Mapua FCC Site Remediation – Review of Post-remediation Monitoring

Prepared for
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Executive Summary

The former Fruitgrowers Chemical Company (FCC) site at Mapua was remediated between 2004 and 2008. Following an audit of the remediation a number of recommendations regarding follow-up monitoring were made. This report reviews the results of the follow-up monitoring.

Soil Sampling Quality Assurance/Quality Control (QA/QC)

Tasman District Council staff took 15 soil samples from FCC-West to be representative of remediated residential quality soil. This was to investigate uncertainty with respect to detection limits for DDT and related isomers (summed as DDX) and a lack of inter-laboratory comparisons at concentrations close to the DDX residential soil acceptance criterion (SAC). The samples were subjected to the same screening analysis used during the remediation and to more precise analysis at the same laboratory and an independent laboratory.

The sample results show a similar soil acceptance/rejection decision would have been reached during the remediation regardless of whether the screening method or the two more precise methods had been employed. However, the results also show that approximately two thirds of the samples, regardless of method, exceed the residential criterion for DDX. This raises a question whether the screening method used during the remediation was systematically underestimating the DDX concentration relative to the current analysis, and therefore whether the intended remediation was not achieved over much of FCC-West, contrary to the conclusion of the Validation Report.

The acceptance criteria were intended to protect the aquatic life from contaminated sediment being washed into the Waimea Inlet. However, it is considered unlikely that significant quantities of soil in excess of the DDX criterion will reach the inlet. All the results comply with the less stringent human health guideline for residential land, making the land safe for residential use.

Ammonia Soil Gas Monitoring

The use of diammonium phosphate during the remediation raises the possibility of ammonia gas being generated within the soil in FCC-East. This could cause a risk to human health if the gas built up in confined spaces and also a threat to plants in amenity planting. A programme of soil gas monitoring in 12 monitoring points was carried out to assess this.

While the monitoring had some deficiencies, the results confirmed the potential for ammonia generation but there appears to be only a low risk of excessive concentrations in the monitored locations, whether in excavations or future buildings that might be constructed. However, not all locations that have the potential for ammonia generation were monitored, as intended by the audit recommendations. While the points monitored probably have a greater potential

for gas generation than much of FCC-East, it cannot be guaranteed that they have the highest potential. In particular, two areas known as subgrades SG6 and SG20 may have a higher potential. While it us understood that there are no plans for construction in these areas, should this change it is recommended that either a soil gas assessment is carried out as part of building design or pre-emptive engineered measures be put in place to prevent gas ingress. In addition, excavation workers/contractors should be made aware of the possibility of ammonia and carry out monitoring if ammonia odour is noticed.

The monitoring has not assisted determining whether ammonia is a threat to any planting within the affected soil.

Groundwater Monitoring

The audit recommended more groundwater monitoring wells to address uncertainties regarding groundwater flow directions, seasonal variations of flow direction and water level, and groundwater contaminant concentrations within the main body of the site. These and the existing wells were to be monitored quarterly for a year after which time the hydrogeological model and future monitoring was to be reviewed.

Overall the intent of the recommendation was fulfilled. The review of the hydrogeological model has clarified that there is a component of groundwater flow in the southerly direction towards the residential properties in Tahi Street, confirming the potential for risk to private bores to the south of the site from groundwater contamination.

Groundwater quality monitoring has confirmed that in the residential part of FCC-West some wells exceed drinking-water standards for nitrate and many wells exceed for aldrin and dieldrin. This confirms the audit recommendation that groundwater under FCC-West be assumed unsuitable for potable use.

Some wells adjacent to residential properties near the southern boundary of FCC-East have excessive pesticide concentrations. However, monitoring at existing private bores in Tahi Street show DDX and aldrin plus dieldrin comply with drinking-water standards. This is consistent with these contaminants having limited mobility within groundwater.

The review of future monitoring recommended all but a few wells be monitored annually, with a smaller set of wells monitored quarterly for a reduced number of analytes. This approach is generally appropriate, but consideration should be given to reducing the intermediate monitoring to six-monthly, in light of the biological monitoring showing the foreshore environment is satisfactory and only limited migration of contaminants towards Tahi Street. If there is some marked future increase in foreshore effects, an increase in groundwater monitoring may be warranted.

Recommendations for a one-off monitoring of lindane to examine a marginal sampling or laboratory quality issue and continuous monitoring of water level and conductivity in one well are questionable.

Marine Sediment and Biota Monitoring

The audit recommended reviewing the marine sediment and biota monitoring programme of the East and West foreshores to confirm its appropriateness, continuing annual monitoring, reviewing the monitoring frequency after two years, and benchmarking the health and diversity of the foreshore ecosystem.

Overall it is considered that the recommendations of the audit have been satisfied with respect to the monitoring programme review and the two monitoring events a year apart. However, there is some uncertainty regarding the consistency of the depths of marine sediment samples. This uncertainty should be addressed in the methodology for future sample collection.

The biota monitoring could not separate out natural variability in the foreshore ecology from possible effects of the residual pesticide contamination in the foreshore sediments. The limited evidence of nutrient enrichment and lack of obvious pesticide impacts on the foreshore ecosystems indicates there is little reason to consider further remediation to improve the foreshore habitat at this stage. The benchmarking undertaken provides a suitable basis for future comparisons.

While results vary from year to year, levels of DDX and ADL in mudflat snails (the main indicator organism) appear to be exhibiting a long-term decreasing trend. Concentrations of DDX and dieldrin within mudflat snails comply or are close to complying with New Zealand Food Safety Authority recommendations. If the apparent reducing trend continues, routine compliance with these recommendations should be achievable at some point in the future.

Sampling of sediment in the stream adjacent to FCC-West found an apparent increase in pesticide concentrations. It is not clear that this increase is real and, if it is, what the mechanism for the increase is. Further monitoring is required to confirm whether the recontamination is in fact occurring and whether this is important.

It is recommended that the annual marine and stream-bed sediment sampling programme continue. Continued annual sampling of mudflat snails at FCC-West and FCC-East, in addition to cockle sampling at FCC-East (and control sites) and continuing the visual assessments of macroalgae cover are also considered appropriate. A review of the entire monitoring scope should be carried out after a further three rounds of monitoring.

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1.0 Introduction

Pattle Delamore Partners Limited (PDP) has been engaged by the Ministry for the Environment (MfE) to review follow-up monitoring of the former Fruitgrowers Chemical Company (FCC) site at Mapua and adjacent foreshore areas, following the site's remediation. The follow-up monitoring arose out of recommendations in the audit (PDP, 2009a) of the Validation Report prepared by Sinclair Knight Merz Limited (SKM, 2008) of the remediation. The Validation Report documents the degree of compliance of the soil and sediment remediation with the resource consents granted by Tasman District Council (TDC).

The recommendations from the audit (henceforth referred to as the Audit Report) are reproduced in Appendix A. This review relates to recommendations 1, 2 3, 4, 5, 6, 7, 9 and 10, and covers recommendations relating to:

- QA/QC soil sampling of the western part of the site (FCC-West) to address an information gap in laboratory analysis quality records.
- Sampling of ammonia in soil gas on the eastern part of the site (FCC-East) where soil containing ammonia compounds is buried.
- Installation and monitoring of additional groundwater wells and a review of the hydrogeological model using the new information.
- Additional monitoring of sediment and biota on the western and eastern foreshores, including comparisons with control sites.

The approach taken in this review is to assess whether the work has been carried out as recommended, whether it has achieved the intent of reducing uncertainty or filling a gap in information, or providing benchmark information for possible future assessment of the success of the remediation, and whether the additional work has been adequately reported.

This review considers the additional work in order of the recommendations, with a separate section for each of soil sampling QA/QC, soil ammonia, groundwater and foreshore monitoring. Conclusions and recommendations are not provided for each section; rather these are provided as a single section at the end of the report.

2.0 Soil Sampling Quality Assurance/Quality Control

2.1 Reason for recommendation and information reviewed

Additional sampling of residential quality soil from the western part of the site (FCC-West) was recommended in the Audit Report to address a QA/QC information gap with respect to detection limits for DDX[1] and a lack of inter-laboratory comparisons at concentrations close to the DDX residential soil acceptance criterion (SAC). With respect to organochlorine pesticides, residential quality soil was required to comply with, on average, an SAC for DDX of 5 mg/kg dry weight and for ADL[2] an SAC of 3 mg/kg.

To assess compliance against the SACs during the remediation, samples were sent to Hill Laboratories, Hamilton. Hills employed a modified version of its normal organochlorine pesticide analytical screening method. The modified method had a detection limit for the individual DDX and ADL compounds of 0.5 mg/kg when applied to FCC-West samples, but some FCC-West samples were also analysed to detection limits of 1 mg/kg. The modified method with the 1 mg/kg detection limit was normally applied to FCC-East samples.

For the commercial quality soil SACs for ADL and DDX of 60 and 200 mg/kg, respectively, these relatively high detection limits were acceptable, as the detection limits are sufficiently below the SACs not to create uncertainty. However, for the residential soil, detection limits of 0.5 m/g and in some case 1 mg/kg, gave effective detection limits on the summations for DDX and ADL of up to 6 and 2.1 mg/kg, respectively. These detection limits are too close to the SACs to give certainty that the soil complied with the SACs. It is good practice to have detection limits of at least 10 times lower than the applicable acceptance criteria.

As a check, following the remediation QA/QC samples were collected from the commercial soil of FCC-East and subjected to more precise analysis at two laboratories, including Hill Laboratories. The comparison proved satisfactory, but as the soil concentrations were well above the detection limits employed for the routine field testing (0.5 and 1 mg/kg) the comparison was not adequate for the residential quality FCC-West soil. Accordingly, additional testing of FCC-West soil was recommended.

To fulfil the recommendation, Tasman District Council staff took 15 soil samples from FCC-West at a depth of about 300 mm from below the surface, i.e. from beneath the imported topsoil layer (Jenny Easton, TDC, pers. comm.). The

[1] The sum of the six isomers of the organochlorine pesticides DDD, DDE and DDT, specifically, 2,4'-DDD, 4,4'-DDD, 2,4'-DDE, 4,4'-DDE, 2,4'-DDT and 4,4'-DDT

[2] Acceptance of soil with respect to the organochlorine pesticides aldrin, dieldrin and lindane was by calculating the sum of aldrin, dieldrin and 10% lindane, otherwise known as ADL.

samples were collected on an approximate grid with a spacing of 30 – 40 m, with each sample representing an area of approximately 1000 m^2. The 15 samples were intended to be representative of remediated soil complying with the residential SACs.

The samples were sent to Hill Laboratories for preparation of sample splits and analysis. Hills carried out analysis using its “Mapua screen method” at individual compound detection limits of 0.5 mg/kg and their normal organochlorine screen method (for simplicity called “Hills Standard” from this point on) with detection limits for the compounds of interest of 0.01 mg/kg or better. Split samples were sent by Hills to the laboratory of AsureQuality Limited, Gracefield, Lower Hutt, for analysis of pesticides in soil with typical detection limits of 0.01 mg/kg. The two laboratory reports, which are the subject of this review, are appended.

2.2 Assessment of results

The assessment of the laboratory results has been carried out using the DDX and ADL summations, rather than the comparing the individual compound results. This is the same as that carried out by SKM for the FCC-East QA/QC sampling (SKM, 2009). In calculating the summations, non-detects have been taken as half the detection limit, again the same as SKM (2009).

AsureQuality has reported both non-detect results (<0.01 mg/kg) and “Trace” values, the latter being results between 0.01 and 0.05 mg/kg which cannot be quantified accurately by the analytical method. In calculating summations “Trace” values have been taken as the mean of 0.1 and 0.05, rounded to 0.03 mg/kg. The tabulated results and summations are presented in Table B-1.

One of the aims of the sampling was to have concentrations at or around the SACs for DDX and ADL. It is immediately apparent that the great majority of the samples in fact exceeded the DDX SAC, in some cases by as much as four times, but there are some samples at about the SAC of 5 mg/kg. It is also immediately obvious that all the results were below the SAC for ADL.

As a first comparison, the Hills Standard and AsureQuality results have both been compared with the Hills Mapua Screen results in Figure 1 below.

Looking firstly at DDX, there is a reasonable one-to-one relationship between the Mapua Screen and the other two, more accurate, analysis methods. Plotting of linear least squares regression lines with the screen method as the independent variable produces similar lines for the two more accurate methods. This gives reasonable confidence that the two more accurate analysis methods are producing close to the “true” concentration, as is the Mapua Screen method.

Considering compliance with the DDX SAC, using one or other of the more accurate methods would have resulted in essentially the same decision as that arrived at using the screen method. The AsureQuality results give a marginally lower estimate for DDX than the two Hill's methods. This means that the Hill's methods would have rejected some soil that would have been accepted if analysed by AsureQuality, i.e. both Hills methods are conservative relative to the AsureQuality method.

