NAVFAC Naval Facilities Engineering Command
ENGINEERING AND EXPEDITIONARY WARFARE CENTER

TECHNICAL MEMORANDUM [200924-WEB-NAVFAC-EXWC-EV-2012]

ADVANTAGES AND LIMITATIONS OF THE INCREMENTAL SAMPLING METHODOLOGY FOR NAVY PROJECTS

Prepared for NAVFAC EXWC under Contract No. N39430-16-D-1802

August 2020

REPORT DOCUMENTATION PAGE

FORM APPROVED
OMB NO. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 01-08-2020	**2. REPORT TYPE** Technical Memorandum	**3. DATES COVERED** *(From – To)* Click here to enter text.

4. TITLE AND SUBTITLE Advantages and Limitations of the Incremental Sampling Methodology for Navy Projects	**5a. CONTRACT NUMBER** N39430-16-D-1802
	5b. GRANT NUMBER Click here to enter text.
	5c. PROGRAM ELEMENT NUMBER Click here to enter text.
6. AUTHOR(S) Dr. David Eskew Sustainment and Restoration Services (SRS)	**5d. PROJECT NUMBER** Click here to enter text.
	5e. TASK NUMBER ESTS Task Order 54
	5f. WORK UNIT NUMBER Click here to enter text.
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Click here to enter text.	**8. PERFORMING ORGANIZATION REPORT NUMBER** Click here to enter text.
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) NAVFAC EXWC EV32	**10. SPONSOR / MONITOR'S ACRONYM(S)** Click here to enter text.
	11. SPONSOR / MONITOR'S REPORT NUMBER(S) Click here to enter text.

12. DISTRIBUTION / AVAILABILITY STATEMENT
Click here to enter text.

13. SUPPLEMENTARY NOTES
Click here to enter text.

14. ABSTRACT
Incremental sampling methodology (ISM) is a structured composite sampling and processing protocol that is designed to reduce data variability and provide a reasonably unbiased estimate of mean contaminant concentrations in a volume of soil. ISM was designed to provide representative samples from specific soil volumes called decision units (DUs). This memorandum describes the advantages and limitations of using an ISM approach, while accounting for Department of the Navy (DON) site types that may or may not be suitable for its use. Other factors for DON Remedial Project Managers (RPMs) to consider in the selection of ISM over traditional discrete or grab soil sampling methods are also examined.

15. SUBJECT TERMS
Click here to enter text.

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF**	**19a. NAME OF RESPONSIBLE PERSON** Kelsey Pauxtis-Thomas
a. REPORT Click here	**b. ABSTRACT** Click here	**c. THIS PAGE** Click here	Click here	Click here	**19b. TELEPHONE NUMBER** ***(include area code)*** Click here to enter text.

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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ACRONYMS AND ABBREVIATIONS

CSM	conceptual site model
CV	coefficient of variation
DON	Department of the Navy
DQO	data quality objective
DU	decision unit
EPC	exposure point concentration
GPS	global positioning system
HDOH	Hawaii Department of Health
ITRC	Interstate Technology and Regulatory Council
ISM	incremental sampling methodology
LDR	land disposal regulation
LUST	leaking underground storage tank
MDEQ	Michigan Department of Environmental Quality
MRP	munitions response program
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PFAS	per- and polyfluoroalkyl substances
PPE	personal protective equipment
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RPM	remedial project manager
RSD	relative standard deviation
SAR	small arms range
SSL	soil screening level
SU	sampling unit
SVOC	semi-volatile organic compound
TCLP	toxicity characteristic leaching procedure
TPH	total petroleum hydrocarbon
UCL	upper confidence limit
USACE	United States Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

1.0 INTRODUCTION

Incremental sampling methodology (ISM) is a structured composite sampling and processing protocol that is designed to reduce data variability and provide a reasonably unbiased estimate of mean contaminant concentrations in a volume of soil. ISM was designed to provide representative samples from specific soil volumes called decision units (DUs). If the sampling is performed for risk assessment purposes, the DU represents the smallest volume of soil about which a risk-based decision is to be made for an average exposure. The volume of soil is defined by the area and depth of soil to which a receptor may be exposed (Interstate Technology and Regulatory Council [ITRC], 2012). This memorandum describes the advantages and limitations of using an ISM approach, while accounting for Department of the Navy (DON) site types that may or may not be suitable for its use. Other factors for DON Remedial Project Managers (RPMs) to consider in the selection of ISM over traditional discrete or grab soil sampling methods are also examined.

