



**US Army Corps
of Engineers®**
Engineer Research and
Development Center



Application of Incremental Sampling Methodology for Subsurface Sampling

Elizabeth J. Corriveau and Jay L. Clausen

April 2021



The U.S. Army Engineer Research and Development Center (ERDC) solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at www.erdclibrary.on.worldcat.org/discovery.

To search for other technical reports published by ERDC, visit the ERDC online library at <http://www.erdclibrary.on.worldcat.org/discovery>.

Application of Incremental Sampling Methodology for Subsurface Sampling

Elizabeth J. Corriveau and Jay L. Clausen

*U.S. Army Engineer Research and Development Center (ERDC)
Cold Regions Research and Engineering Laboratory (CRREL)
72 Lyme Road
Hanover, NH 03755-1290*

Final Report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Corps of Engineers–Baltimore District
Environmental and Munitions Design Center
10 S. Howard St., Room 10040-P
Baltimore, MD 21201

Under “Incremental Sampling Investigation,” funded via Labor Charge Code

Abstract

Historically, researchers studying contaminated sites have used grab sampling to collect soil samples. However, this methodology can introduce error in the analysis because it does not account for the wide variations of contaminant concentrations in soil. An alternative method is the Incremental Sampling Methodology (ISM), which previous studies have shown more accurately captures the true concentration of contaminants over an area, even in heterogeneous soils. This report describes the methods and materials used with ISM to collect soil samples, specifically for the purpose of mapping subsurface contamination from site activities. The field data presented indicates that ISM is a promising methodology for collecting subsurface soil samples containing contaminants of concern, including metals and semivolatile organic compounds (SVOCs), for analysis. Ultimately, this study found ISM to be useful for supplying information to assist in the decisions needed for remediation activities.

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Contents

Abstract	ii
Figures and Tables.....	iv
Preface.....	v
Acronyms and Abbreviations.....	vi
1 Introduction.....	1
1.1 Background.....	1
1.2 Objective.....	2
1.3 Approach	2
2 Incremental Sampling Methodology.....	3
2.1 Sampling site description.....	3
2.2 Equipment.....	4
2.3 Sample collection	5
2.4 Sample preparation.....	9
2.5 Laboratory analysis.....	10
3 Results and Discussion.....	12
4 Conclusion and Recommendations	17
References	18
Report Documentation Page.....	20

Figures and Tables

Figures

1	Location of Maryland study site	4
2	Track-mounted GeoProbe drill rig	5
3	Systematic random Incremental Sampling Methodology consisting of 15 borings within a decision unit. <i>Dash lines</i> indicate the borders within the decision unit where samples were taken	6
4	Example of the sampling approach (not to scale)	6
5	Example of gravel and fill with munition debris	7
6	Example of red brick fill material	7
7	Example of metal slag fill within a cut acetate sleeve from the Soil Sampler	8
8	Illustration of a core wedge sampling technique	9
9	Example of Incremental Sampling Methodology subsample tools	10
10	Examples of the multi-increment sampling approach used in the laboratory (a.k.a. the two-dimensional Japanese Slab Cake method) to prepare the subsample for digestion and extraction	10
11	Revised ISM remediation zone compared to the original grab sampling method remediation zone	14

Tables

1	List of analyzed metals and semivolatile organic compounds	11
2	All semivolatile organic compound sample results with regional screening level exceedances	13
3	All metal sample results with regional screening level exceedances	14
4	Area and volume of decision units with regional screening level exceedances	15
5	Area and volume of soil exceeding regional screening levels broken out by sampling unit	16

Preface

This study was conducted for the U.S. Army Corps of Engineers (USACE) Baltimore District under, “Application of Incremental Sampling Methodology for Subsurface Sampling.” The technical monitor was Mr. Travis McCoun, Program Manager, USACE Military Munitions Design Center.

The work was performed by the Biogeochemical Sciences Branch of the Research and Engineering Division, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Mr. David B. Ringelberg was Acting Branch Chief; Dr. George Calfas was Acting Division Chief; and Dr. Bert Davis was the Technical Director. The Deputy Director of ERDC-CRREL was Mr. David B. Ringelberg and the Director was Dr. Joseph L. Corriveau.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

Acronyms and Abbreviations

bgs	Below Ground Surface
COPC	Contaminant of Potential Concern
CRREL	Cold Regions Research and Engineering Laboratory
Cu	Copper
DU	Decision Unit
EC	Environmental Concern
ERDC	Engineer Research and Development Center
ISM	Incremental Sampling Methodology
ITRC	Interstate Technology and Regulatory Council
Mn	Manganese
Pb	Lead
RSL	Regional Screening Levels
Sb	Antimony
SU	Sampling Unit
SVOC	Semivolatile Organic Compound
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
Zn	Zinc

1 Introduction

1.1 Background

The U.S. Army Corps of Engineers (USACE) Baltimore District tasked the Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL) to prepare a sampling and analysis plan (Clausen et al. 2014) to conduct an Incremental Sampling Methodology (ISM) study of a site located in Maryland. Lead (Pb) is the primary contaminant of potential concern (COPC) found; but elevated concentrations of manganese (Mn) and antimony (Sb), as well as semivolatile organic compounds (SVOCs), are also of concern (CEHNC 2011). The CRREL project team believes the primary source of these are from a former Powder Burning Tower. The residuals from the burning operations are unknown (ERT 2014) and were spread out as fill material to pack in topographic lows across the site.

