Appendix C

Case Studies
CASE STUDIES

C.1 CASE STUDY 1: KURE ATOLL, HAWAII

Site Name: Green Island Landfill and Reburial Pit, Kure Atoll, Hawaii

Contact Name: Roger Brewer, HDOH

Site Location: Kure Atoll is the northernmost island in the Hawaiian Island chain, located approximately 1400 miles northwest of the island Oahu and 56 miles northwest of Midway atoll. The atoll consists of a lagoon encircled by a reef and a single vegetated island, Green Island. Green Island is just under 1.5 miles long and about 0.35 miles wide and has a maximum elevation of 15 feet.

C.1.1 Background and Previous Investigations

This case study summarizes the investigation of a former landfill site on Kure atoll, a remote island in the central Pacific Ocean. A detailed discussion of the investigation is presented in the report Evaluation of Green Island Landfill and Reburial Pit, Former U.S. Coast Guard LORAN Station Kure (USCG 2009). A copy of the report is available from the HDOH Hazard Evaluation and Emergency Response Office.

Kure atoll is the northernmost island in the Hawaiian island chain, located approximately 1400 miles northwest of the island of Oahu and 56 miles northwest of Midway atoll (see Figure C.1-1). The atoll consists of a lagoon encircled by a reef and a single, vegetated island (Green Island, Figure C.1-2). Green Island is just under 1.5 miles long and about 0.35 miles wide and has a maximum elevation of around 15 feet. The island is not inhabited on a permanent basis although it is visited periodically by marine research groups.

A USCG station was located on the atoll from the 1960s through the 1990s. When the station was operating, a small, approximately ½-half acre area on the southwest corner of the island was used to dispose of old electrical components and scrap metal (e.g., capacitors, batteries, and transformers, see Figure C.1-2). Debris and approximately 700 yd³ of PCB-contaminated soil were removed from the site in 1993. Discrete, confirmation soil samples identified concentrations of PCBs as high as 170 mg/kg within the former landfill footprint (see Figure C.1-3). Soil, sediment, and biota samples collected in the surrounding area indicated that PCB contamination was primarily restricted to the landfill site.
Figure C.1-1. Kure Atoll location map. Source: USCG 2009, Figure 2-1.
Figure C.1-2. Green Island map showing location of former landfill area.

Source: USCG 2009, Figure 2-2.

NOTES
1) 1992 data includes both field test lab data and tab data. If sample was analyzed in the lab, the lab data is listed. Data based on the 1993 USACE Waste Pile Site Investigation Report.
2) 1993 Post-Remediation Sample locations are estimates based on Exhibit 2 in the 1994 RMC Remediation Report.
3) Only results greater than 50 ppm shown for both 1992 and 1993.
C.1.2 DU-IS Investigation (2008)

C.1.2.1 DU-IS Investigation Approach

A follow-up study of the former landfill area was carried out in 2008. The investigation focused on the use of decision unit and incremental sampling investigation strategies published by the HDOH Office of Hazard Evaluation and Emergency Response (HDOH 2008b). Note that incremental soil samples are referred to as “multiincrement” soil samples in the HDOH guidance.

C.1.2.2 DU Designation and Investigation Objectives

The footprint of the former landfill area was designated as a spill area DU, based on the past history of the site and the approximate extent of PCB-contaminated soil identified in the earlier investigations. An 80 × 180 foot DU was established, covering an area of approximately 15,000 ft². The targeted depth interval of the DU was 3 feet, although in some cases samples were collected to a depth of 5 feet. The total volume of the soil incorporated by the DU was approximately 2,700 yd³.

The objective of the investigation was to estimate the representative (i.e., mean) concentration of PCBs for the designated DU mass of soil. Identification of the maximum concentration of PCBs for any given aliquot mass of soil within the DU or sample-size hot spots was determined not to be feasible or, more importantly, necessary. The area and volume of the DU were considered to be small enough for evaluation of potential risks to ecological and human receptors. Risk-based decisions on the need for additional remedial actions at the site would be made for the mass of soil incorporated within the spill area DU as a whole. Incorporating these objectives into the design of the investigation was intended to help minimize the need for additional, follow-up investigation and to avoid confusion over the need to investigate and address smaller, sample-size hot spots within the DU as a whole.

C.1.2.3 Landfill DU Characterization

As part of the site investigation, USCG took the opportunity to evaluate the potential advantage and limitations of incremental sampling methodology (ISM) over traditional, discrete sampling approaches. More than 600 discrete samples were collected from within the landfill footprint. Splits of the discrete samples were combined and used to prepare IS samples for targeted areas and depth intervals.

A 10-foot spaced sampling grid was initially established across the entire landfill footprint (see Figure C.1-4). Three depth intervals were targeted for characterization: 0–4 inches (152 samples), 28–36 inches (128 samples), and 36–60 inches (128 samples). A split sample or increment was randomly collected from each discrete sample. Increments for targeted areas and depth intervals were combined into a single ISM sample for that interval. Triplicate ISM samples were prepared for the 36–60 inch interval, for a total of five ISM samples for the DU as a whole.
Each ISM sample was air-dried and passed through a 2 mm (#10) sieve to remove larger particles. An aliquot was prepared by collecting and combining thirty 1 g increments of soil from a sample. The aliquot was tested for PCBs using a RaPID Assay Immunoassay field kit. Splits of discrete samples submitted to a laboratory for gas chromatograph analysis indicated good correlation with the immunoassay field kit data.
Figure C.1-4. Ten-foot and five-foot sampling grids used in 2008 ISM study.

