3 East Recontamination Mechanism

There is not enough information to determine the mechanism of re-contamination of the remedial fill material. However, some of the potential causes are:

- discharge of contaminated sediment via runoff from the site during the remediation works (this appears to have been confirmed as a mechanism in the west, as discussed in Section 6.7.3 below). This includes discharges during the remediation of the surge chamber. Given the eastern foreshore remediation occurred early in the overall remediation project, there was a greater potential for discharges from the site than if the remediation had occurred later;
- discharge of stormwater from the historic site stormwater network;
- migration of surface sediment from outside the excavation extent;
- migration of contaminated fines from the underlying sediment because of grain-size incompatibility between fine underlying sediments and the coarser gravel backfill. Strong currents, tidal fluctuations and wave action may have caused sufficient water movement within the gravel to cause contaminated fines to migrate to the body of the replacement gravel and perhaps the surface over time. This is why a graded sand or geotextile filter is typically placed between soils of different grain sizes in locations where they are exposed to water flows; and

- the potential mixing of the fill with the underlying sediment by the root-raking process (see Section 6.3.3). The likely significance of this is difficult to quantify with the available information. However, if substantial mixing of underlying material did in fact occur, this alone could have been responsible for the subsequent elevated concentrations.

Contamination of sediment via groundwater discharge is not likely to be significant. It is possible to use the groundwater flux estimates discussed in Section 7.0 and typical average contaminant concentrations in on-site groundwater to estimate the potential rate of discharge of OCP contamination to the marine sediments. It is immediately apparent that the rate of re-contamination of sediment through this mechanism would be slow, even if it assumed that all the dissolved contamination is adsorbed to a thin layer of sediment over the foreshore, which is unlikely. The re-contamination of the marine excavation occurred over a short period with a rapid increase in contaminant concentrations. If the contaminated groundwater discharged in a relatively localised area and concentrated in the near surface sediments, it is possible that discharges over the long term (years) could increase sediment concentrations measurably. This would become more significant if the adsorbed contamination was concentrated in the surface of the sediment. However, the level of increase would still be relatively small compared to the residual concentrations that are already present at depth.

As discussed in Section 7.0, the hydrogeological model for the site is uncertain and any such predictions of contaminant flux are also uncertain. Direct measurement of the sediment quality over time is preferable.

Of the potential mechanisms outlined above, the first has been effectively mitigated by the placement of a capping layer of clean soil across the site. Consequently, one of the key potential sources of sediment contamination has been removed i.e. via sediment runoff from the site. This source removal should be recognised as a key facet of the overall sediment remediation. The potential concentrations in sediment discharging from the site while the site was operational and during the remediation works were significantly higher than the current potential sources and the residual contamination in the remediated area.

In a similar manner, the historic discharge from the site stormwater system has been removed as a potential source of contamination of the sediment. The stormwater system was probably effectively cut off before the east sediment remediation, and so was unlikely to be a significant source of re-contamination of the excavation. However, prior to the surge chamber being removed, some stormwater discharges may have still been occurring.

The fact that the key contamination sources from the land have been removed appears to be consistent with the most recent sediment monitoring data from TDC, which indicates that the top 1-2 cm of sediment is improving in quality, probably from deposition of ‘cleaner’ sediment from elsewhere in the channel. For example, the DDX concentrations in a sample from adjacent to a seep at the top of the beach have reduced from

2.4 mg/kg in 2007 to 0.3 mg/kg in the February 2009 monitoring round. The DDX concentrations in shallow sediment further down the beach are an order of magnitude lower. A similar reducing pattern is apparent in ADL concentrations, although the concentrations are much lower than the DDX concentrations. Dieldrin concentrations in sediment samples from the most recent monitoring round ranged from 0.05 mg/kg to less than the laboratory detection limit of 0.001 mg/kg.

The elevated concentrations of DDX compounds outside the excavation remain a potential source of contamination. In time, equilibrium between the surrounding area and the remediated area is expected to occur. Much of this contamination is at depth or beneath gravel armouring and is less likely to mobilise. In addition, as the Mapua Channel is a high energy environment, sediment deposited adjacent to the site is likely to be sourced from a relatively wide area (in addition to sediment runoff from the site). Further away from the site, contaminant concentrations are much lower, potentially resulting in a lower 'average' contaminant concentrations in the sediment deposited on the eastern foreshore.

As discussed, the mechanics of the original recontamination are not well understood, but if it is assumed they are mostly related to the activities on the site or the way the remediation was performed (including coarse gravel over finer sediments), it is probable that these mechanisms are no longer occurring or are much reduced. The possible movement of fines from the contaminated sediment at the base of the excavation, if it has occurred, will reach equilibrium in time (and may have done so), as the pore spaces in the sandy gravel are filled with finer sand and silt, forming a natural filter preventing further migration from this source.

The remaining mechanism is a general redistribution of surface sediments (including some 'clean' site runoff) resulting in a gradual averaging out of concentrations. This will be less than the original foreshore surface concentrations but may never be as low as the SACs in the medium term because the average of the surrounding area is too high. Over time other processes will reduce concentrations through the gradual breakdown of the organic contaminants. With half lives of years, this will be a gradual process.

Continuing direct measurement of the sediment quality is recommended. The length of the surface sediment takes to reach equilibrium with the surrounding area is not known, but it is expected to be a few to several years. Slow natural degradation will then occur, reducing concentrations over time. Calculating the length of time this slow degradation will take to reduce concentrations to the SACs would be a useful exercise to carry out before contemplating any further remedial action.

6.7.2 Remediation to Extent Practicable – East

In a broad context, remediation to the extent practicable has been achieved for the marine sediments in the east. This overall conclusion does not imply that the remediation could not have been carried out more efficiently and achieved a better result for the replacement gravels. The exercise could be repeated and a better outcome could

be achieved for the bulk of the sediment, albeit at a cost, given the risk of re-contamination from the site is much lower. The sediment is not so contaminated that it would create a major disposal problem (as it meets residential criteria), although it would have to be handled carefully.

However, re-deposited surface sediment will still likely be at greater concentrations than the SACs, reflecting the surrounding concentrations. In addition, the benefits of further remediation are likely to be outweighed by the 'costs' such as additional disruption to the current habitat, potential impacts on the wider environment and financial cost, for an outcome at the surface that will not be very different from the current outcome. There would likely be further delay to using FCC East.

The physical constraints are recognised as a key factor relating to whether remediation to the extent practicable has been achieved. Working beneath water is difficult and risks unacceptable effects such as sediment discharge to the estuary. It would be possible to create work areas isolated from the tidal movement, potentially beyond the low tide mark. However, this would be expensive. In addition, water-laden sediment by its nature is difficult to work with.

During the remediation works, the site was used to dewater and dispose of the sediment. For future works, either part of the FCC East site would have to be re-established by stripping the capping layer off over a sufficient area and establishing a bunded working area, or an alternative area would need to be found and secure transport used to prevent discharges during transport. It is inevitable that at least a staging area would have to be established on FCC East. While these things are quite possible, re-excavation would be a more expensive proposition than when carried out as part of the larger works. This reduces the practicality of any further remediation.

Elevated OCP concentrations (mainly DDX) remain in shallow sediment at locations in the wider area that are not practical to remediate, due to physical and cost constraints discussed above. These include locations beneath the nearby wharf and up to 100 m north of the site, adjacent to Mapua Channel. If it is accepted that the entire area of sediment contamination cannot be remediated, this brings into question the benefit of remediating only part of the area.

In addition, the limited data available appears to show that the shallow sediment quality is improving. It may be that the improvement in the chemical quality of the marine habitat will continue without further remediation. Additional data would be required to confirm this conclusion. The removal of the site itself as an ongoing source of contaminated sediment is a key aspect of the sediment remediation, that is, by preventing further runoff of contaminated sediment. This alone has likely resulted in an improvement in surface sediment quality and will allow natural attenuation to slowly improve the situation further. If the improvement in surface sediment quality is sustained, the residual sediment contamination at depth assumes a lesser importance and further remediation of the deeper residual contamination becomes harder to justify. The vertical distribution of contamination and how this might relate to biota at depth in

the sediment is not currently well defined. It is therefore difficult to estimate effects of deeper contamination. If there are no receptors affected by the deeper contamination, its significance is reduced.

As discussed in Section 6.1, the residual OCP concentrations in the sediment are unlikely to represent a risk to the health of recreational users through direct contact. The results are typically well below equivalent human health guidelines (particularly for surface sediment) and exposure would be expected to be intermittent. Consequently, additional remediation is not warranted for this exposure pathway.

Based on the recent monitoring results, no further remediation is warranted due to risks associated with the consumption of seafood in the east. The sediment SAC were based on the consumption of seafood by humans, in particular of the mud snail (*amphibola crenata*). However, these snails are no longer present and the new species is unlikely to be consumed. In any case, based on recent results (TDC, 2009b), the concentrations of OCPs in the flesh of the snails are not at a level of concern for human health even if the snails were consumed. There are other seafood sources in the area with the potential to bioaccumulate. However, a previous study concluded that snails were the most representative bio-indicators for the site (Landcare Research, 2002). For example, crabs, oysters and cockles accumulated lower levels of OCP contamination relative to snails. Further monitoring is justified to confirm that bioaccumulation stays at the present levels.

The average concentrations of DDX in the vicinity of the remedial excavation are well in excess of the ISQG-High marine sediment guidelines from ANZECC (2000), even if an allowance is made for the effect of total organic carbon. This suggests that some form of adverse effects on marine ecosystems is likely. However, similar concentrations exist in the wider area of Mapua Channel. It is therefore difficult to justify further remediating one part of the area without addressing the other. In addition, the available data appear to show that shallow sediment quality is improving in any case. Additional monitoring of the marine ecosystem is warranted to benchmark conditions and enable future improvements (or otherwise) to be gauged.

It should be noted that the habitat on the eastern foreshore has been substantially modified by physical changes imposed by the remediation itself. Where mud snails were previously present, these have been replaced by a mudflat top shell. This is already a significant change to the local marine ecosystem which should be recognised when assessing other effects.

The derivation of the SACs also considered effects of bioaccumulation at higher trophic levels based on a literature review of likely bioaccumulation factors (Egis, 2001). Given that the SACs were not achieved, higher trophic levels may now be at risk. A revisiting of the original study using site data could well show that the original study was too conservative. If so, given that food consumption does not currently appear to be a risk, the SACs could be revised upwards.

6.7.3 Western Foreshore

6.7.3.1 Mass of contamination removed

In a similar calculation to the east, the mass of DDX compounds removed by the west marine excavation is estimated to be in the order of 5 kg. For the west, there is slightly more data indicating the possible extent of the DDX contamination in the Waimea Inlet. Using the available data, it is estimated that in the order of 3.3 kg remains in the tidal mud flat portion of the estuary in the top 0.25 m, beyond the remedial excavation extents. This estimate is uncertain as it is based on limited data. Further contamination probably exists at greater depth, but this is less significant for the marine environment. In addition, the calculation does not include residual contamination in the rushes adjacent to the creek and at depth in the swale. These sources could also include significant quantities of DDX compounds, albeit in a potentially less 'available' location than the surface sediments on the tidal flats. However, the calculation indicates that approximately 60% of the available surface contamination was removed.

While this is less than the 90% suggested by the Site Auditor, it represents the readily accessible contamination. Each additional 10% removal is increasingly difficult and increasingly expensive, with the law of diminishing returns operating. On that basis, it is reasonable to conclude a significant mass of contaminant was removed.

6.7.3.2 West Current Status

The sediment quality in the vicinity of the western foreshore has been characterised to a slightly better level than the eastern foreshore. Initial post remediation sampling indicated that DDX concentrations above 1 mg/kg were present at the extents of the remedial excavation. However, the vast majority of these were located in the stormwater drain ('the creek'), where approximately 15 of about 50 validation samples had concentrations above 1 mg/kg. Three creek validation samples were above 15 mg/kg, with a maximum of 82 mg/kg detected on the north-western bank of the creek.

On the foreshore itself, the initial post-remediation samples were typically well below 1 mg/kg and often below 0.1 mg/kg. Foreshore samples taken at various times in 2007 showed DDX concentrations in shallow sediment of between 0.01 mg/kg and 24 mg/kg, with concentrations typically above 1 mg/kg. These samples were taken over a year after the remediation but while works on the adjacent FCC Landfill were still occurring, potentially indicating some recontamination from site runoff. This is consistent with the apparent subsequent improvement in surface sediment quality after the site was capped with clean soil and grassed (see below).

DDX concentrations in the wider bay are typically well below 1 mg/kg, with an average in the order of 0.15 mg/kg (see Section 6.6), although still 10 or more times above the SAC.

The residual ADL concentrations on the western foreshore are much lower than the DDX concentrations, but still elevated. All ADL concentrations were below 1 mg/kg, with a maximum of 0.49 mg/kg detected. Many of the samples taken from the remediation excavation extents had concentrations of less than 0.01 mg/kg. However, the various sampling events in 2007 indicated concentrations in shallow sediment were typically in the order of 0.1 mg/kg. These results are likely to represent contamination from site runoff.

As with the east, the most recent sediment monitoring data from TDC appears to indicate that the top 1-2 cm of sediment is improving in quality. For example, the DDX concentrations have reduced from typically well above 1 mg/kg in 2007 to generally less than 0.3 mg/kg in the February 2009 monitoring round (a concentration of 0.6 mg/kg was the exception to this). These concentrations are now closer to the approximate average concentration in the adjacent bay (0.15 mg/kg). This would be consistent with movement of shallow sediment from the bay into the remediated area.

A similar reducing pattern is apparent in ADL concentrations, although the concentrations are much lower than the DDX concentrations. Dieldrin concentrations in sediment samples from the most recent monitoring round ranged from 0.02 mg/kg to 0.004 mg/kg.

6.7.3.3 Recontamination Mechanism

The sampling results for the western foreshore suggest similar mechanisms of re-contamination of sediment as the east, that is:

- discharge from site during the remediation works;
- migration of sediment from outside the excavation; and
- migration of sediment from the base of the excavation into the backfill.

As noted previously, contamination from groundwater is not expected to be significant, and certainly not as rapid as the rate at which the initial re-contamination occurred.

There are a number of differences in the situation in the west. Anecdotal reports suggest quite strongly that site discharges did cause at least some of the re-contamination of the remedial excavation, whereas this is less certain for the east. In addition, The DDX concentrations detected in shallow sediment shortly after the remediation were greater than those present in the other main potential source i.e. the adjacent bay. As with the east, the site as a source of sediment contamination has now effectively been removed with the completion of the remediation and establishment of grass on the site.

In the west, the concentrations at the base of the foreshore excavation (i.e. excluding the creek) were typically much lower than in the east. Consequently, it is much less likely that significant re-contamination occurred from the base of the excavation. In any case, as discussed above, this form of migration is more likely to have reached equilibrium by now.

There are also elevated concentrations (relative to the marine SAC) of DDX present in the sediment at the base of creek excavation. These residual DDX concentrations are a potential ongoing source of contamination to the sediment in the bay. However, it is difficult to predict whether this is a significant mechanism relative to other potential re-contamination mechanisms. The creek was covered with a layer of clean gravel and the banks of the creek are now heavily vegetated. Both these factors would tend to reduce the potential for sediment to mobilise from the creek bed.

In May 2007, CH2M HILL collected samples from the creek bed. Samples from within and immediately downstream of the area with the highest residual contamination returned low DDX concentrations. This suggests that the residual contamination along the creek is not particularly mobile, although the data are limited.

This leaves the wider bay as the main potential source of ongoing contamination, but not the predominant source of the initial re-contamination. Previous investigations have shown that sediment with elevated DDX concentrations extends up to 250 m to the south of the western foreshore. It is probable that this is the main ongoing source of sediment contamination for the foreshore. Consequently, it is likely that sediment concentrations close to the beach will reach equilibrium with concentrations in the wider estuary, before then slowly degrading.

It is difficult to estimate the proportion of the overall estuary sediment load that these sources contribute, and hence the likely equilibrium that will be reached. The most recent sediment monitoring round reported DDX concentrations ranging from 0.1 to 0.6 mg/kg. Similar concentrations were present in the wider bay in 2007. Further data would be required to confirm trends in shallow sediment concentrations, but ultimately it is expected that the surface sediment (0 – 50 mm) will reach an average concentration similar to the wider bay, i.e. 0.15 mg/kg [17]. Natural degradation process will also be occurring concurrently, but at much slower rates. As for the east, further study would be required to estimate the rates of natural degradation.

6.7.4 Remediation to the Extent Practicable – West

Remediation to the extent practicable of the marine sediments has broadly been achieved in the west, for the same basic reasons outlined for the eastern sediments; specifically, that it is not possible to remediate the surface sediments to a higher standard than the surrounding surface sediments.

[17] This presupposes that the sampling of the wider bay is reflecting long-term historic contamination which will attenuate only slowly. However, the wider bay was last sampled towards the end of the remediation and the results may have been reflecting transitory runoff from the site during the remediation. If so, the surface sediments in the wider bay may have substantially reduced in the meantime, as sediment migrates from the wider Waimea Inlet, with the foreshore reflecting that in turn.

A potential exception to this is the creek area where re-sedimentation from the wider bay is less likely and the residual contamination is a small volume and quite accessible. However, in this case, additional remediation is not warranted as the residual DDX concentrations are not likely to be currently posing a significant risk. The edges of the creek are heavily vegetated (and typically above water), with little potential for mobilisation of or direct contact with the sediment. This appears to be supported by recent sediment results from the creek which were lower than other areas (CH2M HILL, 2007). However, a check should be made that the flood flows in the creek are not likely to be so high as to cause erosion and the Site Management Plan should include measures to ensure that the creek and banks are not excavated without controls (e.g. during some future drainage improvement works) and are protected from future erosion. Sampling of creek-bed sediments should continue on an annual basis to check that contaminated sediment is not being remobilised. Such monitoring could cease if a lack of remobilisation is confirmed.

Data from 2007 showed that elevated concentrations of DDX compounds existed across much of the tidal flat area to the west of Grossi Point, extending up to 300 m south of the western foreshore. It is not practical to remediate this entire area due to cost, difficulties in handling and disposing of the large quantities of sediment, and likely detrimental effects on the estuary ecosystem. Further remediation of the foreshore area in isolation is therefore not justified.

As with the east, the removal of the site as a source of sediment contamination is a key aspect of the remediation. In the west, the sediment sampling history suggests that site runoff was a major mechanism of re-contamination of the foreshore. It is now likely that the contaminant concentrations in the shallow sediment will reach approximate equilibrium with the concentrations in the wider bay (and ultimately the estuary). Even at the concentrations of the wider bay, some form of impact on the marine ecosystem would be expected, based on a comparison with the ANZECC (2000) marine sediment guidelines. As with the east, additional monitoring of the marine ecosystem is warranted to benchmark conditions and enable future improvements (or otherwise) to be gauged.

The available information indicates that effects on other potential receptors from the residual sediment contamination are not likely to be significant, except possibly for human consumption of seafood. In the case of risks to human health via seafood consumption there is uncertainty as the dataset is small. However, the most recent data indicate that average concentrations in snail flesh are below levels that are likely to cause a significant human health risk. The New Zealand Food Safety Authority provided advice to TDC (TDC, 2008a) that safe average daily intakes would not be exceeded if seafood concentrations were less than 21 mg/kg wet weight for DDX and 0.2 mg/kg wet weight for the sum of aldrin and dieldrin. The most recent DDX concentration of 3.5 mg/kg is well below the guideline and the dieldrin/aldrin concentration is essentially at the criterion of 0.2 mg/kg, indicating a significant risk is currently unlikely. Further monitoring is required to confirm this conclusion as the sample size is too small to be certain.

6.7.5 Recommendations – Marine Areas

As discussed previously, the tidal dilution is such that effects in the wider estuary are unlikely to be significant, particularly in the Mapua Channel. However, there will be some localised effects on the marine ecosystem from the residual OCP contamination in sediment, and from nutrients in the groundwater discharge on the foreshores. The available data indicate that human health is not likely to be at significant risk from the residual contamination in the marine environment (either from direct contact or ingestion of seafood). In addition, recent data appears to indicate that the localised effects are likely to be reducing as surface sediment quality appears to be improving.

The shallow sediment has broadly been remediated to the extent practicable, essentially as it is not possible to remediate the surface sediments to a higher standard than the surrounding surface sediments. The remediation of deeper sediments, while theoretically "sustainable", would be hard to justify on an effects basis. Determining what level of effects on the marine ecosystem is acceptable is a decision for stakeholders such as TDC and MfE. However, if it is accepted that further remediation of the shallow sediment is not practicable, it must also be accepted that some localised impacts on the marine ecosystem are unavoidable.

The following recommendations are made for additional investigation and monitoring associated with the marine areas:

Biota and Sediment Monitoring

The current annual monitoring of sediment and biota by TDC should be continued and expanded. The aim of the monitoring will be to:

- confirm OCP concentrations in snails (as appropriate bio-indicators) remain below levels that might present an unacceptable risk to human health;
- to confirm apparent improving trends in the chemical quality of shallow sediment using a larger sample set; and
- to provide additional information on localised effects of nutrients in groundwater discharges on the foreshores (see Section 7.10.2).

Prior to undertaking the next monitoring round, we recommend a review is undertaken by an appropriately qualified person to confirm that monitoring snails on the eastern foreshore is the most appropriate method of assessing risk via seafood consumption. The new species of snail on the eastern foreshore (mudflat top shell) appear to bioaccumulate less than the original mud snail. Consequently, the new snails may not be an effective bio-indicator. The review should assess the previous reports on the subject, including that by Landcare Research (2002) and take into account recent monitoring data and the likely site use. Consideration should be given to the need for confirmatory sampling of other biota.

