A-065, in K.A. Fields and G.B. Wickramanayake (Chairs), *Remediation of Chlorinated and Recalcitrant Compounds—2010.* Seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2010). ISBN 978-0-9819730-2-9, Battelle Memorial Institute, Columbus, OH, **www.battelle.org/chlorcon**.

Investigation-Scale Evaluation of Multi-Incremental Sampling Methodology

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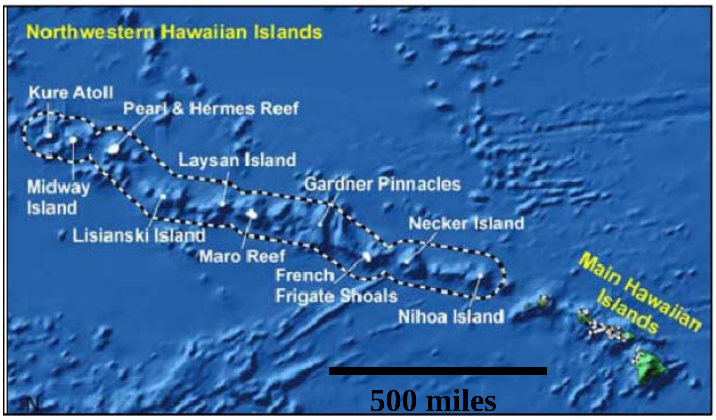
ABSTRACT: A series of discrete and multi-incremental (MI) samples were collected from a former scrap metal dump (SMD) located on Kure Atoll, Northwest Hawaiian Islands. The 170-foot by 80-foot dump area was known from previous investigations to be contaminated with polychlorinated biphenyls (PCBs) from historic disposal of transformers and other electrical equipment. A 10-foot spaced sampling grid was established within the SMD. A total of 396 discrete soil samples were analyzed from three decision units (DUs) established at three depths (0-4 inches, 28-36 inches, and 48-60 inches below ground surface [bgs]). The mean PCB concentration measured in the 10-foot grid samples collected from the shallow, intermediate and deep DUs were 0.47, 0.84 and 31.9 milligrams per kilogram (mg/kg) respectively. Much of the contamination in the deeper portions of the SMD is present in a localized spill area that contains isolated "nuggets" of soil with very high levels of PCBs.

Splits of the 121 to151 discrete samples collected from within each designated DU were combined as individual increments to produce a single MI sample for each DU. Because splits of each sample point used to create the MI samples were analyzed separately as a discrete sample in the field, the resulting analytical data set allows a good comparison of discrete versus MI sample data and the advantages and limitations of each. Analysis of the data showed that the MI samples accurately reflected the mean PCB concentration within the three DUs of the SMD despite the heterogeneous, log-normal distribution of PCBs documented by the discrete sample data.

A Monte-Carlo analysis was conducted on the field PCB data collected to simulate the range of PCB concentrations that would have been determined for the SMD using a traditional Remedial Investigation (RI) approach involving the collection of eight, discrete soil samples. This analysis found that in the deep soils, the standard RI approach would have yielded a false negative result (i.e. underestimated the representative concentration of PCBs for this DU) with respect to action levels published by the Hawai'i Department of Health (HDOH) about 44% of the time, despite the "true" mean PCB concentration (31.9 mg/kg) being significantly higher than the 1.1 mg/kg PCB action level. This analysis also found that 7% to 15% of the time the RI sampling approach would not have detected PCBs at levels above the field analysis reporting limit (0.25 mg/kg) in the DU soils. These false negative results obtained from the RI approach may have eliminated the rationale to conduct additional characterization sampling of the contaminated SMD site.

INTRODUCTION

An environmental investigation was conducted at the former United States Coast Guard Long Range Navigation (LORAN) Station at Kure Atoll in October 2008 (Element Environmental, 2009). Kure Atoll is the northernmost island in the Hawaiian island chain and is located approximately 1,360 miles northwest of Honolulu and about 56 miles northwest of Midway Atoll (Figure 1). Kure Atoll consists of a lagoon encircled by an atoll reef, one vegetated island (Green Island) and several small sand spits that vary in size depending upon the tide, currents and shifting sand. The focus of the investigation involved conducting extensive grid sampling at the SMD located on the south-western end of Green Island. The SMD was used as a disposal point for non-functioning PCB-containing electrical devices, including capacitors and transformers, during operation of the LORAN station between 1961 and 1992.



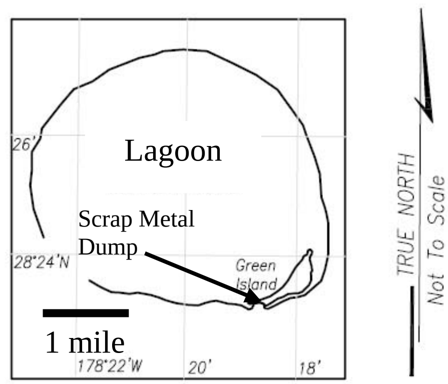


FIGURE 1. Location and site maps of Kure Atoll.

An approximate 170-foot by 80-foot (~13,000 square feet [ft^2]) area was designated a *spill area decision unit* (DU) for the SMD, using the terminology in the HDOH guidance for DU and MI investigation strategies (HDOH, 2008a). A DU is an area, or more specifically a volume or mass of soil, where the representative concentration of a targeted contaminant is to be determined. The extent and size of the DU is established based on information gained from current and previous site characterization activities. Three vertically-stacked DUs were ultimately designated for the SMD--one at the near-surface (0-4 inches, DU-11), a second for the depth interval of 28-36 inches (DU-12), and a third for the depth interval of 48-60 inches (DU-13).

The initial objective of the investigation was to determine the representative, mean concentration of PCBs in the volume of soil that comprises each of these DUs. Establishing these types of *decision statements* at the beginning of a project helps to avoid *site investigation traps*, where the focus of the site investigation inappropriately moves to the scale of individual sample points with no clear site investigation objectives established. This can lead to an unnecessary waste of project funds and at worst the meaningless excavation of individual sample points. When decisions are being made at the scale of an individual, discrete sample, or more specifically a 30-gram aliquot of soil in the case of this project, it is important to step back and rethink the objectives of the investigation.

If the reported, mean concentration of PCBs for each of the DUs was reported to be below the target action level, then no further action was deemed to be necessary. Smaller spill areas or "hot spots" *within* the DU (i.e., smaller than ~13,000 ft^2 in area) that potentially exceed target action levels were not considered to pose a significant threat to human health and the environment, provided that they did not cause the DU *as a whole* to exceed target action levels. This was an important site investigation objective (sometimes referred to as a Data Quality Objective or "DQO") that was agreed upon with the HDOH at the beginning of the project.

If the target action level for PCBs was exceeded, then additional investigation and possibly remedial actions would be required. In practice, only *multi-increment* (MI) samples would be collected within a DU during the initial investigation. The potential collection of additional, *discrete* soil samples to aid in the identification of "hot spots" or concentrated spill areas *within* the original DU would be evaluated only after a review of the initial MI soil sample data. Due to the remote nature of the subject site and limited opportunities for remobilization, however, and as a means to better evaluate the potential role of the MI sampling approaches for future projects, both MI and discrete samples were collected during this study.