Source: USCG 2009, Figure 3-1.

C.1.2.4 Landfill DU ISM Results

Reported concentrations of PCBs in the 0–4 inch, 28–36 inch, and 36–60 inch interval ISM samples were 0.35, 2.5, and 40 mg/kg, respectively (see Figure C.1-5). Reported concentrations of PCBs in the two replicate samples collected from the lowermost interval were 36 and 34 mg/kg. Triplicate data suggested a minimal degree of combined field and laboratory error in the samples. This is not surprising, given the large number of increments (i.e., 128–152) collected from each interval.
Figure C.1-5. Summary of ISM investigation results. Source: USCG 2009, Figure 4-1.

PCB data for each of the three targeted intervals indicated contamination above the USEPA Regional Screening Level of 0.22 mg/kg (USEPA 2008); the lower two intervals also exceeded the HDOH soil action level of 1.1 mg/kg (HDOH 2008a). Both of these screening levels are based on continuous, long-term human occupation of an area and are not necessarily applicable to current conditions on the remote, uninhabited atoll. Potential erosion of the former landfill area and dispersal of PCBs into adjacent aquatic habitats is considered to be the primary hazard posed by the contaminated soil. Reported concentrations of PCBs exceeded the marine sediment probably effects level of 0.709 mg/kg (CCME 2001, as referenced in Buchman 2008).

C.1.2.5 Use of Discrete Data to Identify Localized Spill Area

Further characterization of the landfill DU was warranted based on the initial, incremental sample PCB sample data. As part of the study, each of the 600+ discrete samples collected from the targeted intervals of the DU was tested in the field for PCBs. Tables C.1-1a through C.1-1c present a summary of the discrete data results. The discrete data indicate the presence of an approximately 3000 ft² concentrated area of PCB-contaminated soil at depth in the center of the former landfill footprint (see Figures C.1-5 and C.1-6 and Tables C.1-1a through C.1-1c). This area was targeted for a more detailed ISM investigation. Additional soil samples were collected from a 5-foot grid established across the central spill area and for the 28–36 and 36–60 inches depth intervals (refer to Figure C.1-5). Seventy-four discrete samples were collected from each interval. ISM samples were prepared from splits of the discrete samples in the same manner as described above. Sieves were used to separate the soil samples into four size fractions for analysis, >2 mm, ≤2–0.25 mm, <0.25–≤0.063 mm, and <0.063 mm.
Table C.1-1a. Landfill DU PCB discrete data summary, 0–4 inch depth interval  
(USCG 2009, Table B-1)

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### Table C.1c. Landfill DU PCB discrete data summary, 36–60 inch depth interval

(USCG 2009, Table B-3)

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Figure C.1-6. Identification of central spill area using discrete sample data. Isolated sample points >1.1 mg/kg PCBs indicate heterogeneity of PCB distribution in area outside central spill area at the scale of a laboratory aliquot (i.e., 5 g). See also Figure C.1-5.

Source: Modified from USCG 2009, Figure 6-1.

Elevated concentrations of PCBs were also reported in four isolated, discrete sample points, outside of the central spill area (Figure C.1-6). It is important to recognize that the presence of elevated PCBs at these sample points indicate heterogeneity of PCB distribution in area outside of central spill area at the scale of a laboratory aliquot (i.e., 5 g). These sample point locations do not represent plottable spill areas and cannot be treated as such (e.g., potentially excavated and removed as part of a future cleanup action (refer to HDOH 2008b, Section 4.3.5). Instead, the presence of elevated PCBs in four single-sample points outside of the central spill area more likely indicates that the reported concentration of PCBs, in any given discrete sample collected within this area is likely to exceed 1.1 mg/kg a small percentage of the time. Removal of soil around the four, isolated sample points that happened to be identified during the study would not remove all sample-size spots above this screening level outside of the central spill area or reduce the overall mean concentration of PCBs in the soil for this area.
C.1.2.6 Targeted Spill Area DU ISM Results

Figure C.1-5 and Table C.1-2 summarize the reported concentration of PCBs in ISM samples collected from the 28–36 and 36–60 inch depth intervals of the central spill area DU. The concentration of PCBs was highest for the fine soil fraction (<0.063mm), although the mass of PCBs is present in the ≤2 mm to >0.25 mm soil fraction, which makes up 75%–80% of the samples from both intervals. Based on a weighted average of the individual size-fraction data, the total concentrations of PCBs in the <2 mm soil fraction from the two targeted intervals are 15 mg/kg and 33 mg/kg, respectively.

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<th>PCB concentration (mg/kg)</th>
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C.1.3 Comparison of ISM and Discrete Soil Data

Tables C.1-1a, C.1-1b and C.1-1c provide a summary of the discrete sample data for PCBs for each targeted interval. A statistical evaluation of discrete vs. ISM sample data is currently under way. One objective of the review is to compare estimates of the mean concentration of PCBs in the DU soil based on a specific number of discrete samples vs. one to three multincrement samples drawn from the same data set. Examples of the types of questions to be addressed in the evaluation include the following:

- When is the mean estimated by the ISM samples better than the mean estimated from a randomly selected set of discrete data?
- Is the mean estimated by a 30-point ISM sample (or set of triplicates) better than 5 discrete samples (or 10, 15, 20 samples, etc.)?