Monitoring should be undertaken as follows:

- the annual monitoring frequency should be continued, with the monitoring scope reviewed after two additional monitoring rounds;
- in addition to the current monitoring locations the following sediment sampling locations should be considered:
  - three additional locations parallel to the western foreshore, approximately 20 m from the foreshore edge. The locations should be evenly spaced along the foreshore;
  - two additional locations parallel to the eastern foreshore, approximately 5 m from the base of the sea wall. The locations should be evenly spaced between the current sampling transect and either end of the foreshore.
- at each sediment sampling location, samples from 0 – 0.02 m and from 0.02 – 0.10 m should be collected. A sediment corer with a core extruder should be used to ensure accurate sample depths. Each sample should be analysed for DDX and ADL;
- the snail sampling should continue as previously, unless otherwise indicated by the review on biota sampling outlined above;
- total organic carbon (TOC) should be measured in each sediment sample in the first monitoring round;
- a particle size distribution should be undertaken on 50% of the sediment samples in the first monitoring round;
- detailed field and photographic records should be kept of all observations, e.g. sediment colour, number/size of snails, etc;
- a photographic and written record should be maintained of areas of algal growth. The photos should be taken from the same perspective to enable comparison between monitoring events (see Section 7.10.2);

Marine Ecosystem Health and Bio-diversity Monitoring

Effects on the marine ecosystem are likely given the incomplete remediation of the foreshores. Such effects have not been gauged to this point. It is recommended that investigation of the new foreshore ecosystem be carried out to benchmark conditions and provide a basis for assessing expected improvements in the foreshore sediments into the future.

Determining the biological health of the marine environment close to the site relative to before the remediation is problematic as no benchmark studies were completed prior to the remediation with which results can be compared. However, a controlled study may be achievable by locating similar habitats to the east and west foreshores elsewhere in the inlet and making comparisons. There are a number of survey techniques which can be used to assess ecosystem health and bio-diversity. Sediments at the chosen sites would need to be sampled for OCPs.

7.0 Groundwater

7.1 Introduction

The Validation Report did not consider groundwater. This section assesses:

- the groundwater status;
- whether the groundwater is in compliance with the target criteria set out in the resource consent; and
- the implications of residual groundwater contamination on the receiving environment.

Part of this assessment includes determining whether the groundwater data are representative of actual conditions i.e. assessing the data quality. In addition, the hydrogeological conceptual models put forward in various earlier reports are commented on and potential information gaps identified. Finally, the environmental risks associated with residual groundwater contamination are examined.

7.2 Geology and Hydrogeology

Summaries of the geology and hydrogeology are presented in T&T (2003) and more recently CH2M HILL (2007). The following draws from these documents.

7.2.1 Geology

The original geology at the site is presented as interbedded estuarine deposits (Rabbit Island Gravels and Tahunanui Sand) over the clay-bound Moutere Gravel. The top of the Moutere Gravel dips from west to east across the peninsula at the site location. Cross-sections in the AEE indicate the top of this unit is at less than 1m depth adjacent to the creek in the west, and approximately 6.5 m in the east (T&T, 2003b).

Some modification of the geology of the site had occurred prior to the onset of remediation. This included:

- the emplacement of a landfill to the west of FCC West. This included the construction of a clay bund along the north-western boundary (adjacent to the creek) and along the southern edge of the landfill (adjacent to the west beach). The exact position, depth and integrity of the clay bund is not known;
- the construction by TDC in the mid 1990s of a soil/bentonite cut off wall along the southern boundary of the landfill area;
- extensive land reclamation area along the seaward side of the East FCC ;
- land reclamation in the 1950s or 1960s along the seaward side of FCC East, adjacent to Mapua Channel, including construction of a clay bund/wall on the foreshore.

Since the commencement of remediation (October 2004), significant alteration of the surface geology across the site has occurred:

- surface soils have been excavated (typically to between 0.5 and 3 m) and replaced with fill material comprising treated soil, untreated residential and commercial quality soils, crushed concrete and "oversize" (>10 mm) material. Excavations extended below the groundwater table at many locations. The fill material has been compacted using different methods for different parts of the site;
- the base of much of the fill in FCC East and FCC Landfill consists of a layer of screened oversize material or crushed concrete.
- a system of interconnecting drains (so-called "French drains") consisting of oversized material around the periphery of each backfilled subgrade in FCC East
- an earth bund consisting of Moutere Gravel has been put in place along the boundary between FCC Landfill and FCC West. The bund was installed to depths of between 2.5 and 4 m bgl and is founded in the Moutere Gravel formation (MWH, 2009f). This is at variance with the remediation as-built drawings, which show clay founded on marine sediment backfill. However, photographs in MWH (2009f) show subgrades SG19A, SG19B and SG19C having been excavated down to the Moutere Gravel formation;
- a number of service penetrations through the clay bund along the eastern foreshore were discovered during the remediation works and these were repaired. The removal of the surge chamber at this location resulted in a section of the clay bund being removed, with the excavation extending to a depth of over 5 m. However, the bottom 2.5 m of this excavation was backfilled with sand and gravel rather than clay (MWH, 2008b). Consequently, the eastern clay bund is discontinuous as a barrier to groundwater movement.

Layering of different fill types and the depth to the base of these fill layers is variable across the site. This has included placement of crushed concrete, screened oversize material and treated fines (which has been ground to clay-size particles during the MCD process) below the watertable in various locations. The oversize material and crushed concrete probably have a greater hydraulic conductivity than the material they replaced while the treated fines probably have a lower hydraulic conductivity than the native materials. Testing of the hydraulic conductivity of replacement materials has not been carried out.

7.2.2 Hydrogeology

The sediments overlying the Moutere Gravels form a shallow unconfined aquifer. The Moutere Gravel acts as a confining layer restricting vertical groundwater movement between the shallow aquifer and deeper aquifers. The Waimea Inlet and Mapua Channel form natural boundaries to the aquifer and represent aquifer discharge zones. Recharge to the aquifer is expected to be predominantly from the land mass to the north but also vertical infiltration and leakage from the underlying Moutere Gravels.

Discharge of groundwater occurs to the drain (the creek) excavated along the northwest boundary of the landfill (and from there to the Waimea Inlet), direct to the Waimea Inlet at the beach south of the Landfill and to the Mapua Channel at the FCC East beach. A seepage line on the beach south of the Landfill 2 – 3 m below high tide level was reported by T&T (2003). The reclamation to the east, the bentonite cut off on the boundary of the landfill and the newly installed bund between FCC West and the Landfill are likely to affect groundwater discharges to the Mapua Channel and Waimea Inlet.

Based on groundwater level measurements, Woodward-Clyde (1996) produced a groundwater contour plan which showed discharge at the northern end of the East beach and towards the south-eastern tip of the Landfill. Groundwater was interpreted to be flowing under the cut off wall at this point. A groundwater divide was inferred to run diagonally north-west to south east across the centre of FCC West. Hydrogeological parameters (permeability and porosity) for the aquifer pre-remediation have been estimated as (T&T, 2003b):

- hydraulic conductivity – 1 to 20 m/d; and
- porosity – 0.2 to 0.3.

Calculated linear (or seepage) groundwater velocities were reported in CH2M HILL (2007) to be in the range of 0.04 – 0.55 m/day for FCC East and 0.018 – 0.23 m/day for FCC Landfill. The substantial excavation and backfilling may have altered the bulk hydraulic properties of the aquifer and these values may not still be valid.

Pre-remediation groundwater levels of 1.5 – 2 m below ground level across the site are reported in the AEE (T&T, 2003b). A somewhat greater range of water depths (1 – 2.7) was reported towards the end of the remediation by CH2M HILL (2007) although greater depths would be expected as the ground surface is higher post-remediation. PDP (2009) presents plots of water levels over five years showing a seasonal range of 1 m in monitoring wells BH1 and BH5 near the eastern and western extremities of the site (Figure 1).

CH2M HILL (2007) comments on tidal influences on groundwater levels (based on observations in BH1 and BH2) and indicate response to a 3.7 m tidal range at the time of 0.26 m at 10 m from the shoreline and 0.035 m at 50 m from the shoreline.

Two slightly different interpretations of groundwater flow directions have been derived from groundwater level measurements in on- and off-site wells post-remediation. CH2M HILL (2007) indicates a groundwater divide runs slightly to the west of Tahi Street, running down the centre line of the peninsula, with groundwater flow both westward and eastward of the divide (Figure 6). Recharge to the site and the peninsular south of the site is inferred to be predominantly from infiltration. CH2M HILL (2007) shows westward and southward groundwater discharge to the creek and FCC West beach and eastward discharge to the FCC East beach.

The CH2M HILL interpretation has been criticised on the basis that groundwater measurements were taken both before and after a heavy rainfall event so that the

measurements were not a "snapshot" in time, but represent a range of groundwater conditions over a period when the groundwater level rose due the heavy rain. PDP (2007) has reinterpreted the data to arrive at a contour diagram that is more consistent with pre-remediation flow direction interpretations of Woodward-Clyde (1996) and T&T (2004). Both Woodward-Clyde and T&T (apparently a reinterpretation of the 1996 Woodward-Clyde data) used many more water level monitoring points to construct their contours than are available now.

The PDP (2007) reinterpretation of the CH2M HILL data (Figure 7) shows a southerly component to groundwater flow crossing the southern boundary of the site in addition to the eastward and westward components. This difference in interpretation is important because if no southerly component exists, private bores in various properties along Tahi Street should not be at great risk from contaminants migrating from the site. If a southerly component exists, the off-site wells could be at risk.

CH2M HILL (2007) has estimated groundwater flux through the site to the west and east to be 1.6 to 42 m^3/d and 10.1 to 154 m^3/d, respectively, based on the groundwater gradients derived from their 2007 groundwater investigation and permeability and porosity data provided by Woodward-Clyde. However, the groundwater flux calculations are in error by factors of between 3 and 5 as these calculations should have used the Darcy velocity rather than the seepage velocity (the velocity from the Darcy equation divided by porosity). CH2M HILL's values are compared in Table 6 with correctly calculated values and further groundwater flux estimates using hydraulic gradients from PDP (2007) for water level measurements taken in November 2007.

Table 6: Volume flux calculations, FCC west and East (m^3/day)

	Original CH2M-HILL Calculation [1]	**Corrected CH2M-HILL Calculation [1]**	**PDP Calculation 1 [2]**	**PDP Calculation 2 [3]**
Hydraulic Gradient West East	0.0035 0.008	0.0035 0.008	0.0067 0.026	- 0.013
FCC West	1.6 - 42	0.32 – 13	0.6 – 24	-
FCC East	10.1 - 154	2.0 – 45	6.4 – 146	3.2 – 73

Notes: Assumed hydraulic conductivity range 1 – 20 m/day

Flow area for FCC West = 90 m x 1 or 2 m deep

Flow area for FCC East = 70 m x 3.5 or 4 m deep

1. Hydraulic gradients from data in CH2M HILL (2007) measured between BH4A and BH5A (west) and BH2A and BH1A (east).
2. Hydraulic gradient between same points as CH2M HILL calculation with data from PDP (2007) Figure 5a
3. Hydraulic gradient for FCC East for PDP Calc 2 typical of middle of beach from PDP (2007) Figure 5a.

Two different estimates for the hydraulic gradient for FCC East were used in the revised calculation; one using the measurements from BH2 and BH1A (as CH2M HILL had done) and a second calculation using the contours further north, to better represent the average hydraulic gradient in the eastern part of FCC East.

The corrected and new calculations show a range of groundwater flux estimates and demonstrate the considerable uncertainty with the estimates of both the hydraulic gradient and hydraulic conductivity.

The remediation has changed the shallow geology and potentially the groundwater behaviour, but the effects on the groundwater are difficult to predict and cannot be assessed from the available information. Possible changes include:

- creation of preferential flow paths and/or local flattening of the hydraulic gradient where crushed concrete or oversized material has been placed below the watertable. Similar effects could be expected from the drains around each subgrade in FCC East;
- creation of lower permeability zones where the treated fines have been placed below the watertable;
- changes to the infiltration characteristics of the ground as a result of excavation and backfilling over most of the site and changing the surface cover from sparse vegetation to grass; and
- changes of flow patterns as a result of installing a clay barrier between FCC West and the landfill area and changes to the clay barrier on eastern foreshore.

The effect of these uncertainties is discussed in more detail in Section 7.9.

A better understanding of flow directions and hydraulic gradient requires the installation of more monitoring wells on the site, particularly in the central part of FCC East and within FCC west, including wells on the upgradient boundary. It would be helpful to undertake slug tests in existing and new wells to obtain hydraulic conductivity estimates of the material now in place.

7.3 Groundwater Contamination Sources

Prior to the remediation, site investigations identified the primary contaminants of concern to be organochlorine pesticides DDX and ADL associated with the site's original use. These remain as contaminants of concern for groundwater. Groundwater criteria were derived to protect the marine environment and became a condition of consent during the remediation. During the remediation several other contaminants became of concern as a result of the remediation, specifically:

- The nutrients ammonium, nitrate and phosphorus associated with the use of diammonium phosphate (DAP) and urea as reagents in the MCD soil remediation process. No groundwater criteria were set in the consent for these determinands

as it was not realised that large quantities of DAP would be used during the remediation, although the use of urea was known.

- Copper associated with copper sulphate, and iron in an unknown form, also used as reagents in the MCD soil remediation process. Although copper sulphate was not listed as a reagent in the AEE, an SAC was set within the consents for copper as part of a suite of metals because some heavy metal contamination existed on the site. There was no SAC for iron.

As discussed previously, the remediation generated a number of different material types that were subsequently used as backfill on different parts of the site. Materials with higher contaminant concentrations, conforming to the commercial SAC, were permitted to be buried below 0.5 m depth on FCC Landfill and FCC East. In addition, residual contamination exists at concentrations conforming to commercial soil quality in the undisturbed soil below the remediated areas within FCC East and Landfill. These materials are expected to be the principal ongoing sources of contamination for groundwater on the site. Generation of leachate will occur through vertical percolation of rainfall recharge and, where the contaminated soil is below the water table (either permanently or intermittently) by horizontal migration of groundwater through the fill.

The commercial fill material consists of three basic types – commercial soil, treated fines, and oversize. Commercial soils are those which have not undergone treatment as the concentrations of contaminants were found not to exceed the commercial SACs at the time of excavation, whether within the excavated material or the base of the excavation.

Treated fines are those that have undergone MCD treatment to reduce concentrations below the commercial SAC. The oversize material was the greater than 10 mm fraction that was removed from soil to be treated before it was processed. Typically, the treated fines were mixed with commercial soil and/or oversize before backfilling (MWH, 2009e). However, in some cases unmixed treated fines were placed directly in the excavation. Where an excavation was below the groundwater table and there was standing water at the time of backfill, coarse material such as crushed concrete and/or oversize was end-tipped to form a platform.

Contaminants at excessive concentrations in the soil could generate sufficient leachate that groundwater concentrations would exceed those thought appropriate at the point of discharge of the groundwater to the marine environment. The SACs were derived so that groundwater concentrations would not be excessive (Egis, 2001). The Site Auditor (GHD, 2006b) stated that the broad intention of the remediation was to place commercial quality soil above the water table. It was recognised that there was uncertainty in the derivation of the SACs and that placing commercial soil above the water table was one way of reducing this (Peter Nadebaum, GHD, pers. comm.) In a similar manner, it was assumed that infiltration would be reduced by vegetation and paving. It is obvious that commercial quality material can be expected to have greater leaching potential if placed below the watertable as it is subject to constant leaching from the groundwater flow rather than intermittent leaching from rainfall infiltration.

However, the intention to place commercial quality soil above the watertable was never formalised in the consents, with nothing in the consent preventing material at concentrations meeting the commercial SACs being placed below the watertable. In fact the original Thiess (2004) RAP had an explicit expectation that treated material would be placed below the watertable in stating:

> *Where material is to be placed below the water table (i.e. into standing water)... [it] will have a similar permeability to pre-existing material, achieved through the combination of treated material with screened oversize*.

This was changed in the MfE RAP, with the record of changes to the RAP (MfE, 2007) showing that Work Plan 9 was changed in December 2006 to explicitly require all treated material and commercial grade material, including any oversize, to be placed above the watertable. It would appear that this requirement either came too late in the remediation or was not implemented properly.

The locations of the various materials and the depths to which they were placed are shown in the MWH as-built drawings (MWH, 2008b). The PDP (2007) groundwater issues report compares the estimated watertable elevation with the depth of the various commercial backfill materials to assess whether they could be below the water table. The results show that in a number of areas the treated fines, treated fines mixed with other commercial quality materials, and commercial soil without treated fines are either intermittently or permanently below the water table. As noted in PDP (2007), this estimate was based on uncertain groundwater elevation data which would require a more comprehensive monitoring network to increase certainty.

As noted above, in addition to the historic contamination residues, the MCD treatment process introduced potential contaminants. PDP (2007) reported that within the 20,969 tonnes of treated fines produced between October 2004 and July 2007, there was an estimated 1,970 tonnes of additives comprising sand (57.8%), diammonium phosphate (37%), copper/iron (3.4%) and urea (1.8%). Testing of the treated fines has confirmed the presence of considerably elevated concentrations of nitrogenous compounds and copper.

The average copper concentration in the treated fines is approximately 1,400 mg/kg, significantly above background concentrations, although below the SAC for commercial soil of 5000 mg/kg. Similarly, the average total nitrogen concentration in the backfilled treated fines is about 5,000 mg/kg. Average DDX and ADL concentrations in the backfill materials are considerably lower, and also below their respective SACs of 200 and 60 mg/kg, as discussed earlier, but still constitute significant masses which provide ongoing sources of groundwater contamination, depending on their location and leachability.

Multiplying average concentrations with the mass of treated material results in mass estimates for the various contaminants remaining in backfilled treated fines and commercial soil (Table 7). There is a discrepancy between the amount of copper

calculated from the measured concentrations in the treated fines and the amount of copper and iron that EDL reported adding to the process (PDP, 2007). Using the PDP (2007) figures, copper (as copper sulphate) was at most 3.4% of 1,970 tonnes of additives. This is the equivalent of about 17 tonnes of elemental copper, approximately half the amount calculated from the average concentration. Given the number of samples (159) used to obtain the average concentrations in the treated fines, it would appear that the amount of copper reagents added has been under-reported.

It can be seen that a considerable mass of nitrogen and copper compounds remains, with lesser amounts of DDX and ADL.

Synthetic precipitation leaching procedure (SPLP) tests[18] provide an indication of the leaching potential of contaminants in soil. Such tests performed on soil samples taken from buried backfill indicate leachate concentrations of DDX, ADL and ammonia orders of magnitude above the PETC and ANZECC marine trigger levels (PDP, 2007), demonstrating the potential for leaching. The data for copper show leachate concentrations of the same order as the PETC.

Table 7: Estimated mass of contaminants within backfill in FCE East and FCC Landfill (kg)

Contaminant	Treated Fines	Commercial Soil
DDX[1]	2,580	1630
ADL[1]	250	220
Nitrogen[1]	104,150	not calculated[2]
Copper[4]	34,449	not calculated[3]

Notes: [1] From PDP (2007)
[2] No data available but assumed to be zero in PDP (2007)
[3] Background concentration small relative to treated fines, therefore not calculated
[4] Calculated from average concentration in treated fines and mass of treated fines from PDP (2007)

The testing indicated that contaminant concentrations in leachate are not significantly affected by the type of backfill (treated fines or commercial) but are affected by soil contaminant concentrations. The SPLP results also shows a relative decrease in leachability from nitrogen compounds to ADL compounds and copper, and finally DDX (PDP, 2007).

[18] The SPLP test agitates a soil sample within deionised water and then analyses the water to determine how much contaminant has dissolved.

The SPLP leachate concentrations were compared with groundwater concentrations in PDP (2007) to obtain a sense of how the potential leachability as measured by the SPLP tests is converted to actual groundwater contamination measured in monitoring wells. There is considerable uncertainty in this comparison because of such things as differences between wells in their spatial relationship between the treated material and the wells, whether the treated material is submerged or not near a particular well, the flow direction relative to the treated material and the well, and the infiltration characteristics of the "catchment" for the particular well.

However, PDP (2007) estimated that groundwater concentrations of OCPs were on the order of 10 to 50 times lower than the SPLP leachate concentrations, presumably reflecting the absorption of OCPs onto the aquifer materials. Non polar hydrophobic organic compounds such as DDT and dieldrin are known to adsorb to sediments, having high partition coefficient values[19]. In contrast, ammonia and nitrate are highly soluble and not readily absorbed onto sediments. Ammonia-N concentrations have been measured in groundwater at similar concentrations to the SPLP leachate values and nitrate-N has been measured at significantly higher values than the SPLP leachate test concentrations. PDP (2007) suggested the latter could be a result of some ammonia-N converting to nitrate-N.

Comparison of the leaching tests with groundwater concentrations for copper indicated attenuation of over 100 times. This is not unexpected given the tendency of copper to be absorbed onto the surface of fine soils.

7.4 Consent Monitoring Requirements

Requirements relating to groundwater are covered in conditions 23 to 32 of Consent RM030524. As noted previously, the consents for the project expired in November 2007.

The consent required the monitoring of six on-site bores (BH1, BH2, BH3, BH4, BH5, and BH9) and a minimum of four off-site bores, including 13 Tahi Street, 17 Tahi Street, 26 Tahi Street and 36 Tahi Street. BH1 is on the eastern boundary of FCC East, adjacent to Mapua Channel; BH2 is on the southern boundary of FCC East, adjacent to 13 Tahi Street; BH3 is at the south-western extremity of FCC Landfill; BH5 and BH4 are on the southern and north-western boundaries of the landfill respectively; and BH9 is on the southern boundary of FCC West, adjacent to 18 Tahi Street. The wells are shown on Figure 1.

[19] As measured by the octanol water partition coefficient, or Kow, which is used to predict the mobility (or lack of) of hydrophobic organic compounds in water. Dieldrin and DDT have high Kow values, indicating limited mobility and a preference to absorb to sediments.

A number of additional monitoring wells were installed during the CH2M HILL (2007) investigation in May 2007. Several of these were intended as replacement wells for the original monitoring network and were named BH1A, BH2A, BH3A, BH4A, BH5A, and BH9A (see Figure 1). These are generally within a few metres of the original wells except for BH1A, which is around 20 m from BH1. It appears that BH2 was the only monitoring well listed in the consent to be destroyed during the remediation works.

Monitoring of groundwater in the likely upgradient direction to obtain background concentrations was not specified in the consent.