RESULTS

A total of 200 grams of soil was recovered from each grid sampling point. Grain size analysis found that the SMD soils are dominated by medium to coarse grain sands. Thirty gram splits of each discrete sample collected were combined in the field to produce the MI sample generated for each sampled depth. A total of five MI samples were generated from the three DUs (three primary samples and two duplicates of the deep sample). The field samples collected from each grid point were analyzed onsite by extracting 10 grams of each discrete sample collected and determining the PCB content using quantitative RaPID Assay® immunoassay test kits supplied by Strategic Diagnostics Inc (reporting limit 0.25 mg/kg, detection limit ~0.1 mg/kg). The 1.2- to 1.5-kilogram MI samples generated in the field were transported to a commercial laboratory where the sample was first air dried, run through a 2-millimeter mesh sieve (the retained coarse grain fraction was discarded), and then spread out on a tray to a constant depth. A rectangular metal scoop was used to collect thirty one gram aliquots of soil from the tray in a random manner. The resulting 30-gram sub-sample was then extracted for PCB analysis. The mean, maximum and 95% upper confidence level (UCL) of the 396 discrete samples collected from the three DUs and the corresponding MI sample results are summarized in Table 1.

The range of PCB concentrations measured in the discrete soil samples collected from the DUs are skewed with a log-normal distribution (Figure 2). This pattern of contaminant distribution in soil is relatively common at environmental sites, for both organic and inorganic chemicals (e.g., lead-contaminated soil at shooting ranges, etc.). Figure 3 shows the discrete sample PCB data obtained in the field using the immunoassay method for the three DUs. This figure shows that most of the elevated PCB concentrations are present in a localized spill area of approximately 50 feet by 50 feet. As can be seen in this figure, the SMD contains isolated "nuggets" of soil with very high levels of PCB (up to 3,667 mg/kg).

TABLE 1. Discrete and MI sample PCB results obtained on 10-foot grid samples.

Soil Sample Location	Number of Discrete Soil Samples	Field Data-Discrete Samples			Lab Data-MI Samples	
		Max. Soil PCB Conc.	Mean of All Field Results	95% UCL of All Field Results	Laboratory Data [Aroclor 1254]	Laboratory Data [Aroclor 1260]
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
DU11: 0 - 4 Inches bgs	151	22.7	0.47	0.79	0.35	-
DU12: 30 - 36 Inches bgs	124	19.8	0.84	1.34	1.53	2.53
DU13: 48 - 60 Inches bgs	121	3,667	31.9	91.3	-	40
DU14: Duplicate of DU13 Sample	121	3,667	31.9	91.3	-	36.4
DU15: Duplicate of DU13 Sample	121	3,667	31.9	91.3	-	33.6

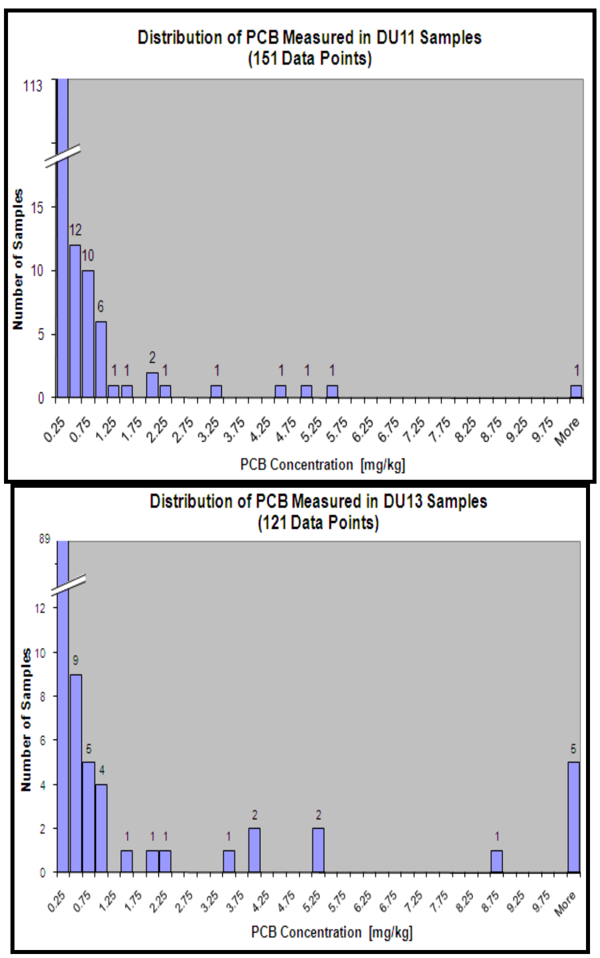


FIGURE 2. Skewed, log-normal distribution of soil PCB concentrations measured in discrete samples from shallow (DU11) and seep (DU13) landfill soils.

			ND	ND	ND	0.1	0.1	0.1	170
		ND	ND	ND	ND	0.1	0.1	0.2	160
		ND	ND	ND	ND	0.2	0.2	0.2	150
		0.1	ND	ND	0.1	ND	0.6	0.1	140
	ND	ND	ND	0.3	ND	0.1	0.2	0.2	130
	ND	ND	ND	0.1	ND	0.2	0.1	0.2	120
ND	1.2	0.7	0.8	0.3	0.6	0.4	0.3	0.5	110
ND	0.2	ND	0.3	ND	0.1	0.5	0.3	0.5	100
ND	ND	3.1	ND	ND	ND	0.1	ND	0.1	90
ND	ND	ND	ND	0.2	0.2	0.3	ND	0.1	80
ND	ND	ND	0.8	ND	0.2	0.6	0.3	0.1	70
ND	ND	ND	0.1	5.3	1.4	0.8	0.5	0.4	60
22.7	ND	ND	ND	ND	0.1	2.0	1.8	ND	50
ND	ND	5.0	ND	ND	ND	0.2	0.9	0.6	40
ND	4.3	1.0	2.2	0.6	0.8	0.5	0.5	0.6	30
ND		0.3	0.2	0.1	0.1	0.2	0.1	0.1	20
ND	ND	ND	0.2	ND	0.2	ND	ND	ND	10
ND	ND	ND	ND	ND	ND	ND	ND	ND	0
80	70	60	50	40	30	20	10	0	Y-Axis

X-Axis (Feet)

DU11: MI Sample Result = 0.35 mg/kg

			ND	ND			0.1		170
		ND	ND	ND	ND				160
		ND	0.1	ND			ND		150
		ND	ND	ND	ND	ND	ND		140
	ND	ND	ND	ND	ND				130
	ND	ND	ND	0.2	ND	ND	ND		120
ND	0.1	ND	ND	ND	1.7	ND			110
0.3	ND	0.6	0.8	0.3	ND	ND			100
ND	ND	2.7	6.9	0.2	2.0	19.8	ND		90
ND	ND	10.3	5.5	4.3	7.6	ND	ND		80
	ND	ND	16.7	11.4	1.5	0.5	ND		70
ND	ND	0.1	0.2	1.3	2.3	1.0	ND		60
ND		ND	ND	ND	1.4	0.7	ND	0.2	50
ND	ND	ND	ND	ND	0.4	0.6		ND	40
ND	ND	ND	ND	ND	ND	0.1	ND	ND	30
ND	ND	ND	ND	ND	ND	ND	ND		20
ND	ND	ND	ND	ND	ND	0.1	0.1	ND	10
ND	ND	ND	ND	ND	ND	ND		ND	0
80	70	60	50	40	30	20	10	0	Y-Axis

X-Axis (Feet)

DU12: MI Sample Result = 2.53 mg/kg

				ND					170
		ND		ND	ND				160
		ND	ND	ND			0.5		150
		ND	ND	ND	ND	ND			140
	ND	ND	ND	ND	ND				130
	ND	ND	ND	0.5	ND	ND	0.1		120
ND	ND	0.1	ND	ND	ND	ND			110
ND	0.1	0.8	1.4	0.1	0.3	ND			100
ND	0.2	2.0	15.9	0.7	0.3	3667	ND		90
ND	2.1	5.2	21.7	3.9	0.8	0.8	ND		80
ND	ND	0.7	24.2	3.4	8.6	87.5	ND		70
ND	ND	0.3	3.9	0.7	5.2	0.2	ND		60
ND	ND	ND	0.1	0.4	ND	ND	ND	ND	50
ND	ND	ND	0.3	ND		0.3	ND	ND	40
ND	ND	ND	ND	ND	ND		ND	ND	30
ND	ND	ND	ND	ND	0.3	0.8	0.3	ND	20
ND	ND	ND	ND	ND	0.1	ND	0.3		10
ND	ND	ND	ND	ND	ND		0.2	0.1	0
80	70	60	50	40	30	20	10	0	Y-Axis

X-Axis (Feet)

DU13: MI Sample Result = 40 mg/kg

FIGURE 3. SMD landfill subdivided into eight RI sampling areas used in Monte Carlo analysis with field PCB data (mg/kg) [red values exceed HDOH EAL].