Specific information that will be determined from the data set is as follows:

- best estimate of “true” mean PCB concentration based on all 93 discrete data points (i.e., adjusted with respect to data variability)
- range of mean estimated by any randomly collected, 30-point ISM sample
- range of mean estimated by any randomly collected set of 30-point, triplicate ISM samples (adjusted with respect to data variability)
range of mean estimated from any randomly collected set of “X” (e.g., 5, 10, 15, 20, 25, 30) number discrete samples (adjusted with respect to data variability)

For the Kure Atoll data set, the objective was to determine the equivalent number of discrete samples to a triplicate set of 30- to 50-point ISM samples. This information will help to determine the cost-effectiveness of collecting ISM samples over discrete samples.

C.1.4 References


C.2 CASE STUDY 2: PETROLEUM CONTAMINATED SOIL STOCKPILE

Site Name: Petroleum Contaminated Soil Stockpile, Prince of Wales Island, Alaska

Contact Name: Earl Crapps, ADEC

Site Location: The site is located on the Prince of Wales Island near Craig, Alaska. Craig is on a small island off the west coast of Prince of Wales Island and is connected by a short causeway. It is 56 air miles northwest of Ketchikan and 220 miles south of Juneau.

C.2.1 Purpose

The purpose of this project was to test the protocols in the Alaska Department of Environmental Conservation multiincrement (MI) sampling guidance.

C.2.2 Location
A small soil stockpile in a rock quarry on Prince of Wales Island near Craig was sampled (see Figure C.2-1). Craig is located on a small island off the west coast of Prince of Wales Island and is connected by a short causeway. It is 56 air miles northwest of Ketchikan and 220 miles south of Juneau.

![Figure C.2-1. Map and aerial photograph of the site location.](image)

**C.2.3 Synopsis**

During the 2006 excavation and removal of an underground heating oil tank, discrete samples were collected which documented diesel range organics (DRO) at 300–900 mg/kg. Stockpile tilling and fertilizing were conducted by the responsible party several times after the soil was moved from its original location in May 2006.

ADEC personnel sampled the stockpile on May 24–25, 2007. MI bulk samples were collected from 90 different locations in the 12–15 yd³ stockpile. Subsamples were sieved to 2 mm and
placed in sample jars for laboratory analysis. Fundamental error (FE), relative standard deviation (RSD), and the 95% UCL of the mean were determined following receipt of analytical results; all calculations were within acceptable parameters. The average DRO concentration was below the Method 2 migration-to-groundwater cleanup level (230 mg/kg).

C.2.4 Field Sampling Procedures

Tools and Materials
- Internet random number generator
- garden shovel
- 20-penny galvanized nails
- hand spade
- stainless steel spoons
- 2-gal zip-lock bags
- colored nylon twine
- 50-foot flexible tape
- 12-foot tape
- stainless steel ruler
- hand calculator
- leather gloves
- disposable latex sampling gloves
- field notebook
- digital camera

Although the edges of the stockpile were not clearly delineated, the stockpile dimensions measured approximately 33 × 13 × 1 feet deep. A 30-cell grid (10 cells long, 3 wide) was constructed using 20-penny nails for stakes and colored twine to form the grid pattern. Each cell measured approximately 40 inches long × 52 inches wide (see Figure C.2-2).

Overall dimensions: 33 × 13 feet
Individual cell dimensions: 52 × 40 inches

NORTH
Random planar and depth coordinates were determined after the cell dimensions were established using an online random number generator. Thirty length coordinates were determined by setting the minimum and maximum numbers in the random number generator between 0 and 40. Thirty width coordinates were determined by setting the minimum and maximum numbers between 0 and 52. Thirty depth coordinates were determined by setting the minimum and maximum numbers between 6 and 12. This method ensured that the top 6 inches of soil would not be sampled, as dictated by the MI sampling guidance.

Sampling locations were determined by assigning X- and Y-axes to the grid. Length was measured along the X-axis beginning at the southwest corner of the cell, followed by a Y-axis, or perpendicular measurement, to determine the width coordinate. A 20-penny nail was pushed into the soil at each coordinate to establish the primary sampling location. For example, the random coordinates for cell #2 were 33 inches along the length (X-axis) and then 18 inches to the north (Y-axis). Beginning at the southwest corner of each cell, this process was repeated until the 30 primary sampling locations were established.
A garden shovel was used to dig the holes to the approximate depth once all planar coordinates were determined. A small hand spade and 12-inch ruler were used to obtain the exact depth at each location and to clean away any soil that may have sloughed from the sidewalls.

Using a stainless steel spoon, three tablespoons of soil (~60 g per increment) were collected from the proper depth at each location and placed in zip-lock bags. If the hole was overexcavated, the sample was taken from the sidewall at the proper depth. This process was repeated until all 30 primary bulk sample increments were collected.

Duplicate and triplicate bulk samples were collected at the same depth as the primary sample within each cell using the procedures described in Figure C.2-3. Sample locations were determined by stepping out approximately one-half the distance of the cell length and width from the primary sample hole. The step-out direction varied depending on the location of the primary sample hole within the cell. For example, if the primary hole was near the far corner to the right, as shown by Figure C.2-3, step-out directions were to the left (duplicate) or down (triplicate). This method ensured an independent and systematic random approach within each cell.

Bulk soil samples, weighing approximately 1.8 kg each, were doubled-bagged, sealed, and taped for shipment (see Figure C.2-4). Samples were not cooled because transit time back to Juneau was minimal. After the samples arrived in Juneau, they were refrigerated until the time of subsampling (see Figure C.2-5).
Figure C.2-4. Photograph showing increment collection.