2.0 BACKGROUND

Field sampling and subsampling account for a major source of error due to the high degree of variability when sampling soil for chemical contamination (Walsh et al., 2019). As shown in Figure 1, the potential for sampling errors from discrete sampling can result from factors such as varying contaminant distribution and soil heterogeneity across a given site. The sampling error can be increased if the sampling approach does not properly account for significant spatial variation in the contaminant distribution and/or the impact that soil properties can have on contaminant fate and transport (United States Environmental Protection Agency [USEPA], 2019). This increased data variability can ultimately lead to a higher level of uncertainty in remedial decisions for the site. The ISM protocol was designed to overcome these issues by collecting many increments (typically 30 to 100) from all parts of a DU, processing the increments by drying, sieving, and grinding (if compatible), thoroughly subsampling, and using larger aliquots of soil for analysis.

Figure 1. Factors that Impact Data Variability and Uncertainty in Discrete Soil Sampling (Source: Battelle)

Figure 2 illustrates both discrete and incremental sampling approaches. With discrete sampling, individual grab samples are collected from select locations based on techniques such as: 1) a judgmental sampling design where an expert picks the locations or 2) a statistical/probabilistic sampling design (NAVFAC, 2019). With incremental sampling, field replicates are collected in different directions in an unbiased manner throughout the entire DU (e.g., see the field replicate points and travel paths in Figure 2). ISM data are typically normally distributed and are considered by practitioners to provide a more representative concentration of the DU compared to discrete samples. In addition, ISM has been found to result in fewer non-detect samples compared to discrete sampling methods which reduces the need to censor data sets in calculations.[1]

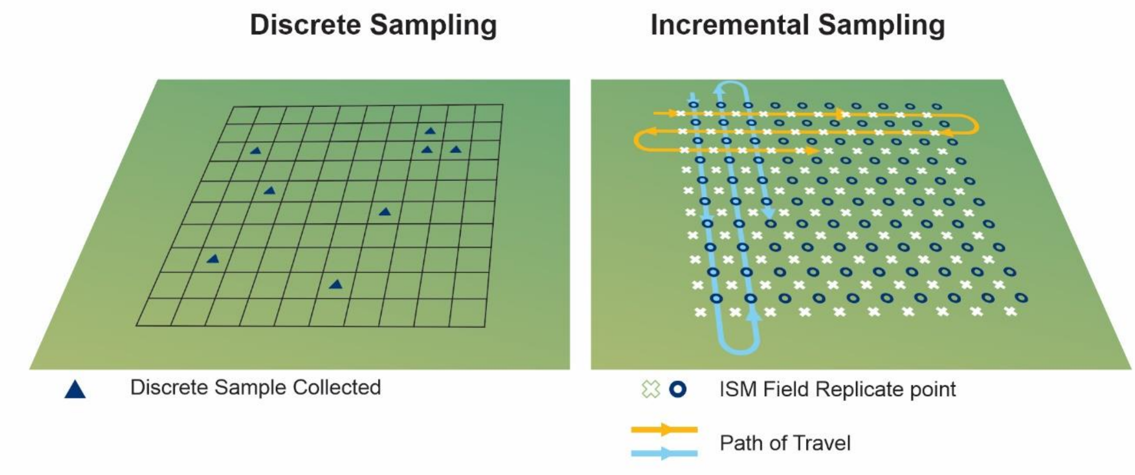

Figure 2. Discrete Sampling and Incremental Sampling Approaches (Source: Battelle)

The first ISM protocol for environmental testing was initially developed in response to the recognition that releases of energetic constituents during military training occurs in highly variable patterns. Studies conducted for characterization of energetic residues resulted in USEPA Method 8330B for explosives (USEPA, 2006a). Recent studies have applied ISM for several other analytes, particularly metals (Clausen et al., 2013); arsenic, lead, polychlorinated biphenyls (PCBs) (Brewer et al., 2017a, 2017b; USEPA, 2019), asbestos (Wroble et al., 2017); and petroleum hydrocarbons (Hyde et al., 2019).