The discrete and MI soil sample data were compared to soil Environmental Action Levels (EAL) published by the HDOH to initially screen for potential environmental hazards posed by the contamination (HDOH, 2008b). The HDOH EAL for PCBs in soil at sites with unrestricted use is 1.1 mg/kg. Figure 3 shows the spatial distribution of discrete soil samples (in red) that contain PCB concentrations greater than the EAL. The corresponding MI sample data for the mid-level (DU-12) and deep (DU-13) DUs indicated that the overall PCB concentration in these soils exceeded the target action level.

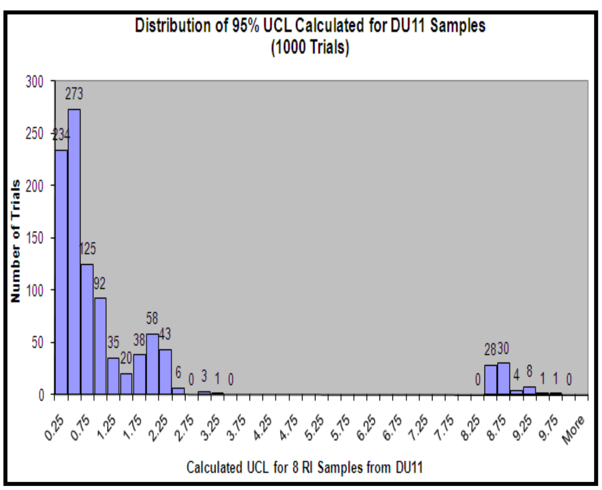
STATISTICAL EVALUATION OF MI VERSUS DISCRETE DATA

A Monte-Carlo simulation was performed on the field PCB data collected from the three 10-foot grid DUs within the SMD. This analysis was performed to compare the MI sampling result with the range in mean and 95% UCL PCB concentrations obtained by randomly selecting measured field grid point sample results from eight separate sub-cells established within the investigation area (Figure 3). This analysis assumes that a typical initial RI of a potential spill area the size of the SMD would involve collection of surface and sub-surface samples at eight discrete locations spread across the estimated lateral extent of the landfill. In practice, the number of samples collected and analyzed at a given site is usually driven by a combination of regulatory requirements and cost considerations.

For the Monte Carlo analysis, the SMD grid was sub-divided into eight approximately equally sized sub-areas (Figure 3). A total of 1,000 individual simulations were performed on the field data collected from each DU. During each simulation, a PCB value measured during the field sampling was randomly selected from each of the eight sub-areas and the mean and 95% UCL value of the resulting combined data set of eight PCB results was calculated. The results of this Monte Carlo analysis for the three DUs are summarized in Table 2 below and depicted on Figure 4.

TABLE 2. Summary of Monte Carlo analysis results.

Monte Carlo Analysis Results (1000 trials)	**Shallow Soils: DU11**	**Intermediate Soils: DU12**	**Deep Soils: DU13**
Mean of Monte Carlo Simulated Means (mg/kg)	0.45	0.84	33.62
Field Measured Mean (mg/kg)	0.47	0.84	31.93
Field Measured 95% UCL (mg/kg)	0.79	1.34	91.3
Percentage of Monte Carlo Simulated RI 95% UCL Results Above UCL (1.1 mg/kg)	**FALSE POSITIVE** 25.1%	45.8%	**CORRECT** 56.1%
Percentage of Monte Carlo Simulated RI 95% UCL Results Below UCL (1.1 mg/kg)	**CORRECT** 74.9%	54.2%	**FALSE NEGATIVE** 43.9%
Percentage of Simulations Where All Eight Randomly Selected Discrete Samples Below Analytical Detection Level of 0.25 mg/kg	10.8%	15.2%	6.8%



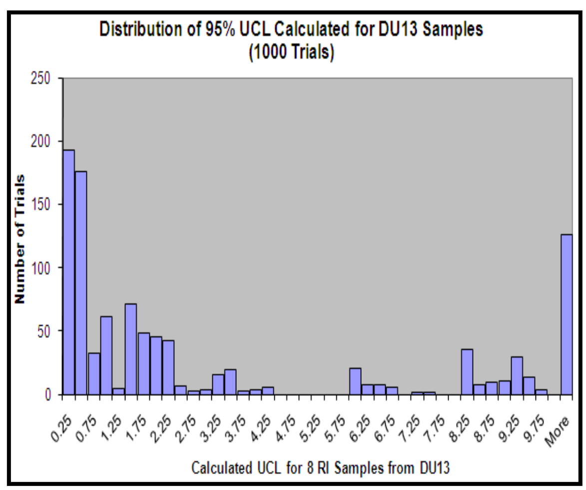


FIGURE 4. Distribution of 95%UCL values calculated in Monte Carlo analysis in shallow (DU11) and deep (DU13) landfill soils.

The frequency of time that the traditional RI sampling approach evaluated in this Monte Carlo analysis led to an incorrect conclusion was evaluated by determining the frequency of false positive and false negative EAL results obtained for the DU11 and DU13 soils, respectively. For these two DUs, the mean and 95% UCL of the field PCB data were higher (DU13) or lower (DU11) than the EAL. The MI and discrete soil sampling results obtained from the DU11 soils indicate that the mean and 95% UCL PCB concentrations present in the 151 discrete grid samples as well as the composite MI sample collected (0.47, 0.79 and 0.35 mg/kg, respectively) are all below the HDOH screening EAL value of 1.1 mg/kg. The Monte Carlo analysis indicates that collection of eight samples from this DU using the traditional RI sampling approach (by sub-sampling the actual grid-PCB field data collected) would have resulted in a false positive result, where the calculated 95% UCL result exceeded the EAL of 1.1 mg/kg, roughly 25% of the time.

The MI and discrete soil sampling results obtained from the DU13 soils indicate that the mean and 95% UCL PCB concentrations present in the 121 discrete grid samples as well as the composite MI sample collected (31.9, 91.3 and 40 mg/kg, respectively) are all significantly above the HDOH EAL (1.1 mg/kg). The Monte Carlo analysis indicates that collection of eight samples from this DU would have resulted in a false negative result, where the calculated 95% UCL result was less than the EAL of 1.1 mg/kg, a stunning 44% of the time, despite the MI sample collected from this depth containing roughly 30 times the PCB concentration of the target regulatory value.