Figure C.2-5. Photograph of soil sifted through a #10 sieve.
C.2.5 Subsampling Procedures

Tools and Materials

- #10 sieve
- stainless steel trays lined with aluminum foil
- stainless steel spatula
- 4-ounce amber sample jars
- bench scale
- wire brush
- liquid soap
- 12-inch ruler
- disposable latex sampling gloves
- notebook and digital camera

Subsampling was conducted in the Department of Transportation and Public Facilities Materials Lab in Juneau, as shown in Figure C.2-6. Six subsamples were collected, including a duplicate for each of the three subsamples for an additional comparative metric.

Bulk samples were sieved to 2 mm using a #10 sieve. Following an initial attempt at sieving the wet soil (sample HWL 1-1), the bulk samples were placed on trays and dried at room temperature for 30 hours prior to subsampling.

Before sieving, the bulk soil samples each weighed approximately 1.8 kg. Less than half of the bulk sample was removed during the sieving process, leaving approximately 1 kg of soil for use during subsampling.

Sieved soil was spread onto a foil-lined tray with dimensions of about 7 × 10 × 3/8 inches thick. The soil was then evenly divided into a 30-square grid. About 1.5 g was collected from a minimum of two locations in each square using a small spatula to ensure that fine particles were not missed.

The 30 subsample increments, weighing approximately 45 g total, were placed in a labeled, wide-mouth sample jar placed on a bench scale. The process was repeated for the remaining two bulk samples and their duplicates; the spatula was cleaned with soap and water between each bulk subsampling event.
C.2.6 Results

Table C.2-1. Laboratory results (DRO by AK 102)

<table>
<thead>
<tr>
<th></th>
<th>#1 Samples</th>
<th>#2 Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWL 1-1</td>
<td>130 mg/kg</td>
<td>HWL 1-2</td>
</tr>
<tr>
<td>HWL 2-1</td>
<td>160 mg/kg</td>
<td>HWL 2-2</td>
</tr>
<tr>
<td>HWL 3-1</td>
<td>110 mg/kg</td>
<td>HWL 3-2</td>
</tr>
<tr>
<td>Mean</td>
<td>133.33 mg/kg</td>
<td>Mean</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>25.17</td>
<td>Standard deviation</td>
</tr>
</tbody>
</table>

Table C.2-2. Fundamental error (based on mass analyzed by the lab)

\[
FE = \sqrt{\frac{20d^3}{m}}
\]

\(d = \) particle size (0.2 cm for all samples)  
\(m = \) sample mass

<table>
<thead>
<tr>
<th>Sample 1-1</th>
<th>Sample 1-2</th>
<th>Sample 2-1</th>
<th>Sample 2-2</th>
<th>Sample 3-1</th>
<th>Sample 3-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>m = 29.98 g</td>
<td>m = 30.04 g</td>
<td>m = 30.05 g</td>
<td>m = 30.01 g</td>
<td>m = 30.03 g</td>
<td>m = 30.02 g</td>
</tr>
<tr>
<td>FE = 0.07</td>
<td>FE = 0.07</td>
<td>FE = 0.07</td>
<td>FE = 0.07</td>
<td>FE = 0.07</td>
<td>FE = 0.07</td>
</tr>
</tbody>
</table>

Table C.2-3. Relative standard deviation

\[
RSD = \frac{100s}{x}
\]

<table>
<thead>
<tr>
<th></th>
<th>#1 Samples</th>
<th>#2 Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSD = (\frac{100(25.17)}{133.33})</td>
<td>RSD = (\frac{100(26.58)}{112.33})</td>
<td></td>
</tr>
<tr>
<td>RSD = 18.9%</td>
<td>RSD = 23.7%</td>
<td></td>
</tr>
</tbody>
</table>

Table C.2-4. 95% Upper confidence limit

\[
95\%UCL = x + \frac{IS}{\sqrt{n}}
\]

<table>
<thead>
<tr>
<th></th>
<th>#1 Samples</th>
<th>#2 Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>(95%UCL = 133.33 + \frac{(2.92)(25.17)}{\sqrt{3}})</td>
<td>(95%UCL = 112.33 + \frac{(2.92)(26.58)}{\sqrt{3}})</td>
<td></td>
</tr>
<tr>
<td>(95%UCL = 176)</td>
<td>(95%UCL = 157)</td>
<td></td>
</tr>
</tbody>
</table>

C.2.7 Quality Control Review

- Field QC protocols were violated because samples were not cooled for shipping.
• Subsampling inconsistency occurred because one subsample was collected wet and the other five subsamples were collected dry.
• Laboratory samples were prepared and analyzed for DRO according to Method AK102. The Laboratory Data Review Checklist was completed for the lab data. All data requirements were met except the 14-day hold time; sample temperatures were thus exceeded due to subsampling challenges and shipping problems.¹

C.2.8 Discussion

Although the stockpile was shallow, it was compacted and difficult to excavate by hand. Field sampling was therefore labor-intensive, requiring approximately 15 person-hours to complete.

Data quality may have been affected by three factors:
• Bulk samples were not cooled for shipping; hydrocarbon degradation due to an increase in microbial activity may have occurred.
• The initial attempt at subsampling was challenging due to high soil moisture content, which caused clumping and clogged the #10 sieve. The next five subsamples were collected after first air-drying the remaining bulk samples; however, data comparability is assumed because of the requirement to report on a dry-weight basis.
• The 14-day holding time and sample temperatures were exceeded. The increased microbial activity due to elevated temperatures may have biased sample results low.