Using the ISM protocol has the potential to reduce the cost of soil investigations in two ways: 1) by reducing the number of samples that need to be analyzed and 2) reducing the need for repeated rounds of sampling to meet project data quality objectives (DQOs). However, cost comparisons based solely on the per-unit costs of sampling and analysis may not accurately characterize the overall cost of ISM relative to conventional sampling. Based on demonstration studies comparing ISM directly with grab sampling at three small arms range (SAR) target berms and reviewing current industry practices, Clausen et al. (2013) estimated that ISM could result in a cost savings of 30% to 60% for soil investigations.

The cost/benefit of ISM versus conventional sampling is also related to the potential to improve remedial decision-making at a site. A higher level of uncertainty in concentration data can lead to

[1] https://www.itrcweb.org/Team/Public?teamID=11

a more conservative approach in designing a remediation strategy and therefore result in higher overall costs. In addition, Clausen et al. (2013) also recognized that the potential cost avoidance from "*implementing a remedial remedy when it is not necessary could be quite large, ranging from tens of thousands to tens of millions of dollars*." However, as discussed below, this is also balanced by the fact that ISM does not provide information on the spatial distribution of contaminants within a DU, which can be useful for refining the remedial footprint at a given site. With an ISM approach, all decisions are taken on a DU basis. Therefore, it is noted that the DU must be "appropriately defined" to ensure proper site characterization (USEPA, 2019).

3.0 ADVANTAGES AND LIMITATIONS OF ISM

Table 1 summarizes the key advantages and limitations associated with an ISM approach for soil investigations.

Table 1. Advantages and Limitations of the ISM Approach

Advantages	Limitations
• Collection of many increments and structured sample processing steps provides more reliable data with greater precision. • Increased sampling coverage equates to better representation of the average concentration for the soil volume in a DU as needed for risk assessment. • Overall sampling costs are reduced because fewer samples are required to meet DQOs. • Higher density sample increments collected throughout the DU increase the chance that soil with high concentrations (hot spots) will be represented.	• Information on the spatial distribution of contaminants within a DU is not provided. • Higher costs are incurred per individual sample. • Specialized soil sampling equipment is needed. • Not all laboratories are set up to handle the larger soil samples and additional processing steps. • ISM training is recommended for field and laboratory staff. • Regulatory stakeholders may be concerned about diluting areas with high concentrations. • Drying, sieving, and milling procedures are not applicable for volatile organic compounds (VOCs) and the required preservation for VOCs can be logistically challenging.

3.1 Advantages

The representativeness of chemical concentrations in a heterogeneous particulate media such as soil is directly tied, in part, to the mass of soil represented by the field sample and subsample tested by the laboratory. Historically, discrete samples for metals analysis may not have been appropriately homogenized prior to subsampling and testing. In addition, removing a very small aliquot for analysis has exacerbated the problem.

The ISM protocol calls for air drying, sieving, and grinding (or milling), thorough homogenization, and systematic uniform subsampling. All of these steps in the ISM protocol increase the chance that the analyzed sample is more representative of the as-received field sample. The increased coverage of the original field sample and the more thorough homogenization methods performed in the laboratory can greatly reduce the total overall cost. ISM typically provides greater representation of actual mean concentrations, increasing the probability of reaching a defensible decision about the need for remediation and also increasing the level of confidence in that decision.

3.2 Limitations

The ISM protocol is specifically designed to produce a representative soil sample for analysis that contains the constituents in the same proportion as in the total volume of the DU—it is designed to generate a reasonably unbiased estimate of mean contaminant concentrations. As a direct consequence of the methodology, an ISM sample does not provide information on the spatial distribution of the constituents. This is a limitation of the ISM protocol and requires careful attention during the development of project goals and DQOs. With proper attention during the systematic planning stage, this limitation can be overcome.

The ISM protocol calls for collection of soil sample increments using a soil coring device with a set diameter and depth to ensure that the increment collected is consistent and that all increments of the sample are collected in equal proportions. The specialized coring devices are readily available and fairly inexpensive. Discrete samples are typically collected with a trowel and, as a result, it is more difficult to verify that soil sample depths are consistent.