Figure 5 depicts the range in Monte Carlo analysis calculated 95% UCL values for the eight randomly selected RI samples in comparison to the "true" 95% UCL value determined for two DUs (DU11 and DU13), based upon the PCB concentrations measured in the 151 and 121 discrete grid samples collected from these two DUs. This figure shows that the use of the standard RI sampling methodology in DU13 would have led to a large over-estimation of the "true" mean PCB concentration within the landfill roughly 6% of the time, as a result of the RI sampling encountering the "nugget" of elevated PCB contamination present at this depth within the landfill. In addition, the standard RI sampling approach would have greatly under-estimated the "true" mean PCB concentration of this DU roughly 89% of the time due to the RI sampling not encountering the elevated "nugget" of PCB contamination present in the landfill. In contrast, random sub-sampling

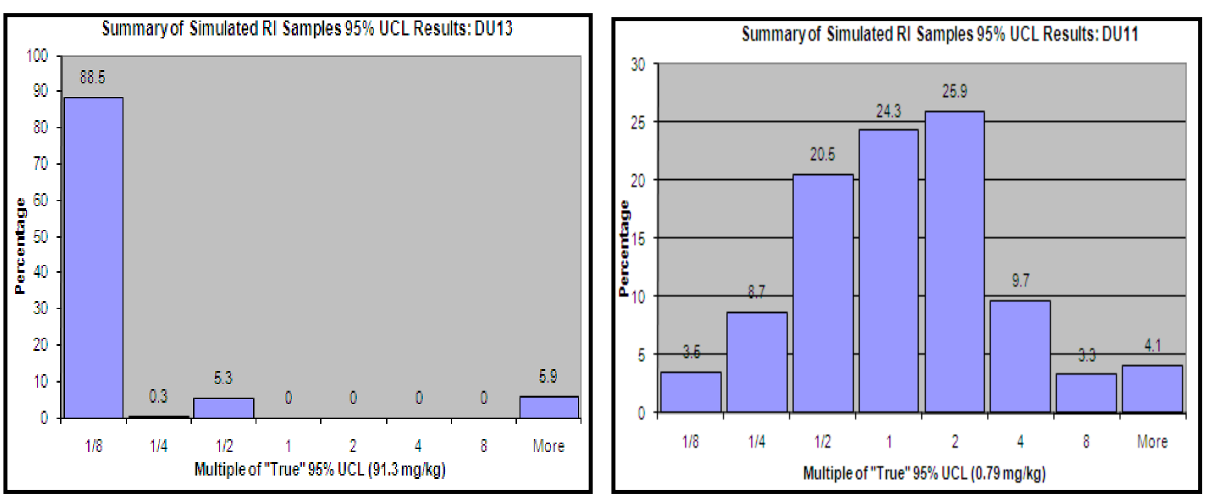


FIGURE 5. Comparison of distribution of simulated 95% UCL values of RI samples to the "true" 95% UCL value for shallow (DU11) and deep (DU13) landfill soils.

of the shallow DU data (DU11), which is less skewed than the deep soil data set (DU13), yielded a roughly normal distribution of simulated 95% UCL values around the "true" UCL value determined in the field samples.

The Monte Carlo analysis also found that the RI sampling approach would not have detected any PCB contamination at levels above the field analysis reporting limit (0.25 mg/kg) between 7 to 15% of the time in the eight random soil samples collected from the three DUs (Table 2). This result would have led to the false conclusion that no PCB contamination exists within the associated depth of the SMD landfill.

SUMMARY

A total of 396 discrete soil samples were collected from three, vertically-stacked DUs within an approximately 13,000 ft^2 former dump area on Kure Atoll (near-surface, 28-36 inches bgs, and 48-60 inches bgs). Splits of the discrete samples were used to prepare single, MI samples for each DU. The resulting MI data indicated that the concentration of PCBs in soil that comprised the mid-level and deep DUs exceeded target action levels. This was confirmed by estimation of 95% UCLs for the corresponding discrete data (albeit at a substantially increased analytical cost).

The sampling results verify that the MI sampling approach is useful as a cost-effective and efficient tool to estimate representative, mean levels of contaminants within a designated decision unit. Within the Scrap Metal Dump area, the MI sampling methodology was effective at incorporating a representative number of isolated "hot-spots" or "nuggets" of contamination into an estimation of the mean PCB concentration for designated DUs as a whole, despite the skewed, log-normal distribution of PCB in the component discrete samples.

A statistical analysis of the extensive field grid-based PCB data set collected on Kure Atoll found that traditional RI sampling of the landfill would have significantly underestimated the MI sampling result roughly 89% of the time in the deep DU soils and would have yielded a false negative result with respect to the screening health risk level for PCB 44% of the time, despite the fact that this DU contains a mean and 95% UCL PCB concentration between 30 to 90 times the regulatory level. The Monte Carlo analysis also showed that standard RI sampling of the SMD landfill would have incorrectly concluded that the various DUs within the landfill contained no PCBs between 7 to 15% of the time.

This analysis was performed on environmental samples collected from a landfill containing multiple sources of contamination. Based upon our findings, MI sampling methods provide more cost-effective and superior quality data in comparison with traditional discrete sampling approaches. The same data quality and coverage can be accomplished with tight grids of discrete samples. The increased analytical costs (minimum 20 to 30 discrete samples per DU required) and distraction often caused by an inappropriate focus on individual samples makes traditional, discrete sampling approaches unappealing beyond possible use to aid in identifying the boundaries of large spill areas that are not already obvious in the field. The inclusion of a large number of individual increments (typically 30 or more per DU) adequately incorporates spatial heterogeneity of contaminants in estimation of representative contaminant concentrations for the targeted area. Establishment of clear, concise site investigation objectives and decision statements at the beginning of the project is critical, with the understanding that additional objectives, decision statements and DUs may be necessary as the project proceeds.

REFERENCES

Element Environmental, LLC. 2009. *Site Investigation Report, Evaluation of Green Island Landfill and Reburial Pit, Former U.S. Coast Guard LORAN Station Kure, Northwest Hawaiian Islands*. Consulting Report prepared for the United States Coast Guard dated May 2009.

Hawai'i Department of Health (HDOH). 2008a. *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (Summer 2008 and updates): Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response. www.hawaii.gov/health/environmental/hazard/eal2005.html

HDOH, 2008b. *Technical Guidance Manual*: Hawai'i Department of Health, Office of Hazard Evaluation and Emergency Response. http://www.hawaiidoh.org/

Investigation-Scale Evaluation of Multi-Incremental Sampling Methodology

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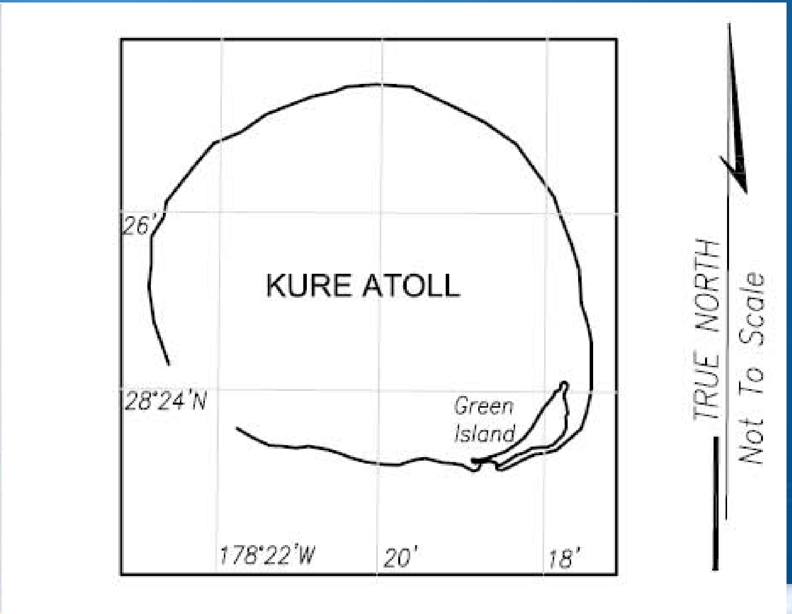
element environmental llc
environmental · engineering · water resources