The minimum suite of parameters to be monitored was specified in the consent as an OCP suite, a metals suite, acid herbicides, electrical conductivity (EC), pH, alkalinity, and static groundwater levels.

The consent specified monitoring of on-site wells prior to and during the remediation, with a monthly frequency for the duration of the works. Monitoring of off-site wells was specified prior to and following commencement of remediation, with a frequency of every three months during the remediation.

Based on advice from the Site Auditor, and with the agreement of TDC, the analytical suite was altered a number of times during the remediation works. In January 2005, ONP and OPP were added to the suite of analytes for all wells, and volatile organic compounds (VOC) were added for the on-site wells. In June 2005, the analytical protocol was changed to become:

- monthly – OCP, EC, pH, total alkalinity and static groundwater levels;
- quarterly – the monthly parameters plus: total kjeldahl nitrogen (TKN), nitrate, total phosphorus, copper and carbaryl (an OPP); and
- annually – the monthly and quarterly parameters plus: VOC, acid herbicides, OPP, ONP and a metals suite.

In October 2005, ammoniacal nitrogen, nitrate and nitrite were introduced on a monthly basis for all on-site wells and for every three-monthly monitoring of the residential wells. Condition 28 of the resource consent sets out Provisional Environmental Threshold Concentrations (PETC) for groundwater as follows:

Table 8: PETC for Groundwater (mg/l)

Contaminant	Threshold Concentration in Groundwater (mg/l)
DDT (2,4 and 4,4 isomers)	0.0004
DDD (2,4 and 4,4 isomers)	0.0006
DDE (2,4 and 4,4 isomers)	0.00005
Lindane	0.0007
Aldrin	0.0003

Table 8: PETC for Groundwater (mg/l)

Contaminant	Threshold Concentration in Groundwater (mg/l)
Dieldrin	0.0010
Chlordane	0.00010
Heptachlor	0.00004
Mercury	0.00004
Copper	0.13
Selenium	0.50
Zinc	0.24
Chromium	0.44

The PETC were derived as trigger values to be applied during the remediation works. If the values were exceeded during the remediation, the consent required additional investigation to determine the source of contamination and implementation of corrective measures.

It is understood that the PETC presented in the table above are intended to be those derived by T&T and presented in Table 8.2 of their Groundwater Assessment Report of May 2003 (T&T, 2003b). The PETC presented in T&T's report were quoted as being based on l00 times the relevant ANZECC 99% Freshwater Level of Protection (LOP) value (ANZECC/ARMCANZ, 2000). The factor of 100 allowed for the 100-fold dilution of groundwater which was estimated to occur in the Mapua Channel.

There are several points which should be noted:

- The PETC presented in both the T&T report and consent **are not** based on the ANZECC 99% freshwater LOPs, but for the most part are based on the marine low reliability trigger values (ANZECC/ARMCANZ, 2000). Exceptions are as follows: DDD (which has never had an ANZECC trigger level); dieldrin (combined marine/freshwater low reliability trigger value); mercury (which is based on the 95% marine LOP divided by 1,000 to allow for bioaccumulation); copper (95% marine LOP); selenium and zinc (which are the only ones based on the 99% freshwater LOP); and total chromium (for which the hexavalent chromium (Cr VI) marine 95% LOP has been used). The basing of the PETC on marine values is reasonable given the intent is to protect the marine environment and the reference to freshwater guidelines in the T&T report appears to be an error;
- No allowance is made for bioaccumulation of DDX, aldrin, dieldrin, chlordane, heptachlor, and selenium;
- Whilst it is understood that allowance has been made for 100-fold dilution in the derivation of the PETC, the value shown in the consent for DDT actually represents 1000-fold dilution of the quoted ANZECC trigger.

- Whilst a figure of 100-fold dilution was used to derive the PETC (except for DDT) the level of dilution for groundwater entering the Waimea inlet was estimated by T&T (2003b) to be only five-fold. However, CH2M HILL (2007) later estimated dilution in the Mapua Channel and Waimea Inlet to be of the order 80,000 – 1.5 million and 1000 – 25,000, respectively.
- The table of PETC in the consent states that the values relate to the assumption of a cut-off wall along the eastern boundary of FCC East. Apart from DDT, this is the same as the table for proposed Condition 55 in the AEE (T&T, 2003a). However, the same values presented in Table 8.2 of the T&T groundwater report state that they relate to the assumption of no cut-off wall along the eastern boundary of FCC east. If a cut-off wall is assumed, the values should have been ten times higher in the consent (except for DDT which was ten times higher), if Table 8.2 of the T&T groundwater report is accepted.

These apparent discrepancies in the derivation of the PETCs have no particular bearing on the application of the consents as the values in the consent prevail. However, in considering the post-remediation effects it is appropriate to adopt a consistent dilution factor for the various contaminants.

7.5 Additional Monitoring by TDC

When the consent expired in November 2007, TDC continued monitoring a reduced number of wells for selected analytes on a three-monthly basis. The wells monitored by TDC included: BH1/BH1A, BH2A, BH5/BH5A, BH9/BH9A and the residential bore at 13 Tahi Street. Where a well pair exists, in some of the earlier TDC monitoring rounds both wells were sampled, but more recently only the 'A' wells have been sampled.

The parameters included in the TDC monitoring are: nitrate nitrogen, ammoniacal nitrogen, total nitrogen, dissolved reactive phosphorus, copper, iron, DDX and ADL.

In November 2008, the monitoring by TDC also included (see Figure 1):

- BHD, in the northeast corner of the site, adjacent to Mapua Channel;
- BHH on the southern boundary of FCC East, adjacent to 13 Tahi Street;
- BHG on the southern boundary of FCC West, adjacent to 18 Tahi Street;
- BH3A and BH4A, along the north-west boundary of FCC Landfill;
- Old BH1 on Tahi Street near the centre of the northern site boundary;
- BHL on Tahi Street approximately 50 m south of the site boundary; and
- eight additional residential bores in Tahi Street properties to the south of the site (17A, 21, 23, 26, 27, 29, 36 and 39 Tahi Street).

7.6 Post remediation groundwater criteria

Groundwater monitoring results post-remediation have been compared with both aquatic ecosystem guidelines (ANZECC, 2000) and the Drinking-water Standards for New Zealand (MoH, 2005). CH2M HILL (2007) used human health and aquatic guidelines for ammonia, nitrate and nitrite but used the consent PETCs for OCPs. PDP (2007), in reporting the monitoring by TDC have variously used aquatic guidelines and drinking-water MAVs (maximum allowable value) and GVs (aesthetic guideline values). The various criteria are summarised in Table 9.

The groundwater presents potential risks through:

- human consumption of groundwater;
- use of groundwater for irrigation;
- industrial use of groundwater;
- discharge of groundwater to an area of human contact recreation in the estuary and Mapua Channel; and
- discharge of groundwater to the marine ecosystem

It is appropriate to compare with human health guidelines where people might come into contact with the groundwater long-term, whether in drinking the water or in contact recreation (where the drinking-water guideline is used as a proxy). It is understood (CH2M HILL, 2007) that none of the private bores in Tahi Street are used for drinking purposes, being used primarily for irrigation. However, there is nothing stopping owners using the water for drinking purposes. In addition, there is a potential for further bores to be constructed and water taken. Tasman District Council's Tasman Resource Management Plan has the following provisions with respect to installing a bore and taking small quantities of water:

- a bore permit is required for a drilled well, but not for a 'dug' well (including by excavator) to a depth of 8 m;
- TDC can only reject a bore permit application on spacing grounds. The minimum spacing for the shallow aquifer is 50 m; and
- taking up to 5,000 L per day for domestic purposes is a permitted activity;

A plan change would be required to control potential abstractions on or adjacent to the site, for example to make such abstractions a discretionary activity for a specific area.

While there is no particular reason why a resident would go to the expense of installing a bore, given the existence of a reticulated supply, there is nothing theoretically stopping such use. Consequently, a potential risk exists if the groundwater is contaminated above drinking-water criteria. Given this, it seems reasonable to compare the groundwater sampling results with human health criteria. This is a more sensitive use than (garden) irrigation use.

Protection of the marine environment has been a primary objective of the remediation. Comparison with the PETCs is intended as a measure of the threat to the marine environment. The PETCs are intended to be protective of the marine environment after mixing, with, as noted above, a 100-fold dilution generally assumed in their derivation (1000-fold for DDT). Implicit in this is the acceptance that there could be some effects on the marine ecosystem at the point of discharge, where dilution would be less. Given this, it seems reasonable to compare the nutrient concentrations, at least with respect to their ability to be toxicants, with guidelines that recognise dilution. This has not been the case to this point in reports on the groundwater to date.

This then raises the question as to what dilution is appropriate. CH2M HILL (2007) calculated dilution of 80,000 to 1.5 million in the Mapua Channel and 1,000 to 25,000 in the Waimea Inlet. These are several orders of magnitude higher than the dilution factors of 100 and five respectively for the channel and inlet calculated by T&T in the AEE (although the greater dilution factor was used to derive the PETCs). The different estimates reflect the different methodologies, with T&T basing its estimates on flow rates past the discharge zones and a 20 m mixing zone, and CH2M HILL basing its estimate on complete mixing within the volume of water emptied during each tidal cycle.

The T&T estimates are very conservative and the CH2M HILL estimates are probably extreme. A more reasonable dilution estimate is perhaps in the range of one to several thousand, which should still be conservative for the channel but less so for the inlet. Inevitably, using larger dilution factors means there is a greater risk at the point of discharge at low tide (and within the pore water within the marine sediment). At least with respect to nutrients, there is a demonstrated excessive level of nutrients at the point of groundwater discharge as evidenced by enhanced algal growth.

The resource consent process did not appear to address the trade-off between local and general effects, except implicitly by accepting conservative dilution factors. Given the on-going groundwater contamination this needs to be considered more explicitly, but requires more information. Clearly there is algal growth from excessive nutrients where groundwater discharges on the east and west foreshores. However, there is no information on the potential effects on the beach/mudflat ecosystems of undiluted or partially diluted groundwater discharges when the tide is out. Meanwhile, in reviewing the results of monitoring to date, comparisons have been made here with aquatic criteria assuming 1,000 – 5,000-fold dilution as reasonable intermediate values between the T&T (2003a) and CH2M HILL (2007) extremes.

Before establishing such guidelines and making the comparisons, it should be noted that CH2M HILL (2007) quotes guidelines for nitrate and nitrite (as NO_3 and NO_2, respectively) in its report yet the results were reported by the laboratory as nitrate-N and nitrite-N. CH2M-Hill did not convert the guidelines to be in terms of nitrogen alone and therefore their comparisons were incorrect in an un-conservative sense. The effect of this is minor if the results are compared with conservative undiluted marine ecosystem guidelines, as the results are generally so high as to well exceed the guidelines, but the error may be significant if dilution is taken into account.

CH2M-HILL also used a low reliability marine nitrate guideline (as a toxicant not nutrient) from ANZECC (2000) which is based on the 95% protection level freshwater guideline. ANZECC (2000) states:

> *Although a marine low reliability figure of 13 000 µg/L (13 mg/L) could be calculated using an AF of 200 (limited data but a lesser factor due to essentiality), it is preferable to adopt the freshwater figure of 700 µg/L for nitrate toxicity as NO_3 (nitrate) as a marine low reliability trigger value.*

However, in 2002, MfE issued a memorandum from the National Institute of Water and Atmospheric Research (NIWA, 2002) which questioned the validity of the 700 µg/L – this value was apparently in error – and derived a corrected value of 31,900 µg/L using the data presented in ANZECC (2000). This revised value is the equivalent of 7200 µg/L nitrate-N. If this value was to be used as a low reliability marine guideline, a somewhat different view of the groundwater monitoring results would result. It is not known whether such a value is appropriate for the marine environment. Further investigation is required.

PDP (2007), in using the human health value for ammonia, incorrectly compares this guideline with ammoniacal-N results. The error is small given the small difference in formula weights. However, the value of 0.3 mg/L used by PDP is to guard against the formation of chloroamines in a chlorinated water supply. This has limited relevance in the current situation and does not appear in the 2008 update of the New Zealand Drinking-water Standard (MoH, 2008). Perhaps a more relevant value is the aesthetic guideline of 1.5 mg/L measured as the ammonium ion. This is the equivalent of 1.2 mg/L measured as ammoniacal-N.

Table 9 provides a comparison of various human health and aquatic guideline values, the latter using 100-fold, 1000-fold and 5000-fold dilutions. The 100-fold dilutions are similar to the PETCs.

Table 9: Comparison of guideline values (mg/L)

Parameter	PETC[2]	Human Health[1]	Aquatic Ecosystem[2] 100-fold dilution	Aquatic Ecosystem[2] 1000-fold dilution	Aquatic Ecosystem[2] 5000-fold dilution
Nitrate-N	-	11.3	720[3]	7,200	36,000
Ammoniacal-N	-	1.2	50[4]	500[4]	2,500
Dissolved Reactive Phosphorus	-	-			
Copper	0.13[5]	2/1	0.13	1.3	6.5
Iron		0.2			
DDT (2,4 and 4,4 isomers)	0.0004	-	0.00004	0.0004	0.002
DDD (2,4 and 4,4 isomers)	0.0006[6]	-	-	-	-
DDE (2,4 and 4,4 isomers)	0.00005	-	0.00005	0.0005	0.0025
DDX		0.001	-	-	
Aldrin	0.0003	-	0.0003	0.003	0.015
Dieldrin	0.001	-	0.001	0.01	0.05
Aldrin + Dieldrin		0.00004	-	-	
Lindane	0.0007	0.002	0.0007	0.007	0.035

Notes:
[1] From NZDWS (MoH, 2008)
[2] Based on low reliability marine value from ANZECC (2000) unless otherwise indicated. For PETCs, 100-fold dilution used except DDT which used 1000-fold dilution.
[3] from NIWA (2002)
[4] moderate reliability value based on 95% protection of marine water species
[5] based on 95% protection of marine species
[5] 99% protection of marine species
[6] no ANZECC (2000) value available. Basis of PETC not known.

7.7 Groundwater Monitoring Data Quality

7.7.1 General Scope and Methods

The groundwater monitoring wells can be divided into three categories:

- private bores intended for water abstraction;
- monitoring wells installed prior to the remediation commencing; and

- monitoring wells installed by CH2M HILL, some of which replaced (or duplicated) existing monitoring wells

Little is known about the private bore construction and their suitability as monitoring wells. Monitoring wells BH1 – BH5 were installed by Groundwater and Environmental Services Limited during the initial characterisation investigation (GES, 2002) and appear to have been constructed to accepted industry standards. The replacement 'A' wells installed by CH2M HILL also appear to have been constructed appropriately.

In both cases, the screens fully penetrate the aquifer and therefore collect a sample that will be some sort of average of the groundwater conditions at the point. This may or may not be a good representation of the conditions at the point, depending on relative permeabilities of layers that the well may intersect and relative contaminant concentrations within those layers. Multiple wells screened at several levels or multilevel low-flow sampling techniques in the existing wells could be employed in an attempt to determine whether particular layers have higher or lower concentrations. However the wells are adequate for the current purposes.

In general, the sampling methods applied appear to be in line with accepted industry practice. There is a suggestion, however, that the initial sampling of the wells by CH2M Hill occurred too early after the wells were installed. It is good practice to leave the wells at least a week or two after installation before sampling, but in the case of the first monitoring of the new wells it was only a few days. The effect of this is not known, but of no great significance, as it is the trends over time that are of most important rather than the results of a single sampling.

One aspect of the protocol that was the subject of discussion during the remediation was whether or not to filter the samples analysed for OCPs. The original consent specified that such samples were to be filtered. However, the method adopted during the remediation works was to sample directly into laboratory prepared bottles with a peristaltic pump and for laboratory to centrifuge the samples to remove sediment (this is noted on the laboratory reports). The subsequent sampling by TDC also sampled directly into bottles and the laboratory is reported to have decanted the sample before using a 0.45 μm filter prior to analysis. The CH2M HILL (2007) investigation report records that OCP samples were allowed to settle in the field before decanting.

It would have been desirable to have adopted the same technique for all groundwater sampling throughout the project to give greater certainty that the sampling results can be compared.

There is no absolute rule on whether to filter samples for pesticide analysis. The obvious objective in groundwater sampling is to determine the concentrations within the groundwater, however, the sampling technique can change these concentrations. Turbid water is one factor, because contaminants can be absorbed onto the sediment suspended within the sample. The sediment is typically an artefact of the sampling, rather than the true state of the groundwater. It is common to filter samples for metals analysis if dissolved concentrations are desired. However, groundwater sampling

procedures typically recommend collecting pesticide samples, for which very low concentrations are typically being measured, without field filtering. This is because of the possibility of the filtering equipment absorbing some of the contaminant, resulting in a falsely low result on analysis. However, if the sample is turbid and the sediment has the contaminant adsorbed onto it, the analytical result would be falsely high.

A partial solution is to let the samples settle and decant the clear supernatant for analysis. This may still leave very fine sediment (colloidal particles). A better alternative is to remove the sediment in the laboratory by centrifuging. It is preferable, however, that the samples are not turbid in the first place, preferably less than 10 – 15 NTU. This can be achieved by constructing and developing the monitoring wells so that little sediment is produced when sampling, and taking great care to minimise the production of sediment during sampling. This can be difficult if the wells are installed in fine soil, but there are techniques available such as employing pre-packed screens or geotextile filter socks.

CH2M HILL recorded turbidity when sampling in 2007 and there appears to be a relationship between higher turbidity and higher OCP concentrations (PDP, 2007). For example, BH5A is typically quite turbid and varies from one sampling occasion to another. However, from the data presented, it is difficult to quantify this effect or assess its potential significance. In any case, the data obtained without filtering are likely to be conservative when compared with actual dissolved concentrations in the aquifer. The practice of measuring the turbidity of samples has continued since 2007 with the ongoing TDC sampling. It is a good practice and should continue with future monitoring.

Notes of the TDC sampling from 2008 indicate that some wells were purged dry, resulting in turbid samples. Avoiding pumping wells dry (which will stir up sediment) and leaving the wells to settle for some hours after purging before sampling would assist in reducing sample turbidity for future monitoring. However, recent sampling suggests most samples (except BH5A) had acceptable turbidity.

7.7.2 Well Location and Monitoring Frequency

The number of on-site wells monitored during and after the remediation works is low for assessing post-remediation conditions. Sites of similar size typically have many more wells. Given the large investment in the remediation to date, the investment in post-remediation monitoring seems low. A more robust monitoring network would enable a better sense of the groundwater flow directions and seasonal variations of flow direction and water level to be gained and a better sense of the variation of contaminant concentrations across the site. Of importance is to confirm the presence of a groundwater divide running roughly north-south through FCC West, to confirm that it is unlikely that contaminated groundwater is flowing from FCC East to FCC West. Further wells could also determine whether there is a southerly component of flow towards the properties on Tahi Street, and how significant this southerly flow might be from FCC East. Better mass flux estimates could also be calculated so that discharge to the marine

environment, particularly to the east, is better understood. The addition of the following wells would result in a more robust network:

- at least one upgradient well in the vicinity of the northwest corner of the site to obtain background;
- a well midway along the western boundary of FCC West;
- a well in the south-east corner of FCC West;
- a well in the former vicinity of the MCD plant;
- a well roughly at the midpoint of the south-western quadrant of FCC West;
- two wells spaced out along the western boundary of FCC East;
- two wells spaced out along a line running north-south midway across FCC-East;
- a well in the vicinity of the former surge chamber location where there is a gap in the clay bund;
- ideally, wells either side of the clay bund installed on the eastern boundary of the FCC Landfill site; and
- in addition to those wells currently monitored, routine monitoring of Old BH1, BHH, BHG and BHD, at least for water level.

Not all wells would necessarily be monitored for contaminants on every occasion, but at least a baseline should be established over an initial year of quarterly monitoring. Possibly a sub-set would be monitored after that, but that would depend on what was found in areas not currently monitored.

As discussed earlier, the hydrogeology on the site is not straightforward, particularly with the potential influence of the various clay bunds on groundwater flow patterns on the site (see Section 7.2). In fact, it is not entirely clear where some of the monitored wells are in relation to the clay bunds. According to information from TDC, the three landfill monitoring wells (BH3A, BH4A and BH5A) are located within clay bunds.

7.7.3 Analytes

The range of analytes tested for is reasonable for characterising the groundwater quality and assessing the key potential contaminants of concern.

7.7.4 Quality Assurance and Quality Control

In general, the QA/QC information for the groundwater monitoring is limited and it is difficult to assess the data quality. In each case the laboratory used was Hill Laboratories and, as discussed in Section 5.3.4.2, the laboratory's internal QA/QC procedures are expected to be in line with industry practice. However, no internal laboratory QA/QC reports were provided for the project.

The groundwater monitoring during the remediation works was undertaken by ChemSearch, Dunedin. QA/QC sampling in the form of a field blank and duplicate was

completed for each monitoring round. However, no analysis of the QA/QC results is provided in the reports.

The CH2M HILL provides an adequate QA/QC assessment for the groundwater sampling during the 2007 investigation. The report discussed the significance of duplicate, rinsate and field blank samples and concludes the QA/QC criteria were met for the investigation (CH2M HILL, 2007). We concur.

No QA/QC information was presented for the post-remediation sampling undertaken by TDC.

7.8 Review of Groundwater Monitoring Results

Monitoring of on-site wells during the remediation showed increasing trends in groundwater concentrations for a number of the key contaminants. In general, there has been a rise in groundwater concentrations in most wells following the commencement of remediation. In many cases the rise was more than an order of magnitude. While there has been a decreasing trend since remediation was completed, the groundwater has not returned to pre-remediation concentrations, suggesting the remediation is having on-going effects on the groundwater quality.

The detected concentrations of DDX and ADL exceeded the PETC in a number of locations, and concentrations of nitrate, ammoniacal-N and dissolved reactive phosphorus (DRP) rose to high concentrations. It is not clear whether any action was taken with respect to PETC exceedances.

The CH2M HILL report (2007) summarises the key results during the remediation and for the monitoring it carried out. A series of reports by PDP summarise the results of the post-remediation monitoring undertaken by TDC. Time series data are presented in these reports for compounds and wells where concentrations are consistently above laboratory detection limits.