While adoption of the ISM protocol is increasing, not all contractors have experience implementing ISM. Therefore, it is important that members of the field sampling crew be experienced with ISM sample collection or receive training prior to mobilization and oversight during field sampling.

The air drying, sieving, grinding, and subsampling procedures developed for energetic compounds and metallic contaminants may not be suitable for use with volatile chemicals. ISM can be adapted for volatile contaminants by using preservatives. A list of suggested preservatives is provided in guidance from the Hawaii Department of Health (HDOH, 2016).

Not all laboratories can handle the larger mass of an ISM sample because extra space is required for air-drying samples. Also, not all laboratories have appropriate grinding equipment. Care must be exercised to ensure that the grinding equipment does not introduce metallic constituents such as chromium during the grinding process (Clausen et al., 2020).

4.0 ISM APPLICATION TO NAVY SITE TYPES

The ISM protocol can be used in all soil contamination investigations when a mean concentration is needed. However, there are applications where ISM will be difficult to apply and likely not cost effective. Less work has been done to establish ISM protocols for sediments; however, the first application of ISM was in an investigation of sediment contamination with white phosphorous that caused the deaths of thousands of dabbling ducks (Walsh et al., 2019).

ISM is applicable where particulate contaminants are dispersed over larges areas, such as military training ranges, SARs, and explosives disposal areas. The USEPA has issued guidance for characterizing munitions response program (MRP) sites using ISM (USEPA, 2012) as has the United States Army Corps of Engineers (USACE) (2009).

ISM has also been applied at non-MRP sites for metals and organic contaminants including PCBs, VOCs (with preservation), semi-volatile organic compounds (SVOCs), total petroleum hydrocarbons (TPH), radionuclides (e.g., uranium), and even recently at per- and polyfluoroalkyl substances (PFAS)-impacted sites. The state of Hawaii now requires the use of ISM for all soil investigations (HDOH, 2016). Michigan has also published specific guidance for ISM investigations (Michigan Department of Environmental Quality [MDEQ], 2018).

4.1 Skeet Ranges

ISM is well suited for investigating contamination at current and former skeet ranges, which involve multiple DUs with relatively large areas. Characterizing these large areas for average chemical concentrations would require a large number of discrete samples, resulting in high analytical costs. In contrast, for a similar investigation, far fewer ISM samples would be needed, and there would be greater confidence in the representativeness of the average concentrations in the DU. Skeet ranges typically comprise several acres. However, if the firing points are known, the patterns of distribution of lead shot and polycyclic aromatic hydrocarbon (PAH)-containing clay targets is predictable. The predictable contamination patterns make it relatively straightforward to define the number, size, and boundaries of the DUs.

4.2 Small Arms Ranges

The application of ISM to SARs has been extensively investigated (Clausen et al., 2013, 2018a, 2018b, 2020; USEPA, 2012). Clausen et al. (2018a,b) investigated four SARs. Their results indicated that ISM samples, each with 30 increments, gave a relative standard deviation (RSD) among seven replicates of 14% for lead and 15% for antimony. An RSD of 30% or less is considered adequately precise for making decisions. Although 30 increments yielded data with sufficient precision for this SAR site, 50 increments per sample are often collected.

4.3 Examples of Site Types Where ISM is Not Recommended

Because the ISM result is an average representation of the DU mean, utilization of ISM for source area identification or extent of contamination usually necessitates the use of much smaller DUs and extensive planning. Specifically, if spatial information of contamination within the source area is necessary for characterizing the site and deciding upon the most appropriate remediation technology, then ISM may not be cost-effective. Instead, an RPM should consider if appropriately designed discrete sampling, an iterative approach, or the combined use of ISM and discrete sampling is warranted. Other examples where ISM may not be applicable are acute risk evaluations, toxicity characteristic leaching procedure (TCLP), several state leaking underground storage tank (LUST) programs and Resource Conservation and Recovery Act (RCRA) Land Disposal Regulations (LDRs). Users should consult their local state or federal regulatory partners to confirm whether ISM can be used in these applications.

5.0 FACTORS TO CONSIDER IN THE SELECTION OF AN ISM APPROACH

DON RPMs should consider the factors below prior to the selection and/or implementation of an ISM approach at their site.