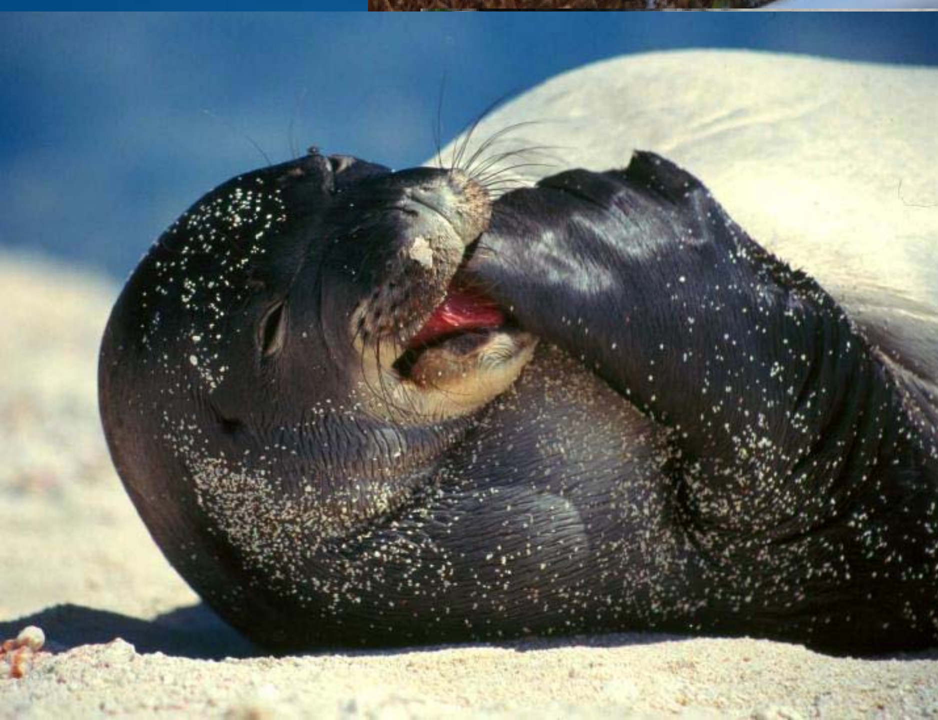
Project Background
Environmental Investigation – Kure Atoll

- Site Setting
  - Papahānaumokuākea Marine National Monument - Located 1,360 miles northwest of Honolulu and 56 miles northwest of Midway Atoll
  - Former United States Coast Guard Long Range Navigation (LORAN) Station - 1961 to 1992
  - Investigation focused on the Scrap Metal Dump

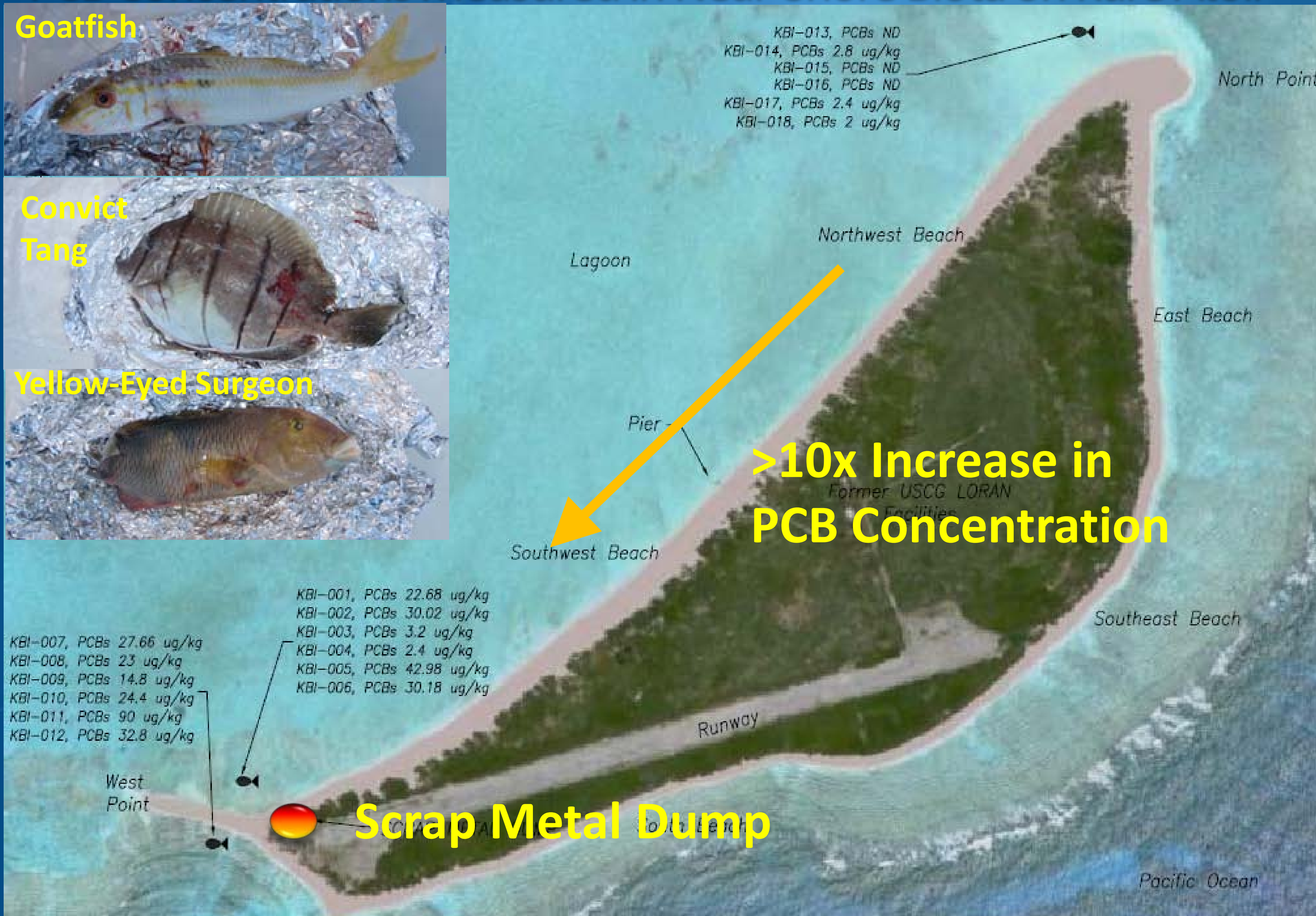
Remote, Inaccessible Former LORAN Station on Kure Atoll



Endangered Monk Seal (*Monachus schauinslandi*) at Scrap Metal Dump



PCB Concentrations Measured in Near-Shore Biota on Kure Atoll



Soil Sampling Strategy

- Multi-increment Sampling
  - Completed DQO Process with Hawaii Department of Health
  - 170-foot by 80-foot Scrap Metal Dump was designated a *spill area decision unit*
  - Three vertically-stacked Decision Units were ultimately designated for the Scrap Metal Dump –
    - Near-surface (0-4 inches, DU-11)
    - Subsurface 28-36 inches (DU-12)
    - Subsurface 48-60 inches (DU-13)

Decision Statements

- If the reported, mean concentration of PCBs for each of the Decision Units was reported to be below the target action level, then no further action was deemed to be necessary.
- If the target action level for PCBs was exceeded, then additional investigation and possibly remedial actions would be required.

Decision Assumption

- Smaller spill areas or "hot spots" were not considered to pose a significant threat to human health and the environment.
- Decision unit is treated as a whole.