In some cases, the post-remediation monitoring by TDC included both the original wells and the replacement 'A' wells installed by CH2M HILL. BH2 was destroyed during the remediation and hence only BH2A could be monitored. Both the original and replacement wells (BH1/BH1A, BH5/BH5A and BH9/BH9A) were monitored for the January 2008 and April 2008 monitoring events (i.e. the first two post remediation events). From that point on only the replacement wells have been. This is reasonable as the two datasets appear similar. For the purposes of this discussion, a reference to a monitoring well such as BH1 includes data from both BH1 and BH1A.

The various contaminants are discussed in more detail below. In general, detailed comment has only been made on data for the wells monitored regularly since the remediation was completed (BH1, BH2, BH5, BH9 and 13 Tahi Street). These wells represent the concentrations that would be going off site if the groundwater flow is crossing the boundary at the particular locations, i.e. they represent downgradient conditions, but they are not necessarily representative of conditions for the particular

boundaries. This is because proximity of submerged or intermittently submerged treated fines could result in higher results than other locations on a particular boundary and more permeable material buried at the base of excavation could cause anomalous high or low results, depending on spatial relationships with treated soil. For example, treated fines, mixed treated fines or commercial material were placed below the watertable or within the zone intermittently submerged in the following locations close to monitoring wells:

- in all the landfill excavation subgrades, within which monitoring wells BH3A and BH5A were installed; and
- in subgrades SG7 and SG9, upgradient of monitoring well BH1A.

In addition, mixed treated fines were placed above the watertable in subgrades SG14 and SG16. Monitoring well BH2 is installed on the boundary of these two subgrades.

Thus these wells might be expected to have higher concentrations than wells installed where there is less treated material or where the treated material is above the watertable. Currently there are no wells in the centre of either FCC east or FCC West, so there is no sense of how representative the current less than ideally placed boundary wells are. It could be that the concentrations measured in, for example, BH1A, are an overestimate of typical conditions for the eastern side of FCC East. The few measurements in BHD suggest that that might be the case.

7.8.1 Pesticide Monitoring Results

DDX Compounds

There appears to have been an increase in DDX concentrations in groundwater associated with the remediation works, with general rises in concentrations in early to mid 2005 (often by an order of magnitude). Typically, this was followed by slight declines, although concentrations have not returned to pre-remediation levels. Looking at the individual compounds in BH1, BH2, BH5 and BH9, it is generally DDD and DDT which are at higher concentrations and showing greater rises compared with DDE.

CH2M HILL (2007) states that there are no clear trends for DDX concentrations in off-site wells (with the exception of 13 Tahi Street). The lack of regular monitoring of other off-site wells means that any seasonal fluctuations cannot be determined. However the monitoring of several off-site wells[20] in November 2008 by TDC found only trace concentrations of DDX at 26 Tahi Street, with all other wells non-detect. The most recent monitoring at 13 Tahi Street (the closest residential bore to the site) indicates DDX concentrations have been below laboratory detection limits in recent monitoring rounds, and hence below the equivalent PETC.

A single monitoring event is not sufficient to show there is no threat to all off-site wells from DDX compounds (and by extension other properties south of the site) but the recent

[20] 17, 21, 23A, 26, 27, 29, 36 and 39 Tahi Street

consistent trend in 13 Tahi Street suggests a similar trend may also exist for the other off-site wells.

In reporting the DDX compounds for TDC in the various quarterly monitoring reports, PDP does not compare the individual compounds against the PETCs, rather it compares the sum of the DDX compounds against human health guidelines. However, all on-site boreholes for which data are presented have exceeded the PETC for the individual DDX compounds at some point during the remediation works. Since May 2008, only BH1 and BH5 have exceeded the criterion. Both these wells are in or close to mixed buried fines material.

In the three most recent monitoring rounds (August 2008, November 2008 and February 2009), the DDT concentrations in BH1 and BH5 were less than twice the PETC of 0.0004 mg/L. Although BH2 has reached around twice the PETC on one occasion, it is currently running at less than the laboratory detection limit (0.00001 mg/L) and looks likely to continue to do so. Apart from a single spike in June 2006, DDT concentrations in BH9 are consistently below the PETC and look likely to continue to be.

A similar pattern is shown for DDD concentrations. In the three most recent monitoring rounds, the DDD concentrations in BH1 and BH5 were up to maximum of about five times above the PETC of 0.0006 mg/L. The DDD concentrations in BH2 and BH9 have remained below the PETC and look likely to continue to do so.

DDE concentrations in BH5 and BH9 consistently exceeded the PETC of 0.00005 mg/L during most of the remediation works, typically by approximately eight times and two times respectively. During recent monitoring rounds, the DDE concentrations in these wells have been closer to or below the PETC. The DDE concentrations in BH1 have been close to or below the PETC throughout the monitoring period. An exceedance of DDE by around two times the PETC occurred in early data in BH2, along with a notable spike in July 2006. However, the DDE concentrations in BH2 appear to have stabilised below the laboratory detection limits (0.00001 mg/L) in recent monitoring rounds.

If the DDX data is considered in light of less conservative dilution factors (remembering the DDT PETC is based on 1000-fold dilution), the recent (and most other) monitoring would have complied in all cases with 1000-fold dilution for DDD and DDE and 5000-fold dilution for DDT.

Apart from the off-site wells, the November 2008 monitoring round undertaken by TDC also included the following additional on-site wells, all close to site boundaries: BHG, Old BH1, BHH and BHD. These had similar DDX concentrations to those on-site wells that are regularly monitored. DDX concentrations in Old BH1 (close to the northern boundary) were below laboratory detection limits.

The November 2008 monitoring round also measured DDX concentrations in BH3 and BH4 on the landfill boundary. DDX concentrations in BH3 were above the PETC and similar to BH5, which is not surprising given the two wells similar relationship to treated fines material. BH4 also showed elevated DDX concentrations, but less so than either

BH3 or BH5. While still within or close to treated fines material, BH4 is on the edge of the landfill with groundwater flow estimated to be parallel to that edge, which may mean the groundwater passes through less treated fines material before reaching BH4.

In comparing the on-site wells with the drinking-water MAV of 0.001 mg/L for DDX in the New Zealand Drinking Water Standards (MoH, 2005), the only wells that have consistently exceeded are BH1 and BH5. During recent monitoring rounds the DDX concentrations in these wells have been between one and three times the MAV, confirming the water is unsuitable for drinking-water purposes. BH3 exceeded the MAV in November 2008 but BH4 did not. No off-site wells have exceeded the drinking water MAV for DDX in any of the monitoring rounds.

ADL Compounds

BH1, BH2, BH5, BH9 and 13 Tahi Street all showed increases in the sum of ADL concentrations starting in mid to late 2005, with BH5 in particular showing a series of elevated peaks until about March 2006. From March 2006 until July 2007, the ADL concentrations in the monitored wells appeared to be approximately static or decreasing, although concentrations have not returned to pre-remediation levels. From September 2007 until present, the ADL concentrations appear to have increased in BH2 and BH5, although the concentrations have oscillated and no consistent trend is apparent.

Looking at aldrin and dieldrin separately, the effects are generally more marked and concentrations higher for dieldrin than for aldrin. At 13 Tahi Street there are no clear trends.

The three most recent monitoring rounds indicate that aldrin concentrations in BH1 are well below the PETC and look likely to continue to be so. The aldrin concentration in BH2 peaked slightly above the PETC of 0.003 mg/L in November 2008, but was below the laboratory detection limit (0.000005 mg/L) in the monitoring rounds immediately prior to and after that round. In BH5, aldrin levels have occasionally come close to the PETC during the remediation works, but in more recent data have been half the PETC or less and look likely to continue to do so. Aldrin levels in BH9 have always been less than a third of the PETC, frequently much less, and look likely to continue to meet the PETC.

The most recent monitoring data indicate that the dieldrin concentrations in BH1 are well below the PETC of 0.001 mg/L and look likely to continue to be so. The dieldrin concentration in BH2 has recently been close to or slightly above the PETC on each occasion, a general increase on earlier data which was typically half this level or less. In BH5, the PETC for dieldrin has been frequently exceeded (generally fluctuating between half and 1.5 times the PETC although much more in the second half of 2005) and this looks likely to continue. Dieldrin levels in BH9 are generally less than a half of the PETC and frequently much less. The most recent data for BH9 are a third of the PETC or less, and this well looks likely to continue to meet the PETC. The November 2008 monitoring of BH3 and BH4 complied with the PETCs for both aldrin and dieldrin

The most recent monitoring data indicate that BH1 is meeting the PETC of 0.0007 mg/L for lindane, although the concentration in August 2008 was close to exceeding the criterion. The lindane concentrations in BH2 in the last three monitoring rounds have consistently exceeded the PETC, and have done so since about October 2006. Prior to that time, the results were always below the PETC in BH2. The peak concentration was recorded in August 2008 at 0.012 mg/L (17 times the PETC); while the next two results have been successively lower, with the most recent result at 0.0059 mg/L (8.4 times the PETC). The lindane concentrations in BH5 have recently fluctuated from below the PETC to approximately five times the criterion. This is consistent with previous results in that well. The lindane concentrations in BH9 have fluctuated from below the PETC up to about five times the criterion, and look likely to continue to do so.

The lindane concentrations in the 13 Tahi Street bore have been consistently below the PETC of 0.0007 mg/L, with a maximum concentration detected of 0.00014 mg/L in April 2006 (about one fifth of the PETC). All results are also below the drinking water MAV (0.002 mg/L).

The additional wells along the site boundary included in TDC's November 2008 monitoring round found similar ADL concentrations to those on-site wells that are regularly monitored. A dieldrin concentration of 0.0075 mg/L in Old BH1 exceeded the PETC of 0.001 mg/L. Other ADL compounds were also present in this well, although at concentrations below the PETC (and therefore MAVs). The only off-site wells where ADL concentrations were detected were 26 Tahi Street where a trace dieldrin concentration was detected, and in BHL where a trace aldrin concentration was detected. Both concentrations were well below the corresponding PETC.

If criteria were adopted with greater dilution than assumed in the PETCs, then all the ADL compounds would have complied in recent monitoring except the lindane concentrations in BH2 in August and November 2008, which would not have complied with 1000 times dilution but would have complied with 5000 times dilution.

The drinking-water MAV for the sum of dieldrin and aldrin (0.00004 mg/L) has consistently been exceeded in on-site wells. In BH1 and BH2 on FCC East, the concentrations have typically been about five to twenty times the MAV. In BH5 (FCC Landfill), the aldrin plus dieldrin (A+D) concentrations in recent monitoring rounds have been between 30 and 40 times the MAV. In BH9 (FCC West), the concentrations have recently ranged between five and ten times the MAV.

The drinking water MAV for A+D has also been consistently exceeded in the residential bore at 13 Tahi Street. In recent monitoring rounds, the concentrations were about two to five times the criterion. The data for other off-site wells is limited. However, in the November 2008 monitoring round, all A+D concentrations were below the MAV at the nine other off-site monitoring locations, and only two locations recorded A+D concentrations above the laboratory detection limits.

Chlordane and heptachlor

PETCs were derived for chlordane and heptachlor. Chlordane and heptachlor have not been detected above the laboratory detection limit of 0.000005 mg/L in any of the wells in recent monitoring events. These compounds do not qualify as contaminants of concern and will not be considered further.

Non-PETC Pesticide Compounds

Concentrations of various ONP and OPP compounds have been detected above laboratory detection limits in a number of wells, both on and off-site. However, the data are limited as these analyses were only included annually, with the last round completed in January 2007. In the on-site wells detected OPP and ONP compounds included atrazine (up to 0.003 mg/L), carbaryl (up to 0.001 mg/L), diuron (up to 0.001 mg/L) and simazine (up to 0.003 mg/L). Trace concentrations of various OPP and ONP compounds were also detected in the residential bores at 13 and 26 Tahi Street, and to a lesser extent at 17A Tahi Street. All detected concentrations in the off-site wells were below the corresponding drinking water MAV (MoH, 2005).

In a similar manner, trace concentrations of various acid herbicides were detected in a number of on-site wells and a single off-site well (26 Tahi Street) during the January 2007 monitoring. However, all concentrations were well below the corresponding MAV.

These compounds will not be considered further.

7.8.2 Metals Monitoring Results

Copper

Copper concentrations in the monitored boreholes have been below the PETC of 0.13 mg/L in all wells, except for a single exceedance (0.16 mg/L) in BH5 in the January 2007 monitoring round. Until the most recent monitoring round, the laboratory detection limit used was 0.01 mg/L. Concentrations in all wells have been less than 0.02 mg/L in the three most recent monitoring rounds, and typically below the laboratory detection limit. In the most recent monitoring round, a lower detection limit of 0.001 mg/L was used. A maximum concentration of 0.01 mg/L was detected in this round, in the sample from BH2.

All concentrations are well below the drinking water MAV of 2 mg/L (MoH, 2005).

There are no clear trends in the copper concentrations which might be related to the remediation works. There were two peaks in BH5 (July 2005 and January 2007) which were elevated compared to other results from that well. In addition, there appeared to be an increase in concentrations in BH2 from late 2007 to late 2008. However, recent concentrations in these monitoring wells have been much lower.

There has been concern expressed that the use of copper compounds as a reagent in the MCD process has resulted in unacceptable contamination of both the soil and

groundwater. However, it would appear that the copper is not leaching sufficiently for it to be of concern, at least as measured in the various wells. It is of concern that the detection limit used or most monitoring events was not clearly below the PETC, leaving some uncertainty. However, if greater dilution was allowed, copper is not a concern for the marine environment in the monitored wells.

Subject to measurements of groundwater quality within a better distribution of wells across the site (see Section 7.7.2), copper does not appear to be of concern.

Other Metals

Only limited data are available for the other metals which have PETC, as analyses were only undertaken annually for these elements. PETC exist for chromium (0.44 mg/L), mercury (0.00004 mg/L), selenium (0.5 mg/L) and zinc (0.24 mg/L). Drinking-water MAVs (MoH, 2008) exist for chromium (0.05 mg/L) mercury (0.0007 mg/L) and selenium (0.01 mg/L). The aesthetic guideline value for zinc is 1.5 mg/L.

The chromium concentrations were well below the PETC and MAV for both on and off-site wells. Concentrations were below laboratory detection limits (0.0005 – 0.001 mg/L) except for a single detectable concentration of 0.0022 mg/L at 13 Tahi Street in the January 2007 monitoring round (most recent).

Mercury was detected at concentrations above the PETC of 0.00004 mg/L in the May 2005 monitoring round in BH3 (0.00012 mg/L) and BH4 (0.0177 mg/L). No concentrations of mercury have been detected above the laboratory detection limit of 0.00008 mg/L in recent monitoring rounds. However, the detection limit is above the PETC of 0.00004 mg/L and compliance with this criterion cannot therefore be determined. It is unlikely that there will be significant exceedances of the PETC for mercury as there have been only low concentrations detected in soil on the site.

No selenium concentrations were detected above the PETC or MAV as concentrations were all below the laboratory detection limits (0.001 – 0.005 mg/L).

All zinc concentrations were below the PETC of 0.24 mg/L except for a concentration of 0.63 mg/L which was detected in the well at 36 Tahi Street, although this is below the drinking-water GV. It is unlikely that this relates to site derived contamination as the zinc concentrations in on-site wells were much lower (all less than 0.1 mg/L).

These metals will not be considered further.

7.8.3 Nutrient Monitoring

As noted earlier, there were no PETCs derived for nutrients, as there was no appreciation originally that nutrients could become a particular concern. Results for various compounds analysed for are discussed below.

Nitrate-nitrogen

Nitrate-nitrogen concentrations in groundwater increased significantly from about mid 2007, both in on-site wells and in 13 Tahi Street. Recent concentrations have been lower, but still typically elevated relative to background concentrations.

The on-site wells with the most elevated concentrations have been BH2, BH5 and BH9. The nitrate-nitrogen concentrations in BH2 and BH5 have ranged up to about 300 and 400 mg/L, respectively (in mid to late 2007). More recently concentrations in these wells have been below 100 mg/L. BH9 had peak concentrations of about 200 mg/L and is also currently running at less than 100 mg/L.

Nitrate is both a nutrient and a toxicant, if at high enough concentrations. If a PETC had been derived in a similar manner to the other compounds, but using the NIWA (2002) recommended aquatic guideline instead of the ANZECC (2000) value, then a PETC of 730 mg/L would have been set. Current and past concentrations comply with this value.

The nitrate-nitrogen concentrations in 13 Tahi Street also peaked in 2007 (at about 50 mg/L), with recent concentrations at approximately 10 mg/L or less. In the November 2008 monitoring round, data from other off-site wells showed concentrations above background levels (about 3 mg/L) in most of the downgradient residents bores. Concentrations in these bores typically ranged from about 5 to 10 mg/L. Only one off-site well exceeded the drinking water MAV of 11.3 mg/L (MoH, 2005) in that monitoring round, with a concentration of 13 mg/L detected at 26 Tahi Street.

CH2M HILL were of the opinion that the nitrate detected at 26 Tahi Street was likely to have come from a source other than the site, based on their conceptual groundwater model of little southerly component to the groundwater flow. A leaking sewer or old septic tank was suggested as the source. PDP (2007), on the other hand, considered the result was supportive of a southerly component in the off-site groundwater flow.

Ammonia-nitrogen

Ammonia-nitrogen concentrations in groundwater also increased significantly during the remediation works, although the pattern is not consistent between wells. Recent concentrations have been lower, but still typically elevated relative to background concentrations.

The on-site wells with the most elevated concentrations have been BH1, BH2 and BH5. The ammonia-nitrogen concentrations in BH2 and BH5 have ranged up to about 850 mg/L, although at different times (November 2006 and May 2008 respectively). More recently concentrations in BH2 have been below 100 mg/L and in BH5 have been approximately 10 mg/L. BH1 had peak concentrations of about 600 mg/L in May 2008 and is currently running at less than 200 mg/L. Concentrations in BH9 peaked at about 70 mg/L in late 2006 and are currently less than 10 mg/L.

It may be that concentrations will now stay lower than they have in the past, but given concentrations were high within the last year this is not certain. Further monitoring is required to confirm the apparent reducing trend.

As noted earlier, CH2M HILL inappropriately compared incorrect aquatic guideline values without considering dilution. If 100-fold dilution is taken into account resulting in a criterion of 50 mg/L, only BH1 and BH2 would exceed by up to about three times. If dilution of 1000-fold was used, all recent results (and most results throughout the remediation) would comply. There could be toxic effects at the discharge points where little dilution has had a chance to occur.

The ammoniacal-nitrogen concentrations in 13 Tahi Street have been consistently less than 1 mg/L. The November 2008 monitoring round confirmed similar conditions in other off-site wells, with a maximum concentration of 0.16 mg/L detected.

No off-site wells have exceeded the aesthetic drinking water GV of 1.5 mg/L (MoH, 2008).

Dissolved reactive phosphorus

Dissolved reactive phosphorus concentrations have increased significantly in a number of the on-site wells. The peak concentration for BH2 (approximately 150 mg/L) was detected in the May 2008 monitoring round. The last two results for BH2 have been about 15 mg/L. BH5 has also exhibited elevated peaks, with the maximum phosphorus concentration in this well of about 115 mg/L detected in July 2005. The next highest result in BH5 was 55 mg/L in July 2007, with recent results around 2 mg/L. Phosphorus concentrations in BH1 and BH9 have typically been less than 1 mg/L, other than a peak of about 5 mg/L in BH9 in October 2006.

Phosphorus concentrations in the bore at 13 Tahi Street have been much lower than on-site concentrations, with a maximum of about 0.15 mg/L. In the November 2008 monitoring round, the phosphorus concentrations in other off-site wells were even lower, with a maximum of about 0.06 mg/L.

PDP (2007) compared the results with an ANZECC (2000) marine trigger value for Southeast Australia of 0.01 mg/L. In the interim, until better values are developed, Southeast Australia is considered to be similar to New Zealand conditions. Phosphorus is not a particular concern for on-site wells other than close to discharge points on the foreshores, i.e. in wells BH1, BHD, BH3 and BH5. If a 100-fold dilution was applied (groundwater trigger of 1 mg/L), recent concentration in BH5 and BH1 are at similar or slightly higher concentrations. November 2008 results on wells near the foreshores, BH3 and BHD, were much lower than BH1 and BH5, at 0.024 and 0.075 mg/L, respectively. The results in the foreshore wells suggest that while phosphorus will be contributing to local effects at discharge points, there is no particular concern after dilution.

Algal growth

Algal growth on the eastern and western foreshores is not formally monitored but it has been mentioned in various reports, particularly the annual TDC biota and sediment monitoring reports. It appears to be a direct response to groundwater with excessive nitrate and phosphorus being discharged on the foreshores following leaching from treated fines. As noted earlier, treated fines are placed close to both the eastern and western foreshores.

Photographs in the TDC reports suggest it is present as a light discontinuous covering over much of the eastern beach and as a heavier growth along a seepage line and locally within the "swale" channel on the western foreshore. Other than the photographs, it would appear that there has been no systematic survey of the extent or effects of the algae. CH2M HILL (2007) noted the potential for effects on local water quality and biodiversity from excessive algal growth. However, in reviewing the comments in various reports, including the TDC reports, no sense has been gained of whether the algae extent is increasing, whether it varies seasonally or whether it is having an effect on the marine biota. No particular alarm has been expressed in the reports reviewed.

Mapping the extent of the algae at quarterly intervals for a year and then annually would assist determining whether it is increasing and therefore whether it could become an unacceptable problem.

7.8.4 CH2M HILL Seep Sampling

CH2M HILL (2007) collected water from two seeps discharging onto the eastern beach by excavating a small pit along a visible seep line. An attempt was also made to collect a seep from the western foreshore but this was unsuccessful. Monitoring of pH and redox potential indicated the water was similar to groundwater although monitoring of electrical conductivity suggested a seawater influence. CH2M HILL concluded the water was indeed groundwater, although impacted by intruding marine water. Given seawater was probably still draining from the sediments at the time of collection, it is likely that these and any similar samples will be at least partially diluted by seawater. Comparing the electrical conductivity of the samples with the electrical conductivity of seawater samples collected during the same investigation, one sample could have been diluted as much as 50% by seawater and the other sample appears to be about 90% seawater.