For ADL there is also a reasonable one to one relationship between the methods, although because there is "left censoring" for the screen method data (i.e. results are below the detection limit) there is a range of results for the more accurate methods for the same or similar apparent value for the screen method. This is an artefact of the high detection limits for the ADL components, but is unimportant as this effect is well below the SAC for ADL.

The relationship between the AsureQuality and the Mapua Screen method ADL results is poorer than between the two Hill's methods. The regression line for the AsureQuality results is biased by a single high result, which appears to be a statistical outlier. If this result was excluded then a better relationship is achieved. Excluding the outlier and the non-detect values, the AsureQuality results are, on average, lower than the corresponding Hill's results. If these also applied at the SAC (which is above the range of results) the consequence would be more conservative decisions using the Hill's methods than the AsureQuality method.

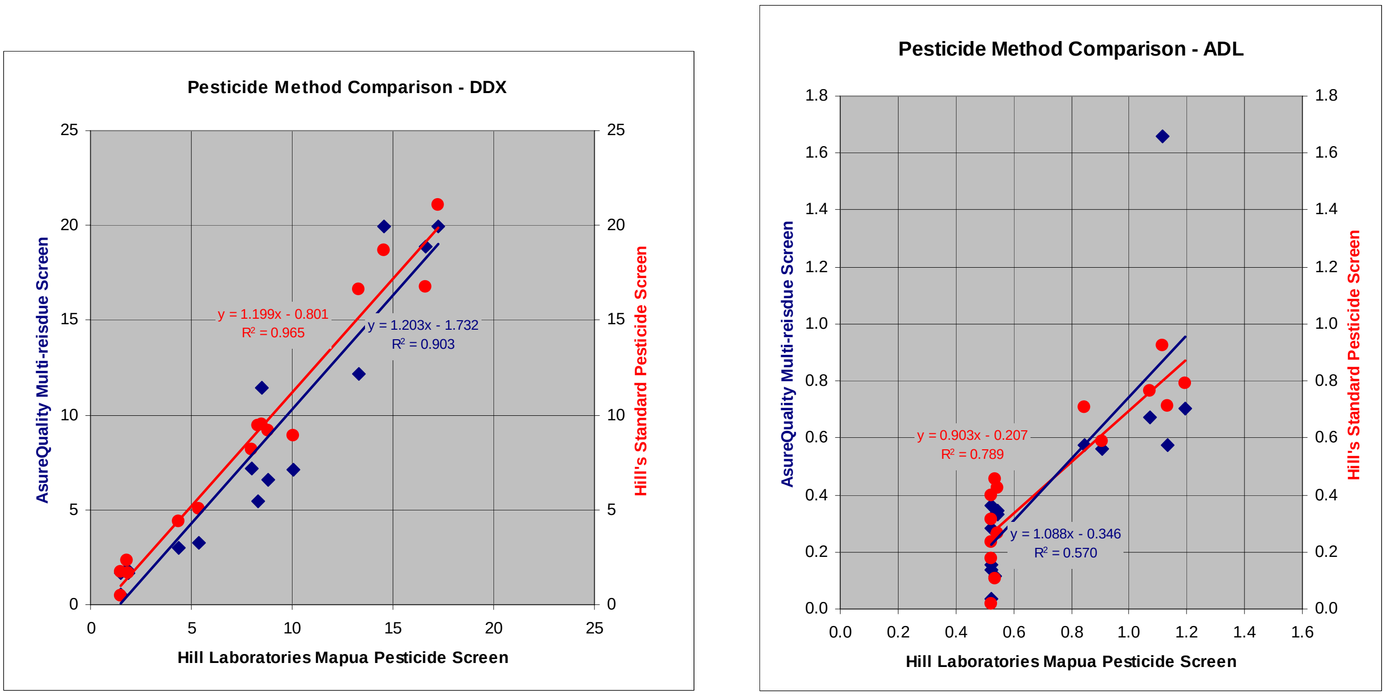


Figure 1: Comparison of analytical methods – DDX and ADL

2.3 DDX results relative to the SAC

All of the laboratory results should have complied with the residential DDX and ADL SACs, as all the samples were from land that has been remediated to residential standard. It was not the original intent of the sampling to compare the results with the SACs, as the soil was expected to comply with the residential SACs. While all the results did indeed comply with the ADL SAC, only five of the fifteen samples complied with the DDX SAC using the Hill's results, or six of the 15 samples using the AsureQuality results.

This is not an issue with respect to the use of FCC-West for residential purposes, as the SAC was derived to protect the aquatic life within the Waimea Inlet from contaminated sediment washed from FCC-West into the estuary. All the results are comfortably below the recently announced soil contamination standard for DDX for residential land of 70 mg/kg (MfE, 2011). Therefore, as noted in the Audit Report, FCC-West is fit for its intended residential purpose with respect to soil quality. However, the uncertainty noted in the audit regarding whether concentrations of DDX always meet the residential SAC has not been resolved. In fact the uncertainty has increased as a result of the additional sampling, suggesting that up to two thirds of the residential soil in FCC does not meet the DDX SAC, whereas sampling during the remediation found only an occasional excursion over the SAC.

As noted earlier, the fact that both the AsureQuality and Hill's standard methods produce similar results for the same samples gives confidence that the "true" DDX concentrations lie close to the recorded values. The Hill's Mapua Screen also gives similar results. It is therefore difficult to explain why the testing during remediation averages much lower concentrations for DDX (below 5 mg/kg) than the current results, other than that the screen method used during the remediation was systematically underestimating the DDT isomer concentrations. This would also mean that the screen method used in the current sampling is not giving the same results as the screen method during the remediation sampling. The alternative explanation is that the current sampling just happened to sample a number of locations that exceeded the SACs.

For DDX, the controlling pathway for the residential site use SAC was found to be sediment runoff effects on the marine aquatic ecosystem. As noted in the Audit Report, 0.15 m of imported topsoil was placed over the remediated soil and FCC-West can be expected in future to have considerable cover of paving, buildings or grass. This will reduce the likelihood of sediment runoff and possibly makes the derived SAC conservative. However, where there is exposed soil in future, for example in gardens, 0.15 m of clean cover soil will not be sufficient to prevent some of the deeper soil which is in excess of the SAC being brought to the surface. Over time, with working of the soil in gardens, the average concentration of DDX in exposed surface soil could be about half the concentration of the deeper soil (i.e. if soil is worked to a depth of 300 mm, twice the depth of the clean cover soil and a typical maximum depth that turning soil over with a shovel might reach). If that situation eventuates, and if the 15 soil samples taken for the current study are representative of the soil immediately beneath the clean cover over all of FCC-West, then around 30% of the area (four or five of the 15 sampled locations, depending on which sample results are believed) would still be in excess of the DDX SAC.

However, a better representation of the future risk to the marine environment is probably an average concentration over FCC-West after the assumed mixing between the surface and deeper soil occurs. An arithmetic average concentration of the 15 locations after surface mixing would be 4.3 mg/kg while an upper bound estimate of the mean (UCL 95) would be 6.2 mg/kg (using half the mean concentration of the Hills and AsureQuality results). In practical terms, given the approximations involved in the calculations, both these estimates are similar to the DDX SAC value. Overall, while the concentrations are higher than intended from the remediation, the marine environment is probably still suitably protected.

3.0 Ammonia Soil Gas Monitoring

3.1 Reason for audit recommendation

Diammonium phosphate was used as an additive during the soil remediation process. This resulted in nitrogenous compounds, including ammonia, being at elevated concentrations where the treated soil (known as treated fines) was buried in FCC-East. The possibility of ammonia gas being at sufficient concentrations to be phytotoxic and even present a health hazard was raised in the audit report. Consequently, a programme of soil gas sampling and analysis for ammonia was recommended at locations where buried treated fines or mixed material containing treated fines exists. This was to include subgrades SG3, SG7 and SG14 where cement-stabilised marine sediments and treated fines co-exist. The higher pH of cement-stabilised soil is thought to have a greater potential for generating ammonia.

3.2 Information reviewed

The following information was reviewed:

- *Former Fruitgrowers Chemical Company Site (FCC), Mapua - Ammonia Gas Survey Investigation*, report prepared for Tasman District Council by URS New Zealand Limited, Christchurch, 8 February 2010 (URS, 2010a)
- *Former Fruit Growers Chemical Company Site (FCC) Mapua Ammonia Gas Survey Investigation - Part 2*, letter report to Tasman District Council, URS New Zealand Limited, Christchurch, 21 May 2010 (URS, 2010b)
- Additional information provided by URS on the sampling method by e-mail (dated 23 March 2010) via Jenny Easton of Tasman District Council

3.3 Review

3.3.1 Monitoring procedure

Testing was carried out in 12 soil gas monitoring points installed within holes drilled between 0.7 and 1 m deep distributed across subgrades SG3, SG7 and SG14. The watertable is reported to have been between 1.4 and 1.8 m deep in the vicinity. The monitoring points were installed on 28 January 2010 and first monitored the following day and again on 12 April 2010. Monitoring consisted of measuring ambient ammonia concentrations around the site with a portable instrument and then measuring concentrations in each well. The portable instrument used for the monitoring was manufactured by Aeroqual. Reference to the manufacturer's literature[3] shows the instrument has a minimum detection limit of 0.5 ppm and an accuracy of calibration of $<\pm 5$ ppm.

A slightly different procedure for monitoring the wells was used on the two monitoring occasions. On the first occasions the wells were purged for two minutes at 0.2 litres per second (equivalent to about 12 well volumes over two minutes) and the reading taken over a five minute period. Wells that recorded above 0 ppm after five minutes were retested for a duration of 30 minutes and a further reading taken. Atmospheric pressure at Nelson Airport was rising at the time of the monitoring.

Two aspects of the monitoring give concerns for the reliability of this first monitoring:

- Monitoring with a rising barometric pressure is not best practice. Measured concentrations can be expected to be lower as rising barometric pressure will cause atmospheric air to enter the ground and dilute the soil gas that may be present.

- Retesting of wells after 30 minutes apparently involved purging the wells for a total of 37 minutes, the initial two minutes, five minutes for the initial reading and a further 30 minutes for the second reading. Depending on the relative horizontal and vertical permeability of the soil, such a long purging period risks drawing in atmospheric air from the surface, giving a false ammonia reading. Purging at 0.2 litres per second is a volume of about 440 litres of air over 37 minutes, equivalent to the pore volume of 1.5 m^3 of soil, assuming a soil porosity of 0.3.

On the second monitoring occasion, the ammonia concentration was measured within the monitoring well immediately after the cap was removed for a period of five minutes and then purged for two minutes and then monitored again over a period of five minutes. Atmospheric pressure was falling at the time of monitoring.

The second monitoring occasion is expected to have given more reliable readings than the first.

3.3.2 Gaps in information

The intent of the recommendation was not to limit the monitoring to subgrades SG3, SG7 and SG14, but to monitor a selection of locations where there is a potential for ammonia to be generated. Subgrades SG3, SG7 and SG14 were specifically to be included because of the possibility of alkaline conditions (as a result of cement stabilisation) promoting the generation of ammonia. However, these subgrades contained treated fines mixed with other materials and

[3] See http://www.aeroqual.com/gases

therefore, despite the possibility of alkaline conditions, may have a lower potential for generation of ammonia than subgrades with undiluted treated fines.

The remediation as-built drawings in Appendix F of the Validation Report show there are two subgrades containing undiluted treated fines at shallow depth; SG6 and SG20. In addition, there are a number of other subgrades with treated fines mixed with other materials immediately below the 500 mm of surface cover (e.g. SG17). These subgrades may have a greater potential to generate ammonia than the generally deeper (often below the watertable) mixed treated fines in SG3, SG7 and SG14. It would therefore have been prudent to have also checked for ammonia in one or more of these other subgrades with possibly higher potential for generating ammonia. As it stands, there is uncertainty whether the worst-case locations have been checked.

3.3.3 Assessment of results

The results were compared in URS (2010a) and URS (2010b) with Texas Commission on Environmental Quality Effects Screening Levels (ESL), on the basis that these have been developed to be protective of human health, odour/nuisance effects and effects on vegetation. The value given for short term exposure is 0.25 ppm.

During the January monitoring, one result at 5 minutes exceeded the guideline by more than an order of magnitude (3.8 ppm), but was recorded as 0 ppm at 30 minutes. All other results were 0 ppm, regardless of recording time. The report for the January monitoring (URS, 2010a) noted that the 30 minute readings fell within the definition of short-term and as these readings were all less than the short-term ESL, all readings complied. The report concluded generation of ammonia in subgrades SG3, SG7 and SG14 was limited and therefore unlikely to pose any risk to human and plant health. There are a number of difficulties with this conclusion:

- the manufacturer's detection limit for the monitoring instrument is greater than the screening value used, i.e. the zero readings should have been recorded as <0.5 ppm rather than 0.0 ppm;
- the monitoring method over 30 minutes is of dubious validity; and
- the ESL is of dubious validity for the particular situation.