The intent of this report is to describe in detail the ISM subsurface soil approach used to identify areas where the COPCs exceed U.S. Environmental Protection Agency (USEPA) Regional Screening Levels (RSL) and to determine the nature, extent, and maximum fill depth for each decision unit (DU). ISM is a structured composite sampling and processing protocol designed to reduce data variability and to increase sample representativeness for a specified volume of soil under investigation. This report often uses the terms DU and sampling unit (SU). A DU is a volume of soil where a decision or action is desired. The DU herein is divided into upper and lower SUs, which are smaller sampling areas within the DU (ITRC [Interstate Technology and Regulatory Council] 2020). The upper SU consisted of fill material from the surface down to a depth of 0.3 m (1 ft)* below ground surface (bgs), and the lower SU consisted of fill material present from 0.3 to 1.2 m (1 ft to 4 ft) bgs.

DUs were established around any location where an RSL exceedance occurred based on preexisting data (ERT 2014; CEHNC 2011; EA Engineer-

* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *U.S. Government Publishing Office Style Manual*, 31st ed. (Washington, DC: U.S. Government Publishing Office, 2016), 248–252, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

ing 2011; MKM Engineering 1999; Parsons 1999) obtained using the conventional sampling methodology known as grab sampling. Grab sampling is a method for collecting soil samples from a discrete point. With conventional grab sampling, typically several grab samples are collected from an area suspected to be contaminated, and then the sampling results are extrapolated between the points (Clausen, Georgian, and Bednar 2013; ITRC 2020; Hewitt et al. 2007). However, there is growing evidence that ISM may be a better method for soil sampling because, unlike grab sampling, the ISM approach provides results representative of the area of interest with reduced sampling variability and increased accuracy in detecting COPCs (Clausen, Georgian, and Bednar 2013; Clausen, Georgian, Bednar, et al. 2013).

1.2 Objective

This study had two objectives:

1. Demonstrate the benefits of ISM for subsurface sampling to determine if DUs at potentially contaminated sites of concern exceed the USEPA RSL.
2. Determine the nature and extent of the COPCs at the site and subsequently determine the area of remediation required.

1.3 Approach

This study resampled a study area because of it was previously known to contain COPCs, including Pb, Mn, Sb, and SVOCs (CEHNC 2011). We determined DU locations by reviewing previous grab sampling data; and within each DU location, we drilled 15 borings in a systematic random pattern. From each boring, we collected two ISM samples (upper and lower SUs); and the 15 increments for each SU were combined together to yield a single sample. A total of 122 ISM samples were collected from the site. Samples were shipped to ERT Laboratory who prepped and analyzed the samples for metals using USEPA Method 6010C (USEPA 2006b); and SVOCs using USEPA Method 8270D (USEPA 2007). In addition to ISM samples, we collected 15 grab samples to later compare the ISM and grab-sample data sets.

2 Incremental Sampling Methodology

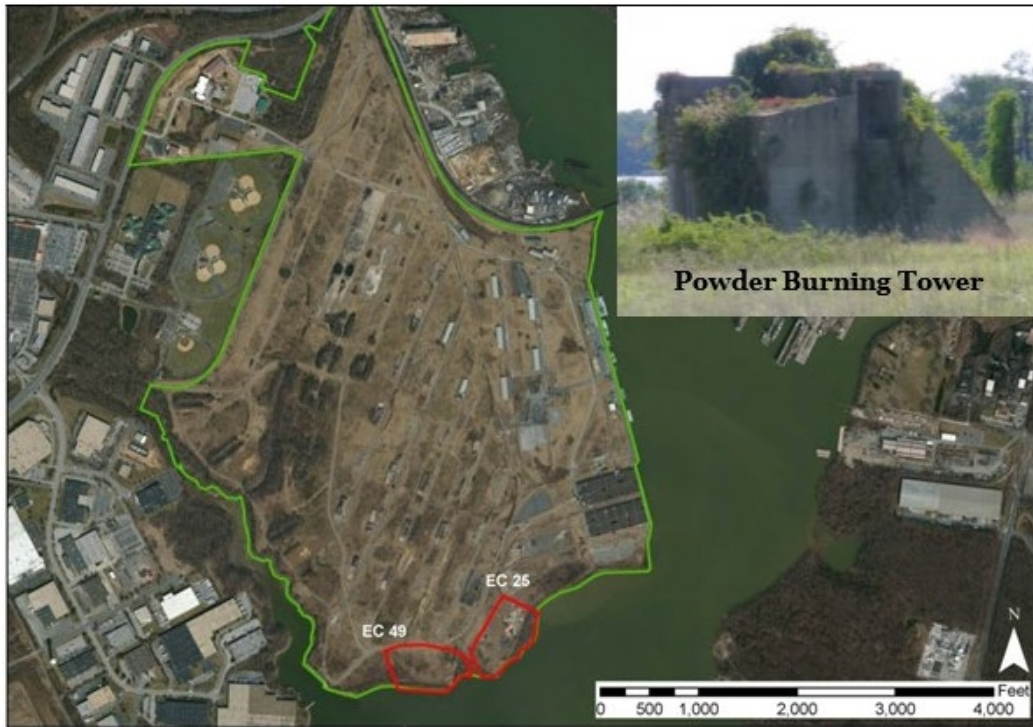
2.1 Sampling site description

We investigated two areas that cover roughly 8 hectares (20 acres). The surface soil consists of nonnative material, referred to as fill, used to pack in topographic lows. The fill material was generated from historical burn activities conducted at a former Powder Burning Tower (Figure 1). Integration of previous investigation findings (ERT 2014; CEHNC 2011; EA Engineering 2011; MKM Engineering 1999; Parsons 1999) established a maximum depth of 1.2 m (4 ft) for the fill material. These previous studies defined fill as munition debris; scrap; or cultural debris, such as wood scrap or concrete block.