Soil Sampling – Scrap Metal Dump

- Typically, only *multi-increment* samples would be collected within a Decision Unit during the initial investigation.
- MI and discrete samples collected due to the remote nature of the subject site

Soil Sampling – Scrap Metal Dump

- 170 ft x 80 ft Sampling Grid – 10 ft spacing
- Discrete Soil Sampling – 396 samples
  - 0-4 inches 0.47 mg/kg
  - 28-36 inches 0.84 mg/kg
  - 48-60 inches 31.9 mg/kg
- Contamination in deeper portions of the SMD is present in a localized spill area that contains isolated "nuggets" of soil with very high levels of PCBs.

Sampling Grid Established

Location of MI DUs Surrounding the Scrap Metal Dump

MI Testing Results Summary-SMD and Vicinity

Decision Unit (DU)	DU Location	Sample Depth	Sample ID	PCB Concentration
1	Adjacent to SMD-South Side	4”	KMI-001	0.337 mg/kg
2	Adjacent to SMD-North Side	4”	KMI-002	ND
3	Adjacent to Lagoon-North of SMD	4”	KMI-003	ND
4	Adjacent to Lagoon-Northeast of SMD	4”	KMI-004	ND
5	West of SMD	4”	KMI-005	ND
6	South of SMD	4”	KMI-006	ND
7	South of Scrap Metal Storage Area	4”	KMI-007	ND
8	Scrap Metal Storage Area	4”	KMI-008	ND
9 (duplicate of 8)	Scrap Metal Storage Area	4”	KMI-009	0.0049 J mg/kg
10 (duplicate of 8)	Scrap Metal Storage Area	4”	KMI-010	ND
11	Entire SMD	4”	KMI-011	0.353 mg/kg
12	Entire SMD	36”	KMI-012	2.53 mg/kg
13	Entire SMD	60”	KMI-013	40 mg/kg
14 (duplicate of 13)	Entire SMD	60”	KMI-014	36.4 mg/kg
15 (duplicate of 13)	Entire SMD	60”	KMI-015	33.6 mg/kg

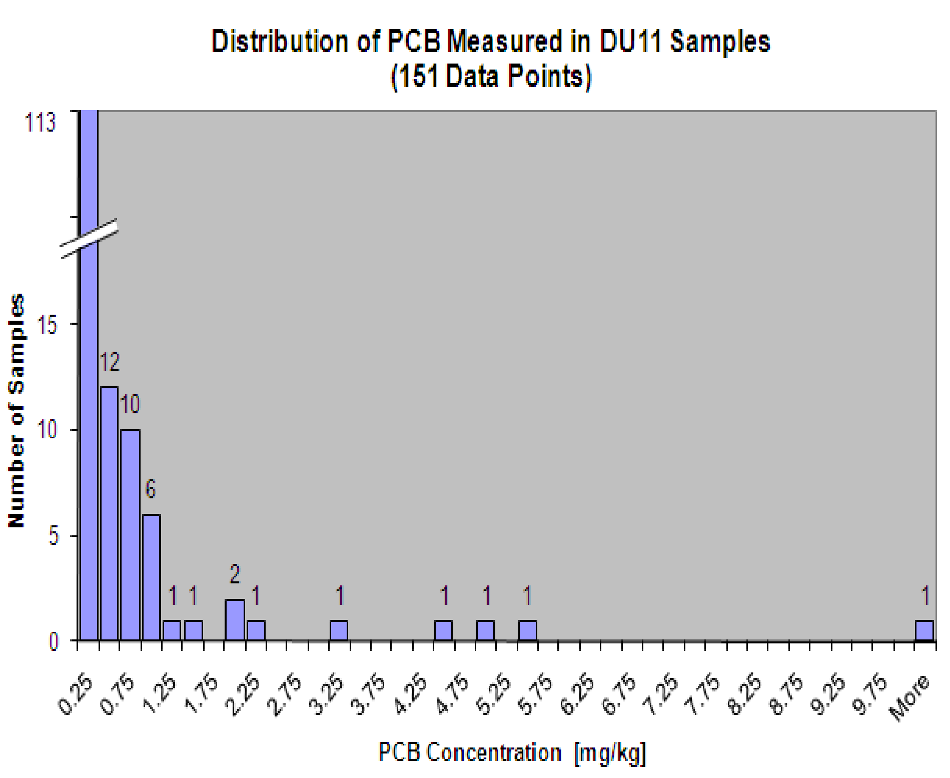
Discrete & MI Sample Comparison

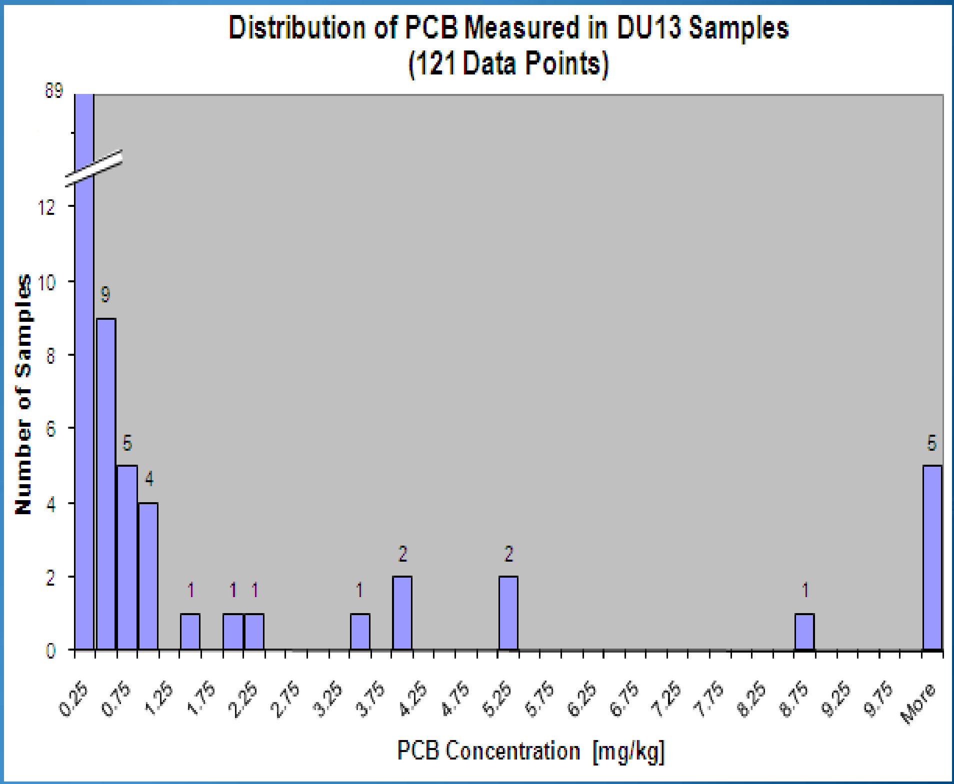
- Analysis of the data showed that the MI samples accurately reflected the mean PCB concentration within the three DUs of the SMD despite the heterogeneous, log-normal distribution of PCBs documented by the discrete sample data.