During the April monitoring two wells recorded detectable concentrations on first opening the wells (0.1 and 2.3 ppm), with one of these recording detectable concentrations after purging (1.2 ppm). The report concluded that, despite the exceedance of the ESL in one well, the generation of ammonia in subgrades SG3, SG7 and SG14 was limited and therefore unlikely to pose a risk to human and plant health via gas penetration into buildings.

Reference to the source documentation for the ESL[4] shows that the ammonia values are protective of human health only, without consideration of odour/nuisance effects or effects on vegetation, thus any conclusions with respect to plant health are not valid. In addition, further research into the background of the ESLs shows that the short-term ESL for ammonia was simply taken as 1% of the occupational standard (the long-term ESL is 0.1% of the occupational standard). As ESLs are intended to be a first screening for possible effects of atmospheric pollutants for all land uses, including residential, it is questionable whether they are an appropriate guideline for commercial land where the concern is the collection of gas in a confined space. However, they should be conservative for that situation.

In an occupational setting the legal requirement is compliance with the Workplace Exposure Standards (DoL, 2010). The short term WES for ammonia is 35 ppm and the 8-hour time-weight average (TWA) is 25 ppm.

The monitoring results have confirmed there is at least some potential for generation of ammonia in subgrades SG3, SG7 and SG14. The monitoring results are not helpful in determining whether this is the likely limit of ammonia generation. The two assessments are also not helpful in assessing whether the detected concentrations would affect plant health.

In landfill gas assessments, a rule of thumb is that constructing buildings with soil concentrations greater than 25% of hazardous concentrations (the lower explosive limit in the case of methane) should not be permitted, and protective measures should be implemented for lower concentrations. While the consequences of explosion are much greater than toxic effects of ammonia, applying this rule of thumb would suggest that soil concentrations in excess of about 6 ppm should be guarded against by appropriate engineering measures and possibly avoided entirely.

Measured values within subgrades SG3, SG7 and SG14 were in the low ppm range at some locations, but generally much lower, suggesting that the likelihood of excessive concentration building up within confined spaces is generally low, and therefore no particular precautions need to be taken for buildings in these areas (or other locations where lesser amounts of treated fines have been buried). However, given that monitoring was not carried out at all locations with the potential to generate elevated ammonia concentrations, this conclusion cannot be extended to all of FCC-East, particularly subgrades SG6 and SG20 where undiluted treated fines are at shallow depth. Subgrades SG8, SG12 and SG17 with mixed treated fines at shallow depth are presumably at less risk than the subgrades with un-diluted treated fines, but are possibly

[4] See http://www.tceq.texas.gov/toxicology/esl/list_main.html

similar to subgrade SG3, with similarly shallow mixed treated fines, in which the highest ammonia concentration was measured.

It is fortunate that ammonia has an odour threshold much lower than the workplace standard, therefore it is unlikely that ammonia would not be noticed should there be a build-up in excavations that may be carried out in FCC-East. Excavation workers/contractors should be made aware of the possibility of ammonia and carry out monitoring if ammonia odour is detected in confined spaces.

With respect to constructing buildings, there is still uncertainty with respect to subgrades SG6 and SG20, with perhaps a lesser uncertainty for subgrades SG8, SG12 and SG17. However, it is understood that TDC has no plans for construction of buildings in these areas (Jenny Easton, pers. comm.).

With respect to plants, no information has been found as to what soil concentrations might inhibit growth. In general, plant health is not a consideration for commercial developments as soil can be replaced, however, soil replacement is not effective in the case of gas. A trial and error approach could be adopted.

4.0 Groundwater Monitoring

4.1 Reasons for audit recommendations

The network of on-site groundwater monitoring wells following the remediation works was sparse compared to sites of a similar nature and size. This resulted in uncertainties regarding the groundwater flow directions, and seasonal variations of flow direction and water level. In addition, there was little information on contaminant concentrations in groundwater within the main body of the site, and variations of those concentrations across the site. Accordingly, the Audit Report recommended installing several more monitoring wells. Of importance in selecting well locations was:

- confirmation that it is unlikely that contaminated groundwater is flowing from FCC-East to FCC-West;
- clarifying whether there is a southerly component of groundwater flow from FCC-East towards the residential properties on Tahi Street, and if so, how significant any ADL, DDX and nitrate contamination in the groundwater under those properties might be, given some of the properties have wells; and
- improving estimates of the mass flux of contaminants discharging to the marine environment.

The Audit Report further recommended that the existing and new wells be monitored quarterly for a year after which time the hydrogeological model was to be reviewed. As part of the assessment, a water balance for the site was to be developed. Ongoing monitoring was to be reviewed as part of the assessment.

4.2 Information reviewed

The following groundwater monitoring reports were reviewed:

- *Groundwater Monitoring at the Former FCC Site, Mapua – July 2009 Sampling Update*. Letter report to Tasman District Council, Pattle Delamore Partners Limited, Christchurch, 26 August 2009 (PDP, 2009b)
- *Groundwater Monitoring at the Former FCC Site, Mapua – November 2009 Sampling Update*. Letter report to Tasman District Council, Pattle Delamore Partners Limited, Christchurch, 28 January 2010 (PDP, 2010a)
- *Groundwater Monitoring at the Former FCC Site, Mapua – February 2010 Sampling Update*. Letter report to Tasman District Council, Pattle Delamore Partners Limited, Christchurch, 19 March 2010 (PDP, 2010b)
- *Groundwater Monitoring Review Following Soil Remediation at the Mapua FCC Site*. Report to the Tasman District Council prepared by Pattle Delamore Partners Limited, Christchurch, March 2011 (PDP, 2011)

The main document is the final document (PDP, 2011); the other reports being a record of some of the monitoring events contributing to the main report. The report of the July 2009 quarterly monitoring (PDP, 2009b) was before the additional monitoring wells were installed, with the November 2009 monitoring event (PDP, 2010a) being the first after the additional wells were installed. Only passing consideration was given to the quarterly reports in this review.

4.3 Information gaps

A number of the quarterly reports were not seen. This is not considered an important gap, as the March 2010 review report summarises the data over the year-long period of monitoring.

For wells within FCC-West and wells close to or within the residential properties on Tahi Street, it would have been helpful to have considered aldrin+dieldrin separately from lindane, in assessing potential risk to human health from groundwater use. Instead the report has used ADL. It is not clear why ADL is being used because the groundwater monitoring conditions in the original resource consents for the remediation required separate consideration of aldrin, dieldrin and lindane. Since then the drinking-water maximum allowable values (MAV) have been revised by the Ministry of Health, with an MAV for aldrin and dieldrin combined now being 0.00004, but the MAV for lindane remaining the same at 0.002 mg/L. Using ADL in the report makes a proper comparison with the individual MAVs impossible.

The report does not tabulate the important laboratory results nor append the laboratory reports. While the data is presented graphically as time plots, the lack of tabulated results means individual results cannot be ascertained with any certainty.

4.4 Review of groundwater monitoring

4.4.1 New monitoring well locations

The recommended new monitoring well locations and corresponding new wells, with comments as to suitability are as follows:

Recommended wells	Newly installed wells	Comment
At least one upgradient well in the vicinity of the northwest corner of the site to obtain background.	BH113	Fulfils intent of recommendation.

A well midway along the western boundary of FCC-West.	BH105	Fulfils intent of recommendation.
A well in the south-east corner of FCC-West.	BH103	Fulfils intent of recommendation
A well in the former vicinity of the MCD plant.	BH106	Fulfils intent of recommendation.
A well roughly at the midpoint of the south-western quadrant of FCC-West.	–	Not installed.
Two wells spaced out along the western boundary of FCC-East.	BH107, BH108	Generally fulfils intent of recommendation although BH107 is further south than ideal.
Two wells spaced out along a line running north-south midway across FCC-East.	BH110, BH111	Fulfils intent of recommendation.
A well in the vicinity of the former surge chamber location where there is a gap in the clay bund.	BH112	Fulfils intent of recommendation.
Ideally, wells either side of the clay bund installed on the eastern boundary of the FCC Landfill site.	BH101, BH102	Fulfils intent of recommendation
Wells additional to that recommended.	BH104, BH109	Centre of FCC-East and central southern part of FCC-West.

Eleven wells were recommended and a total of 13 wells were actually installed by TDC, generally at the locations recommended. The new and existing wells were monitored quarterly for an appropriate range of parameters, again as recommended. In addition, a number of new and existing wells were slug-tested to obtain estimates of hydraulic conductivity at a range of locations and within a range of backfill types.

Overall the intent of the recommendation with respect to installing and monitoring additional wells was fulfilled.

4.4.2 Hydrogeological model review

A review of the hydrogeological model was carried out as recommended. This included:

- reassessing the groundwater flow directions for different groundwater levels;
- calculating a water balance; and
- calculating groundwater throughflow and, combined with groundwater contaminant concentrations, estimating contaminant mass flux at the east and west foreshores.

The groundwater throughflow was calculated in two ways; using hydraulic conductivity estimates from the slug tests and calculating an average hydraulic conductivity using tidal fluctuations. When the water balance was considered, the estimate from the tidal fluctuations appears to be more reliable; throughflow calculated using the lower (by about an order of magnitude) average hydraulic conductivity estimate from the slug tests was lower than the estimated infiltration for the site, in violation of basic water balance considerations.

The essential conclusions of the hydrogeological review were:

- groundwater enters the site from throughflow from the land to the north of Aranui Road, as well as from the direct infiltration of rainwater from within the site soils (an expected conclusion);
- the majority of the groundwater moves through the site and exits to the Mapua Channel to the east and to the western site drain and the Waimea Inlet to the south-west;
- a small proportion of the site contributes to groundwater flow across the southern boundary of the site, which then moves towards the west and eastern coastal margins of the Mapua peninsula;
- the slug tests suggest local hydraulic conductivities of 0.8 – 9 m/day, equivalent to silty sand, whereas the tidal analysis suggests a bulk hydraulic conductivity of the order of 10 – 100 m/day, equivalent to clean sand; and
- an indicative throughflow is 72,000 m^3/year (200 m^3/day) of which about a sixth (12,000 m^3/year) is from rainfall infiltration.

The report noted that tidal analysis was more likely to be correct for the bulk groundwater flow while the slug test results were indicative of the local strata in which the wells were installed. The report also noted that the slug tests involved only a small volume of aquifer strata and that the results might have been influenced by the filter sock and backfill placed around the standpipes. While the report does not state this, the implication is that the slug test results may underestimate the local hydraulic conductivity. In addition, while PDP

(2011) states that the slug test results are typical of silty sand, review of the borehole logs for both the new and existing monitoring wells (the latter in CH2M HILL, 2007) shows the wells are predominantly installed in sand and sandy gravel, rather than silty sand. The logs reinforce the possibility that the slug tests have resulted in underestimates.

The hydrogeological model review in PDP (2011) (greatly facilitated by the more robust monitoring network) has clarified that there is indeed a component of groundwater flow in the southerly direction towards the residential properties in Tahi Street, as predicted by PDP (2007). Previously (as summarised in the Audit Report), there were conflicting interpretations, with CH2M HILL (2007) showing little flow crossing the site's southern boundary. The confirmed southerly flow component confirms the potential for risk to private bores to the south of the site from groundwater contamination. The current (PDP, 2011) interpretation suggests greater southerly flow during times of high (winter) water levels than at times of low water level.

4.4.3 Groundwater monitoring results

The groundwater report (PDP, 2011) summarises the groundwater sampling in the 13 new and 11 existing wells, and two foreshore seeps, for the four quarterly monitoring events to that point. The report also updates the interpretation of sampling in the five existing wells (including 13 Tahi Street) for which a much longer record exists. The format of the latter interpretation is the same as previous monitoring reports, in that time-series plots are presented for nitrate-N, ammonia-N, phosphorus, DDX, ADL, conductivity, copper and iron. The report also presents site plans showing the spatial relationship of wells with exceedances of drinking-water MAVs for nitrate and DDX for November 2010. Similar diagrams are presented for other analytes for which MAVs do not exist, showing different coloured symbols for different concentration bands. The colour coding provides an immediate, and very useful, visual representation of the spatial variation of the contaminants across the site, albeit in broad concentration bands.

It is apparent that some wells exceeded the nitrate MAVs in FCC-West in November 2010 but all the wells in the residential part of FCC-West complied with the DDX MAV. A similar diagram is presented for ADL, but as noted above it is not possible to interpret such a diagram against the aldrin + dieldrin (A+D) or lindane MAVs. It would have been useful to have had similar diagrams for other monitoring events, although the report notes that contaminant concentrations tended to be highest for the November 2010 event.