One sample exceeded the ANZECC (2000) low reliability guideline for DDT (0.0000004 mg/L) by 6000 times and the other by 92 times, indicating the potential for effects. Similarly, dieldrin exceeded the low reliability guideline by 73 and 84 times in the two samples. However, both samples had high turbidity and the results may have been affected by DDT attached to the sediment.

When compared with results from BH1 and BHD, some analytes had similar concentrations, some analytes had higher concentrations (particularly DDX in one seep,

suggesting a sediment source) and some very much lower. Given the probable low quality of the samples the seep sampling was of limited value.

It would be useful to repeat the seep sampling exercise on both foreshores in an attempt to obtain a better sense of concentrations in the water discharging on the beach. However, care would have to be taken that the samples were more representative of the groundwater, and not contaminated with beach sediments. Rather than simply excavating holes to sample from, temporary standpipes would likely provide better quality samples. Decanting the samples and centrifuging in the lab would also be necessary.

7.9 Hydrogeological Uncertainties

There are a number of uncertainties and gaps in the information used to develop the hydrogeological model. These are presented in Appendix C. Further comment is made on the major uncertainty with respect to groundwater levels and flow directions below.

It would be expected that the pattern of groundwater levels would mirror the shape of the peninsula or, more specifically, the shape of the groundwater seepage line around the peninsula. The contours that have been presented all broadly match this pattern; however, there is still a significant difference between the interpretations which would influence the migration path of contaminants from the site. There is also some uncertainty relating to the rainfall, tidal and seasonal influences on groundwater and how their transient effects interact with timings at which readings were taken.

CH2M HILL's contours are based on readings taken at various times on the 23rd and 24th May 2007 after an earlier rain event on the 23rd May (the original intention of taking all readings within a short period of time on the 22nd May was achieved for on-site wells but not for off-site/residential wells). CH2M HILL acknowledges that as the readings were taken over a prolonged period of time after the rainfall event, some tidal variation may have occurred between readings. It is also possible that recession effects following the rainfall event could have affected the readings. The readings therefore do not necessarily represent a "snapshot" in time and the derived flow directions could be at variance with a true snapshot.[21]

Some indication of the potential effects of tidal variation can be obtained from the figures presented by CH2M HILL, but without knowing the times at which the readings were taken and the corresponding tide levels, the effect cannot be more accurately determined.

The impact of groundwater level recession on groundwater levels can also not be determined from the data available, although CH2M HILL note rainfall responses of 0.1 m

[21] It should be noted that the levels shown for BHG and BH9A on CH2M HILL's figure and in their Table 7.1 do not correspond, although the contouring is consistent with the tabulated values.

in most wells after "a few hours" and 1 m in BH5A after 1.5 hours. The latter figure appears suspicious as this would require approximately 300 mm of rainfall with 100% of this going to recharge in the rainfall event (assuming a porosity of around 30%) to create this rise. Alternative explanations such as the leakage of runoff into the well need to be ruled out. If effects of rainfall are only 0.1 m then this would not significantly alter the groundwater contour pattern, but this cannot be confirmed.

There is also uncertainty regarding groundwater levels to the north of the site. The on-site wells provide a good cross-section through the peninsula and the residential wells provide a good indication of groundwater levels to the south of the site. However, there is an absence of data in the centre and to the north of the site. The potential locations of additional wells are suggested in Section 7.7.2.

PDP (2007) re-contoured the CH2M HILL data with the omission of the off-site wells in order to utilise only those wells for which measurements were taken before the rainfall event. However, whilst levels for these wells were recorded prior to the rainfall event the values presented in the table and those that have been used for the re-contouring were actually recorded at some time after the rainfall event. A second contour plan presented by PDP is based on groundwater levels recorded over two days when no rainfall occurred. The contours also incorporate data from two wells to the north of the site, which help to confirm levels and contour pattern in the northern part of the site. It is not clear from the PDP report if the levels were recorded at the same time during the tidal cycle on each day and therefore what the potential effect of tidal variations may be.

It is worth noting that the groundwater levels recorded by PDP are generally higher than those recorded by CH2M HILL, possibly reflecting seasonal differences, with the higher levels coming out of winter and the lower levels in the lead up to winter. It is also worth noting that in the PDP contour map, the groundwater level in BH9A (on the southern boundary of FCC West) appears to be similar to that recorded previously, whereas most other bores show higher levels than previously recorded. This leads to a slightly unusual contour pattern in this area. It is unclear why this is the case. If this point were ignored then it would be possible to interpret the contours in a way which is a little closer to the CH2M HILL contours but nowhere near as extreme and with a reduced, but still significant, southerly component of groundwater flow.

All of the reviewed interpreted contours are reasonable interpretations of the data and may in fact reflect the natural variation in the shape of the groundwater table under different conditions. This along with uncertainties associated with the data – tidal influence, rainfall influence, reliability of BH9A – means that southerly component of groundwater flow cannot be reasonably ruled out. This could potentially result in contamination reaching groundwater wells to the south of the site.

It should be noted that the remediation does not appear to have had a significant impact on the groundwater flow pattern (although note the lack of data in the centre of the site) and therefore any wells which showed no detection of the contaminants of concern prior to remediation (i.e. were outside the migration pathway) are unlikely to show detections

now. The main issue is therefore restricted to any increases in concentrations of contaminants of concern as a result of the remediation activities rather than original level of groundwater contamination.

Unfortunately, the data reviewed contains pre-remediation results for only four off-site wells (13, 17A, 26, and 36 Tahi Street) three of which (all bar 17A) show detects for dieldrin and/or DDE. This suggests that there is indeed a significant component of southward flow (which may be variable dependant on seasonal and/or tidal influences). Of the off-site wells, only 13 Tahi Street shows any response to the remediation activities, although effects in the other wells may be delayed dependent on travel times.

Off-site wells currently show concentration of contaminants of concern above the PETCs and ammonia and nitrate concentrations above the drinking water guidelines. The risk is therefore that concentrations of these will increase further as a result of remediation, although the risk is academic if these wells are not used for drinking water.

7.10 Discussion

The groundwater under the site has residual contamination which will remain for an extended period unless some form of groundwater remediation is carried out. However, it is by no means clear that the groundwater contamination is creating an unacceptable risk, or risks that cannot be managed. The main potentially significant contaminants are DDX, dieldrin and nutrients. Copper does not seem to be an issue.

The location of monitoring wells relative to backfilled treated material is helpful in interpreting the monitoring results. As discussed above, PDP (2007) assessed where various types of commercial quality backfill were placed relative to the watertable. The assessment is not certain, given the lack of monitoring wells to accurately define where the watertable is. However, treated fines, mixed treated fines or untreated commercial material were placed below the watertable or within the zone intermittently submerged, in the following locations close to monitoring wells:

- in all the landfill excavation subgrades, within which monitoring wells BH3A and BH5A were installed (although the position of these wells relative to the clay bund is not clear); and
- in subgrades SG7 and SG9, upgradient of monitoring well BH1A.

In addition, mixed treated fines were placed above the watertable in subgrades SG14 and SG16. Monitoring well BH2 is installed on the boundary of these two subgrades.

It is perhaps not surprising that the highest concentrations measured in wells tend to be where treated materials have been placed in the ground at or close to the watertable, where they can provide an ongoing source of groundwater contamination. These wells are not necessarily the most representative of the site, given that they will tend to reflect extreme conditions.

The mass of DDX, ammonia and nitrate in the ground will ensure an ongoing source for some years, possibly decades. The uncertainty of mass flux calculations means this is difficult to predict. Refinement of the groundwater flow directions and a better distribution of wells would clarify the flux.

The remediation appears to have mobilised the OCP contaminants to some degree, although this seems to have settled down over the last year or so. This mobilisation may have been a result of simply being disturbed by the excavation and backfilling or it may be a result of replacing the soil in locations below the watertable with consequential enhanced leaching. It is therefore not possible to judge whether the SACs derived to protect the groundwater underestimated the leaching potential, or whether breaching the assumptions behind the derivation has made the difference i.e. placing commercial quality material below the watertable and FCC East not yet being predominantly paved or covered in buildings.

Certainly, reducing the infiltration capacity on FCC East will reduce the amount of leaching and therefore groundwater contamination. However, the contribution from the material permanently or intermittently under the watertable is probably much greater than from infiltration. Therefore, reducing the infiltration will not have the same major effect that it would have had if there no treated material had been placed below the watertable. Reducing the infiltration will be only a partial “fix”.

It might be that, in time, the DDX and ADL concentrations in groundwater will reduce as the backfill “ages”. This will occur through substantially irreversible adsorption processes within the soil tending to reduce the mobility of these contaminants, but that will be a long-term effect.

There is no reason to suspect that the highly soluble ammonia and nitrate will reduce in mobility over time. The large source will continue to contaminate the groundwater for at least the short to medium term. The relative proportion of nitrate may increase as ammonia converts to nitrate.

As noted above, it is by no means clear that the groundwater contamination is creating an unacceptable risk, or risks that cannot be managed. Considering remediation of groundwater is therefore premature. Remediation should only be considered when an unacceptable risk is confirmed and it cannot be managed in some other way. Remediation of groundwater would be expensive, potentially uncertain and have to continue for many years. The cumulative cost would be at least many hundreds of thousands of dollars.

The potential risks from the residual groundwater contamination are to:

- existing and potential groundwater users;
- the local effects to the foreshore ecosystem; and
- the wider effects on the aquatic ecosystem.

These are discussed separately below.

7.10.1 Groundwater Users

Abstraction of water in small quantities is currently a permitted use under TDC's Tasman Resource Management Plan. Potential risks arise for two groups of people; current bore owners south of the site and potential future bore owners within FCC West or south of the site. It is assumed that industrial use of groundwater on FCC East will be prohibited through the use of a management plan or within lease agreements executed by TDC as owner and future tenants.

Management plans are less affective for private residential properties. Unless tied in some way to the property title, management plans may not survive transfer of a property to a new owner. The requesting of Land Information Memorandums (LIM) cannot be relied on (although TDC should ensure that appropriate information is on LIMS that are requested). Education of residents may be effective initially, but with time (and ownership changes) may be less effective. A plan change is an alternative, putting restrictions on constructing bores and abstracting water, but is relatively expensive, not completely certain to get through the public process and slow.

However, it is by no means certain that specific controls are required. To a large degree the presence of a reticulated supply means that the incentive to construct a bore does not exist. Existing bores are used for irrigation, for which the water is of an adequate quality. While drinking bore water from an irrigation supply cannot be absolutely excluded, a child drinking from a hose, for example, occasional exposure carries much less risk.

The drinking water MAVs are derived assuming a 15 kg child (generally the critical receptor) drinks 1 L of water every day for an extended period of time, i.e. chronic exposure. Occasionally drinking bore water, even if contaminated, carries a much lower risk in direct proportion to the smaller average daily consumption. The MAV would increase by the same proportion, perhaps 100-fold, if it is assumed occasional consumption averages no more than 10 ml per day i.e. a small glass per fortnight).

At no point within FCC West or off-site is the groundwater contamination measured to date excessive with respect to MAVs. In fact, at worst, the contamination near the southern boundary and off-site to the south is only marginally over MAVs. Further monitoring is required to confirm this, ideally backed up with the installation of more on-site monitoring wells to obtain a better sense of any southerly groundwater flow component. However, off-site wells to the south generally appear to have an adequately low risk, with 13 Tahi Street (and 18 Tahi Street, if it had a bore) having the greatest risk.

The lack of information on most of FCC West means that the risk cannot be assessed. It must be assumed that the water is unsuitable for human consumption until such time as it is demonstrated otherwise. However, the removal of the most contaminated soil should have resulted, or will result in time, in improved the water quality. This assumes there is a groundwater divide prevent movement of contaminated groundwater from east to west.

The groundwater is probably suitable for irrigation use and, given the reduction in soil contamination, may be suitable for potable use.

7.10.2 Local Foreshore Effects

Local foreshore effects are occurring with respect to algal growth. In addition, measured concentrations of DDX and ADL, in wells closest to the foreshore and in foreshore seeps, suggest that there will be local toxic effects at seep discharge points and where seepage discharge runs over the foreshore surface at low tide.

With respect to nutrients the effects are worse than the pre-remediation situation, as nutrient enrichment was a direct result of the additives used in the MCD process, made worse by placing the treated soil in less than ideal places. For DDX and ADL compounds the situation is less clear, with some wells showing small increases and other wells showing small decreases compared with the pre-remediation situation. Comparing recent results with monitoring carried out in 1996 by Woodward-Clyde (1996) there appears to be an improvement in a number of wells, but the 1996 samples may have suspect quality through containing sediment. The more recent baseline survey by T&T (2004) suggest there has been a general deterioration of groundwater quality with respect to OCPs in the wells close to the foreshores, suggesting mass flux of these contaminants is larger now than before the remediation. However, given the concentration fluctuations that have occurred in the current wells and the uncertainty of snapshots several years ago, this conclusion is tentative. A longer period of monitoring would make this more certain.

The question is now whether local effects are acceptable. To meet water guideline values at the points of discharge would require many orders of magnitude improvement for the DDX and ADL compounds. However, given the sediment on both foreshores is still contaminated, and is likely to remain so for an extended period of time then attempting to improve the groundwater further is not warranted.

7.10.3 Wider Effects

Groundwater is discharging to both the Mapua Channel and Waimea Inlet where it will receive large dilution. At low tide the discharge will receive less and delayed dilution while a high tide the dilution will be large and near immediate.

The consent PETCs assumed 100-fold dilution (except for DDX which was 1000-fold dilution). A dilution of 100-fold dilution seems unreasonably small, given the large tidal flushing that occurs. Factors of one to several thousand seem more reasonable. At these factors, dilution should be sufficient to ensure marine water guidelines are met.

Close to the two beaches, however, the CH2M HILL (2007) sampling appears to show that insufficient dilution is occurring. However, the sampling is very limited and has some uncertainties as to whether the samples were representative. The worst results were at low tide. This could be a result of sediment being entrained into the water by seepage flows or wave action, as the samples were noted as turbid. A potential confounding

effect is that the sampling was carried out during a rainfall event, which may have caused more runoff across the beach and therefore more entraining of sediment.

It is likely that significant dilution will be occurring within a short distance from the shore. However, consideration could be given to more marine sampling both close to the site and further afield to assess the actual concentrations in the water. This sampling would need to be carefully designed to ensure that the objectives were met. If it is found that insufficient dilution is occurring to meet marine water quality guidelines, a decision then has to be made whether remediation is required, or whether to simply monitor the situation. Given the potential cost of remediation, a proper investigation of alternatives would then be required, including, if necessary, bench trials. International literature abounds with descriptions of groundwater remediation projects that failed to meet the objectives while consuming large amounts of money over many years.

8.0 Audit Summary and Conclusions

8.1 Introduction

This audit has examined a large number of documents and consulted individuals to gain a good understanding of the remediation process. It was often not clear from the validation documents as to what methods were actually applied during the various facets of the remediation, but additional information obtained during the course of the audit has clarified these aspects. Close to 6,000 pages of documents have been examined. The validation sampling results have been examined in detail and check calculations carried out on results presented in the Validation Report and elsewhere. By these means sufficient confidence has been obtained to arrive at the conclusions set out below

8.2 Soil Remediation

8.2.1 General

The basic conceptual model used in the derivation of the soil acceptance criteria (SAC) and the approach to the derivation is generally appropriate. Consequently, if the relevant SACs are complied with for a particular part of the site, then that part of the site is typically fit for its intended purpose. However, compliance with the SACs will not always necessarily be protective of site receptors. Potential exceptions are:

- direct ingestion of groundwater, as the derivation of the SACs for DDX and ADL do not appear to have taken this pathway into account (and effects on groundwater are greater than expected);
- effects of groundwater discharge on the marine ecosystem, again because of greater than expected effects on groundwater, and uncertainties with respect to the hydrogeology; and
- no criteria were derived for nitrogenous compounds or phosphorus, which were used in significant quantities as additives in the soil treatment process.

Based on the history of chemical usage on the site and the results of the various investigations undertaken to characterise the site, we consider that the analytical suites implemented were generally suitable for the purpose of validating the soil and sediment remediation. A lower frequency of testing for metals in residential backfill during the remediation resulted in some uncertainty in the compliance of this material. However, subsequent in-situ sampling of residential backfill for key metals has provided a reasonable confidence that heavy metals are not likely to be of concern.

The reporting on data quality in the Validation Report is limited. In addition, some of the procedures implemented during the project have not always been ideal. The aspect of the remediation that is most sensitive to this is the compliance of residential soil with the DDX and ADL criteria. While there is sufficient confidence in the data quality to confirm that the conclusions arrived at in the Validation Report are likely to be valid, there are

specific instances where confidence in the data quality is reduced. Where this is the case, other information has been relied on to provide additional confidence. Specific comments are:

- Overall, confidence was gained that the soil and marine sediment sampling was undertaken in a professional manner, using methods consistent with accepted industry practice. A review of site documents gives confidence that the intended procedures were generally implemented in a detailed and methodical manner. A factor providing additional confidence were the people involved. The two principals of the company that supervised the remediation and carried out the sampling (EMS) were very experienced environmental professionals.
- In general, the analytical methods used during the remediation are suitable for characterising the site. The key exception to this relates to the detection limits for DDX and ADL analyses, which are relatively close to the residential SACs in some cases. While the use of detection limits close to the target criteria is not good practice, in this case other factors provided reasonable confidence that the analytical precision was, on the whole, adequate.
- The analytical QA/QC is not well documented. A retrospective sampling exercise on FCC East provided some additional QA/QC data for the materials on that part of the site. Split duplicate samples were analysed at separate laboratories to check on the consistency of the primary laboratory used during the remediation works. Greater confidence would be gained by repeating the QA/QC sampling on residential soil in FCC West, with the primary laboratory using the same method (and detection limits) used for the routine testing during the remediation.

8.2.2 FCC West Remediation

The validation sampling results show that FCC West is fit for its intended purpose with respect to soil quality, subject to the minor uncertainties outlined below. On average the soil quality complies with the SACs and in particular meets the ADL and DDX SACs. Probable isolated local exceedances are not so great as to be unacceptable..

The issue resulting in some uncertainty relates to detection limits for DDX and inter-laboratory comparisons at concentrations close to the DDX residential SAC. A programme of sampling (or reanalysis of archived samples) to evaluate this is recommended.

8.2.3 FCC East Remediation

With the exception the two uncertainties outlined below, the FCC East site is also fit for its intended purpose with respect to soil quality. This is in the context of a Site Management Plan being implemented to control excavation into commercial quality material, so that this material is not brought to the surface where it may migrate to the marine environment, or disposed of inappropriately off site (e.g. to a site with a more sensitive site use such as residential). The Validation Report concludes that FCC East

meets the SAC for an open space and commercial use. Overall, we concur with this conclusion.

Issues that result in some uncertainty are:

- The potential for ammonia gas to be generated from treated fines material and possible effects on human health. A programme of soil gas testing is recommended, whether in the near future or at the time of building design and construction. Even if ammonia exists in the soil, the issue can be managed. The site management plan should be amended to manage the risk.
- The possibility of phytotoxic effects on deep-rooted plant species used in amenity planting. This is readily managed by soil replacement. The Site Management Plan should address this risk.

8.2.4 FCC Landfill Remediation

With the exception of the minor uncertainties discussed below, the FCC Landfill site is fit for its intended purpose with respect to the soil remediation. This is also in the context of a Site Management Plan being implemented to control excavation into commercial quality material, so that this material is not brought to the surface where it may migrate to the marine environment, or disposed of inappropriately off site. The Validation Report concludes that FCC Landfill meets the SAC for an open space use. Overall, we concur with this conclusion.

The uncertainties with respect to fitness for purpose relate to the possibility of ammonia generation and phytotoxicity of copper in treated fines. However, these are not significant human health issues for day to day use as open space. Carrying out further investigation to assess the risk from ammonia is not required on FCC Landfill. The potential risks from ammonia and copper during excavation or to plant health are readily managed by way of the Site Management Plan.

8.2.5 Residential Property Remediation

Based on the results of the soil remediation, the four residential properties are suitable for their intended purpose. The Validation Report concludes that the soil quality in the four sites meets the SACs. We concur with this conclusion.

8.3 Marine Sediment Remediation

8.3.1 Eastern Foreshore

The remediation of the eastern foreshore was not successful in achieving the target SAC of 0.01 mg/kg for DDX and ADL. Post-remediation sampling has confirmed concentrations of DDX 100 times above the SAC remain at some locations in the vicinity of the remedial excavation. Elevated DDX concentrations are also present in adjacent un-

remediated areas, including shallow sediment up to 100 m to the north of the site (including beneath the adjacent wharf), with concentrations of between 1 and 60 mg/kg detected.

The ADL concentrations on the eastern foreshore are much lower than the DDX concentrations, but still elevated. The post remediation sampling showed that most ADL concentrations were less than 100 times the SAC but concentrations 10 times the SAC were common.

Re-contamination of the remedial excavation occurred during the remediation works. The mechanism of this is unclear, but a significant proportion may have been due to site runoff. Reworking of the foreshore backfill by an excavator may also have brought underlying contaminated material to the surface. Recontamination by contaminated groundwater is not a credible mechanism. Since the remediation was completed, surface sediment quality appears to be improving, probably through deposition of cleaner sediment. This improvement will be limited by the quality of the surrounding sediment in the short to medium term, but will slowly improve by natural attenuation over the long term. The greatest benefit to the eastern foreshore is the removal of the land-based contaminant source. The removal of this source will now allow natural attenuation to play its part.

In a broad context, remediation to the extent practicable has been achieved for the marine sediments in the east. The additional benefits of further remediation are likely to be outweighed by the "costs" such as additional disruption to the current habitat, potential impacts on the wider environment and expense, for an outcome at the surface that will not be very different from the current outcome. Re-deposition of sediment with elevated contaminant concentrations from surrounding areas will reoccur until slower natural attenuation processes take over.