FE is a result of not representing proportional concentrations of all particles in the population. Adequate mass (30 g) and a maximum particle size of 2 mm control FE. As expected, the FE for each of the samples was well below the required 15% since the particle size was ≤2 mm and the sample masses were >30 g.

RSD is a measure of data precision and is used as a QC measure to assess the MI sampling procedure and the mean concentration of the DU. The RSD calculations were 18.9% for Samples #1 and 23.7% for Samples #2. The RSD limit for a normal distribution is about 30%; therefore, one can be confident that the MI sampling results are representative.

The 95% UCL for Samples #1 was 176 and for Samples #2 was 157, indicating that the DRO cleanup level of 230 mg/kg has been met.

C.2.9 Conclusions and Recommendations

• QC problems could cause ADEC to reject the data under some circumstances, such as closing the site to a human health–based threshold.

¹ Samples were temporarily misplaced in Seattle, returned to Juneau, and then repackaged and sent to the analytical lab in Colorado.
The random number generator worked well to establish 3-D, independent sampling coordinates. A simpler method, and equally effective, would be to generate a random location for the first cell and apply that coordinate to all other cells.

Even though the stockpile was shallow and had been periodically mixed, the MI sampling guidance was strictly followed to ensure that the top 6 inches was not sampled. This should be standard practice, even for shallow, well-tilled stockpiles.

While 20-penny galvanized nails worked to establish the field grid, they pulled out too easily; wooden stakes would have performed better. For large DUs, cell corner stakes would be sufficient rather than delineating the entire grid with twine.

To minimize field time, QC for properly designed MI sampling could possibly be reduced for low-risk petroleum sites where concentrations are expected to be well below levels that may be a human health concern. Examples are direct contact and inhalation where migration to groundwater is not a concern or where groundwater is already being monitored. The merits of this recommendation will be evaluated at the end of the 2007 field season.

Proper sampling oversight can best be achieved by the third-party contractor directly employed by the responsible party. For this reason, a contractor may wish to conduct subsampling in a controlled environment prior to shipment to the selected laboratory. The merits of this recommendation will be evaluated at the end of the 2007 field season.

Sieving wet soil is problematic. Although holding times and temperatures should be maintained to the extent practicable, contaminants such as weathered diesel are not expected to significantly degrade. Air-drying prior to sieving may therefore be justified for DRO and residual-range organics in some cases, particularly at lower-risk sites. If volatile contaminants are a concern, separate samples should be collected according to procedures in the guidance. The merits of air-drying prior to sieving will be evaluated at the end of the 2007 field season.

At sites where the action level is human health direct contact or inhalation, where migration to groundwater is a significant issue, or where another exposure pathway is a potentially significant concern, splitting each increment subsample as an additional laboratory QC measure may be prudent. FE, RSD, and 95% UCL calculations can be independently performed on the two data sets; archived lab samples could be evaluated if there are significant differences. The merits of this recommendation will be evaluated at the end of the 2007 field season.

C.3 CASE STUDY 3: FORMER GOLF COURSE FIELD DEMONSTRATION OF ISM

Site Name: Former Golf Course

Contact Names: Kelly Black, Neptune and Company, Inc.; Deana Crumbling, USEPA; Ligia Mora-Applegate, Florida Department of Environmental Protection; Mark Malinowski, California
C.3.1 Background

The ITRC ISM Team identified this site for a field demonstration of ISM. The site was a former golf course where both fertilizers and herbicides containing arsenic were applied.

C.3.2 Site Investigation

This former golf course will become a residential development. While it was an active golf course, arsenic was applied in two ways. MSMA was used as an herbicide to stunt the growth of unwanted plant life, mostly on the fairways. Also, arsenic-rich fertilizer was used frequently on the course. Fertilizer was used more heavily on the tee boxes and greens than on the fairways. The contaminant of concern (COC) is arsenic and soils are the media of concern. Preliminary characterization showed that arsenic is the only COC, and that it ranges from about 0 to nearly 100 mg/kg in some areas, with significant contamination limited to the top 6 inches of soil.

Beyond characterization and collection of data suitable for human health risk assessment, investigation of this site was also used as a field demonstration of various theories relating to ISM; therefore, several alternative sampling designs (incremental and discrete) were implemented concurrently, allowing comparison of their efficacy.

Three-quarter-acre DUs were identified for investigation as representative exposure units for a human health risk assessment. In each DU, both discrete and ISM samples were collected. DU 1 was an area where previous remediation had been conducted, and the soils were expected to be quite homogeneous in regards to arsenic contamination. DU 2 and DU 3 were selected based on an expectation that they might have more elevated levels of arsenic. Similar approaches were taken for DUs 2 and 3, so in the interest of brevity, only results from DU 1 and DU 2 will be presented herein.

C.3.2.1 DU 1

This DU was a 105 × 105 foot square that comprised one-quarter of an acre. It was investigated with three different sampling approaches:

- A grid was placed on the site with each grid cell being 17.5 × 21 feet such that there were 30 cells covering the site. A systematic random sampling approach was used to collect ISM samples composed of 30 increments. Three such ISM samples were collected.
- A grid was placed on the site with each grid cell being 10.5 × 10.5 feet such that there were 100 cells covering the site. A systematic random sampling approach was used to collect ISM samples composed of 100 increments. Three such ISM samples were collected.
Ten discrete samples were collected using simple random sampling (i.e., the locations of the 10 samples were randomly allocated across the site).