The report does not specifically discuss the incidence of MAVs being exceeded within FCC-West over the year of quarterly monitoring. This is important as the regional plan permits installation of groundwater bores with minimal restrictions within this residentially-zoned area and therefore exceedances result in a potential health hazard. However, it is apparent from the time plots presented in the report that the nitrate-N MAV was exceeded on several occasions for new well BH104 and existing well BH9A, but all wells within the residential part of FCC-West (but not the landfill) complied with the DDX MAV throughout the year.

Unfortunately a similar assessment cannot be made for A+D on the information presented. However, past monitoring has shown that A+D typically makes up about 80 to 90 % of the ADL in groundwater. Given the drinking-water MAV for A+D is 0.00004 mg/L, an "equivalent MAV" for the A+D component of ADL would be about 0.00004/0.8, or 0.00005 mg/L. It is apparent from the ADL time plot (although a logarithmic scale on the vertical scale would have greatly assisted interpretation) that most results in FCC-West, and also 13 Tahi Street, exceeded this adjusted MAV over the year of monitoring.

This confirms the recommendation in the Audit Report that the groundwater under FCC-West should be assumed to be unsuitable for human consumption. The monitoring shows this to be the case for A+D for most of the monitoring well locations and for nitrate-N at some locations. The reality is that few if any bores would be installed for drinking-water purposes, given the reticulated supply, and therefore a health risk would not arise, but it is not possible to entirely discount this.

Wells with notably high ADL concentrations close to the southern boundary of the site adjacent to residential properties include BH103 and BHH. However, other information in the report suggests that, even though the groundwater flow direction indicates groundwater with contamination in excess of drinking-water guidelines is encroaching on residential properties, the concentrations at existing private bores are below the DDX and A+D MAVs (see Figure 27 of PDP (2011)). This is consistent with contaminants such as dieldrin and DDT having limited mobility within groundwater; such contaminants having a strong tendency to bind to organic material within the aquifer materials. The report notes that none of the private bores are used for potable water, all properties being on the reticulated town supply.

4.4.4 Contaminant mass flux

The report presents mass flux calculations for the discharge of total nitrogen, DDX and ADL to the eastern and western foreshores by multiplying the average groundwater concentration in wells near each foreshore and an estimate of the groundwater discharge to each foreshore. The groundwater discharge was calculated using the lower hydraulic conductivity estimated from the slug testing (0.35 m/day), rather than the estimate from the tidal analysis, on the basis that "*the lower hydraulic conductivity values … are representative of the strata from* *where the contaminant concentrations have been measured*". The report further notes that the mass flux calculations are "*a very broad ballpark indication*".

Using the low hydraulic conductivity estimate (which translates to a discharge rate of 1.36 m^3/day compared with 197 m^3/day if the "bulk" hydraulic conductivity is used) is to use the low extreme of what is a large range of possible estimates of mass flux (covering about two orders of magnitude) particularly, as noted above, the hydraulic conductivity estimates from the slug tests may be underestimates of the true situation. However, to calculate mass flux using groundwater discharge calculated from the hydraulic conductivity estimate from the tidal analysis (which would result in values about 140 times higher than presented in Table 5 of PDP (2011)) is probably to go too far to the other extreme. Ideally, the report would have presented both the low and high estimates as the possible extremes, rather than just a low estimate as a "ballpark". Then it would have been clear that the most that can be said is the "true" contaminant mass flux for the November 2010 monitoring lies somewhere between the two extremes. However, to calculate more accurate values would require more accurate determination of the hydraulic conductivity than has been possible to date.

The groundwater report correctly notes that that there is significant dilution within the marine environment, and points out the main issues requiring consideration are local effects at the discharge points before significant dilution has occurred. The monitoring to date of the eastern and western foreshore seeps indicates substantial dilution has already occurred at the sample points. In addition, biological monitoring by Davidson et al. (2011), not available to the authors of PDP (2011) at the time of writing their report, shows minimal effects on the health of the foreshores (as measured by algae cover and shellfish and macroinvertebrate species diversity). As is discussed in Section 5.0, below, Davidson et al. (2011) were not able to distinguish possible effects from contamination from natural variation. That is not to say that nutrients discharging to the foreshores are not causing effects such as algal blooms but these effects are not so great as to be worse than typical algal blooms elsewhere. Given these finding, obtaining more accurate estimates of contaminant mass flux has assumed a lower importance than before.

4.5 Recommendations for ongoing monitoring

The groundwater report reviewed the numbers and frequency of wells to be sampled in future. The following recommendations were made:

- annual sampling (in November) for all but six of the existing and new monitoring wells, including off-site wells;
- sampling a smaller set of eight wells quarterly, being three of the five existing long-term wells and five new wells ;

- quarterly monitoring for only turbidity, pH, electrical conductivity, nitrate-N, ammoniacal-N, DDX and ADL (i.e. removing copper, iron, dissolved reactive phosphorus, nitrite-N, TKN and total N from the quarterly monitoring as less significant);
- as a one-off, monitoring of lindane in bores at 21, 23, 29 and 36 Tahi street, and analysis of quality control samples, in an attempt to confirm that low-level lindane detections in these wells in November 2010 was a sampling or laboratory problem; and
- installing a transducer to continuously monitor water level and conductivity in BH 110 so as to better understand the generation of contaminant leachate;

We concur with the general approach of annual monitoring as the main focus and reducing both the number of wells more frequently sampled and the number of analytes. However, we are not convinced that all the recommendations are appropriate. Specific comments, in the context that the biological monitoring of the foreshores has generally shown a satisfactory situation (information not available to the authors of PDP (2011)) and therefore there is now less concern with respect to groundwater discharges, and in the context that there is only limited migration of contaminants towards Tahi Street to the south, are:

1. Consideration should be given to reducing the intermediate monitoring to six-monthly rather than quarterly. It is the long term trends rather than the detail of the variation from one monitoring event to the next that is most important. If there is a marked increase in observed effects on the foreshore, e.g. sudden appearance of much greater algal blooms than at present, then closer examination of the groundwater may then be warranted.

2. The one-off monitoring of lindane in the off-site wells is not necessary given the small detections in November 2010 were about two orders of magnitude lower than the drinking-water MAV. While there should be a general focus on high quality sampling and laboratory analysis, the focus should be on more important analytes such as dieldrin. Analysis of blank samples is appropriate as part of the normal sampling.

3. The appropriateness of continuous monitoring of water level and conductivity in one well is questionable. While it is probable that there is a link between water level and groundwater contaminant concentration as a result of more or less treated fines being submerged, attempting to establish a relationship with effects on the foreshore are likely to be beyond what data from a single well will provide. From the data presented for BH110, there is not an obvious relationship between conductivity and water level, or between each of conductivity and water level and nitrate-N, ADL and DDX.

5.0 Marine Sediment and Biota Monitoring

5.1 Overview

Recommendations 6, 7 and 9 from the Audit Report relate to the post-remediation marine sediment and biota sampling. In summary the recommendations were:

- Review of the monitoring programme by an appropriately qualified person to confirm the current monitoring programme was sufficient.
- Continuing with annual monitoring, taking account of any recommendations from the review above, with a review of the monitoring frequency after a further two rounds.
- Benchmarking of the health and diversity of the marine ecosystem on the foreshores.

The detail of the recommendations is in Appendix A.

5.2 Review of Monitoring Programme

5.2.1 Reason for recommendation and information reviewed

The Audit Report recommended that the marine sediment and snail sampling programme should be reviewed given the altered habitat and the different species that had recolonised the FCC-East site following the foreshore remediation. The review was to:

- confirm that monitoring topshell snails on the eastern foreshore (as opposed to mudflat snails which were originally sampled but did not recolonise following remediation) is the most appropriate method of assessing risk via seafood consumption;
- consider the need for confirmatory sampling of other biota and extending the programme to improve its statistical robustness; and
- determine whether the sediment sampling is properly representing the quality of the surface sediments.

The following document was reviewed:

- *Review of snail sampling protocols for the east intertidal shore adjacent to the FCC remediation site, Mapua* report prepared for the Tasman District Council and the Ministry for the Environment by Davidson Environmental, September 2009 (Davidson 2009).

5.2.2 Assessment

Davidson (2009) reviewed previous reports including that produced by Landcare Research in 2002 (Landcare, 2002), as specifically recommended in the audit report. During a site visit associated with the monitoring programme review, it was noted that mudflat snails were actually present at the FCC-East site for the first time since the remediation works were completed. Based on this observation it was considered that mudflat snails may in fact be present in sufficient numbers to collect a composite sample during future monitoring. The presence of other candidates (such as cockle and crab) for ongoing contaminant sampling at the FCC-East site was also assessed.

The review acknowledged that contaminant levels historically recorded from topshell snails at the site are dramatically lower than the levels recorded from mudflat snails, potentially related to the fact that topshell snails often feed on hard strata such as shells and rocks (which may exhibit lower contaminant levels) rather than exclusively on soft sediments. However, both species had shown a declining trend in contaminant levels in the three monitoring rounds carried out following the foreshore remediation.

Overall, the review by Davidson (2009) resulted in no recommended changes concerning the monitoring at FCC-West and the following recommendations in relation to the ongoing sampling regime for FCC-East:

- topshell snail monitoring should continue as results can be directly compared to 2007 – 2009 data. Separate sampling of topshells from hard and soft substrata was suggested as a means of indicating whether there is a relationship between the substratum and contaminant levels in topshells;
- collection of one sample from a cockle bed located at the south end of the FCC-East site to help determine the relationship between snail contaminant levels and contaminant levels within this edible shellfish, to aid in the assessment of human health risks at the site;
- at least one and preferably two composite mudflat snail samples (depending on species abundance) should be collected within 10m of the foot of the rock wall; and
- after the first sampling event, the FCC-East site should be seeded with at least 300 mudflat snails collected from the western control site, as one year (before subsequent sampling) should provide sufficient time for the snails to exhibit any contamination from the tidal flats at the FCC-East shore.

Davidson (2009) considered but rejected sampling of additional species as a method of determining whether contaminant levels are declining as it would likely provide no better indication of contaminant levels than existing sampling.

The Audit Report queried the statistical robustness of the sediment sampling to that point. The report recommended that in addition to the existing the following sediment sampling locations should be considered:

- three additional locations parallel to the western foreshore, approximately 20 m from the foreshore edge, evenly spaced along the foreshore;
- two additional locations parallel to the eastern foreshore, approximately 5 m from the base of the sea wall.

However, the monitoring review did not discuss these suggestions nor did it include discussion on the sample size in relation to statistical robustness, although such things may have been considered but not reported.

Overall it is considered that the review was carried out as recommended by the audit (PDP 2009a). The recommendations made by Davidson (2009) are considered to be generally appropriate to guide the ongoing sampling programme and increase the level of information available with which to measure the environmental effects of the residual contamination present at the FCC site.

5.3 2009/2010 Marine Sediment and Biota Sampling Rounds

5.3.1 Reason for recommendation and information reviewed

In addition to the recommendation to review the appropriateness of the monitoring programme, a number of specific recommendations were made in the Audit Report with respect to the sediment and biota monitoring. These were intended to increase the level of information available on which to base future decisions on whether the local foreshore effects are acceptable relative to the likely large cost and environmental disruption of attempting further remedial works at the FCC site. This was in the context of the foreshore remediation not achieving the sediment SACs set out in the resource consent, and therefore being less successful than intended.

The main recommendation was to continue with the monitoring for a further two annual rounds to give a better dataset to judge an apparent improving trend, followed by a review of the ongoing extent and frequency. A number of technical recommendations were also made, including:

- Sampling of sediments both at the surface (0–2 cm) and below the surface (2–10 cm) to see whether sediment deposition was having an effect on surface contaminant concentrations.
- Measuring total organic carbon (TOC) and undertaking a particle size distribution on 50% of samples collected during the first monitoring round to obtain a better understanding of the substrate.
- Keeping detailed field and photographic records of all observations.

Sediment and biota sampling was carried out in October 2009 and November 2010, and was reported in the two documents that are the subject of this review:

- *Post-remediation monitoring of sediments and biota from estuarine sites located adjacent to the former Fruitgrowers Chemical Company (FCC) site, Mapua, Nelson* (Davidson et al. 2010).
- *Draft Post-remediation monitoring of sediments and biota from estuarine sites located adjacent to the former Fruitgrowers Chemical Company (FCC) site, Mapua, Nelson (sample 2)* (Davidson et al. 2011).