5.1 Need for Systematic Planning

Systematic planning following the USEPA (2006b) DQO process is a required part of any environmental investigation, but it is especially important for an investigation using ISM. Systematic planning is based on the scientific method and includes concepts such as objectivity of the approach and acceptability of results. MDEQ (2018) provides a useful description of the additional considerations needed during systematic planning for an ISM-based investigation, with emphasis on the need for a well-developed conceptual site model (CSM).

The key to successful ISM design lies in the selection of the DUs. DUs should be based on the specific end use of the data that must be identified during the systematic planning process. DUs should be defined so that the mean concentration value obtained through ISM is relevant to the explicitly articulated end use of the data (USACE, 2009).

Particular attention to researching the site history is needed to define potential source areas. This information is vital for designation of DUs that encompass soil volumes that are likely to have elevated contaminant concentrations without including a large proportion of areas that are likely not to be contaminated.

If sufficient historical information is not available to support DU definitions with confidence, then preliminary field investigations may be required to reduce the degree of uncertainty. For example, preliminary geophysical investigations may be useful to identify locations of previous site activity. If the boundaries of the source areas are not well known, transects across the suspected areas may be needed. Because of the typically high point-to-point heterogeneity of contaminant concentrations (Brewer et al., 2017a,b), experience indicates that these transects should be conducted using five-point composite samples with the recommended ISM laboratory processing steps to dampen the range of concentration variation and allow better recognition of the contamination patterns in the CSM.

5.2 Human Health Risk Assessment

Risk-based soil-screening values are based on the estimated average daily intake of a contaminant over time. Assuming a random walk model, a receptor is assumed to be exposed equally to all parts of an exposure area. Therefore, the average soil contaminant concentration across the exposure unit is the most appropriate value for evaluating the potential exposure of a receptor to site contaminants over a long period. If the ISM results are to be compared directly to soil screening levels (SSLs) for direct exposure, DUs should be about the same size as the exposure unit upon which the SSL is based (USEPA, 1996) and of the appropriate location and depth consistent with the receptor exposure assumptions.

For baseline human health risk assessments at the Remedial Investigation (RI) stage, it is necessary to define the nature and extent of contamination and to establish exposure point concentrations (EPCs). As indicated by USEPA (1989), the EPCs should be based on a 95% upper confidence limit (UCL) calculated using data from discrete samples, to add a margin of safety in the event that the sample mean is underestimated.

Average concentrations are most representative of the concentrations at a site that would be contacted over time (USEPA, 1992). ISM gives a confident estimate of the true mean concentration and may be substituted for a 95% UCL. If, however, project requirements dictate that a 95% UCL must be generated, this may be achieved using replicate ISM samples. A minimum of three replicate ISM samples from a DU are necessary to quantify the uncertainty of estimated mean concentrations (USACE, 2009). Chebyshev is recommended to be used for three replicates.

Chebyshev Method

The Chebyshev method is a statistical method that can be used to calculate the UCL in cases where the data distribution is not normal. For scenarios where the 95% UCL calculation exceeds the maximum observed value, the ProUCL software will suggest an alternative UCL computation method based upon the Chebyshev inequality. This statistical method tends to yield a more conservative estimate of the UCL (EPA, 2015).

5.3 Ecological Risk Assessments

For ecological risk assessments, the size and depth of the DUs required may be different from those for human health risk assessments, sometimes significantly so. The baseline ecological risk assessment will establish assessment endpoints (valued resources that require protection), which will help determine appropriate DU sizes. Home range size, feeding and nesting patterns, and burrowing activities should all be considered in establishing appropriate DUs to assess ecological risk.

Note that not all ecological entities necessarily require protection and, therefore, the smallest home range of all organisms that could be present may not necessarily be the proper focus. DUs for ecological risk assessment may need to focus on areas of preferred habitat within a site, and those receptors that require and utilize that habitat (USACE, 2009).

In addition, it must be emphasized that ISM samples that have been processed by drying and grinding may not be appropriate for toxicological testing for certain species as the nature of the soil will be different from that of the actual in-situ exposure conditions. It is highly recommended that practitioners contact a trained biologist/risk assessor/toxicologist when considering the use of ISM for ecological studies.