Apart from localised effects on the marine ecosystem, the effects of the residual sediment contamination on other potential receptors are not likely to be significant. This includes risks to human health via consumption of seafood, as indicated by monitoring of OCP concentrations in sea snails, although further monitoring is required to confirm this. Recreational users of the foreshore are not at risk from direct contact with soil or water.

8.3.2 Western Foreshore and Creek

The remediation of the western foreshore and creek was also not successful in achieving the target SAC of 0.01 mg/kg for DDX and ADL. Initial post-remediation sampling found DDX concentrations more than 100 times the SAC were present in the base of the remedial excavation. However, the majority of these were located in the creek discharging to the foreshore. On the foreshore itself, the initial post-remediation samples were typically well below 1 mg/kg and often below 0.1 mg/kg. Subsequent sampling in 2007 found higher DDX concentrations, almost certainly a result of site runoff during the remediation works. DDX concentrations measured in 2007 in the wider bay are typically well below 1 mg/kg, with an average in the order of 0.15 mg/kg. The residual ADL

concentrations on the western foreshore are much lower than the DDX concentrations, but still elevated. As with the east, the most recent sediment monitoring on the western foreshore indicates the top 1-2 cm of sediment is improving in quality.

Remediation to the extent practicable of the marine sediments has broadly been achieved in the west, for the same basic reasons outlined for the east above; specifically that it is not possible to remediate the surface sediments to a higher standard than the surrounding surface sediments (assuming the wider bay is still as measured in 2007 and was not just reflecting temporary effects of runoff from the remediation site). It is not practical to remediate this entire area due to the cost, difficulties in handling and disposing of the large quantities of sediment, and the likely detrimental effects on the estuary ecosystem.

Some moderately elevated concentrations of DDX remaining in sediment adjacent to the creek could be remediated relatively easily. However, removal of these hotspots is not warranted as they present no particular risk as creek-bed gravel and vegetative cover prevents sediment mobilisation and hence a pathway to potential receptors. The Site Management Plan should ensure that measures are in place to control excavation in the area and to prevent the creek from being eroded.

As with the east, the removal of the site as a source of sediment contamination is a key aspect of the remediation. It is expected that the contaminant concentrations in the shallow sediment will reach approximate equilibrium with the concentrations in the wider bay and the elimination of the land-based source will allow natural attenuation processes to slowly reduce concentrations further.

In the case of risks to human health via seafood consumption, additional data is required to confirm the apparent low risk as the dataset is limited. Recreational users of the foreshore are not at risk from direct contact with soil or water.

8.4 Groundwater

Prior to the remediation, site investigations identified the primary contaminants of concern to be organochlorine pesticides associated with the site's original use i.e. DDX and ADL. These remain as contaminants of concern for groundwater. During the remediation several other contaminants became of concern as a result of the remediation, specifically:

- the nutrients ammonium, nitrate and phosphorus associated with the use of diammonium phosphate (DAP) and urea as reagents in the MCD soil remediation process; and
- copper associated with copper sulphate, and iron in an unknown form, also used as reagents in the MCD soil remediation process.

The groundwater under the site has residual contamination which will remain for an extended period unless some form of groundwater remediation is carried out. However, it is by no means clear that the groundwater contamination is creating an unacceptable

risk, or risks that cannot be managed. The main potentially significant contaminants are DDX, dieldrin and nutrients. Copper does not appear to be presenting unacceptable risks.

It is not possible to fully quantify the risks presented by DDX, dieldrin and nutrients as the hydrogeological model for the site has significant uncertainties relating to:

- the detail of groundwater flow directions, particularly in relation to whether off-site flows occur to the south towards private irrigation bores in Tahi Street;
- the detail of groundwater quality over much of the site, with routine sampling currently being carried out in a relatively few perimeter monitoring wells; and
- a consequent uncertainty in the volume flux of water discharging to the Mapua Chanel and Waimea Inlet and the mass flux of contaminants discharging to these water bodies.

Additional data is required to address these uncertainties.

There is apparently discharge of DDX and dieldrin to the marine environment in excess of the PETCs and discharge of nutrients causing algal growth on the foreshores. However, given the uncertainties, contemplating groundwater remediation is premature. Remediation should only be considered when unacceptable effects are confirmed and cannot be managed in some other way. Remediation of groundwater would be expensive, potentially uncertain and have to continue for many years.

The potential risks from the residual groundwater contamination are to:

- existing and potential groundwater users;
- the local effects to the foreshore ecosystem; and
- the wider effects on the aquatic ecosystem.

8.4.1 Groundwater use

Abstraction of water in small quantities is currently a permitted use. Potential risks arise for two groups of people: current bore owners south of the site; and potential future bore owners within FCC West or south of the site. It is assumed that industrial use of groundwater on FCC East will be prohibited through the use of a management plan.

The lack of groundwater quality information on most of FCC West means that the risk cannot be properly assessed. While the presence of a reticulated water supply means that there is little incentive to construct a bore for a private supply, this will not guarantee that a private bore will not be constructed. Given this, and in the absence of good information, it must be assumed that the water is unsuitable for human consumption until such time as it is demonstrated otherwise. Some form of management of groundwater use on FCC West is recommended until that time.

In reality, the groundwater is probably suitable for irrigation use and, given the reduction in soil contamination, may be suitable for potable use. The quality is expected to improve with time as effects from past soil contamination reduce.

Management plans are not an effective tool in a residential setting. Greater certainty would require either a plan change or TDC placing restrictions on property titles before it sells the properties. However, it is recommended that the actual groundwater quality be determined and the risks assessed, before stronger controls are contemplated. Informal controls such as resident education and the disincentive provided by the reticulated supply are sufficient until the water quality is better known.

If the water quality proves to be adequate then no further controls are required. Otherwise, TDC must determine the best statutory instrument to exercise stronger control.

Existing bores to the south of the site are used for irrigation, for which the water is of an adequate quality. Apart from monitoring, no further action is required.

8.4.2 Foreshore effects

Discharge of nutrients is causing some local foreshore effects in the form of algal growth. Concentrations of DDX and ADL in wells closest to the foreshore and in seeps suggest that there will be local toxic effects at seep discharge points and where seepage discharge runs on the surface at low tide.

With respect to nutrients, the effects are greater than the pre-remediation situation, as nutrient enrichment was a direct result of the additives used in the MCD process. For DDX and ADL compounds the situation is less clear, with some wells showing small increases and other wells showing small decreases compared with the pre-remediation situation.

The question is now whether local effects are acceptable. To meet water guideline values at the points of discharge would require orders of magnitude improvement for the DDX and ADL compounds. This will not be achieved in the short to medium term without groundwater treatment. Such treatment would be relatively expensive, of uncertain effectiveness and required for an extended period of time, potentially decades.

It is not clear that the effects are unacceptable. Anecdotal reports are that similar algae effects are present elsewhere in the estuary. In addition, residual OCP contamination of the foreshore sediments is possibly outweighing any local effects of contaminated groundwater discharges. It has been recommended elsewhere that the health of the local ecosystem be better assessed. If this assessment shows that effects on the ecosystem are acceptable, then it can be reasonably concluded that the groundwater discharges are acceptable in this regard.

8.4.3 Effects after dilution

Groundwater discharging to both the Mapua Channel and Waimea Inlet is subject to large dilution. Effects to the wider estuary are therefore unlikely to be significant at the concentrations currently being measured in the groundwater. Further groundwater monitoring and better definition of the mass flux discharging to estuary should be undertaken to confirm this. Consideration could also be given to more seawater sampling, both close to the site and further afield, to directly measure actual concentrations.

9.0 Recommendations

A variety of uncertainties or gaps in information have been described in this audit. In general, these uncertainties are not sufficient to greatly reduce confidence in the results of the remediation. However, carrying out the recommendations below will provide an additional measure of confidence or reduce the need to manage residual risks. Other recommendations are to provide a benchmark to assess future natural improvements in the site's condition.

1. Undertake a similar programme of QA/QC soil sampling in FCC West to that completed on FCC East. The sampling should target the residential backfill material and the primary laboratory should use the same analytical techniques (and detection limits) used for routine testing during the remediation. The sampling is to address a QA/QC information gap with respect to detection limits for DDX and inter-laboratory comparisons at concentrations close to the DDX residential SAC.

2. A programme of soil gas sampling and analysis should be carried out for ammonia gas in locations where buried fines or mixed material exists. This should include subgrades SG3, SG7 and SG14 where cement-stabilised material and treated fines co-exist. If ammonia is found, interpretation should include consideration of migration to confined spaces and whether further testing at specific building locations may be required at the time of development. If a potential risk is found, the Site Management Plan should be updated to ensure adequate procedures are in place for excavation workers, including procedures for evaluating the atmosphere in confined spaces. If a significant risk is found by the sampling programme, the risk of gas penetration into future buildings will also need to be addressed in the Site Management Plan.

   The soil gas sampling could be carried out in the near future to eliminate the current uncertainty or, alternatively, the Site Management Plan could be updated on the assumption a risk exists and soil gas sampling carried out on a case-by-case basis prior to the design and construction of future building developments.

3. Additional groundwater monitoring wells should be installed as follows:

   - at least one upgradient well in the vicinity of the northwest corner of the site to obtain background;
   - a well midway along the western boundary of FCC West;
   - a well in the south-east corner of FCC West;
   - a well in the former vicinity of the MCD plant;
   - a well roughly at the midpoint of the south-western quadrant of FCC West;

- two wells spaced out along the western boundary of FCC East;
- two wells spaced out along a line running north-south midway across FCC-East;
- a well in the vicinity of the former surge chamber location where there is a gap in the clay bund; and
- ideally, wells either side of the clay bund installed on the eastern boundary of the FCC Landfill site.

4. The additional wells and the following current wells should be included in a groundwater monitoring programme: BH1A, BH2A, BH5A, BH9A, Old BH1, BHH, BHG, BHD and 13 Tahi Street. The wells should be monitored for the same set of parameters measured in the current TDC monitoring (including groundwater elevation). The wells should be monitored on a quarterly basis for one year, with the monitoring frequency and number of wells monitored reviewed after that time. It is expected that a subset of wells would continue to be monitored for water quality but that all wells should continue to be monitored for water level. The monitoring should include appropriate QA/QC procedures. A selection of wells should be tested for hydraulic conductivity, to represent a range of backfill materials across the site.

5. The groundwater monitoring data should be used to update the hydrogeological model for the site, with a particular focus on groundwater flow direction and estimates of mass flux of contaminants discharging to the marine environment. As part of the assessment, a water balance should be developed for the site under existing and potential future conditions. A review of the Site Management Plan may be required following update of the hydrogeological model.

6. Prior to undertaking the next sediment and snail monitoring round, an appropriately qualified person should review the monitoring programme to confirm that the current programme is sufficient and appropriate given the altered habitat and different species that have re-colonised FCC East. The review should assess the previous reports on the subject, including that by Landcare Research (2002) and take into account recent monitoring data and the likely site use. Consideration should be given to the need for confirmatory sampling of other biota and extending the programme to improve its statistical robustness. The review should also consider whether the sampling is properly representing the quality of the surface sediments.

7. Sediment monitoring should be undertaken as follows (taking into account any recommendations from the review in Item 6):

   - the annual monitoring frequency should be continued, with the monitoring scope reviewed after two additional monitoring rounds;

- in addition to the current monitoring locations the following sediment sampling locations should be considered:
  - three additional locations parallel to the western foreshore, approximately 20 m from the foreshore edge. The locations should be evenly spaced along the foreshore;
  - two additional locations parallel to the eastern foreshore, approximately 5 m from the base of the sea wall. The locations should be evenly spaced between the current sampling transect and either end of the foreshore; and
  - three surface samples of the creek-bed sediment, evenly spaced along the portion of the creek adjacent to the site boundary.
- at each sediment sampling location, samples from 0 – 0.02 m and from 0.02 – 0.10 m should be collected. A sediment corer with a core extruder should be used to ensure accurate sample depths. Each sample should be analysed for DDX and ADL;
- the snail sampling should continue as previously, unless otherwise indicated by the review on biota sampling outlined above;
- total organic carbon (TOC) should be measured in each sediment sample in the first monitoring round;
- a particle size distribution should be undertaken on 50% of the sediment samples in the first monitoring round;
- detailed field and photographic records should be kept of all observations, e.g. sediment colour, number/size of snails; and
- a written and photographic record should be maintained of areas of algal growth. The photos should be taken from the same perspective to enable comparison between monitoring events.

8. A check should be made that flood flows in the creek are not likely to be so high as to cause significant erosion.

9. Benchmarking of the health and diversity of the marine ecosystem on the foreshores should be carried out, comparing the foreshore against suitable control sites. There are a number of survey techniques which can be used to assess ecosystem health and bio-diversity.

Carrying out the above recommendations will enable decisions on whether the local foreshore effects are acceptable relative to the likely large cost and environmental disruption of attempting further remediation.

Consideration could also be given to the additional recommendations set out below to further benchmark conditions and provide a means of comparison with future monitoring:

10. Sampling the groundwater seeps on both the western and eastern foreshores and testing for a similar set of parameters to the groundwater samples. Care

would be required to ensure that the samples are representative of groundwater and not contaminated with beach sediment. An alternative to sampling the seeps directly could be installing standpipes on the foreshore to target shallow groundwater immediately before it discharges. Quarterly sampling for one year (at the same time as the groundwater sampling is completed) would be appropriate.

11. Additional sampling of marine water, both close to the site and further afield, to assess the actual concentrations within the Mapua Channel and Waimea Inlet.

References

ANZECC/ARMCANZ, 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), October 2000.

CH2M HILL, 2007. *Groundwater and Sediment Investigation Report - Former Fruitgrowers Chemical Company Site, Mapua*, CH2M HILL Australia Pty Ltd, New Zealand, August 2007.

EDL, 2007. *Affidavit of Mr Brent Pascoe in Support of the Adjudication Claim between Environmental Decontamination Limited and The Attorney General on behalf of the Chief Executive of the Ministry for the Environment*, Brent Pascoe, Environmental Decontamination Ltd, 13 December 2007.

Egis, 2001. *Derivation of Risk-based Acceptance Criteria for Human Health and the Environment - Revised Report - Former Pesticide Plant, Mapua, New Zealand*, Egis Consulting, Australia, 7 February 2001.

EMS, 2006. *FCC West Foreshore Remediation*, Effective Management Systems Limited, 13 July 2006.

EMS, 2007. *EMS Quality Assurance / Quality Control Procedures - Developed for the FCC Fruitgrowers Remediation*, Effective Management Systems Limited, 30 September 2007.

GES, 2002. *Characterisation Investigation Fruitgrowers Chemical Company Site, Mapua - Final Report*, Groundwater and Environmental Services, February 2002 (Date of February 2001 on front of report is incorrect).

GHD, 2005a. *Mapua Validation Plan,* memorandum to MfE, Peter Nadebaum, GHD (Pty Ltd), 21 January 2005.

GHD, 2005b. *Notes from the various meetings,* memorandum to MfE, Peter Nadebaum, GHD (Pty Ltd), 8 April 2005.

GHD, 2005c. *Mapua Validation Protocol,* memorandum to MfE, Peter Nadebaum, GHD (Pty Ltd), 1 July 2005.

GHD, 2005d. *Final Validation Protocol,* attachment in email to MfE, Susan Walsh, GHD (Pty Ltd), 25 July 2005.

GHD, 2005e. *FCC Mapua – Remedial Action Plan, July 2005,*letter to MfE, Peter Nadebaum, GHD (Pty Ltd), 31 August 2005.

GHD, 2006. *Mapua Coastal Excavation - Western Estuary*, memorandum to MfE, Peter Nadebaum, GHD (Pty Ltd), 24 February 2006.

GHD, 2006b. *Mapua – Site Visit,* memorandum to MfE, Peter Nadebaum, GHD (Pty Ltd), 1 December 2006.

Landcare Research, 2002. *Investigation of Organochlorine Contamination in Biota and Sediment Collected from Mudflats Adjacent to the Fruit Chemical Company (FCC) Site at Mapua,* K O'Halloran and JE Cavanagh, Centre for Environmental Toxicology, Landcare Research, Lincoln, March 2002.

MfE/MoH, 1997. *Health and Environmental Guidelines for Selected Timber Treatment Chemicals*, Ministry for the Environment/Ministry of Health, Wellington, June 1997.

MfE, 1999. *Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Ze*aland. Ministry for the Environment, Wellington, New Zealand, August 1999.

MfE, 2004a. *Contaminated Land Management Guidelines 5 – Site Investigation and Analysis of Soils,* the Ministry for the Environment, Wellington, February 2004.

MfE, 2004b. *Fruitgrowers Chemical Company (FCC) Contaminated Site - Remediation Project Mapua - Monthly Report - December 2004*, Ministry for the Environment, December 2004.

MfE, 2005. *Remedial Action Plan & Management Plan - Fruitgrowers Chemical Company - Mapua Site*, Ministry for the Environment, July 2005.

MfE, 2006. *Identifying, Investigating and Managing Risks Associated with Former Sheep-dip Sites*, Ministry for the Environment (MfE) of New Zealand, November 2006.

MfE, 2007. *Amendments to Remedial Action Plan & Site Work Plans, Fruitgrowers Chemical Company Mapua Site*, Ministry for the Environment, August 2007.

MoH, 2005. *Drinking-water Standards for New Zealand 2005,* Ministry of Health, Wellington, August 2005.

MWH, 2008. *Mapua FCC Remediation Project - Volume Balance Diagram*, MWH New Zealand Limited, Richmond, 31 August 2008.

MWH, 2008b. *Remediation of the FCC Site at Mapua – As Built Drawings,* MWH New Zealand Limited, Richmond, 12 September 2008.

MWH, 2009a. *Imported Soil*, Juliet Westbury, MWH New Zealand Limited, Richmond, 14 April 2009.

MWH, 2009b. *Foreshore and Creek Validation*, Juliet Westbury, MWH New Zealand Limited, Richmond, 14 April 2009.

MWH, 2009c. *Buffer Zone*, Juliet Westbury, MWH New Zealand Limited, Richmond, 15 April 2009.

MWH, 2009d. *Tahi St*, Juliet Westbury, MWH New Zealand Limited, Richmond, 16 April 2009.

MWH, 2009e. *Mapua FCC: Outstanding Questions*, Paul Russell, MWH New Zealand Limited, Richmond, 21 April 2009.

MWH, 2009f. *Earthworks Monitoring Report and Fill Certification - Mapua Fruitgrowers Chemical Company Plant Site Remediation*, MWH New Zealand Limited, Richmond, April 2009.

MWH, 2009g. *Mapua FCC Audit*, Paul Russell, MWH New Zealand Limited, Richmond, 12 May 2009.

NEPC, 1999a. *Schedule B(1) Guideline on the Investigation Levels for Soil and Groundwater*, National Environment Protection (Assessment of Site Contamination) Measure (NEPM), National Environment Protection Council of Australia, 1999.

NEPC, 1999b. *Schedule B(7a) Guideline on Health-Based Investigation Levels*, National Environment Protection (Assessment of Site Contamination) Measure (NEPM), National Environment Protection Council of Australia, 1999.

NSWEPA, 1998. *Contaminated Sites: Guidelines for the New South Wales Site Auditor Scheme,* New South Wales Environmental Protection Agency, 1998.

PDP, 2007. *Report on Groundwater Issues Arising from the Mapua FCC Site, at Completion of the MCD Soil Remediation Process*, Pattle Delamore Partners Ltd, Christchurch, December 2007.

PDP, 2008. *Groundwater Monitoring at Former FCC Site - August Sampling Update*, Mapua, Peter Callander, Pattle Delamore Partners Ltd, August 2008.

PDP, 2008b. *Groundwater Monitoring At Former FCC Site, Mapua - November Sampling Update, Mapua*, Peter Callander, Pattle Delamore Partners Ltd, 16 December 2008.

PDP, 2009. *Groundwater Monitoring At Former FCC Site, Mapua - February Sampling Update, Mapua*, Peter Callander, Pattle Delamore Partners Ltd, 13 March 2009.

RIVM, 2001. *Technical Evaluation of the Intervention Values for Soil/Sediment and Groundwater*, National Institute of Public Health and the Environment, Bilthoven, The Netherlands

Standards Australia, 1997. *AS 4482.1-1997 Guide to the sampling and investigation of potentially contaminated soil - Non-volatile and semi-volatile compounds,* Standards Australia.

Guide to the sampling and investigation of potentially contaminated soil - Non-volatile and semi-volatile compounds

SKM, 2008. *Site Validation Report for the Former Fruitgrowers Chemical Company Site, Mapua*, Sinclair Knight Merz, Auckland, New Zealand, 11 December 2008.

T&T, 2003a. *FCC Mapua Site Remediation - Assessment of Environmental Effects*, Tonkin & Taylor Ltd, May 2003.

T&T, 2003b. *Groundwater Assessment Report - FCC Site Remediation, Mapua*, Tonkin & Taylor Ltd, May 2003.

T&T, 2004. *Report on Baseline Soil and Groundwater Sampling, Mapua, Nelson*, Tonkin & Taylor Ltd, December 2004.

TDC, 2002. *Report on Removal of Contaminated Soil from 20 Tahi Street - August 2002*, Tasman District Council, August 2002.

TDC, 2007a. *Report on Sediment Contamination under the Mapua Wharf*, Jenny Easton, Tasman District Council, 3 August 2007.

TDC, 2007b. *Commercial Quality Soil in the Road Reserve Beside FCC West*, Dennis Bush-King, Tasman District Council, 10 September 2007.

TDC, 2007c. *Report on Assessment of Mud Snail and Estuarine Sediments West Side of Grossi Point Peninsular. 24 October 2007* , Jenny Easton, Tasman District Council, 7 January 2008.

TDC, 2008a. *History of West FCC Beach Remediation*, Jenny Easton, Tasman District Council, 14 January 2008.

TDC, 2008b. *Soil Tests for Mercury in Residential Soil on the West FCC*, Internal Report, Tasman District Council, 22 August 2008

TDC, 2009a. *Mapua Validation Report,* letter to MfE, Tasman District Council, 7 January 2009.