The discrete samples were collected identically to the increments; thus, the volume of the ISM samples was roughly 30 or 100 times the volume of each discrete sample. Each sample or increment was expected to be representative of the soils in the top 6 inches bgs. Data from each sampling approach were analyzed, and a 95% UCL was calculated for each. For the discrete samples, a 95% UCL can be collected directly from the set of n observations; it is not necessary to repeat the discrete sampling protocol multiple times to calculate a 95% UCL. For the ISM approach, a 95% UCL can be calculated because three replicate ISM samples (each based on 30 or 100 increments) were collected. As explained in Section 4 and Appendix A, while both discrete and ISM sampling may be expected to yield unbiased estimates of the mean for most sampling protocols, they represent different distributions with different standard deviations (SDs). Therefore, the methods can be expected to yield similar estimates of the mean but different confidence limits for the estimate of the mean. The 95% UCLs were compared to the Florida Department of Environmental Protection (FDEP) cleanup level of 2.1 mg/kg arsenic in soil to determine whether the site presents an unacceptable human health risk.

For the ISM approach with 30 increments, concentrations among the three replicates ranged 1.8–1.9 mg/kg with an arithmetic mean and SD of 1.8 and 0.08 mg/kg, respectively. For the ISM approach with 100 increments, concentrations among the three replicates were all roughly 1.7 mg/kg with an arithmetic mean and SD of 1.7 and 0.03 mg/kg, respectively. The 95% UCLs calculated using either Student’s-t or Chebyshev yielded approximately the same result (rounded to two significant figures). The 95% UCLs were 2.0 and 1.8 mg/kg for the 30- and 100-increment samples, respectively. Since the upper-bound estimates of the mean are both below the action level of 2.1 mg/kg, either ISM sampling design would have provided evidence that arsenic at this site does not pose an unacceptable risk and that the site could be left in its current condition for the impending residential development.

For the n = 10 discrete samples collected from DU 1, arsenic concentrations ranged 0.7–5.4 mg/kg with an arithmetic mean of 2.0 mg/kg, SD of 1.4 mg/kg, and coefficient of variation of 0.7, which indicates that the data exhibit low skew. The data are not normally distributed, so a bootstrap technique was used to calculate the UCL. The 95% UCL using a bias-corrected accelerated bootstrap is 3.0 mg/kg. That level is above the threshold of interest and is considered an indication that the arsenic in soil at this site might cause an unacceptable risk for residents.

It is interesting that the data collected via discrete samples and the data collected via ISM lead to different results for this DU. In one case, the data show no unacceptable human health risk due to arsenic at this DU. In the other case, the data show that there is, indeed, an unacceptable risk due to arsenic at this site. In addition, for the ISM approach, the decision to collect three replicates allowed for an evaluation of the confidence in the estimate of the mean. Since all of the individual ISM results were within approximately 10%–20% of the action limit, any single result may have introduced uncertainty about the level of protectiveness of the risk assessment. Demonstrating that three individual ISM results and the corresponding 95% UCL are all below the action level provides stronger evidence that arsenic does not pose an unacceptable risk for DU 1. The ISM samples that are based on 90 (3 × 30 increments) or 300 (3 × 100 increments)
sample locations achieve better spatial coverage of the site than the 10 discrete samples, but both
types of sampling approaches yield an unbiased estimate of the mean. It is important to recognize
that any of these sampling approaches might be considered reasonable for this site, yet they lead
to different conclusions and may even lead to different decisions regarding the need for remediation.

C.3.2.2 DU 2

This DU was a 52.5 × 210 foot rectangle that composed one-quarter of an acre. This DU was investigated with four different sampling approaches:

- A grid was placed on the site with each grid cell being 17.5 × 21 feet such that there were 30
cells covering the site. A systematic random sampling approach was used to collect samples
composed of 30 increments. Three such ISM samples were collected.

- Thirty discrete samples were collected from immediately adjacent to the 30 systematic
random sample locations used in the first of the 30-increment ISM samples collected.

- A grid was placed on the site with each grid cell being 10.5 × 10.5 feet such that there were
100 cells covering the site. A systematic random sampling approach was used to collect
samples composed of 100 increments. Three such ISM samples were collected.

- The 100-cell grid was divided into four equal-sized quadrants. These quadrants were set by
putting a big cross through the middle of the rectangular shape of the DU and allocating one
corner to each quadrant. Five ISM samples with 25 increments each were collected from
each quadrant. Then the quadrants were redrawn based on the CSM and prior information
regarding expected arsenic concentrations. Specifically, one quadrant covered only the area
of the former green (expected to have higher arsenic than other quadrants that included
portions of the fairway), the next quadrant included a small portion of the green, and the third
and fourth quadrants were composed solely of fairway.

Data from each sampling approach were analyzed, and the mean, SD, standard error (SE) of the
mean, and 95% UCL were calculated for each. The 95% UCLs were compared to the FDEP
cleanup level of 2.1 mg/kg arsenic in soil. In all cases, the 95% UCLs for DU 3 exceeded the
threshold value of 2.1 mg/kg; however, the 95% UCLs for some of the quadrants did not exceed
this threshold.