Below the fill material lies native surface soil, which consists of a well-drained, upland silty sand surface over poorly graded sand with silt and gravel as the subsoil (CEHNC 2011). Most of the ground surface consists of areas with highly dispersed open grass. Sand and grass with a few trees and several small sand mounds cover the northeastern portion of the site (Figure 1). Marshland, a few trees, and nonnative stone cover the southern portion of the site.

The mean annual air temperature at the Baltimore Washington International Airport is 12.8°C (55.04°F), ranging from average monthly temperatures of approximately 1.7°C (35°F) in the winter to about 23.9°C (75°F) in the summer (National Climatic Data Center 2014). July is the warmest month, and January is the coldest. The mean annual precipitation at the Baltimore airport is 106.7 cm (42 in.), where 60% of the rainfall occurs between April and October. The site is located within 10 miles of the Baltimore Washington International Airport.

Figure 1. Location of Maryland study site.



2.2 Equipment

The team collected soil samples between 2 June and 19 June 2014 using a GeoProbe Model 54LT drill rig (Figure 2) equipped with the Macro-Core MC5 Soil Sampler, where removable acetate sleeves were inserted inside. Borings were advanced from grade to 1.2 m (3.94 ft) below grade using a drill rod with a 2.54 cm (1 in.) inner diameter. Once the soil boring was extracted from the subsurface, the acetate sleeve was extruded from the Macro-Core MC5 Soil Sampler and cut using a core-splitter. The material was logged to identify the fill depth.

The sampling equipment was not decontaminated between the collection of soil cores within a DU as the 15 core samples were combined to yield a single sample for the DU. Before moving from one DU to the next, we decontaminated nondedicated sampling equipment, such as knives to split the core, by using a tap-water and Liquinox wash, a tap-water rinse, and a triplicate distilled water rinse.

Figure 2. Track-mounted GeoProbe drill rig.



2.3 Sample collection

For this study, 15 borings were drilled in a systematic random pattern within each DU (Figure 3). ITRC (2020) generally recommends a minimum of 30 increments, or in this case, 30 borings, per DU. Given, the size of the DUs, 30 by 30 m (100 by 100 ft), and the amount of mass expected per sample, greater than 1 kg (2.2 lb), we considered 15 borings adequate to characterize a given DU using ISM. The location of the first boring was determined randomly within the DU. Once this position was selected, the locations of the remaining 14 borings within the DU were selected in a systematic pattern (Figure 3).

Two ISM (upper and lower SUs) samples were collected (Figure 4) from each boring if fill was present beyond 0.3 m (1 ft). Examples of fill observed during the demonstration at the Maryland site included gravel and munition (Figure 5), red brick fill (Figure 6), and metal slag fill (Figure 7). The upper SU involved the collection of an increment from 0 to 0.3 m (1 ft) bgs. The lower SU involved the collection of an increment from 0.3 m (1 ft) bgs to the base of the fill (maximum depth was expected to be 1.2 m [4 ft] bgs). The majority of the lower SU samples were collected from 0.3 to 0.6

m (1 to 2 ft) bgs. The 15 increments for each SU were combined together to yield a single sample. Because the 15 upper increments and 15 lower increments per DU were combined into separate SUs, geographical coordinates for the individual boring locations are not needed. The upper and lower SU samples represent a geographical area and not a single point; thus, the resulting data represents the concentration of the analyte across the entire DU. Consequently, this sampling approach does not provide results for an individual boring.

Figure 3. Systematic random Incremental Sampling Methodology consisting of 15 borings within a decision unit. *Dash lines* indicate the borders within the decision unit where samples were taken.

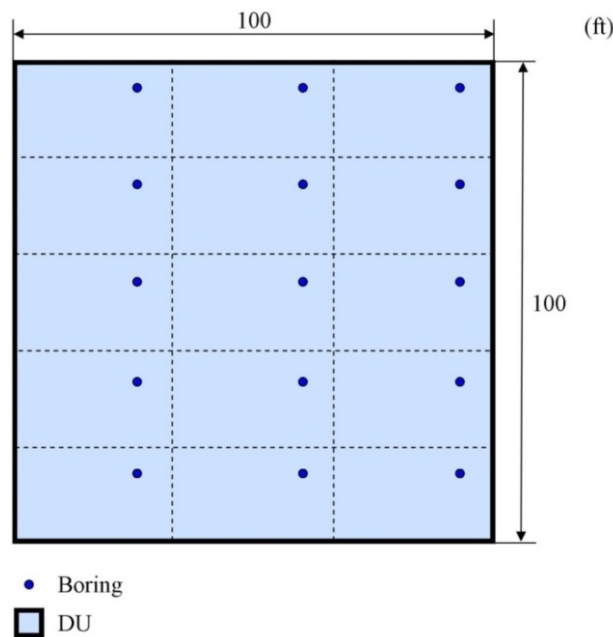


Figure 4. Example of the sampling approach (not to scale).