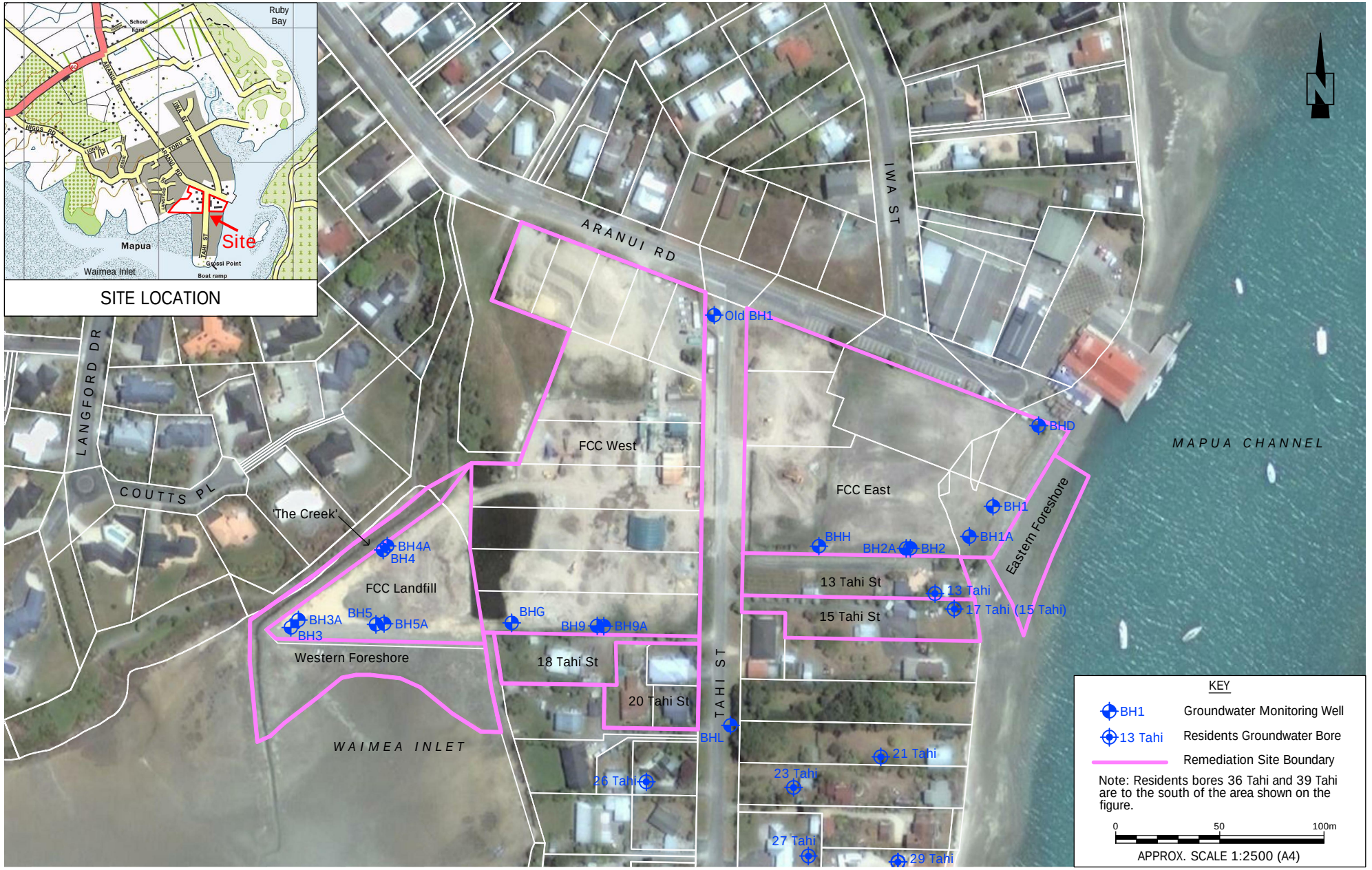
TDC, 2009b. *Report on snails and Sediment Quality, Third Annual Round after FCC West and East Beach Remediation*, Jenny Easton, Tasman District Council, 3 March 2009.

Thiess, 2004. *Remedial Action Plan - Fruitgrowers Chemical Company Site, Mapua*, Thiess Services Pty Limited, July 2004.

US EPA, 2009. *ProUCL Version 4.00.04 Technical Guide*, EPA/600/R-07/041, United States Environmental Protection Agency, Office of Research and Development, Washington, DC

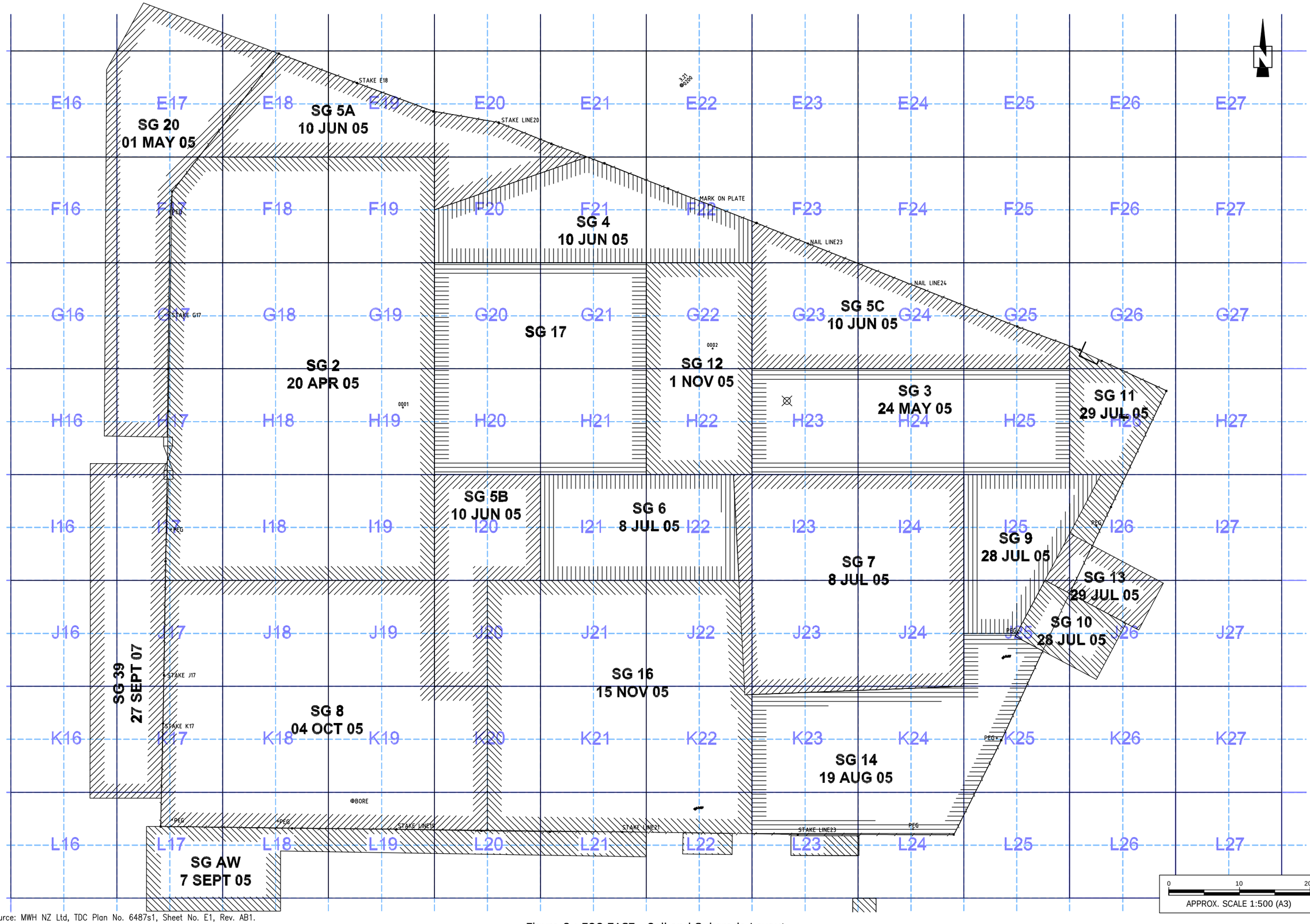
Woodward Clyde, 1996, *Mapua Site Remediation - Assessment of Environmental Effects*, Woodward-Clyde (NZ) Ltd, October 1996.

Appendix A – Figures



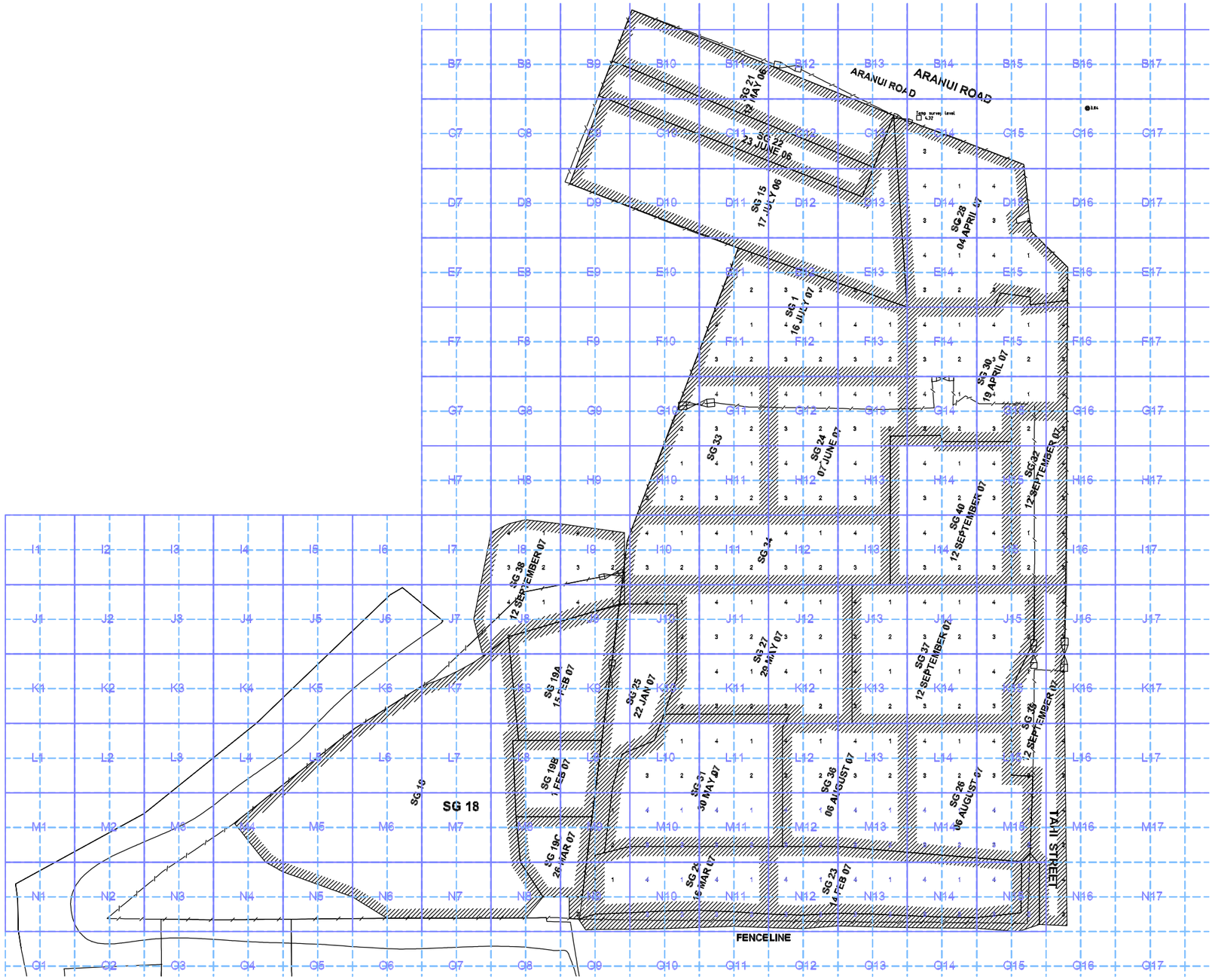
Source: Aerial imagery derived from Google Earth Pro (may not be spatially accurate).
Cadastral information derived from LINZ data.

Figure 1 : SITE LOCATION



Source: MWH NZ Ltd, TDC Plan No. 6487s1, Sheet No. E1, Rev. AB1.

Figure 2 : FCC EAST - Cell and Subgrade Layout

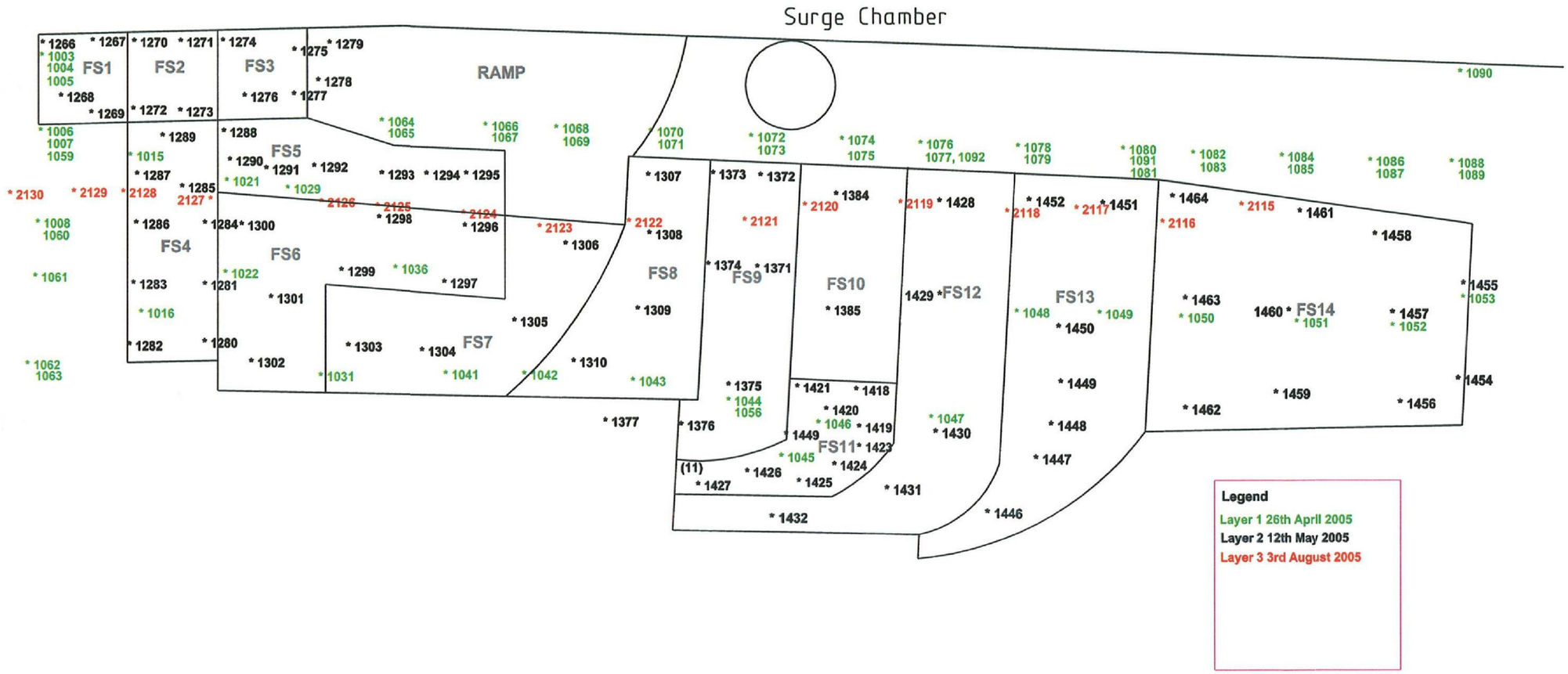


0 10 20 30 40 50m

APPROX. SCALE 1:1000 (A3)

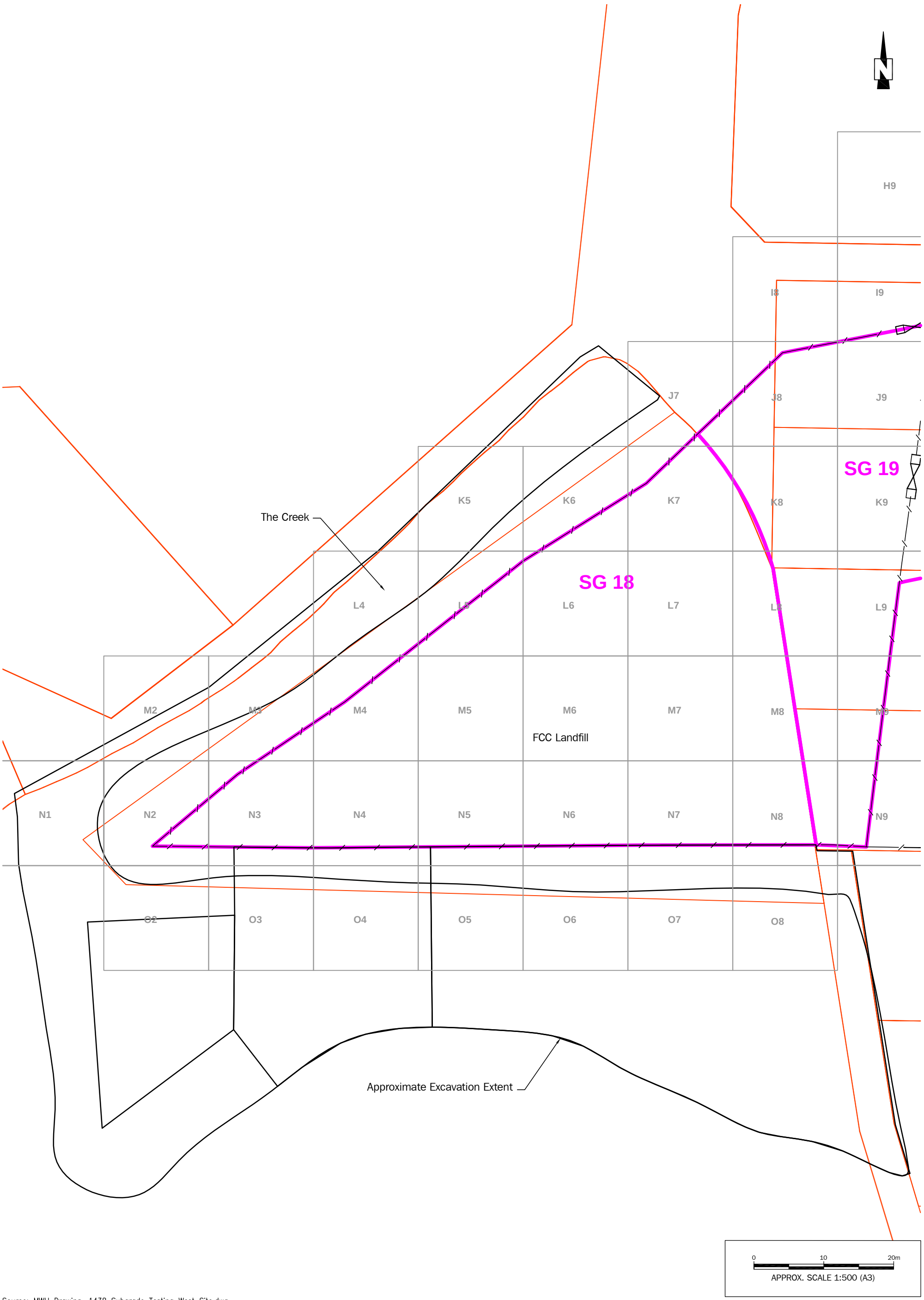
Source: MWH NZ Ltd, TDC Plan No. 6487/1s1, Sheet No. W1, Rev. AB.

Figure 3 : FCC WEST and FCC Landfill- Cell and Subgrade Layout



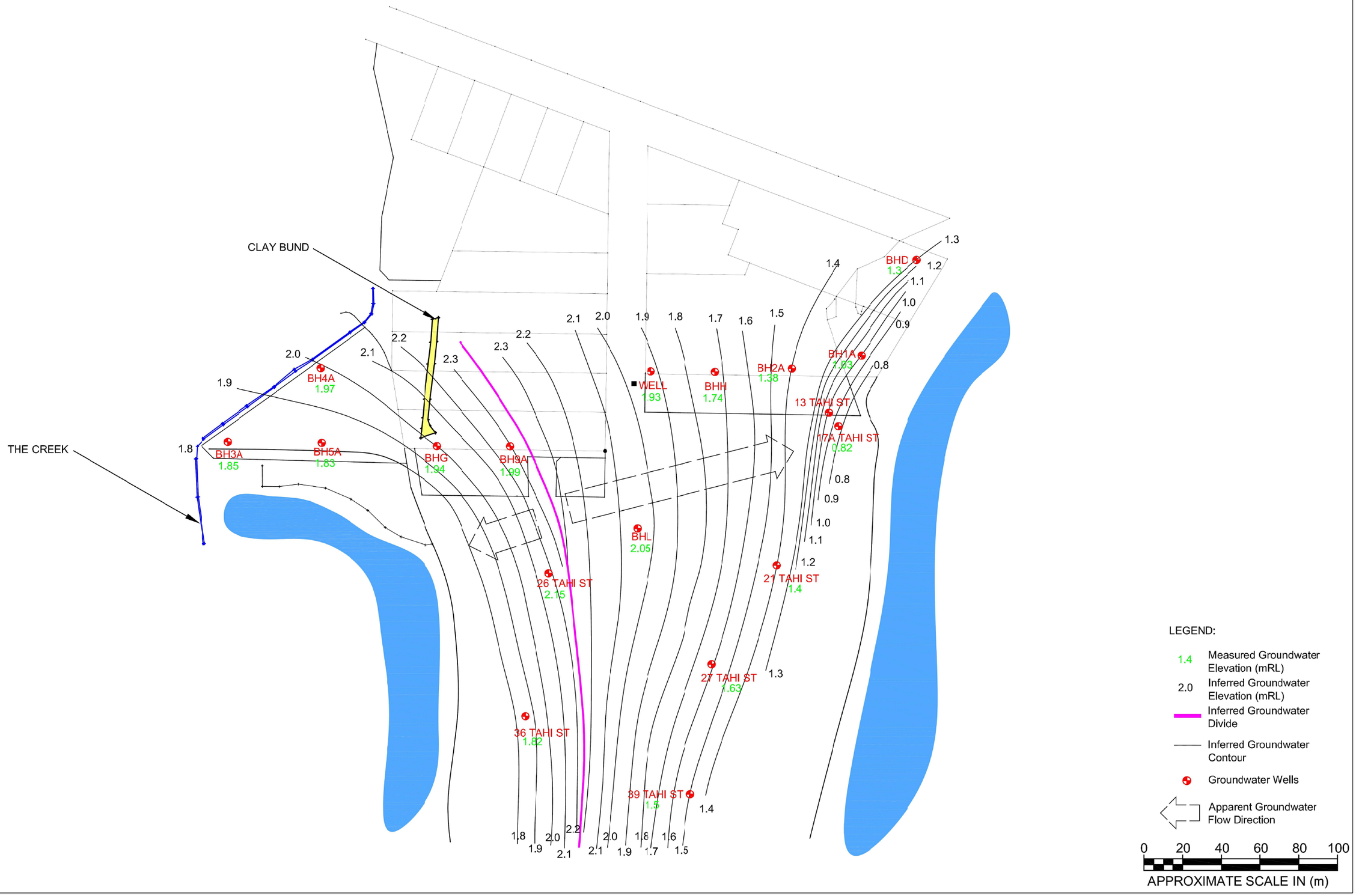
Source: SKM, 2008 Figure 41

Figure 4 : EAST MARINE EXCAVATION - Approximate Sample Locations



Source: MWH Drawing, 1438 Subgrade Testing West Site.dwg

Figure 5 : WEST MARINE EXCAVATION - Approximate Extent



Source: CH2M HILL 2007 (may not be spatially accurate)

Figure 6 : CH2M HILL (2007) Predicted Groundwater Flow Direction

Source: PDP 2007 (may not be spatially accurate).