Discrete and MI Sample PCB Results

Soil Sample Location	Number of Discrete Soil Samples	Field Data-Discrete Samples			Lab Data-MI Samples	
		Max. Soil PCB Conc.	Mean of All Field Results	95% UCL of All Field Results	Laboratory Data [Aroclor 1254]	Laboratory Data [Aroclor 1260]
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
DU11: 0 - 4 Inches bgs	151	22.7	0.47	0.79	0.35	-
DU12: 30 - 36 Inches bgs	124	19.8	0.84	1.34	1.53	2.53
DU13: 48 - 60 Inches bgs	121	3,667	31.9	91.3	-	40
DU14: Duplicate of DU13 Sample	121	3,667	31.9	91.3	-	36.4
DU15: Duplicate of DU13 Sample	121	3,667	31.9	91.3	-	33.6

Discrete PCB Results on Shallow and Deep Discrete Soil Samples

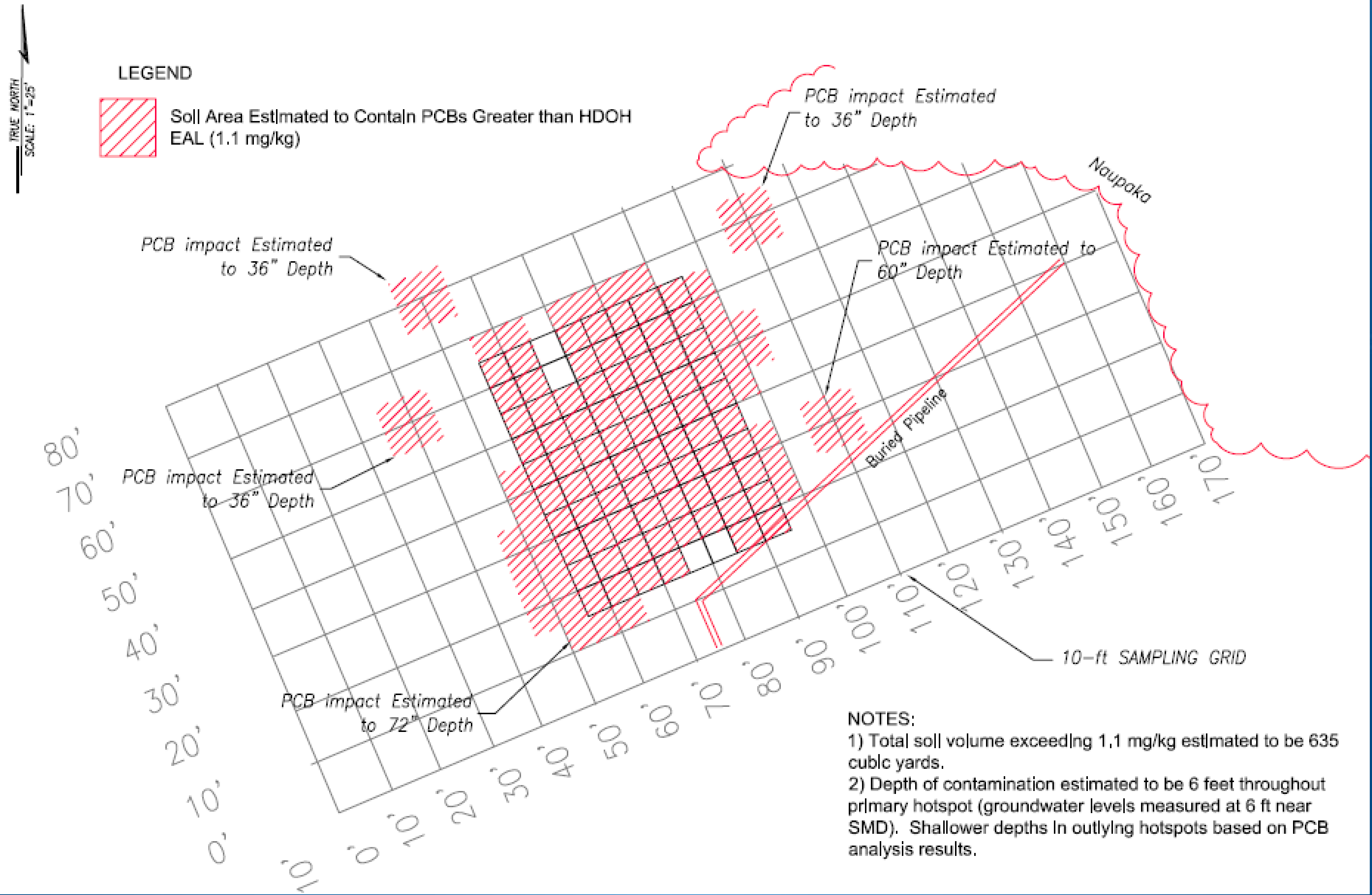




- Skewed, Log-Normal Distribution of Soil PCB Concentrations
- Measured in Discrete Samples from Shallow (DU11) and Deep (DU13) Landfill Soils

Analyzed >500 Samples for PCBs in 10 Days

Lateral Extent of Soils Containing PCB Concentrations Greater than 1.1 mg/kg



NOTES:

1) Total soil volume exceeding 1.1 mg/kg estimated to be 635 cubic yards.

2) Depth of contamination estimated to be 6 feet throughout primary hotspot (groundwater levels measured at 6 ft near SMD). Shallower depths in outlying hotspots based on PCB analysis results.

Discrete PCB Sampling Results (mg/kg) in Three MI DUs

			ND	ND	ND	0.1	0.1	0.1	170
		ND	ND	ND	ND	0.1	0.1	0.2	160
		ND	ND	ND	ND	0.2	0.2	0.2	150
		0.1	ND	ND	0.1	ND	0.6	0.1	140
	ND	ND	ND	0.3	ND	0.1	0.2	0.2	130
	ND	ND	ND	0.1	ND	0.2	0.1	0.2	120
ND	1.2	0.7	0.8	0.3	0.6	0.4	0.3	0.5	110
ND	0.2	ND	0.3	ND	0.1	0.5	0.3	0.5	100
ND	ND	3.1	ND	ND	ND	0.1	ND	0.1	90
ND	ND	ND	ND	0.2	0.2	0.3	ND	0.1	80
ND	ND	ND	0.8	ND	0.2	0.6	0.3	0.1	70
ND	ND	ND	0.1	5.3	1.4	0.8	0.5	0.4	60
22.7	ND	ND	ND	ND	0.1	2.0	1.8	ND	50
ND	ND	5.0	ND	ND	ND	0.2	0.9	0.6	40
ND	4.3	1.0	2.2	0.6	0.8	0.5	0.5	0.6	30
ND		0.3	0.2	0.1	0.1	0.2	0.1	0.1	20
ND	ND	ND	0.2	ND	0.2	ND	ND	ND	10
ND	ND	ND	ND	ND	ND	ND	ND	ND	0
80	70	60	50	40	30	20	10	0	Y-Axis
X-Axis (Feet)									
DU11: MI Sample Result = 0.35 mg/kg									

			ND	ND			0.1		170
		ND	ND	ND	ND				160
		ND	0.1	ND			ND		150
		ND	ND	ND	ND	ND	ND		140
	ND	ND	ND	ND	ND				130
	ND	ND	ND	0.2	ND	ND	ND		120
ND	0.1	ND	ND	ND	1.7	ND			110
0.3	ND	0.6	0.8	0.3	ND	ND			100
ND	ND	2.7	6.9	0.2	2.0	19.8	ND		90
ND	ND	10.3	5.5	4.3	7.6	ND	ND		80
	ND	ND	16.7	11.4	1.5	0.5	ND		70
ND	ND	0.1	0.2	1.3	2.3	1.0	ND		60
ND		ND	ND	ND	1.4	0.7	ND	0.2	50
ND	ND	ND	ND	ND	0.4	0.6		ND	40
ND	ND	ND	ND	ND	ND	0.1	ND	ND	30
ND	ND	ND	ND	ND	ND	ND	ND		20
ND	ND	ND	ND	ND	ND	0.1	0.1	ND	10
ND	ND	ND	ND	ND	ND	ND		ND	0
80	70	60	50	40	30	20	10	0	Y-Axis
X-Axis (Feet)									
DU12: MI Sample Result = 2.53 mg/kg									