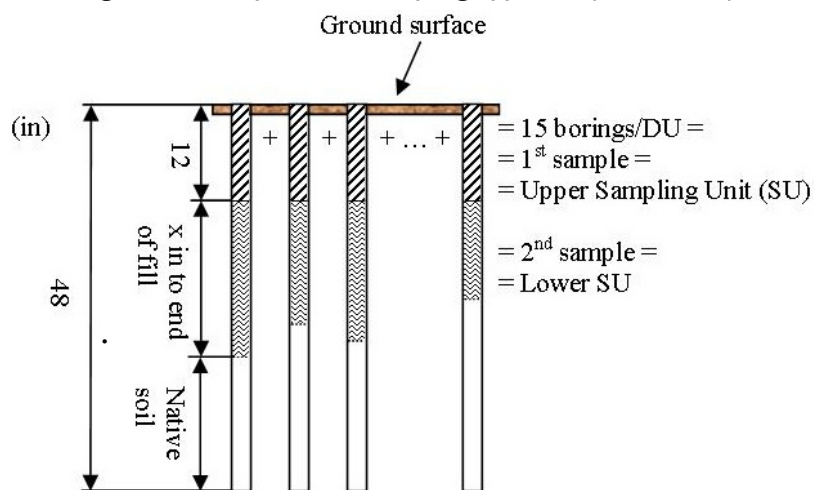


Figure 5. Example of gravel and fill with munition debris.



Figure 6. Example of red brick fill material.



Figure 7. Example of metal slag fill within a cut acetate sleeve from the Soil Sampler.



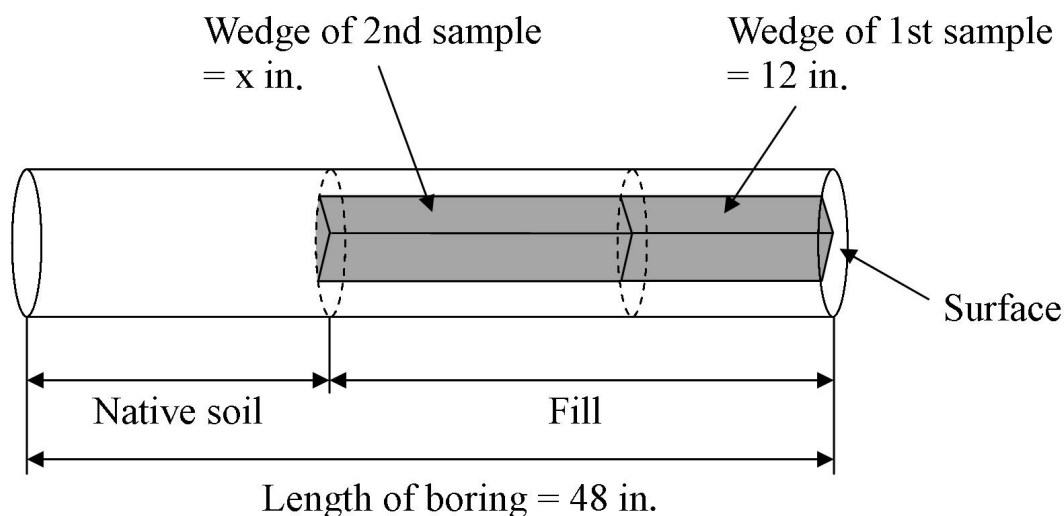
The splitting of the two SU intervals was done after cutting the acetate liner. All of the samples were stored in a cooler with ice immediately following collection and remained on ice until delivered to RTI Laboratories for sample preparation and analysis. The target volume of soil shipped to the analytical laboratory was approximately 1 kg (2.2 lb) as most analytical laboratories are not setup to handle larger volumes. The upper SU samples had an estimated mass of 1 to 2 kg (2.2 to 4.4 lb) for the 0.3 m (1 ft) interval. The lower SU samples had an estimated mass of 1 to 4 kg (2.2 to 8.8 lb). To reduce the volume of soil shipped to the analytical laboratory and processed, we used a core wedge technique prior to shipping (ITRC 2020).

The core wedge involves cutting the core lengthwise and removing a wedge of material to reduce the sample mass (Figure 8). For the upper SU, the cores were cut in half initially to reduce the soil volume by one half. Because there was a concern that the soil volume was still too large, beginning the second day of field work, the cores were cut into thirds to reduce the soil volume by two-thirds.

In addition to collecting ISM samples, fifteen grab samples were collected from 15 different DUs for a later comparison with the ISM approach. Instead of drilling an additional boring for the grab sample within a DU, we used half of the remaining material from one of the 15 ISM borings. When

a grab sample was desired, one-third of the soil along the length of one boring was removed from the acetate sleeve and placed directly, without any homogenization, into an amber, 8 oz, wide-mouth glass jar, equating to approximately 500 g (1.1 lb) of material. Consequently, the grab sample represents a specific point within the DU that was sampled. The grab samples represented a depth interval of 0.3 m (1 ft).

Figure 8. Illustration of a core wedge sampling technique.



2.4 Sample preparation

At RTI, the ISM samples were spread out to a 1 to 2 cm (0.4 to 0.8 in.) thickness on a tray, air-dried at room temperature for several days, and then sieved with a #10 mesh to remove the material larger than 2 mm (0.08 in.). The material less than 2 mm (0.08 in.) in size was mechanically pulverized for 60 sec using a milling apparatus. The pulverized material was then spread out to a 1 to 2 cm (0.39 to 0.78 in.) thickness on a tray, and a flat-edged scoop with sides (Figure 9) was used to collect 20 increments to make up the subsample for SVOC analysis. With the exception of naphthalene, there is no concern for the potential loss SVOCs from sample processing due to high boiling points. The 20 subsample increments were collected in a systematic random fashion similar to the field sampling approach. This sampling approach is sometimes referred to as the two-dimensional Japanese Slab Cake design (Figure 10). The SVOC sample was extracted following USEPA Method 3550C (USEPA 1996a). After a SVOC subsample was removed from the sample container, a second subsample was removed and used for metal analysis and milled for an additional 4 × 60 sec with a 60 sec cooling period between grinding efforts.