5.3.2 Assessment

The sampling as carried out included:

- Assessment of levels of pesticides in sediment. Samples were collected from the locations which had previously been sampled during the post-remediation consent monitoring and at the additional locations recommended in the Audit Report.
- Collection of shallow (0 – 2 cm) and deep (10 – 20 cm) samples at all sampling locations in 2010 and most sampling location in 2009, with the exception being no deeper samples were collected within the stream in 2009.
- Assessment of oganochlorine pesticides (OCP) in molluscs (mudflat and topshell snail, cockle).
- Analysis of TOC in all 2009 samples of shallow and deep sediments.
- Particle size analysis of over 50% of the 2009 samples.
- Redox assessment of sediments.

5.3.2.1 Conduct of the sampling

The 2009 and 2010 sediment and biota sampling was generally undertaken as recommended in the Audit Report. However, the deeper sediment samples were reported as being collected from 10 – 20 cm, not 2 – 10 cm as recommended in the audit. The intent of the recommendation for the deeper sampling was to assess sediment likely to be within the range of biological activity, typically the top 10 cm of sediments (Simpson et al. 2005). However, discussion with the primary author (Rob Davidson, pers. comm.) has clarified that in fact all of the deeper samples were collected from locations close to 10 cm in depth and always between 7 and 13 cm depth, despite what is stated in the reports. It is noted that Table 1 of each report states the samples are from 10 – 20 cm in depth, while Page 30 of Davidson et al. (2010) states that the samples are from 15 –20 cm in depth, as do several of the tables (e.g. Table 6 in Davidson et al. 2010 and Table 6b in Davidson et al. 2011). These discrepancies are unfortunate.

For future reporting it is recommended for the sake of transparency and repeatability that the actual depth of each individual sample be stated in the report. The interpretation of long-term trends can be meaningful only if there is confidence that the sampling has been carried out consistently (including at consistent depth) across monitoring events.

The exact method of sampling sediment is not clear. The Audit Report recommended using a sediment corer with a core extruder to ensure depth consistency and therefore increase confidence in any long-term trends exhibited by the monitoring results. It is unclear from the description of the sampling method whether depth consistency would have been achieved.

5.3.2.2 Pesticides in sediment results

The results of the sediment monitoring as indicated by Davidson et al. (2010 and 2011) can be briefly summarised as follows:

- Around two thirds of the shallow samples collected from the FCC-West and FCC-East foreshore impact sites met the SAC for ADL (0.01 mg/kg) in both 2009 and 2010. None of the shallow samples from the stream impact sites met the SAC for ADL in either year, however.
- None of the shallow samples from any of the foreshore or stream impact sites achieved the SAC for DDX (0.01 mg/kg) in 2009 or 2010.
- The highest values for DDX and ADL in the surface samples collected were detected in the three stream samples. The two upstream sampling sites returned higher concentrations in 2010 than the samples from 2009. Levels of DDX at the upper and middle stream sites in 2010 were 7.18 and 4.94 mg/kg, respectively, compared with 5.36 and 1.09 mg/kg in 2009; while levels of ADL were 0.17 and 0.10 mg/kg, respectively, compared with 0.06 and 0.06 mg/kg in 2009.
- Shallow samples from both the West and East control sites exceeded the SAC for DDX in 2010.
- Over half of the deeper samples from the foreshore impact sites met the SAC for ADL in each monitoring round, however only a few of the deeper foreshore samples met the SAC for DDX.
- None of the three deeper stream samples from 2010 met the SAC for ADL or DDX, however the results were lower than those from samples collected at the surface.
- Deeper sediment samples from the control sites also returned results at or above the SAC for DDX; the West Control site in 2009 and the East Control site in 2010 (not both control sites in 2010 as reported by Davidson et al. (2011) – see note below).
- The highest contaminant concentrations in the deeper samples were detected in the samples from the FCC-East foreshore.

- Several deeper samples from the FCC-East site returned markedly higher DDX concentrations in 2010 compared with the 2009 samples (e.g. JME 088 – 0.14 vs 23.76 mg/kg; JME 087 – 0.08 vs 11.98 mg/kg).
- The highest results for ADL across all samples in both rounds (0.33 mg/kg in 2009 and 0.22 mg/kg in 2010) were detected in the deeper sediment samples from JME 090 which is by the rock wall at FCC-East.
- An assessment of long-term (2005-2010) trends for pesticide levels in surface sediments (where data are available) indicates that the mean concentrations of DDX, lindane and dieldrin have decreased from the levels found in 2005 and 2007 to much lower levels from 2008 onwards.

With respect to the control site, the elevated DDX result for the deeper sample at the West Control site in 2010 appears to have been miscalculated by Davidson et al. (2011) in Table 6b. Based on the reported results for DDT and its derivatives, which include five non-detects (<0.0011 mg/kg) and one detection of 0.0013 mg/kg for 4,4-DDT, the correct DDX value would appear to be 0.00405 mg/kg, which is below the SAC.

For the surface samples from the two control sites which were reported to exceed the SAC for DDX in 2010, it is noted that one third (East Control) and one half (West Control) of the relevant analytes were at non-detect levels, with the detections generally only slightly above the detection limits. The ADL and DDX levels have been calculated by Davidson et al. (2011) using half of the detection limit when non-detects were reported for various analytes. This method is widely applied and acceptable (see MfE 2004, Guideline No. 5), but it should be noted that it could result in over-estimation of the actual level of contaminants present.

Notwithstanding the above, the results from the control sites indicate that there are chlorinated pesticides present in sediments at the control sites. Davidson et al. (2010) report that both control sites were sampled prior to sampling of impact sites and therefore cross-contamination during sampling is improbable, and that it is likely that the contamination at deep control sites is due to historic contamination of the wider estuary, while the contamination of shallow sediments may be due to the more recent relocation of contaminated sediments within the estuary. Future re-sampling at the control sites will help clarify whether there is contamination at these sites or whether these results are an anomaly.

In terms of the long-term trend analysis presented in Table 7 of Davidson et al. (2011), it appears that the ADL results for both control sites from the 2009 and 2010 monitoring rounds have been inserted into the DDX columns of the table in error. It is uncertain whether these incorrect results have been used to calculate the means for DDX presented in the graph in Figure 10[5]. Use of the correct result has the effect of raising the calculated means very slightly compared to using the dataset presented in Table 7, however not to the extent that the interpretation of long-term trends by the authors would differ.

Comment on stream results

Samples from the upper and middle stream sampling had higher ADL and DDX concentrations in the 2010 sampling compared with the 2009 sampling, however the lower (downstream) site had the reverse. Davidson et al. (2011) considered the increases to be beyond that expected from normal variability and concluded that it is probable that a contaminated soil hotspot buried close to the stream is contaminating the stream substrate via seepage of groundwater from adjacent terrestrial sediments. The authors asked for comment from the auditor regarding the latest results.

The source of the recently detected increase in contamination levels in the stream surface sediments is unclear, however we consider it unlikely that it is a result of seepage of contaminated groundwater as suggested by Davidson et al. (2011). Concentrations of DDX and ADL in the groundwater are too low to have caused such a large change in a short period.

There are several possibilities for the observed results, all of which, on their own or in combination, are more likely than the postulated seepage mechanism. These are, in no particular order:

(a) The stream bottom is as is has been since the remediation and the two sampling rounds have simply picked up spatial variability, as it is not possible to sample exactly the same place on each occasion.

(b) The change is real as a result of residual contamination from the base of the remediation excavation slowly working its way up to the surface through the relatively open-textured gravel of the replacement bed (although the deeper samples having lower concentrations tends to suggests otherwise).

(c) The stream is contaminated upstream of where it has been remediated (i.e. outside the legal boundaries of the site) and this has worked its way down to the sampled stretch of the stream.

(d) Residual contamination within the banks of the remediated stream section has been eroded during flood events between the two sampling events.

[5] Noting that the caption for Figure 10 states that the data in the figure are averages from pooling control and impacted sites. It would seem statistically invalid to combine control and impacted sites when the objective is to assess the reduction in contaminant concentrations of the remediation, i.e. on the impacted sites.

A less likely reason is:

(e) Transport of contaminated soil from the remediated FCC-West. However, as FCC-West should be completely covered with imported "clean" soil and is well grassed, any small amount of sediment that might be transported should not be contaminated.

The Audit Report noted that there were elevated concentrations (in excess of 1 mg/kg) of DDX present in the sediment at the base of the creek remediation excavation. 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. Thus there is a potential source remaining under the backfilled creek bed. The audit also noted that some moderately elevated concentrations of DDX were remaining in sediment adjacent to the creek, creating a source should the bank erode. However, at that time it was considered that as the creek was covered with a layer of clean gravel during remediation and the banks of the creek were heavily vegetated, the potential for sediment to mobilise from the creek bed and/or adjacent hotspots was reduced. No erosion of the stream bed or banks was specifically noted in the recent monitoring rounds therefore no conclusion can be drawn as to whether bank erosion is a likely source.

It should be noted that soil contamination is typically variable over short distances, and even sample duplicates taken from the same nominal location can be quite different. The differences between the observed results taken at different times from what will inevitably be slightly different locations are not particular great in that context. Thus Davidson et al.'s view that the results are a definite indicator of recontamination between 2009 and 2010 is not necessarily the case. Further sampling is required over an extended period to confirm or otherwise such a hypothesis.

5.3.2.3 Mollusc contaminant sampling

The results of the sampling of snails and cockles from FCC West and East foreshores can be summarised as follows:

- Samples of cockles in FCC-East returned low results for DDX and ADL relative to the two snail species sampled.
- Samples of topshells from FCC-East while relatively low for both DDX and ADL, returned slightly higher results in both 2009 and 2010 compared with 2008.
- Samples of mudflat snails from FCC-East, not sampled since before the remediation began, had DDX concentrations a little above 1 mg/kg in both years, about a third of the concentration last measured in 2005. ADL concentrations (principally dieldrin) were about an order of magnitude lower than the DDX concentration in 2009 and 2010.

- ADL and DDX concentrations in topshells were lower than concentrations recorded in mudflat snails from FCC-East, as was expected. Slightly higher results were obtained for those topshells living in soft sediments compared with those collected from hard substratesa.
- Samples of mudflat snails from FCC-West had higher concentrations of both DDX (22.09 mg/kg) and ADL (0.525 mg/kg) compared with samples taken earlier in 2008 (Easton 2008) and in February 2009 Easton (2009). Subsequent samples taken in June 2010 (Easton, 2010) and November 2010 (Davidson, etc al., 2011) were lower, with the November 2010 results similar to those obtained by Easton in February 2009.

<u>Comment on mollusc results</u>

DDX and ADL in cockles from FCC-East were elevated above levels found in cockles from the control site, but according to the authors, the levels recorded (0.0033mg/kg in 2009 and 0.0026 mg/kg) are comparable to studies of cockles in other urban estuaries and were below available US and Canadian guidelines for the protection of wildlife consumers and human health. The actual guideline values are not presented in the report and this would be useful in future reporting to provide some context.

Overall, while results vary from year to year, levels of DDX and ADL in mudflat snails (the main indicator organism) appear to be exhibiting a long-term decreasing trend, however no statistical analysis has been undertaken to confirm this. No ongoing risk assessment is provided in relation to the levels obtained and no guideline or acceptable values are presented in the reports to provide context to the results, although it is noted that these have been stated in past reports (e.g. Easton, 2008 and Easton, 2009) as 20 mg/kg wet weight for DDX and 0.2 mg/kg wet weight for dieldrin, based on New Zealand Food Safety Authority (NZFSA) advice to TDC for human consumption of 20 snails per day.

Accepting the NZSFA advice as reasonable, some brief analysis of the FCC-West snail and sediment results since 2007 for both DDX and dieldrin has been attempted here. The snail and sediment data include that obtained by Easton (2007, 2008, 2009 and 2010). These results are shown in Table 1, below.