Figures C.3-1 and C.3-2 represent the data from DU 2 in box plots. The black circles on these
box plots show the actual data points. The thick black line across the middle of each box is the
median result. The thinner black lines above and below that are the 75th and 25th quantiles,
respectively. That is, they represent the range in which the middle 50% of the data fall. The
middle red line is the mean of the data, and the red lines above and below it represent the upper
and lower confidence limits on that estimate of the mean.
Figure C.3-1 shows side-by-side box plots of the results of the first three (full-DU) sampling approaches. The first box represents the discrete data. The second and third boxes show the “lab-prepped” sample results, that is, the results from the samples that were carefully dried, sieved, homogenized and subsampled in a laboratory in accordance with the methodologies presented in EPA Method 8330B. The “field prepped” results shown in the final two boxes come from the same ISM samples, but subsampling of the material was performed in the field prior to shipping the main ISM sample to the laboratory for processing. The purpose of doing the field subsampling and then careful lab subsampling was to determine whether the samples that were processed in the lab would have less variability than those subsampled in the field. In Figure C.3-1 it is easy to see that there is very little difference between the results for these two types of subsampling protocols; however, it is important to note that the material being sampled here was easily mixed and that due to the nature of the contamination and the soil type, it is not surprising
that field-homogenizing was nearly as effective as the more stringent USEPA SW-846 Method 8330B-type preparation. Any extrapolation of this particular finding beyond such a simple matrix and contaminant should be considered with great caution. In other situations, it is very likely that there may be a pronounced decrease in the variability between results when a thorough homogenization protocol is used.

It is also interesting to note, and apparent on Figure C.3-1, that there was not a notable improvement in the results between samples that contained 30 increments and those that contained 100 increments. The simulations performed by the ITRC ISM Team and presented in Section 4 of this document support this finding, and in fact show that only in cases with strongly skewed or variable data is there much value in collecting more than 30 increments per sample.

Finally, in Figure C.3-1 shows that the discrete data behave exactly as expected in comparison to the ISM data. Due to the smaller sample support for the discrete data, they are expected to be much more variable than ISM data. ISM physically averages over 30 or 100 samples, thus making each result essentially an average of many single discrete samples. While the means from the different sampling approaches shown in this figure do not significantly disagree, it is very clear that the discrete samples span a much wider concentration range and are more variable than the ISM results. This is a finding that matches the theory behind ISM, is borne out in the simulation studies, and can generally be expected to be true for most types of environmental investigations. Accordingly, one would anticipate that the magnitude of the UCL generated with discrete sampling with typical samples sizes (e.g., n = 10 to 30) would be greater than UCLs generated with ISM sampling.

Figure C.3-2 shows the results (in box plot form) of the quadrant sampling. Ideally, a DU would be composed of largely homogeneous media (at least in regards to the parameters of interest). If the CSM is not convincing, or if there is some reason to believe that the DU may have gross spatial heterogeneity (i.e., different concentrations of the chemical of interest in different areas of the DU), then partitioning the DU and taking separate ISM samples in each partition might be a useful strategy. For this former golf course, there was reason to believe that the greens and tees would have different concentrations of arsenic than the fairways, so partitioning into quadrants was employed.
Figure C.3-2: ISM results for DU 2 by quadrant.

In Figure C.3-2, the boxes representing samples A-1 through D-1 show the results from the samples based on the original quadrants selected purely by breaking the 100-cell grid into four conveniently shaped sections without any recourse to prior knowledge or expectations for the site. The final four boxes representing samples A-2 through D-2 show the results for the samples from the quadrant configuration based on the CSM and our prior knowledge of the site. It is evident that, indeed, beginning with the quadrant placed on the green (1) and moving out to the fairway (4), there is a clear and significant difference in concentrations of arsenic trending down with distance from the green. It is interesting that data presented in the box plots for quadrants A-1 through D-1 would certainly have provided some interesting conversation among the project team if we did not actually already have a reason to suspect there were spatial differences across this DU.

Based on these results, it is likely that remediation would be considered necessary throughout DU-2. However, the project team might also decide to revisit the CSM and conduct additional sampling to better define the areas that would require remediation.
C.3.3 Lessons Learned

The information presented in this case study is only a small portion of the interesting information learned by implementing ISM during this field demonstration. Other aspects that will be presented in a final report on this study include the time required for various aspects of the sampling; cost comparisons (based on time, resources, and analytical costs, including sample preparation); Monte Carlo simulations from the discrete and ISM data to test theories on the value of the information; evaluation of the observed data distributions and their similarity to the simulated distributions used in Section 4; and comparison of results from ground vs. unground samples.

From the analyses presented herein, there are a few important ideas to consider:

- In cases where the concentration of the COC is near the threshold of interest, it is prudent to be aware that any conclusions made about the site are based on a sample of data, and even if collected in a careful and appropriate manner, it may or may not lead to the same conclusion that would be reached based on another sample of the data. The expected variability in sample results is a primary reason why a common DQO is to collect sufficient data to calculate a UCL for a parameter estimate.

- Partitioning DUs into subareas may provide an opportunity to discern spatial differences that would not be apparent if ISM samples were collected from the entire DU as a whole.

- Discrete sampling is generally expected to yield a distribution of results with approximately the same arithmetic mean but higher SD, SE, and 95% UCL than ISM sampling of the same DU.

- For this site, there was no added benefit to increasing the number of increments from 30 to 100 per ISM sample. For locations in which the sample mean and corresponding 95% UCL are close to a decision threshold, increasing the number of increments can reduce the SE (and corresponding UCL) enough to alter the decision. The challenge for most sites, particularly in the absence of pilot data, is that a risk assessor typically lacks a priori knowledge about how close the population mean may be to a decision threshold.