Figure 9. Example of Incremental Sampling Methodology subsample tools.

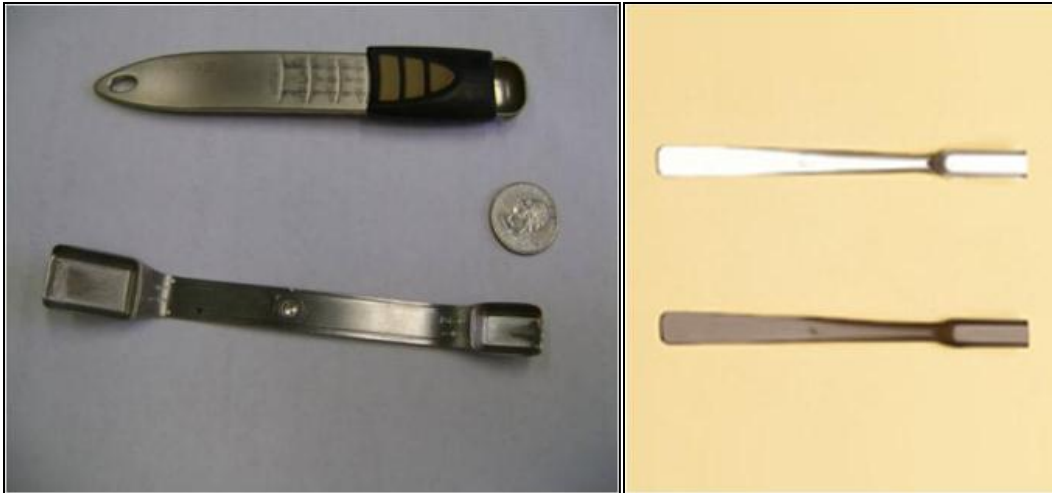


Figure 10. Examples of the multi-increment sampling approach used in the laboratory (a.k.a. the two-dimensional Japanese Slab Cake method) to prepare the subsample for digestion and extraction.



The subsample for metals analysis was collected in the same manner as that obtained for SVOC analysis. A 2 g (0.07 oz) subsample was prepared and digested instead of the 0.5 g (0.017 oz) quantity specified in USEPA Method 3050B (USEPA 1996b) with further modifications as discussed in Clausen et al. (2013a). The modifications included milling of the soil, incremental sampling to prepare the subsample digestion aliquot, and a larger digestion mass. The sample preparation procedures for this study generally followed those outlined in USEPA (2006a); Hewitt et al. (2007); ITRC (2020); and Clausen, Georgian, and Bednar (2013).

2.5 Laboratory analysis

Each sample was analyzed for metals—copper (Cu), Mn, Pb, Sb, and zinc (Zn)—and SVOCs. The metals analysis was conducted using USEPA Method 6010C (USEPA 2006b), and SVOCs analysis followed USEPA Method 8270D (USEPA 2007). The SVOCs analysis included the polycyclic aromatic hydrocarbon compounds listed (Table 1).

Table 1. List of analyzed metals and semivolatile organic compounds.

SVOCs	SVOCs	Metals
Acenaphthene	Dibenzo(a,h)anthracene	Antimony
Acenaphthylene	Fluoranthene	Copper
Anthracene	Fluorene	Lead
Benzo(a)anthracene	Ideno(1,230cd)pyrene	Manganese
Benzo(a)pyrene	Naphthalene	Zinc
Benzo(b)fluoranthene	Phenanthrene	
Benzo(k)fluoranthene	Pyrene	
Chrysene		

3 Results and Discussion

Tables 2 and 3 provide all SVOCs and metal sample results with RSL exceedances.

SVOCs and metal exceedances were identified in both upper (0–0.3 m [0–1 ft) and lower (0.3–1.2 m [1–4 ft]) SUs. Worth noting is the detection of lead in two lower samples that was not detected in the upper samples. The lower samples in which lead was detected with RSL exceedances include CB-ISM-11b at 1500 mg/kg and CB-ISM-56b at 5800 mg/kg (Table 3). The significance of this finding is that ISM detected contaminant levels exceeding the RSL that would have otherwise been missed using the conventional grab sampling. This is because the ISM consists of many increments, thus affording better spatial coverage than the grab sampling method where a single sample would miss contaminants as they are not uniformly spatially distributed.

A review of the grab-sample data indicates that when a given analyte is detected in both ISM and grab samples, the grab sample tends to have a lower value 62% of the time. One exception was DU63 where the upper SU ISM sample yielded an Mn value of 43,000 mg/kg whereas the upper SU grab sample, obtained from Boring 7, yielded a value of 210,000 mg/kg Mn (Table 3). Another example occurred at DU45 where benzo(a)pyrene was detected in the upper SU at a concentration of 2.5 mg/kg for the grab sample obtained from Boring 10 (Table 2) whereas the ISM sample yielded a value of 1.0 mg/kg. The RSL for benzo(a)pyrene is 2.11 mg/kg. In Figure 11, the original area of concern is outlined in red, and the propose remediation area determined by earlier studies using the grab sampling method is outlined in pink. The proposed remediation area prior to ISM characterization was 20,812 m² (224, 020 ft²) and the estimated volume of impacted soil was 31, 717 m³ (1,120, 072 ft³ or 41,484 yd³).