Table 1: FCC-West Mudflat Snail and Sediment DDX and Dieldrin Concentrations (mg/kg) [1]

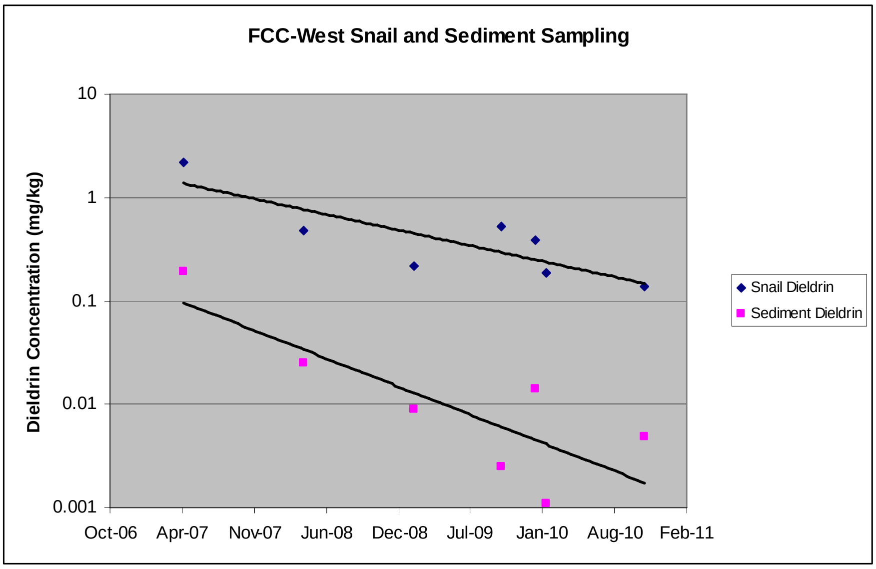
	Snail DDX	Sediment DDX	Snail Dieldrin	Sediment Dieldrin	BAF	
					DDX	Dieldrin
May-07	51.14	16.6	2.18	0.19	3	11
Apr-08	10.34	0.987	0.48	0.025	10	19
Feb-09	3.5	0.23	0.22	0.009	15	24
Oct-09	22.09	0.1416	0.52	0.0025	156	208
Jan-10	13	0.49	0.39	0.014	27	28
Feb-10[2]	5.8	0.0515	0.185	0.0011	113	168
Nov-10	4.716	0.144	0.139	0.0049	33	28
				Mean	**59**	**79**
				Geometric mean	**37**	**48**

Note: 1. Snail concentration are wet weight and sediment concentrations are dry weight
2. Means of two locations

When plotted against time (see Figure 2 next page) a reducing trend for sediment and snails for both DDX and dieldrin is apparent, although there is a relatively large amount of scatter (e.g. the October 2009 results). The lines fitted to the data (exponential, which show as straight lines on semi-logarithmic plots) suggest a reducing trend. The trend shown is probably too steep, with the line expected to flatten out with time if more data were available.

Davidson et al. (2010) showed a similar reducing trend (in the bar plot of Figure 10) for average concentrations in sediment (rather than just the sediment associated with the snail samples) but did not attempt to plot trends in snails.

Table 1 also shows calculated bioaccumulation factors (BAF), being the ratio of snail and sediment concentrations. Examination of the data suggests that the BAF may increase as the sediment concentration reduces. To examine this, the BAF values were plotted against sediment concentration (Figure 3).



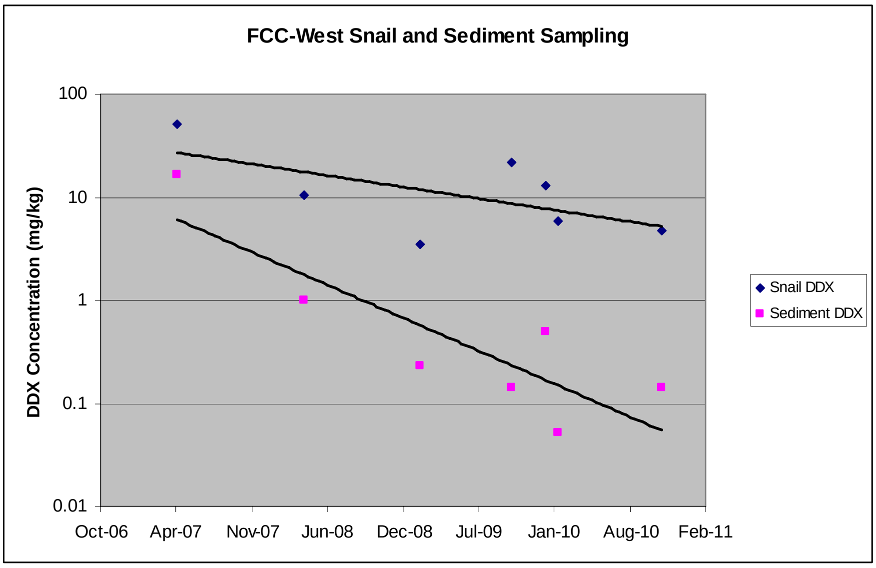


Figure 2: Variation of Snail and Sediment DDX and Dieldrin Concentrations with Time

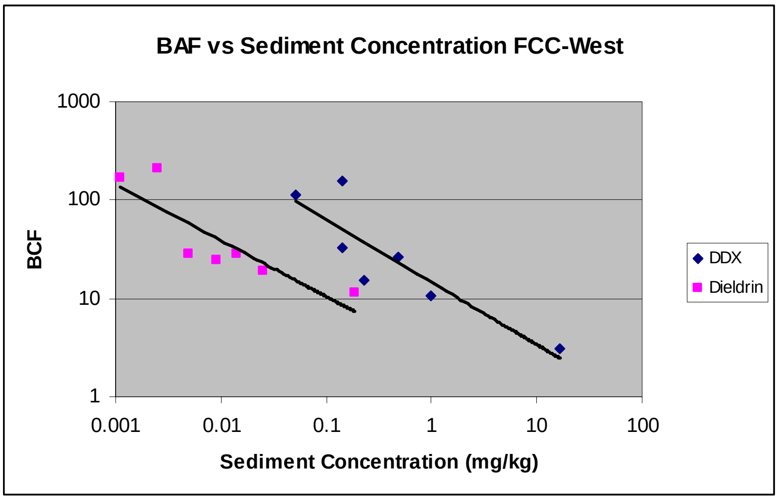


Figure 3: Snail BAF versus Sediment Concentration

Again there is considerable scatter (masked by the log-log plot), but the data do suggest an inverse relationship between BAF and sediment concentration. While there are insufficient data to develop a relationship with any certainty, the trend lines suggest that DDX sediment concentrations less than about 1 – 2 mg/kg will result in the mudflat snail DDX concentration complying with the NZFSA advice (i.e. a BAF of about 10 applies at this concentration). Similarly, for dieldrin a sediment concentration of less than about 0.002 mg/kg may result in compliance with the NZSFA advice (BAF of about 100). (Note: the October 2009 results have a significant influence on the trend lines, suggesting possible statistical outliers).

The original sediment SACs were set on the basis of an allowable shellfish concentration of 0.1 mg/kg (understood to be the default value where a food maximum residue level has not been set) and BAFs of 10 for both dieldrin and DDX (Egis, 2001). Given the NZFSA advice for dieldrin is a little higher than that used to set the SACs, but the BAF appears to be considerably higher, the SAC for dieldrin may not, in fact, be protective for human consumption of mudflat snails. However, the uptake of dieldrin appears to be much lower for some other shellfish such as cockles, for which there would be no concern.

5.3.2.4 Total organic carbon and particle size analysis

The assessment of total organic carbon (TOC) and particle size has been undertaken as recommended in the audit. However, no attempt was made to use the results to consider bioavailability and/or bioconcentration in the molluscs.

5.4 Marine Ecosystem Benchmarking

5.4.1 Audit Recommendation

The Audit Report recommended benchmarking of the health and diversity of the marine ecosystem on the foreshores, comparing the foreshores against suitable control sites. Related to this was a recommendation to maintain a written and photographic record of areas of algae on the foreshore thought to be resulting from nutrient-rich groundwater seeps.

The intent was to:

- gauge whether the residual pesticide contamination was having an adverse effect on the foreshore ecosystem relative to other areas within the estuary without such contamination;
- provide a benchmark against which future improvements in the foreshore sediments may be assessed; and
- provide additional information on localised effects on the foreshore of nutrients in groundwater.

5.4.2 Monitoring

A variety of biological sampling and other monitoring was conducted at FCC and control sites in the spring of both 2009 and 2010 (Davidson et al., 2010 and 2011). This consisted of:

- photographs of macroalgae cover collected from the impacted foreshores and control sites. Three locations were selected at the FCC-West site and two were chosen for FCC-East. The locations were marked in such a way that near identical photographs could be taken on each occasion;
- estimating percentage macroalgae cover from the a series of 1m^2 quadrats on each foreshore;
- sampling macroinvertebrates from four impacted foreshore sites and two control sites. At each site, surface counts of conspicuous macroinvertebrates were carried out; and
- collecting three replicate core samples from each macroinvertebrate site for sorting and identification of species. All cockles obtained from core samples were measured for maximum length. To increase the sample size, additional cockles were collected and a representative sub-sample was also measured.

5.4.3 Conduct of monitoring

The biological monitoring fieldwork appears to have been carried out appropriately to fulfil the intent of the audit recommendation, although field sheets are not included in the report and were not examined. It is noted that redox cores (not specifically recommended by the audit) have been collected and photographed as a further measure of nutrient enrichment; a useful enhancement.

5.4.4 Results

Macroalgae cover was absent or at low levels at the control sites. Lower levels of microalgae were noted at FCC-East compared with FCC-West. The macroalgae cover at FCC-West was dominated by *Enteromorpha* sp. confirming the freshwater influence on the foreshore. Macroalgae percentage cover (expressed as mean values from 14 contiguous $1m^2$ quadrats sampled at each impact and control site) declined at all sites between 2009 and 2010.

Davidson et al. (2011) are of the view that the FCC East and West sites have a low biomass bloom of macroalgae when compared to some blooms in estuaries around New Zealand. The authors concluded that the relatively small spatial scale and low biomass suggest that nutrient enrichment is not excessive in this area

Macroinvertebrate cores and surface counts found no obvious evidence that species diversity or numbers of individuals are lower at the FCC East and West sites compared with the control sites. In addition, the populations at FCC East and West are not dominated by enrichment-indicating species. There are clear differences in community composition between the sites but Davidson et al. (2011) concluded that this was mainly related to environmental variables, rather than the pesticide contamination. The authors noted that estuarine environments are notoriously patchy, with relatively high variation being commonplace, even between sites situated in close proximity.

5.4.5 Conclusion

While there is some evidence of nutrient enrichment, the limited nature of this and the lack of obvious pesticide impacts on the foreshore ecosystems suggests there is little reason to consider further remediation to improve the foreshore habitat at this stage.

The results of the two studies provide a suitable basis for future comparisons.

5.5 Review of Future Monitoring Scope

Davidson et al. (2011) have provided recommendations for future monitoring at the site, as was recommended in the Audit Report. Based on the results obtained in 2009 and 2010, and in particular the increases in contaminants noted at FCC-East and in the stream, the authors have recommended (with our further comment added):

1. Further collection of surface and within sediment invertebrate data is not required as there is a sufficient baseline dataset for any future comparison.

   We concur with this assessment. Any future collection of such data would be on an ad hoc basis as a result of a perceived significant change to conditions, e.g. a significant change to algae coverage, a major change in observed snail populations or significant changes in sediment contaminant concentrations. The need for further invertebrate sampling should be reassessed in each annual monitoring report.

2. Annual monitoring of contaminants from all sample locations at shallow and deep strata should continue, with a periodic review to assess the need for ongoing monitoring.

   We also concur with this recommendation, however only because of the linkage with the snail sampling (see next recommendation). If snail sampling frequency is able to be reduced then sediment sampling frequency can be reduced in concert. All samples should be analysed for ADL and DDX.

   Care should be taken to ensure samples are taken from consistent depth intervals across monitoring rounds. Detailed field observations, including sediment colour, should be recorded for each sample.

3. Topshell snail collection at the FCC-East site not be continued for any future monitoring as there are now sufficient numbers of mudflat snails to obtain a sample and mudflat snails are a better indicator of mollusc contamination than topshells. Cockle sampling should be continued during any ongoing monitoring.

   We concur with this recommendation, however Davidson et al. (2011) did not state whether sampling of other molluscs should continue. Recent sampling has shown dieldrin to be generally above the NZFSA maximum residue limit recommendation for dieldrin in shellfish at FCC-West, with an excursion above the NZFSA recommendation for DDX in 2009. Given this, continued annual sampling of mudflat snails at FCC-West is appropriate.

   For the two occasions sampling was possible since the remediation, the concentrations of ADL and DDX in mudflat snails from FC-East were lower than FCC-West for DDX but similar to FCC-West for dieldrin. Given there are only two sample occasions with results close to the NZFSA dieldrin recommendation, continued mudflat sampling is also appropriate for FCC-East.

If future samples consistently drop below the NZFSA residue limit recommendations (at least two consecutive results) then consideration can then be given to reducing the sampling frequency. Regardless, we recommend that a review of the entire monitoring scope is carried out after a further three rounds of monitoring. At that stage there will be a dataset of at least five for each sample location and depth, providing the opportunity for long-term trend analysis to be undertaken.

Information on the number and size of the individuals making up the samples should continue to be recorded.

4. Ongoing monitoring of redox and macroalgae is unnecessary unless contaminant levels increase to levels of concern or nuisance blooms occur.

   We do not fully support this recommendation. The redox cores were not a specific recommendation of the audit and it is agreed that ongoing collection of these is not necessary. However, it is stressed that detailed field observations should be kept of the appearance of sediments at the time each sediment sample is collected. This information could be useful in interpreting results e.g. sudden changes in contaminant levels.