				ND					170
		ND		ND	ND				160
		ND	ND	ND			0.5		150
		ND	ND	ND	ND	ND			140
	ND	ND	ND	ND	ND				130
	ND	ND	ND	0.5	ND	ND	0.1		120
ND	ND	0.1	ND	ND	ND	ND			110
ND	0.1	0.8	1.4	0.1	0.3	ND			100
ND	0.2	2.0	15.9	0.7	0.3	3667	ND		90
ND	2.1	5.2	21.7	3.9	0.8	0.8	ND		80
ND	ND	0.7	24.2	3.4	8.6	87.5	ND		70
ND	ND	0.3	3.9	0.7	5.2	0.2	ND		60
ND	ND	ND	0.1	0.4	ND	ND	ND	ND	50
ND	ND	ND	0.3	ND		0.3	ND	ND	40
ND	ND	ND	ND	ND	ND		ND	ND	30
ND	ND	ND	ND	ND	0.3	0.8	0.3	ND	20
ND	ND	ND	ND	ND	0.1	ND	0.3		10
ND	ND	ND	ND	ND	ND		0.2	0.1	0
80	70	60	50	40	30	20	10	0	Y-Axis
X-Axis (Feet)									
DU13: MI Sample Result = 40 mg/kg									

SMD Landfill Sub-Divided into 8 RI Sampling Areas
Used in Monte Carlo Analysis with Field PCB Data (mg/kg)
[Red Values Exceed Hawaii Department of Health
Environmental Action Level of 1.1 mg/kg]

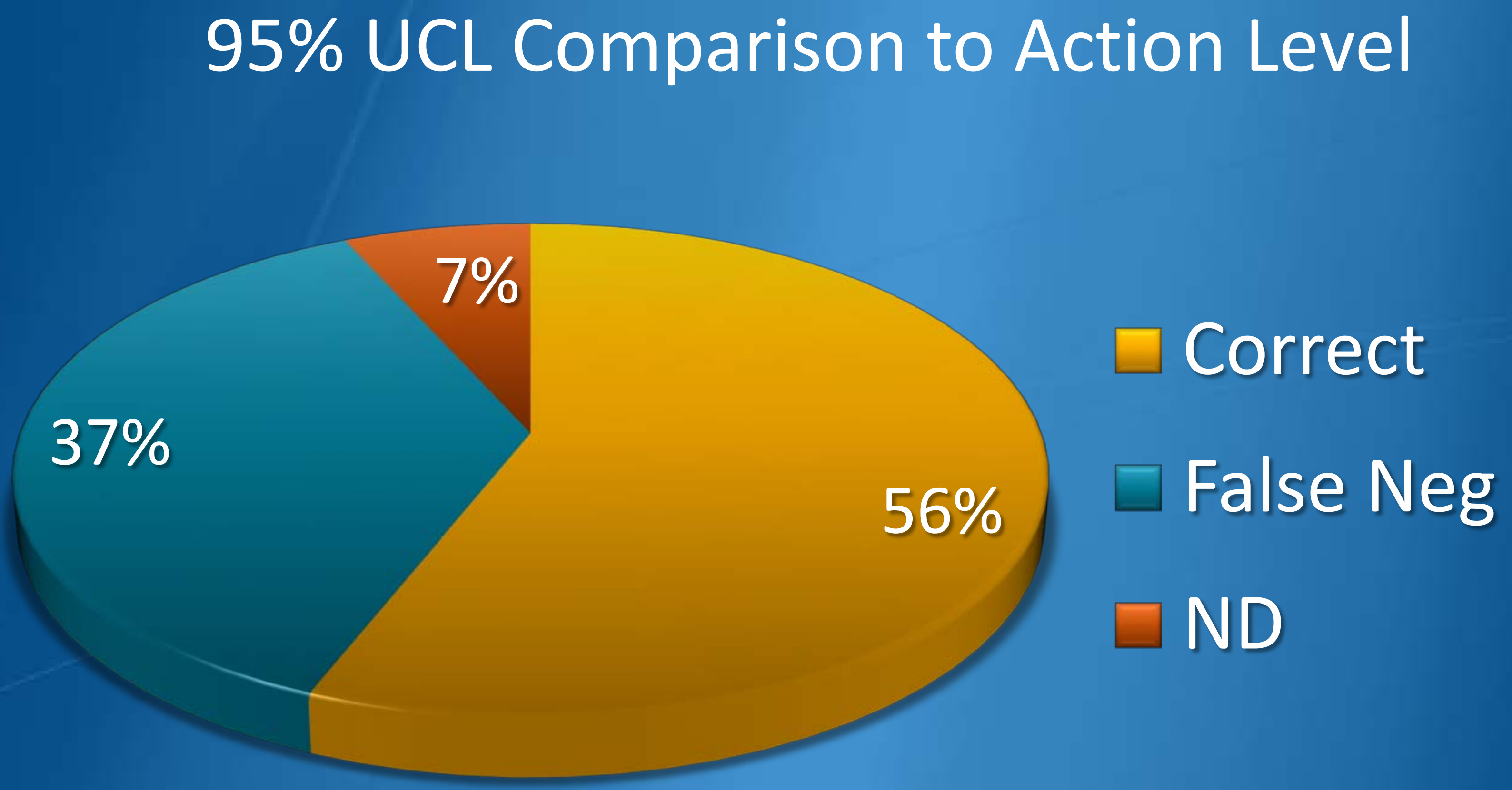
Monte Carlo Analysis

- A Monte-Carlo analysis was conducted on the field PCB data collected to simulate the range of PCB concentrations that would have been determined for the SMD using a traditional Remedial Investigation (RI) approach involving the collection of eight, discrete soil samples.

Summary of Monte Carlo Analysis Results

Monte Carlo Analysis Results (1000 trials)	**Shallow Soils: DU11**	**Intermediate Soils: DU12**	**Deep Soils: DU13**
Mean of Monte Carlo Simulated Means (mg/kg)	0.45	0.84	33.62
Field Measured Mean (mg/kg)	0.47	0.84	31.93
Field Measured 95% UCL (mg/kg)	0.79	1.34	91.3
Percentage of Monte Carlo Simulated RI 95% UCL Results Above UCL (1.1 mg/kg)	**FALSE POSITIVE** 25.1%	45.8%	**CORRECT** 56.1%
Percentage of Monte Carlo Simulated RI 95% UCL Results Below UCL (1.1 mg/kg)	**CORRECT** 74.9%	54.2%	**FALSE NEGATIVE** 43.9%
Percentage of Simulations Where All Eight Randomly Selected Discrete Samples Below Analytical Detection Level of 0.25 mg/kg	10.8%	15.2%	6.8%

Deep Soil DU 13



Summary

- MI sampling approach is useful as a cost-effective and efficient tool to estimate mean concentration in DU.
- MI results indicated that subsurface soils exceeded target action levels. This was confirmed by 95% UCLs for the corresponding discrete data.

Summary

- The inclusion of a large number of individual increments (typically 30 or more per DU) adequately incorporates a representative number of isolated "hot-spots" or "nuggets" of contamination into an estimation of the mean, despite the skewed, log-normal distribution of PCB in the discrete samples.

Summary

- Traditional RI sampling
  - Underestimated the MI sampling result roughly 89% of the time in the deep DU soils.
  - Yielded a false negative result with respect to the screening health risk level for PCB 44% of the time in the deep DU soils.

Summary

- The increased analytical costs (minimum 20 to 30 discrete samples per DU required) and distraction often caused by an inappropriate focus on individual samples makes traditional, discrete sampling approaches unappealing beyond possible use to aid in identifying the boundaries of large spill areas that are not already obvious in the field.

Acknowledgments

- United States Coast Guard – Honolulu Civil Engineering Unit
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- Hawaii Department of Land and Natural Resources

Questions?