The revised remediation area is based on those DUs where at least one COPC denoted by a color (yellow = Pb, pink = Cu and Pb, Orange = Mn, and green = SVOC) exceeded the RSL. Uncolored DUs in Figure 11 did not exhibit COPCs exceeding the RSLs. The revised area of contamination was determined by summing together all those DUs having RSLs exceedances. The total area encompassed by the RSL exceedances is 18,582 m² (200,018 ft²). Thus, the revised remediation area represents a 12% reduction.

To determine the volume of impacted soil, a calculation was performed for each DU whereby the area was multiplied by the maximum fill depth observed. Then the fill volume of the individual DUs was summed to yield the total volume of fill material exceeding RSLs. For the upper SU, the depth interval is 0–0.3 m (0–1 ft); and for the lower SU, the depth interval is 0.3–0.6 m (1–2 ft), except for DU56. The depth interval for the lower SU at this DU is 0.3–0.91 m (1–3 ft) as fill was identified to a depth of 0.9 m (3 ft). This calculation yields a total impacted volume of soil of 7929 m³ (280,018 ft³ or 10,371 yd³) (Table 4), which is a 75% reduction of the volume of soil requiring remediation based on the grab sampling results.

Table 2. All semivolatile organic compound sample results with regional screening level exceedances.

Field Sample ID	Laboratory Sample ID	Analyte	Value (mg/kg)	Qualifier	RSL (mg/kg)
Upper Sampling Unit 0–0.3 m (0–1 ft)					
CB-ISM-26a	1406520-009B	Benzo(a)pyrene	3.6	-	2.11
CB-ISM-27a	1406520-011B	Benzo(a)pyrene	3.4	-	2.11
CB-ISM-28a	1406564-002B	Benzo(a)pyrene	3.9	-	2.11
CB-ISM-29a	1406564-005B	Benzo(a)pyrene	7.6	-	2.11
CB-ISM-32a1	1406690-004B	Benzo(a)anthracene	28.0	J	21.1
CB-ISM-32a1	1406690-004B	Benzo(a)pyrene	21.0	J	2.11
CB-ISM-32a1	1406690-004B	Benzo(b)fluoranthene	28.0	J	21.1
CB-ISM-32a1	1406690-004B	Dibenzo(a,h)anthracene	5.4	J	2.11
CB-ISM-32a2	1406690-003B	Benzo(a)pyrene	2.9	-	2.11
CB-ISM-32a3	1406690-001B	Benzo(a)pyrene	3.4	-	2.11
CB-ISM-38a	1406690-005B	Benzo(a)pyrene	6.1	-	2.11
CB-ISM-39a	1406690-008B	Benzo(a)anthracene	65.0	-	21.1
CB-ISM-39a	1406690-008B	Benzo(a)pyrene	54.0	-	2.11
CB-ISM-39a	1406690-008B	Benzo(b)fluoranthene	67.0	-	21.1
CB-ISM-39a	1406690-008B	Dibenzo(a,h)anthracene	9.0	-	2.11
CB-ISM-39a	1406690-008B	Indeno(1,2,3-cd)pyrene	26.0	-	21.1
CB-ISM-40a	1406614-003B	Benzo(a)pyrene	5.1	-	2.11
CB-ISM-41a	1406690-010B	Benzo(a)pyrene	3.3	J	2.11
CB-ISM-61a	1406966-007B	Benzo(a)pyrene	2.5	-	2.11
CB-D-45a*	1406564-012A	Benzo(a)pyrene	2.5	-	2.11
Lower Sampling Unit 0.3–1.2 m (0–4 ft)					
CB-ISM-38b	1406690-002B	Benzo(a)pyrene	2.4	-	2.11
CB-ISM-39b	1406690-009B	Benzo(a)pyrene	4.5	-	2.11
CB-ISM-41b	1406690-007B	Benzo(a)pyrene	2.2	-	2.11

* The result is for a grab sample with units µg/kg dry soil.

J = estimated value.

Table 3. All metal sample results with regional screening level exceedances.

Field Sample ID	Laboratory Sample ID	Analyte	Value (mg/kg)	Qualifier	RSL (mg/kg)
Upper Sampling Unit 0–0.3 m (0–1 ft)					
CB-ISM-26a	1406520-009C	Lead	4600	-	1235
CB-ISM-42a	1406769-001C	Lead	4200	-	1235
CB-ISM-43a	1406769-002C	Lead	1800	-	1235
CB-ISM-44a	1406769-007C	Lead	1300	-	1235
CB-ISM-47a	1406769-013C	Lead	3200	-	1235
CB-ISM-48a	1406769-010C	Copper	96,000	-	40,900
CB-ISM-48a	1406769-010C	Lead	6000	-	1235
CB-ISM-49a	1406769-008C	Lead	1800	-	1235
CB-ISM-55a	1406966-003C	Manganese	23,000	-	22,700
CB-ISM-63a	1406A35-005C	Manganese	43,000	-	22,700
CB-D-63a*	1406A35-007B	Manganese	210,000	-	22,700
Lower Sampling Unit 0.3–1.2 m (0–4 ft)					
CB-ISM-11b	1406390-005C	Lead	1500	-	1235
CB-ISM-44b	1406769-005C	Lead	1900	-	1235
CB-ISM-47b	1406769-014C	Lead	2600	-	1235
CB-ISM-56b	1406966-002C	Lead	5800	-	1235

* The result is for a grab sample with units µg/kg dry soil.

Figure 11. Revised ISM remediation zone compared to the original grab sampling method remediation zone.



Table 4. Area and volume of decision units with regional screening level exceedances.