   It is considered that regular macroalgae assessment should continue at the site at least in the interim, as it would be useful to confirm the influence of nutrient discharges in groundwater and whether algal levels are stable. The Audit Report noted that nutrient discharges resulting from the use of diammonium phosphate during the remediation can be expected to continue for an extended period of time.

   The ongoing macroalgae assessment should consist of continuing to take and assess the panoramic photographs, with the more intensive quadrat-based assessment being undertaken only if a marked increase in bloom is observed at any of the sites. If increases in algae are noted, any relevant groundwater monitoring results from the perimeter of the site should be examined to see if there is a linkage.

5. Ongoing monitoring of TOC and particle size is unnecessary unless contaminant levels increase to levels of concern or nuisance blooms occur.

   We concur with this recommendation.

6. Four additional sample sites within the stream be collected; three on the northern bank of the stream and one upstream of the existing sample locations, in order to clarify if an unidentified contaminant "hotspot" at the site is influencing instream contaminant levels.

We are not convinced that such sampling will be adequate to clarify whether an unidentified hotspot is recontaminating the stream. Also, as noted in our earlier comments on the 2009 and 2010 stream sampling results, it has not been definitively established that recontamination is occurring and, if it is, there are a number of possible mechanisms.

A much larger number of samples than suggested by Davidson et al. (20011) would be required to establish possible sources of recontamination, but this still would not necessarily establish whether recontamination is actually occurring. In addition, it is not clear whether what is known to this point is a problem for either the stream or the inlet. Given this, our view is that ongoing annual monitoring of the stream-bed sediment at the same locations as 2009 and 2010 is appropriate to better establish:

(a) whether recontamination is actually occurring and whether this is having a significant adverse effect on the stream (and therefore might lead to further investigation to guide possible further remediation); and

(b) whether contaminated sediment in the stream is mobile and, if so, whether it is a significant source of contamination for the FCC-West foreshore (and therefore might also lead to further remediation).

In addition to the sediment monitoring the stream adjacent to the FCC site should be examined for evidence of seeps or bed/bank erosion.

Finally, in addition to the Davidson et al. (2011) recommendations (as modified by our comments), we recommend that a risk assessment section be added to the report. This could be brief (in the absence of any significant unexpected increases in contaminant levels) but would greatly assist putting the results as a whole into context. Any contemplation of additional remediation (e.g. within or adjacent to the stream channel) would need to be justified on the basis of excessive risk to human and environmental receptors.

6.0 Conclusions and Recommendations

6.1 Soil Sampling QA/QC

Comparison of the QA/QC sample results found good correspondence was achieved between the Hill's Mapua Screen analysis method and the Hill's and AsureQuality standard methods for both ADL and DDX. Given this, a similar decision would have been reached whether to accept or reject soil during the remediation regardless of whether Hill's Screen Method or one of the other two more accurate methods had been used.

The Mapua Screen method used during the remediation and the screen method used on the current samples are supposedly the same, however, given the Validation Report found the majority of samples from soil remaining on FCC-West complied with the DDX SAC but around two thirds of the 15 samples from the current study exceed the DDX SAC, there is a question whether the screening method used during the remediation was systematically underestimating the DDX concentration relative to the screen and standard methods used in the current study.

If it is assumed the current 15 samples are representative of the FCC-West soil immediately below the 0.15 m thick clean topsoil layer, the intent of the remediation to comply with the SAC was not achieved over much of FCC-West with respect to DDX, contrary to the conclusion of the Validation Report.

If it is further assumed that soil from the 0.15 m deep clean surface layer will be mixed over time within gardens with a similar amount of the contaminated soil from below the surface layer, and the exposed soil within gardens is the source of the risk to the marine environment that the DDX SAC is intended to counter, then the average concentration after mixing indicated by the current sampling is similar to the SAC and therefore the risk to the marine environment posed by the currently recorded concentrations appears acceptable.

6.2 Ammonia Soil Gas Monitoring

Monitoring of soil gas in three FCC-East subgrades where mixed treated fines have been buried during the remediation confirmed the potential for ammonia generation. However, the monitoring within subgrades SG3, SG7 and SG14 found only low concentrations of ammonia gas. Comparison with workplace exposure limits suggests only a low risk of excessive concentrations within confined spaces within future building constructed in these areas.

The recommendation within the Audit Report was not intended to be restricted to the three subgrades that were monitored. Other subgrades, in particular subgrades where undiluted treated fines were buried at shallow depth (SG6 and SG20), may have a greater potential for ammonia build-up.

While the current monitoring gives some comfort that excessive ammonia concentrations will not build up in confined spaces over most of FCC-East, there is uncertainty for subgrades SG6 and SG20. While it is understood there are no plans for construction in these areas, should this change it is recommended that either engineered measures be put in place to prevent gas ingress or a soil gas assessment is carried out as part of building design.

Ammonia has an odour threshold much lower than the workplace exposure standard, which means that it is likely to be noticed before hazardous concentrations build up. Excavation workers/contractors should be made aware of the possibility of ammonia and carry out monitoring if ammonia odour is detected in excavations or other confined spaces.

The monitoring has not assisted determining whether the detected ammonia concentrations are a threat to any plants that might be planted within the affected soil.

6.3 Groundwater Monitoring

Overall the intent of the recommendation with respect to installing and monitoring additional wells was fulfilled.

A review of the hydrogeological model was carried out as recommended. This review has clarified that there is a component of groundwater flow in the southerly direction towards the residential properties in Tahi Street, confirming the potential for risk to private bores to the south of the site from groundwater contamination. The current interpretation suggests greater southerly flow during times of high (winter) water levels than at times of low water level.

Groundwater quality monitoring found that some wells in FCC-West exceeded the nitrate MAVs in the residential part of FCC-West but all the wells in this part of the site complied with the DDX MAV. Results presented for ADL rather than the individual compounds precludes a comparison with the individual compound MAVs. However, based on the assumption that aldrin + dieldrin typically makes up about 80 to 90 % of the ADL in groundwater, most results in FCC-West, and also 13 Tahi Street, exceeded an adjusted MAV over the year of monitoring. This confirms the recommendation in the Audit Report that the groundwater under FCC-West should be assumed to be unsuitable for human consumption.

Wells with notably high ADL concentrations close to the southern boundary of the site, adjacent to residential properties, include BH103 and BHH. However, other information in the groundwater report suggests that concentrations at existing private bores are below the DDX and aldrin + dieldrin MAVs. This is consistent with contaminants such as dieldrin and DDT having limited mobility within groundwater.

Slug testing of a number of new and existing monitoring wells to obtain hydraulic conductivity estimates was carried out as recommended in the audit. The average hydraulic conductivity obtained of 0.35 m/day is consistent with a silty sand aquifer. This is somewhat at odds with the observed geology reported in the borehole logs; typically sand and sandy gravel, suggesting that the slug test may be underestimating the hydraulic conductivity. An alternative analysis, using tidally induced groundwater level fluctuations, resulted in an average estimate of 50 m/day, consistent with a sand aquifer.

Calculations of contaminant mass flux of total nitrogen, DDX and ADL in the report used the lower hydraulic conductivity estimate. The resultant mass fluxes are probably low estimates. It is likely the mass flux actually lies somewhere between the estimates produced using the low hydraulic conductivity value and higher estimates that could have been calculated using the higher hydraulic conductivity values. However, as the report notes, substantial dilution of the groundwater discharges is available in the marine environment. Given the biota monitoring by Davidson et al. (2011) shows minimal effects on the health of the foreshores, obtaining more accurate estimates of contaminant mass flux has assumed a lower importance than before.

The groundwater monitoring programme was reviewed as recommended in the audit. We generally concur with the report’s recommended approach of annual monitoring for most wells with a reduced number of wells sampled and the number of analytes reduced during the intervening quarterly events. However, in light of the results of biological monitoring in the foreshore environment being satisfactory and only limited migration of contaminants towards Tahi Street we recommend:

- consideration should be given to reducing the intermediate monitoring to six-monthly rather than quarterly. If there is a marked increase in observed effects on the foreshore, closer examination of the groundwater may then be warranted;
- the proposed one-off monitoring of lindane in the off-site wells to assess a sampling or laboratory quality issue is not necessary; and
- the proposed continuous monitoring of water level and conductivity in one well is not necessary.

Future monitoring should separately report and interpret aldrin, dieldrin and lindane, not the ADL summation. Including the tabulated monitoring data in the reports rather than just in graphs would be helpful.

6.4 Marine Sediment and Biota Monitoring

The monitoring programme was reviewed and two rounds of marine sediment and biota monitoring a year apart were generally carried out appropriately. A key recommendation of the monitoring review was to return to sampling mudflat snails from the eastern foreshore, as sufficient recolonisation since the remediation has now occurred.

There were some deficiencies in the implementation and reporting of the two monitoring rounds. In particular, the deeper sediment samples were not strictly collected in accordance with the audit recommendation and the monitoring reports contain a number of discrepancies with respect to the sample depths. In addition, the exact method of sediment sampling is not clear. This affects the confidence placed on long-term trends inferred from the data, whether current or in the future. Future monitoring should be carried using a methodology that ensures consistent sample depths.

The biota monitoring could not separate out natural variability in the foreshore ecology from possible effects of the residual pesticide contamination in the foreshore sediments. While there is some evidence of nutrient enrichment, the limited nature of this and the lack of obvious pesticide impacts on the foreshore ecosystems suggests there is little reason to consider further remediation to improve the foreshore habitat at this stage. The results of the two studies provide a suitable basis for future comparisons.

Pesticide concentrations within mudflat snails (the main indicator organism for risk to human health from shellfish gathering) vary from year to year. However, concentrations of DDX and ADL appear to be exhibiting a long-term decreasing trend. Despite the residual pesticide concentrations in the foreshore sediment exceeding the remediation target, concentrations of DDX and dieldrin within mudflat snails comply or are close to complying with NZFSA recommendations. If the apparent reducing trend continues, routine compliance with these recommendations should be achievable at some point in the future.

Sampling of sediment in the stream adjacent to FCC-West found an apparent increase in pesticide concentrations. The monitoring report suggested recontamination from groundwater seepage, however we consider this unlikely. There are several possible explanations for the observed results and further sampling of stream-bed sediment is required to determine whether recontamination is in fact occurring.

Key recommendations relating to the ongoing monitoring recommended by Davidson et al. (2011) are as follows:

1. The need for any further invertebrate sampling should be reassessed in each annual monitoring report.

2. Annual monitoring of ADL and DDX contaminants from all sample locations at shallow and deep strata should continue. Care should be taken to ensure samples are taken from consistent depth intervals across monitoring rounds. Detailed field observations, including sediment colour, should be recorded for each sample.

Topshell snail collection at the FCC-East site should not be continued. Cockle sampling should be continued during any ongoing monitoring. Continued annual sampling of mudflat snails at FCC-West and FCC-East is appropriate. Information on the number and size of the individuals making up the samples should continue to be recorded.

If future samples consistently drop below the NZFSA residue limit recommendations (at least two consecutive results) then consideration can then be given to reducing the sampling frequency. Regardless, we recommend that a review of the entire monitoring scope is carried out after a further three rounds of monitoring.

3. Ongoing sampling of redox cores is unnecessary, however detailed field observations should be kept of the appearance of sediments at the time each sediment sample is collected. Ongoing monitoring of TOC and particle size is also unnecessary unless contaminant levels increase to levels of concern or nuisance blooms occur.

4. Regular macroalgae assessment (continuing to take and assess the panoramic photographs) should continue at the site at least in the interim, with the more intensive quadrat-based assessment being undertaken only if a marked increase in bloom is observed at any of the sites. If increases in algae are noted relevant groundwater monitoring results from the perimeter of the site should be examined to see if there is a linkage.

5. Ongoing annual monitoring of the stream-bed sediment is appropriate to better establish whether recontamination is actually occurring, whether contaminated sediment in the stream is mobile and whether there are any resulting significant adverse environmental effects. This should be reviewed after three years. In addition, the stream adjacent to the FCC site should be examined for evidence of seeps or bed/bank erosion. Sampling of the stream banks is not recommended unless recontamination is confirmed and an associated environmental risk identified.

6. A risk assessment section should be added to the Monitoring Report.

References

Canadian Council of Ministers of the Environment (CCME) (1999). *Canadian Environmental Quality Guidelines. Canadian Tissue Residue Guidelines for the Protection of Wildlife Consumers of Aquatic Biota*. Canadian Council of Ministers of the Environment, Winnipeg, Canada

CH2M HILL (2007). *Groundwater and Sediment Investigation Report - Former Fruitgrowers Chemical Company Site*, Mapua, CH2M HILL Australia Pty Ltd, New Zealand, August 2007.