Figure 7 : PDP (2007) Predicted Groundwater Flow Direction

W01738100D001 v4.dwg [W01738100l001.jpg] May-09

Appendix B – Documents Reviewed

BR, 1992. Mapua Site - Sediment and Shellfish Quality Appraisal, Bioresearches, 1992.

CH2M HILL, 2007. Groundwater and Sediment Investigation Report - Former Fruitgrowers Chemical Company Site, Mapua, CH2M HILL Australia Pty Ltd, New Zealand, August 2007.

CUoO, 2004. Mapua Groundwater Analysis, Chemsearch, University of Otago, December 2004.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, January 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, February 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, March 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, April 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, May 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, June 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, July 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, August 2005.

CUoO, 2005. Mapua Groundwater Analysis, Chemsearch, University of Otago, September 2005.

CUoO, 2006. Mapua Groundwater Analysis, Chemsearch, University of Otago, March 2006.

CUoO, 2006. Mapua Groundwater Analysis, Chemsearch, University of Otago, June 2006.

CUoO, 2006. Mapua Groundwater Analysis, Chemsearch, University of Otago, August 2006.

CUoO, 2007. Mapua Groundwater Analysis, Chemsearch, University of Otago, January 2007.

CUoO, 2007. Mapua Groundwater Analysis, Chemsearch, University of Otago, February 2007.

CUoO, 2007. Mapua Groundwater Analysis, Chemsearch, University of Otago, March 2007.

CUoO, 2007. Mapua Groundwater Analysis, Chemsearch, University of Otago, August 2007.

CUoO, 2007. Mapua Groundwater Analysis, Chemsearch, University of Otago, September 2007.

DEL, 2005. Suggested Protocol for Sampling Mud-Flat Snails from Estuarine Habitats Located Adjacent to the Mapua FCC Site, Rob Davidson, Davidson Environmental Ltd, January 2005.

EDL, 2003. MCD Process Description, Environmental Decontamination Limited, 20 March 2003

EDL, 2007. Affidavit of Mr Brent Pascoe in Support of the Adjudication Claim between Environmental Decontamination Limited and The Attorney General on behalf of the Chief Executive of the Ministry for the Environment, Brent Pascoe, Environmental Decontamination Ltd, 13 December 2007.

EDL, 2007. Close-Out Report Requirement under part C1 Technical Specification No.23, Brent Pascoe, Environmental Decontamination Ltd, September 2007.

Egis, 2001. Derivation of Risk-based Acceptance Criteria for Human Health and the Environment - Revised Report - Former Pesticide Plant, Mapua, New Zealand, Egis Consulting, Australia, 7 February 2001

EMS, 2006. FCC West Foreshore Remediation, Effective Management Systems Limited, 13 July 2006.

EMS, 2007. EMS Quality Assurance / Quality Control Procedures - Developed for the FCC Fruitgrowers Remediation, Effective Management Systems Limited, 30 September 2007.

GECL, 2008. Former Fruitgrowers Chemical Company Site, Mapua: Assessment of the Possible Releases to Air During Soil Processing - Report to the Parliamentary Commissioner of the Environment, Bruce Graham, Graham Environmental Consulting Ltd, February 2008.

GES, 2002. Characterisation Investigation Fruitgrowers Chemical Company Site, Mapua, Final Report, Groundwater and Environmental Services, February 2002 (Date on front of report of February 2001 is incorrect).

GHD, 2003-2008. Site auditor correspondence, Peter Nadebaum, GHD (Pty Ltd), July 2003.

GHD, 2003. Review of Health and Environmental Protection Criteria for DDT and Aldrin/Dieldrin, GHD (Pty Ltd), July 2003.

GHD, 2006. Mapua Coastal Excavation - Western Estuary, Peter Nadebaum, GHD (Pty Ltd), 24 February 2006.

HSE, 2005. Mapua Remediation Earthworks - FCC West Foreshore Methodology for Excavation of Marine Sediments, Hiway Stabilisers Environmental, 1 September 2005.

HSE, 2007. Mapua Remediation Earthworks - Close Out Report - Revised January 2007, Hiway Stabilisers Environmental, January 2007.

iKnow, 2006. Mapua Implementation Project - Mapua Soil Remediation Process Mapping, Tina Weir, Knowledge Management Consultant, Iknow New Zealand Ltd, October 2006.

MfE, 2003. Mapua Final Consent Conditions, Ministry for the Environment, May 2003.

MfE, 2004-2007. Fruitgrowers Chemical Company (FCC) Contaminated Site - Remediation Project Mapua - Monthly Reports, Ministry for the Environment, December 2004 - August 2007.

MfE, 2005. FCC Mapua - Quarterly Validation Report - Oct 04 to Feb 05, Ministry for the Environment, March 2005.

MfE, 2005b. Treated Soil Validation, letter to EDL, Nigel Ironside, Ministry for the Environment, 21 march 2005

MfE, 2005c. Fruitgrowers Chemical Company (FCC) Contaminated Site - Remediation Project Mapua - Quarterly Validation Report - March to May 2005, Ministry for the Environment, June 2005.

MfE, 2005d. Remedial Action Plan & Management Plan - Fruitgrowers Chemical Company - Mapua Site, Ministry for the Environment, July 2005.

MfE, 2007. Amendments to Remedial Action Plan & Site Work Plans, Fruitgrowers Chemical Company Mapua Site, Ministry for the Environment, August 2007.

MWH, 2008. Mapua FCC Remediation Project - Volume Balance Diagram, MWH New Zealand Limited, Richmond, 31 August 2008.

MWH, 2009. Earthworks Monitoring Report and Fill Certification - Mapua Fruitgrowers Chemical Company Plant Site Remediation, MWH New Zealand Limited, Richmond, April 2009.

MWH, 2009. Foreshore and Creek Validation, Juliet Westbury, MWH New Zealand Limited, Richmond, 14 April 2009.

MWH, 2009. Imported Soil, Juliet Westbury, MWH New Zealand Limited, Richmond, 14 April 2009.

MWH, 2009. Mapua FCC Audit, Paul Russell, MWH New Zealand Limited, Richmond, 12 May 2009.

MWH, 2009. Mapua FCC: Outstanding Questions, Paul Russell, MWH New Zealand Limited, Richmond, 21 April 2009.

MWH, 2009. Tahi St, Juliet Westbury, MWH New Zealand Limited, Richmond, 16 April 2009.

NCEL, 2007. Certified Fill Report, Ministry for the Environment Contract - Mapua Remediation Earthworks, Mapua, Nelson, John Higginbotham, Nelson Consulting Engineers Ltd, June 2007.

PDP, 2007. Report on Groundwater Issues Arising from the Mapua FCC Site, at Completion of the MCD Soil Remediation Process, Peter Callander, Pattle Delamore Partners Ltd, December 2007.

PDP, 2008. Groundwater Monitoring at Former FCC Site - August Sampling Update, Mapua, Peter Callander, Pattle Delamore Partners Ltd, August 2008.

PDP, 2008. Groundwater Monitoring at Former FCC Site, Mapua, Peter Callander, Pattle Delamore Partners Ltd, March 2008.

PDP, 2008. Groundwater Monitoring At Former FCC Site, Mapua - November Sampling Update, Mapua, Peter Callander, Pattle Delamore Partners Ltd, 16 December 2008.

PDP, 2008. Groundwater Monitoring at Former FCC Site, Mapua, Peter Callander, Pattle Delamore Partners Ltd, June 2008.

PDP, 2009. Groundwater Monitoring At Former FCC Site, Mapua - February Sampling Update, Mapua, Peter Callander, Pattle Delamore Partners Ltd, 13 March 2009.

SKM, 2008. Site Validation Report for the Former Fruitgrowers Chemical Company Site, Mapua, Sinclair Knight Merz, Auckland, New Zealand, 11 December 2008.

T&T, 2003. FCC Mapua Site Remediation - Assessment of Environmental Effects, Tonkin & Taylor Ltd, May 2003.

T&T, 2003. Groundwater Assessment Report - FCC Site Remediation, Mapua, Tonkin & Taylor Ltd, May 2003.

T&T, 2004. Report on Baseline Soil and Groundwater Sampling, Mapua, Nelson, Tonkin & Taylor Ltd, December 2004.

TDC, 1998. Former Pesticide Plant, Mapua, New Zealand - Derivation of Risk-Based Acceptance Criteria for Human Health and the Environment, Tasman District Council, July 1998.

TDC, 2002. Report on Removal of Contaminated Soil from 20 Tahi Street - August 2002, Tasman District Council, August 2002.

TDC, 2005. Report on macroinvertebrate and sediment quality monitoring for FCC site remediation, Tasman District Council, 27 April 2005.

TDC, 2007. Commercial Quality Soil in the Road Reserve Beside FCC West, Dennis Bush-King, Tasman District Council, 10 September 2007.

TDC, 2007. Report on Sediment Contamination under the Mapua Wharf, Jenny Easton, Tasman District Council, 3 August 2007.

TDC, 2007. Report on snails and sediment a year after East and West beach remediation, Tasman District Council, 11 July 2007.

TDC, 2007. West Beach Resample - 11 07, Tasman District Council, 6 November 2007.

TDC, 2008. History of West FCC Beach Remediation, Jenny Easton, Tasman District Council, 14 January 2008.

TDC, 2008. Report on Assessment of Mud Snail and Estuarine Sediments West site of Grossi Point Peninsular. 24 October 2007, Tasman District Council, 7 January 2008.

TDC, 2008. Soil tests for mercury in Residential soils on the West FCC. Tasman District Council, 22 August 2008.

TDC, 2009. Report on snails and Sediment Quality, Third Annual Round After FCC West and East Beach Remediation, Jenny Easton, Tasman District Council, 3 March 2009.

TSPL, 2004. Remedial Action Plan - Fruitgrowers Chemical Company Site, Mapua, Thiess Services Pty Ltd, July 2004.

WCL, 1993. Fruitgrowers Chemical Company - Mapua - Site Audit Report, Woodward-Clyde (NZ) Ltd, March 1992.

WCL, 1993. Phase II Site Investigation - Mapua, Woodward-Clyde (NZ) Ltd, November 1993.

WCL, 1993. Risk Assessment - Mapua, Woodward-Clyde (NZ) Ltd, December 1993.

WCL, 1993. Site Investigation, Mapua, Woodward-Clyde (NZ) Ltd, May 1993.

WCL, 1993. Soil and Groundwater Investigation, Mapua, Woodward-Clyde (NZ) Ltd, June 1993.

WCL, 1995. Groundwater Investigation, Mapua, Woodward-Clyde (NZ) Ltd, May 1995.

WCL, 1996, Mapua Site Remediation - Assessment of Environmental Effects, Woodward-Clyde (NZ) Ltd, October 1996.

Appendix C – Hydrogeological Uncertainties

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
Definition of geology beyond the site	There is no indication of the geology outside the site area, particularly downgradient of the site. It is implied in the reports reviewed that similar conditions to those at the site exist outside the site but this is not substantiated.	The implications of this relate to the extent of the aquifer and the impact of aquifer geometry on the flux and direction of contaminants. The assumption of similar conditions outside the site is likely to be conservative as the most likely alternative would be the pinching out or truncation of the aquifer which would reduce the extent of contaminant migration off-site. This gap in information is therefore of low risk.	None required
Uncertainty in groundwater levels and flow direction	See discussion in text		

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
Definition of aquifer base on-site	No details of the variation in the base of the aquifer (e.g. contours) are provided in the reports reviewed other than one value each for the eastern and western parts of the site and a single cross-section.	Whilst the groundwater levels will indicate the direction of groundwater flow (although this is uncertain as discussed below), the aquifer transmissivity (a product of the thickness and permeability) will determine the flux. Variation in the depth of the aquifer appears to have been considered in the calculations provided by CH2M HILL through the adoption of ranges of saturated aquifer thickness values for the beaches to the east and west of the site. The risk of significant variation from the values shown is unlikely and therefore the risk is low.	Produce saturated thickness isopachs for transmissivity determination and confirmation of fluxes.
Moutere Gravel hydraulic properties	No hydrogeological properties of the Moutere Gravel are presented in the reports reviewed to allow confirmation as an aquitard. However, based on the soil description the designation seems reasonable.	If the gravels were considered as part of the aquifer then the implications would not be significant. The risk associated with this is considered to be low.	None required.

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
Bund and cut-off wall construction	Only limited information has been provided on the various clay bunds / cut-off walls on the site i.e. along the eastern foreshore and various boundaries of FCC Landfill. There is little discussion of the impact of these features on the groundwater flow directions and therefore discharges to the estuary or Mapua Channel.	The potential impact of these features is to reduce flow across them to an extent that would depend on their construction. This could result in the diversion of groundwater around them and, potentially, divert water toward receptors to the south. Similarly, the gravel backfill in the centre of the eastern bund could result in preferential groundwater at that point. However, the interpreted groundwater flow directions have been based on the observed groundwater levels which are the most direct indicators of groundwater flow directions. There will be a lag between any changes to the groundwater system and the appearance of effects as contamination will take time to migrate under the new conditions. If these features had been in place prior to the contamination of the site then there would be no doubt that the contamination plume was equilibrated to their presence; however more recent installation raises the issue of time lag. Consideration of the effects of these features is required although it is considered likely that the effects of the time lag for contamination effects are minimal and the gap in information is considered low risk.	Confirm of bund/cut off wall construction and hydraulic properties and/or installation of more monitoring wells, and reassess impact on groundwater flow.

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
Preferential flow zones	Whilst it is understood all service trenches on-site were removed (but not under Tahi Street), no comment is made on their presence off-site and their potential to influence contaminant migration.	Service trenches and other similar man-made excavations have the potential to act as high permeability pathways that could allow relatively more rapid migration of contaminants locally. Most service trenches would be expected to be no deeper than 1.5 m and based on the site groundwater levels, groundwater over most of the developed parts of the site might be expected to be below this. In addition the effects of such high permeability pathways would influence groundwater levels. The implications of this are that contaminants may be transported to areas of the site more distant and rapidly than expected. The level of risk associated with this gap is not quantifiable.	Confirm depth to underground services and compare with depth to groundwater. If service trenches are below groundwater level, assess potential for migration pathways.
Effect of fill on aquifer properties	There is little assessment on the potential impact of emplacement of fill of different hydraulic properties from the original ground on the groundwater flow and contaminant migration.	Where the base of the fill is above the groundwater level no direct impact on groundwater flow would be expected aside from a localised alteration to recharge; however, where the fill extends down into the saturated zone, the difference in hydrogeological properties will impact the groundwater flow pattern. The degree of this impact will be dependent on the proportion of saturated aquifer that has been replaced with fill and the difference between	None required

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
		fill and natural ground properties. This could alter the groundwater flow pattern and divert contaminated groundwater to receptors to the south. Groundwater levels recorded prior to remediation and during remediation appear to be broadly similar and therefore this does not appear to have had a significant effect and is therefore considered low risk.	
Discharge rate estimation	The discharge calculations presented by CH2M HILL correctly incorporate porosity in the calculation of groundwater velocities but incorrectly incorporate it in the calculation of flux. Determination of groundwater velocity (specifically “average linear velocity”) requires hydraulic gradient, permeability, and porosity; determination of flux requires hydraulic gradient, permeability and cross-sectional area.	The fluxes calculated by CH2MHill should be reduced by between a factor of three and five based on the porosity values that they have used. There is no risk in this as use of the correct calculation would be less conservative.	Recalculated in text.

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
Methodology for calculation of discharge dilution	There is considerable variation in the estimates of dilution that have been put forward by T&T and CH2M HILL which suggests a high level of uncertainty.	CH2M HILL calculate dilution of 80,000 to 1.5 million in the Mapua Channel and 1,000 to 25,000 in the Waimea Inlet. These are several orders of magnitude higher than the dilution factors of 100 and five respectively for the Channel and Inlet calculated by T&T in their AEE. This reflects the different methodologies with T&T basing their estimates on flow rates past the discharge zones and a 20 m mixing zone and CH2M HILL basing theirs on complete mixing within the volume of water emptied during each tidal cycle. The discharge dilution rate has a direct effect on potential effects on the marine ecosystem. The T&T estimate is very conservative and the CH2M HILL estimate probably extreme. With respect to the marine ecosystem within the sea there is therefore very low risk in using the two dilution rates (five and 20) for the basis of the PETCs. What is not addressed in either estimate however is that there will be periods where there is undiluted groundwater seepage during low tide which will impact on the ecosystems based on the surface and within the beach sediments within the discharge zones. This has already been noted in the enhanced algal growths in these areas (presumably because of increased nutrient concentrations in the groundwater from use of urea and	Maintain T&T dilution factors. Review acceptability of undiluted groundwater discharge concentrations on local surface ecosystems. Carry out marine biota sampling and compare with existing biota (snail) sampling elsewhere.

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
		diammonium phosphate). This risk is considered to be high.	
Uncertainties in parameters used for discharge estimation	See next issue below		
No site water balance	There is very little discussion of recharge across the site, how it has changed during and after remediation and what it could be under future site use, and no attempt to calculate a water balance in any of the material reviewed.	Whilst there will be uncertainties in the precise volumes of runoff, evapotranspiration, and recharge across the site, they are likely to be less than those associated with estimation of aquifer transmissivity and hydraulic gradient for which uncertainty can often be in the range of orders of magnitude. The level of uncertainty in the current throughflow calculations is considered to be medium to high and therefore the uncertainty over the selection of the appropriate PETCs is also medium to high. It should be noted that the impact of the change in throughflow is only of relevance to the marine environment; protection of groundwater for future use such as for drinking is unaffected.	Develop a water balance for the site under existing and potential future conditions and review PETCs with respect to marine ecosystem protection.
Groundwater abstraction	There is no discussion relating to the effects of groundwater abstraction that may occur from nearby private wells (current or future). In	Unaccounted for abstraction from these wells could result in the drawing in of contaminated groundwater and influence groundwater patterns if the wells are in the same aquifer. Conversely, wells	Confirm well construction and abstraction rates and assess potential impacts on groundwater flow patterns.

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
	addition there is no confirmation of the construction and the aquifer which is being exploited by these wells.	drawing from deeper aquifers are unlikely to influence groundwater flow patterns or be at risk of drawing in contaminated groundwater. In general the takes are expected to be low and therefore the risk of changing flow directions low.	
Time of travel	Calculations have been made for the groundwater velocities based on the CH2M HILL groundwater contours; however, no calculation has been made based on the alternative contours presented by PDP.	The alternative contours presented by PDP indicate that there is a component of groundwater flow to the south; however, without an estimation of the time of travel it is uncertain how long it will take for any effects of remediation to reach the groundwater receptors to the south.	Travel time to groundwater receptors is calculated based on PDP's alternative groundwater contours.
Attenuation	There is very little discussion of attenuation processes in the soil which may serve to reduce groundwater concentrations. This is not an issue for areas where direct observation is possible but is for those where it is not (e.g. receptors to the south)	Taking no account of attenuation is conservative as it will lead to prediction of lower concentrations at distance. The current assessment is therefore conservative and there is therefore no risk.	None required.
Declining versus constant source	In general there is little discussion regarding the nature of the contaminant source within the soil in terms of its persistence. It is generally implied that the source is constant.	The approach that has been taken is a conservative one and therefore there is no risk associated with this.	None required.

Table B-1: Identification of issues/gaps

Issue/Gap	Description	Implication	Recommended Action
Remaining contamination in source soils/saturation of source soils	This relates to calculations of contaminants remaining on site and in fill and the differing impact of contamination sources above and below the water table.	Most data indicate that any increases in the concentration of contaminants of concern have now peaked. This means that for current conditions the effects of the remediation on groundwater have been observed and are known and issues relating to the contamination source (which is assumed to not change in future – see previous comment on constant source) are not of great relevance. The exception to this would be changes in site use that increase the rate of infiltration through the soil and/or raise the watertable and result in greater volumes of fill below the watertable. In this case increases in the concentration of contaminants of concern could occur. However, given the current site land use (grassed) future site use is unlikely to have this effect. The risk associated with this is therefore low.	Ensure that infiltration is not greater than current for future site use or assess effects if future development has the potential to increase infiltration (e.g. disposing of stormwater by infiltration).