DU Number	SU Exceeding RSL	Area of DU with RSL Exceedance (ft ²)	Area of DU with RSL Exceedance (m ²)	Maximum Fill Depth (ft)	Maximum Fill Depth (m)	Volume Exceeding RSL (ft ³)	Volume Exceeding RSL (m ³)	Volume Exceeding RSL (yd ³)
11	b	10,000	929	2.0	0.61	20,000	566	741
26	a	3793	352	1.0	0.30	3793	107	140
27	a	10,000	929	1.0	0.30	10,000	283	370
28	a	10,000	929	1.0	0.30	10,000	283	370
29	a	16,225	1507	1.0	0.30	16,225	459	601
32	a	10,000	929	1.0	0.30	10,000	283	370
38	a,b	10,000	929	2.0	0.61	20,000	566	741
39	a, b	10,000	929	2.0	0.61	20,000	566	741
40	a	10,000	929	1.0	0.30	10,000	283	370
41	a, b	10,000	929	2.0	0.61	20,000	566	741
42	a	10,000	929	1.0	0.30	10,000	283	370
43	a	10,000	929	1.0	0.30	10,000	283	370
44	b	10,000	929	2.0	0.61	20,000	566	741
47	a,b	10,000	929	2.0	0.61	20,000	566	741
48	a	10,000	929	1.0	0.30	10,000	283	370
49	a	10,000	929	1.0	0.30	10,000	283	370
55	a	10,000	929	1.0	0.30	10,000	283	370
56	b	10,000	929	3.0	0.91	30,000	850	1111
61	a	10,000	929	1.0	0.30	10,000	283	370
63	a	10,000	929	1.0	0.30	10,000	283	370
Total		200,018	18,582			280,018	7929	10,371

a = upper SU 0–0.3 m (0–1 ft); b = lower SU 0.3–0.6 or 0.91 m (1–2 or 3 ft).

DU = decision unit; SU = sampling unit, RSL = regional screening level.

Breaking out the area of soil with RSL exceedances by upper and lower SUs yields 12,079 m² (130,018 ft²) for the upper SU, 2787 m² (30,000 ft²) for the lower SU, and 3716 m² (40,000 ft²) for DUs with both upper and lower SU RSL exceedances (Table 5). This area of RSL exceedances yields the following volume of impacted soil: 3682 m³ (130,018 ft³ or 4815 yd³) for the upper SU, 1982 m³ (70,000 ft³ or 2593 yd³) for the lower SU, and 2265 m³ (80,000 ft³ or 2963 yd³) for SUs with both upper and lower RSL exceedances (Table 5).

Table 5. Area and volume of soil exceeding regional screening levels broken out by sampling unit.

SUs	Area of DU with RSL Exceedance (ft ²)	Area of DU with RSL Exceedance (m ²)	Maximum Fill Depth (ft)	Maximum Fill Depth (m)	Volume Exceeding RSL (ft ³)	Volume Exceeding RSL (m ³)	Volume Exceeding RSL (yd ³)
a	130,018	12,079	12	4	130,018	3682	4815
b	30,000	2787	7	2	70,000	1982	2593
a,b	40,000	3716	7	2	80,000	2265	2963

a = upper SU 0-0.3 m (0-1 ft); b = lower SU 0.3-0.6 or 0.91 m (1-2 or 3 ft).

DU = decision unit; SU = sampling unit; RSL = regional screening level.

4 Conclusion and Recommendations

This study successfully demonstrated applying the ISM method for subsurface sampling. ISM allowed the entire area of each DU to be sampled evenly, thereby reducing variability. COPCs were successfully measured and aided the decision-making regarding site remediation. As indicated earlier, the use of ISM reduced the area determined to require remediation by 12%. The principle COPCs identified were Pb and benzo(a)pyrene. Other COPCs observed exceeding RSLs on occasion were Cu, Mn, benzo(a)anthracene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Although the results to date strongly suggest that ISM is superior to the grab method for surface sampling, future efforts should more closely compare ISM and the grab sampling method for subsurface samples. Determining which method is optimal for investigating environmental sites of concern for remediation purposes is important because increased accuracy and reduced variability in sampling methodology will help improve the decisions made regarding site remediation. ISM improves decision-making, which may potentially reduce the remediation area. As shown in this study, the ISM approach reduced the remediation area by 12% and volume by 75% compared to the grab sampling approach. This reduction in remediation area and volume can help to significantly reduce costs. ISM also improves accuracy by increasing the probability that individual particulates are encountered in the sample through the collection of field increments as well as the additional sample processing steps in the laboratory. This increased accuracy can further improve the identification of the area requiring remediation. In conclusion, this study successfully demonstrated ISM for subsurface sampling at a site in Maryland, resulting in a time and cost savings during the investigation stage and ultimately subsequent remediation. Beyond this, the ISM subsurface soil sampling approach and benefits have applicability to the wider environmental industry.