Davidson, R. J. (2009). *Review of snail sampling protocols for the east intertidal shore adjacent to the FCC remediation site, Mapua*. Survey and monitoring report no. 607, prepared for Tasman District Council and Ministry for the Environment, Davidson Environmental Ltd, Nelson.

Davidson, R. J.; Richards, L.A.; Easton, J. (2010). *Post-remediation monitoring of sediments and biota from estuarine sites located adjacent to the former Fruitgrowers Chemical Company (FCC) site, Mapua, Nelson*. Survey and monitoring report no. 616, prepared for Tasman District Council and Ministry for the Environment, Davidson Environmental Ltd, Nelson.

Davidson, R.J.; Richards, L.A.; Easton, J. (2011). *Post-remediation monitoring of sediments and biota from estuarine sites located adjacent to the former Fruitgrowers Chemical Company (FCC) site, Mapua, Nelson (sample 2)*. Survey and monitoring report 680, prepared for Tasman District Council and Ministry for the Environment, Davidson Environmental Ltd, Nelson.

DoL (2010) *Workplace Exposure Standards and Biological Exposure Indices*. 4th Edition, September 2010, Department of Labour, Wellington

Easton, J. (2007). *Report on snails and sediment a year after East and West beach remediation.* Tasman District Council, Internal Report, 11 July 2007

Report on Snails and Sediment Quality, second annual round after FCC west and east beach remediation. Tasman District Council, Internal Report 9 June 2008

Easton, J. (2009). *Report on Snails and Sediment Quality, third annual round after FCC west and east beach remediation*. Tasman District Council, Internal Report, 3 March 2009

Easton, J. (2010). *Repeat sampling of West FCC, using the two new sites on FCC West beach,Feb 17th 2010*. Tasman District Council, Internal Report, 4 March 2010

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

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 (2004). *Contaminated Land Management Guidelines No.5: Site Investigation and Analysis of Soils*. Ministry for the Environment, Wellington, New Zealand.

MfE (2011). *Methodology for Deriving Standards for Contaminants in Soil to Protect Human Health*. Ministry for the Environment, Wellington, June 2011. http://www.mfe.govt.nz/publications/hazardous/deriving-standards-for-contaminants-in-soil/index.html

PDP (2007). *Report on Groundwater Issues Arising from the Mapua FCC Site, at Completion of the MCD Soil Remediation Process*, Report to Tasman District Council, Pattle Delamore Partners Ltd, Christchurch, December 2007.

PDP (2009a). *Audit of the Remediation of the former Fruitgrowers Chemical Company Site, Mapua*, Report prepared for the Ministry for the Environment, Pattle Delamore Partners Limited, Wellington, 30 June 2009

PDP (2009b)*Groundwater Monitoring at the Former FCC Site, Mapua – July 2009 Sampling Update*. Letter report to Tasman District Council, Pattle Delamore Partners Limited, Christchurch, 26 August 2009

PDP (2010a) *Groundwater Monitoring at the Former FCC Site, Mapua – November 2009 Sampling Update*. Letter report to Tasman District Council, Pattle Delamore Partners Limited, Christchurch, 28 January 2010

PDP (2010b) *Groundwater Monitoring at the Former FCC Site, Mapua – February 2010 Sampling Update*. Letter report to Tasman District Council, Pattle Delamore Partners Limited, Christchurch, 19 March 2010

PDP (2011). *Groundwater Monitoring Review Following Soil Remediation at the Mapua FCC Site*. Report to the Tasman District Council prepared by Pattle Delamore Partners Limited, Christchurch, March 2011

SKM (2008). *Site Validation Report for the Former Fruitgrowers Chemical Company Site, Mapua*, Sinclair Knight Merz, Auckland, New Zealand, 11 December 2008.

Simpson SL, Batley GE, Chariton AA, Stauber JL, King CK, Chapman JC, Hyne RV, Gale SA, Roach AC, Maher WA (2005). *Handbook for Sediment Quality Assessment*. CSIRO. Bangor, NSW.

URS (2010a) *Former Fruitgrowers Chemical Company Site (FCC), Mapua - Ammonia Gas Survey Investigation*, report prepared for Tasman District Council by URS New Zealand Limited, Christchurch, 8 February 2010

URS (2010b) *Former Fruit Growers Chemical Company Site (FCC) Mapua Ammonia Gas Survey Investigation- Part 2*, letter report to Tasman District Council, URS New Zealand Limited, Christchurch, 21 May 2010

Appendix A Recommendations from Remediation Audit Report

The following recommendations are reproduced from the Audit Report (PDP, 2009a). The recommendations were made to reduce some uncertainties and gaps in the information provided for the remediation audit, and 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.

Appendix B FCC-West QA/QC Sampling Results

Table B-1: Results of FCC-West Soil Sampling Analysed by Three Methods

TDC Sample ID	West Soil JME 110	West Soil JME 111	West Soil JME 112	West Soil JME 113	West Soil JME 114	West Soil JME 115	West Soil JME 116	West Soil JME 117	West Soil JME 118	West Soil JME 119	West Soil JME 120	West Soil JME 121	West Soil JME 122	West Soil JME 123	West Soil JME 124
Hills Mapua Pesticide Screen (Detection Limit 0.5 mg/kg)															
2,4'-DDD	1	0.98	0.86	< 0.50	1.5	1.1	< 0.51	< 0.50	1	1.4	0.73	0.55	< 0.50	< 0.50	< 0.52
4,4'-DDD	3.2	2.9	2.9	< 0.50	3.8	2.4	< 0.51	1	1.9	3.8	2.1	1.5	< 0.50	< 0.50	1.4
2,4'-DDE	< 0.50	< 0.51	< 0.52	< 0.50	0.55	< 0.50	< 0.51	< 0.50	< 0.50	< 0.51	< 0.50	< 0.50	< 0.50	< 0.50	< 0.52
4,4'-DDE	1.5	1.4	1.1	< 0.50	2.3	1.6	0.6	0.81	1.7	2	1.2	1.3	< 0.50	< 0.50	0.92
2,4'-DDT	< 0.50	< 0.51	< 0.52	< 0.50	1.1	< 0.50	< 0.51	< 0.50	0.75	0.78	< 0.50	0.87	< 0.50	< 0.50	< 0.52
4,4'-DDT	2.6	4.3	2.6	< 0.50	8	7.7	< 0.51	1.8	11	6.3	3.8	4	< 0.50	0.59	2.3
DDX	**8.80**	**10.09**	**7.98**	**1.50**	**17.25**	**13.30**	**1.88**	**4.36**	**16.60**	**14.54**	**8.33**	**8.47**	**1.50**	**1.84**	**5.40**
Aldrin	< 0.50	< 0.51	< 0.52	< 0.50	< 0.50	< 0.50	< 0.51	< 0.50	< 0.50	< 0.51	< 0.50	< 0.50	< 0.50	< 0.50	< 0.52
Dieldrin	< 0.50	< 0.51	< 0.52	< 0.50	0.86	0.57	< 0.51	< 0.50	0.84	0.79	0.63	0.92	< 0.50	< 0.50	< 0.52
Lindane	< 0.50	< 0.51	< 0.52	< 0.50	< 0.50	< 0.50	< 0.51	< 0.50	< 0.50	< 0.51	< 0.50	< 0.50	< 0.50	< 0.50	< 0.52
ADL	**0.53**	**0.54**	**0.55**	**0.53**	**1.14**	**0.85**	**0.54**	**0.53**	**1.12**	**1.07**	**0.91**	**1.20**	**0.53**	**0.53**	**0.55**
AsureQuality Pesticide Screen (Detection Limit 0.01 mg/kg)															
2,4'-DDD	0.59	0.59	0.56	0.03	1.1	1.1	0.03	0.2	0.86	0.96	0.47	0.31	0.03	0.087	0.38
4,4'-DDD	2.4	2.3	2.2	0.061	5.1	4	0.03	0.5	5.1	5.5	0.86	0.54	0.063	0.2	0.71
2,4'-DDE	0.22	0.24	0.24	0.03	0.34	0.32	0.03	0.08	0.25	0.36	0.15	0.11	0.03	0.065	0.11
4,4'-DDE	0.97	1.2	1.4	0.078	2	1.7	0.51	0.55	1.6	2.5	1.1	1.1	0.21	0.35	0.7
2,4'-DDT	0.47	0.7	0.48	0.051	1.4	0.83	0.21	0.46	2.1	2	0.79	2	0.21	0.29	0.6
4,4'-DDT	1.9	2.1	2.3	0.25	10	4.2	0.82	1.2	9	8.6	2.1	7.4	1.1	0.84	0.74
DDX	**6.55**	**7.13**	**7.18**	**0.50**	**19.94**	**12.15**	**1.63**	**2.99**	**18.91**	**19.92**	**5.47**	**11.46**	**1.64**	**1.83**	**3.24**
Aldrin	0.03	0.03	0.03	<0.01	0.03	0.03	<0.01	0.03	0.057	0.03	0.078	0.03	<0.01	<0.01	0.03
Dieldrin	0.33	0.3	0.31	0.03	0.54	0.54	0.11	0.25	1.6	0.64	0.48	0.67	0.13	0.15	0.3
Lindane	0.03	0.03	0.03	<0.01	0.03	0.03	<0.01	0.03	0.03	0.03	0.03	0.03	<0.01	<0.01	0.03
ADL	**0.36**	**0.33**	**0.34**	**0.04**	**0.57**	**0.57**	**0.12**	**0.28**	**1.66**	**0.67**	**0.56**	**0.70**	**0.14**	**0.16**	**0.33**

Notes:
1. Yellow shading indicates values have been reported as "Trace". The laboratory defines Trace values as being between 0.05 mg/kg and the detection limit of 0.01 mg/kg. In the table and for the purposes of calculation such values are shown as the average of the two values, rounded to two decimal places.
2. Blue shading indicates value below the reported detection limit. In calculations, a value of half the detection limit has been used.
3. DDX = the sum of the six DDD, DDE and DDT isomers.
4. ADL = the sum of aldrin, dieldrin and 10% lindane

Table B-1: Results of FCC-West Soil Sampling Analysed by Three Methods

TDC Sample ID	West Soil JME 110	West Soil JME 111	West Soil JME 112	West Soil JME 113	West Soil JME 114	West Soil JME 115	West Soil JME 116	West Soil JME 117	West Soil JME 118	West Soil JME 119	West Soil JME 120	West Soil JME 121	West Soil JME 122	West Soil JME 123	West Soil JME 124
Hills Standard Oganochlorine Analysis (Detection Limit = 0.01 mg/kg)															
2,4'-DDD	0.74	0.78	0.79	0.036	1.1	1.2	0.026	0.25	0.79	1	0.56	0.36	0.061	0.11	0.33
4,4'-DDD	2.1	2.1	2.1	0.088	3.4	3.7	0.098	0.7	1.9	2.7	1.5	0.83	0.15	0.29	0.85
2,4'-DDE	0.32	0.34	0.27	0.017	0.41	0.39	0.019	0.1	0.38	0.77	0.19	0.14	0.045	0.075	0.13
4,4'-DDE	1.4	1.5	1.2	0.086	1.9	1.8	0.54	0.61	1.9	2.7	1.2	1.1	0.28	0.34	0.71
2,4'-DDT	0.84	0.69	0.62	0.035	1.3	1.2	0.18	0.46	1.8	1.5	1.2	1.8	0.22	0.24	0.51
4,4'-DDT	3.8	3.5	3.2	0.21	13	8.3	0.79	2.3	10	10	4.8	5.3	1	1.3	2.5
DDX	**9.20**	**8.91**	**8.18**	**0.47**	**21.11**	**16.59**	**1.65**	**4.42**	**16.77**	**18.67**	**9.45**	**9.53**	**1.76**	**2.36**	**5.03**
Aldrin	0.057	0.042	0.055	< 0.010	0.05	0.055	< 0.010	0.02	0.2	0.062	0.073	0.07	0.09	< 0.010	0.024
Dieldrin	0.34	0.41	0.37	0.014	0.66	0.65	0.1	0.29	0.72	0.7	0.51	0.72	0.14	0.17	0.24
Lindane	0.019	0.014	0.017	< 0.010	0.024	0.023	< 0.010	0.02	0.063	0.026	0.036	0.029	0.061	< 0.010	0.024
ADL	**0.40**	**0.45**	**0.43**	**0.02**	**0.71**	**0.71**	**0.11**	**0.31**	**0.93**	**0.76**	**0.59**	**0.79**	**0.24**	**0.18**	**0.27**

Notes:
1. Blue shading indicates value below the reported detection limit. In calculations, a value of half the detection limit has been used.
2. DDX = the sum of the six DDD, DDE and DDT isomers.
3. ADL = the sum of aldrin, dieldrin and 10% lindane