C.4 CASE STUDY 4: HAWAIIAN HOMELANDS DEVELOPMENT, KAPOLEI, OAHU, HAWAII

Site Name: Hawaiian Homelands Development, Kapolei, Oahu, Hawaii

Contact Name: Roger Brewer, HDOH

Site Location: The East Kapolei Affordable Housing Project property is located in East Kapolei, Kapolei, Oahu, Hawaii.
C.4.1 Background and Previous Investigations

This case study summarizes the investigation of a 400-acre, former sugarcane field and a ½-acre pesticide mixing area located within the field. The area was being developed for residential and commercial use. The primary COCs were arsenic, PCP, dioxins (associated with past use of PCP), and triazine herbicides, each used in the past for weed control. A detailed discussion of the sugarcane field investigation is provided in the report *East Kapolei Affordable Housing Project Kapolei, Oahu, Hawaii, Final Site Assessment Report* (TTEMI 2007). A summary of the pesticide mixing area investigation is provided in the report *Site Investigation Report and Environmental Hazard Evaluation, East Kapolei II Pesticide Mixing and Loading Site* (ESTC 2007, 2010).

DU and ISM (ISM, referred to as “multiincrement sampling” or “MIS” in the reports) investigation approaches were used to investigate the site. The pesticide mixing area, where heavy pesticide contamination had been previously identified, was investigated separately from the field area. This approach allowed the field area to be cleared for development early in the process. Except as noted, 30- to 50-increment ISM samples were collected from DUs and subsampled in the laboratory for preparation of aliquots and analysis.

C.4.1.1 Field Area Investigation

The field was investigated through the characterization of 59 hypothetical, residential lot-size DUs (5000 ft\(^2\)) randomly located within the 400-acre field (Figure C.4-1, TTEMI 2007). Using the terminology proposed in the ITRC ISM document, the entire field could be alternatively considered to be the DU, and in the individual lots, DUs as SUs. Previous suggestions to characterize the field using a similar number of discrete samples were rejected due to poor coverage of individual DU areas (e.g., a single discrete sample at each of the 59 target locations vs. a 30-point ISM sample).

Testing a minimum of 59 hypothetical lots ensured that contaminant levels in 95% of the lots not tested were no higher than in the most contaminated DU identified (HDOH 2008). After locating the center point for a DU in the field, a 5000 ft\(^2\) area was marked off and a 40-point ISM sample collected (total 59 ISM samples and 2360 increments; see Figure C.4-1). Triplicate samples were collected in 10% (six) of the DUs. Samples were collected over a 5-day period. Reported concentrations of targeted contaminants in all the DUs were below environmental action levels for residential use and the fields were cleared for development (e.g., maximum 100 ng/kg toxicity equivalent [TEQ] dioxins).

C.4.1.2 Pesticide Mixing Area Investigation

The pesticide mixing area was ringed with 33 1000 ft\(^2\) and 5000 ft\(^2\) DUs to verify that the boundary of heavy contamination had been adequately identified, based on previous discrete sample investigations (Figure C.4-2, ESTC 2007). A 0–6 inch surface ISM sample was collected from each DU (total 33 samples and 990 increments, plus replicates).
Figure C.4-1. ISM investigation of a 400-acre former sugarcane field and 59 hypothetical, lot-size (5000 ft\(^2\)) DUs characterized.
Figure C.4-2. ISM investigation of a ½-acre pesticide mixing area DU within the former sugarcane field.
The interior of the mixing area was divided into 15 DUs (ESTC 2010). A suspected area of especially heavy contamination was subdivided into three small spill-area DUs (<2000 ft²), with the remaining area divided into 12 DUs equal to or less than the default, residential-lot exposure area of 5000 ft². Each of the 15 DUs was subdivided into up to four “sampling unit” (SU) layers to investigate the vertical distribution of contaminants. An ISM sample was collected within each surface and subsurface SU (total 31 SUs), with triplicates collected in three units. Twenty direct-push borings were installed in the three spill-area DUs to characterize subsurface contamination (i.e., one 20-increment ISM sample per subsurface SU layer). Subsurface SUs in the outer DUs were accessed and sampled by trenching.

A total of 64 ISM samples composed of 2000+ increments, plus replicates, was collected. Significant dioxin contamination was identified in all 15 DUs (maximum 650,000 ng/kg TEQ dioxins) and heavy triazine contamination within the targeted spill areas (see Figure C.4-2). Both the lateral and vertical extent of contamination was significantly greater than estimated based on earlier, discrete sample data, increasing the volume of contaminated soil by a factor of at least 3. The ring DU ISM samples also identified a 15,000 ft² area of dioxin-contaminated soil on the south side of the mixing area that was likewise missed by earlier discrete samples (see Figure C.4-2).

In 2009, the USEPA collected 83 surface and subsurface discrete samples around the perimeter of the mixing area to confirm that the extent of contamination had been adequately identified (USEPA 2009, unpublished). The discrete samples similarly suggested that contamination around the mixing area was below target action levels. The samples failed to identify the outer area of contamination identified in ring DUs to the south, however. The investigations confirm that ISM samples, essentially very good “composite” samples with additional lab requirements, are better able to capture small hot spots and overall contaminant heterogeneity within a targeted area.

**C.4.2 References**