References

- CEHNC. 2011. *Final Site Inspection Report, Former Curtis Bay General Services Administration Property Site, Anne Arundel County, Maryland*. Prepared for General Services Administration, Mid-Atlantic Region 3, Philadelphia, PA by USACE Huntsville.
- Clausen, J. L., A. Wagner, and A. Coplin. 2014. *Final Sampling and Analysis Plan for the Incremental Sampling Investigation Former Curtis Bat Ordnance Depot Baltimore, Anne Arundel County, Maryland*. Prepared for the U.S. Army Corps of Engineers Baltimore District. Hanover, NH: U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory.
- Clausen, J. L., T. Georgian, and A. Bednar. 2013. *Incremental Sampling Methodology (ISM) for Metallic Residues*. ERDC/CRREL TR-13-5. Hanover, NH: U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory. <http://hdl.handle.net/11681/8566>.
- Clausen, J. L., T. Georgian, A. Bednar, N. Perron, A. Bray, P. Tuminello, G. Gooch, N. Mulherin, A. Gelvin, M. Beede, S. Saari, W. Jones, and S. Tazik. 2013. *Demonstration of Incremental Sampling Methodology for Soil Containing Metallic Residues*. ERDC/CRREL TR-13-9. Hanover, NH: U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory. <http://hdl.handle.net/11681/8482>.
- EA Engineering. 2011. *Final Environmental Survey and Analysis Report, U.S. Army Ordnance Depot, Curtis Bay Depot, Baltimore, Anne Arundel, Maryland*. Sparks, MD: EA Engineering, Science, and Technology, Inc.
- ERT. 2014. *Draft EC-25 Engineering Evaluation/Cost Analysis for Military Munition Response Program and Installation Restoration Program. Remedial Investigation/Feasibility Study and Engineering Evaluation/Cost Analysis*. Former Curtis Bay Ordnance Depot, Anne Arundel County, Maryland. Contract No. W912DR-090D-0012, Delivery Order 0007. Prepared for the U.S. Army Corps of Engineers. Silver Springs, MD: ERT, Inc.
- Hewitt, A. D., T. F. Jenkins, M. E. Walsh, M. R. Walsh, S. R. Bigl, and C. A. Ramsey. 2007. *Protocols for Collection of Surface Soil Samples at Military Training and Testing Ranges for the Characterization of Energetic Munitions Constituents*. ERDC/CRREL TR-07-10. Hanover, NH: U.S. Army, Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory.
- ITRC (Interstate Technology and Regulatory Council). 2020. *Technical and Regulatory Guidance: Incremental Sampling Methodology. ISM-2*. Washington, DC: Interstate Technology and Regulatory Council, Incremental Sampling Methodology Team. <https://ism-2.itrcweb.org/>.
- MKM Engineering. 1999. *Geophysical Survey and UXO Removal Report Curtis Bay Depot, Maryland*. Maryland: MKM Engineering.

- National Climatic Data Center. 2014. "1981–2010 Climate Normals." Normal Data Access from Baltimore Washington International Airport, MD. Accessed March 21, 2014. Asheville, NC: National Oceanic and Atmospheric Administration, National Climatic Data Center. <http://www.ncdc.noaa.gov/land-based-station-data/climate-normals/1981-2010-normals-data>.
- Parsons. 1999. *Preliminary Assessment Curtis Bay Depot Curtis Bay, Maryland*. Prepared for U.S. Army Corps of Engineers Huntsville Center. Pasadena, CA: Parsons Engineering Science, Inc.
- USEPA (U.S. Environmental Protection Agency). 1996a. "Method 3550C: Ultrasonic Extraction." In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*. SW-846. Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. <http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/3550c.pdf>.
- . 1996b. "Method 3050B: Acid Digestion of Sediments, Sludges, and Soils." In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*. SW-846. Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. <http://www.epa.gov/wastes/hazard/testmethods/sw846/pdfs/3050b.pdf>.
- . 2006a. "Method 8330B: Nitroaromatics, Nitramines, Nitrate Esters by High Performance Liquid Chromatography (HPLC)." In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Office of Solid Waste and Emergency Response*. SW-846. Washington, DC: U.S. Environmental Protection Agency.
- . 2006b. "Method 6010C: Inductively Coupled Plasma-Atomic Emission Spectrometry." In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Office of Solid Waste and Emergency Response*. SW-846. Washington, DC: U.S. Environmental Protection Agency.
- . 2007. "Method 8270D: Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)." In *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*. SW-846. Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) April 2021		2. REPORT TYPE Technical Report / Final		3. DATES COVERED (From - To) FY19–FY20	
4. TITLE AND SUBTITLE Application of Incremental Sampling Methodology for Subsurface Sampling				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT	
6. AUTHOR(S) Elizabeth J. Corriveau and Jay L. Clausen				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) 72 Lyme Road Hanover, NH 03755-1290				8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/CRREL TR-21-7	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Corps of Engineers–Baltimore District Environmental and Munitions Design Center 10 S. Howard St., Room 10040-P Baltimore, MD 21201				10. SPONSOR/MONITOR'S ACRONYM(S) USACE	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES “Incremental Sampling Investigation,” funded via Labor Charge Code					
14. ABSTRACT <p>Historically, researchers studying contaminated sites have used grab sampling to collect soil samples. However, this methodology can introduce error in the analysis because it does not account for the wide variations of contaminant concentrations in soil. An alternative method is the Incremental Sampling Methodology (ISM), which previous studies have shown more accurately captures the true concentration of contaminants over an area, even in heterogeneous soils. This report describes the methods and materials used with ISM to collect soil samples, specifically for the purpose of mapping subsurface contamination from site activities. The field data presented indicates that ISM is a promising methodology for collecting subsurface soil samples containing contaminants of concern, including metals and semivolatile organic compounds (SVOCs), for analysis. Ultimately, this study found ISM to be useful for supplying information to assist in the decisions needed for remediation activities.</p>					
15. SUBJECT TERMS Characterization, Contamination, Contaminant of potential concern (COPC), Environmental sciences, Incremental Sampling Methodology (ISM), Metals, Remediation, Semivolatile organic compounds (SVOCs), Soil pollution, Soils–Sampling, Subsurface sampling					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)