5.4 Defining Decision Units

Defining the area, location, depth, and boundaries of the DUs is a very important step in the systematic planning process for an investigation using ISM methods. The area of the DUs should be based on what is known about potential releases at the site, on the expected land uses, and critical ecological receptors. To obtain regulatory acceptance, it is important that the DU not be defined to include uncontaminated areas which may unintentionally result in diluting contamination in known source areas.

The designation of DUs should be planned based on the smallest area that may need to be remediated; however, sampling designs have been proposed that would accommodate division of DUs into smaller sampling units (SUs). The smaller SUs can be decided ahead of time and the sample handling techniques can be designed to maintain subsamples from the SUs for separate analysis later if needed. Criteria for selecting SUs should be decided in the systematic planning process. DUs do not need to be of the same size or shape throughout the study but should be based on what is known about the site and needs for risk assessment.

5.5 Comparing ISM Results with Existing Background Datasets

An additional consideration for defining DUs is the need to evaluate background levels of naturally-occurring soil constituents or widespread anthropogenic contaminants. This is particularly critical if the screening levels for the suspected site contaminants are near or, in some cases, below naturally-occurring background. Examples include the human health screening level for arsenic and the avian soil screening level for lead. For example, Vosnaskis et al. (2009) reported that background threshold values exceeded risk-based screening levels in seven states.

Existing site-specific background datasets derived from discrete sampling are not directly comparable with ISM data. A set of discrete sample results provides a measure of the distribution of concentrations in relatively small volumes of soil throughout the DU, whereas a set of ISM samples provides measure of the distribution of mean concentrations, each of which is an estimate of the population mean for the entire DU (ITRC, 2012). Although there are statistical methods for comparing the means of discrete and ISM datasets, this should only be done with sufficient knowledge of the datasets and statistical theory.

For the most valid comparison of ISM data to background, the background area should be recollected using ISM and should be of a scale and soil type similar to the potentially contaminated areas. This may not be feasible if the background data are used for comparing background and contaminant concentrations across multiple DUs (ITRC, 2012). In many cases, however, existing site background datasets that have been collected using discrete sampling can still be useful for performing comparisons to naturally-occurring background for most constituents.

5.6 Need for the Collection of Replicate Samples

Risk-based screening levels and exposure calculations are based on the estimated average daily intake of a contaminant. A receptor is assumed to be exposed equally to all parts of an exposure unit. Therefore, the average soil contaminant concentration across the exposure unit is the most appropriate value for evaluating the potential exposure of a receptor to site contaminants over a given period of time. To protect against potential underestimation of the mean, USEPA guidance recommends that the 95% UCL of the mean be used as the exposure point concentration (USEPA, 1989). Use of the 95% UCL of the mean is also frequently required by state regulators.

The use of replicates produces a more robust and complete dataset and supports more defensible decisions, but the need and number of replicate samples necessary to meet DQOs and quality control requirements are project-specific decisions. Many federal, state, and local agencies require replicates as a standard part of sampling plans, but not all regulatory agencies require replicates under all circumstances (ITRC, 2020).

A minimum of three replicates is necessary to provide a measurement of the variance (RSD or coefficient of variation [CV]) in the DUs. Although triplicate samples in all DUs are preferred, the variance across multiple DUs can be assumed to be equal based on qualitative information. This assumption requires understanding that the uncertainty in the precision of estimates of the means based on single samples from each DU is unknown. In consultation with regulatory authorities at the planning stage, the project team must decide whether an extrapolation of the variance from a limited number of DUs to all DUs sufficiently manages uncertainty for the pending remediation decisions. Some regulatory agencies may not allow this type of extrapolation and replicates in all DUs may be necessary when a precision estimate is needed for each DU (ITRC, 2020).

Guidance recently issued by the states of Hawaii (HDOH, 2016) and Michigan (MDEQ, 2018) require that triplicate samples be collected in at least 10% of the DUs. The RSD between replicates is used to assess data precision and reproducibility (and, therefore, the confidence) in the data generated. The level of uncertainty that can be accepted is site-specific and is dependent on the DQOs established during the systematic planning process. An RSD of less than 30% between replicates is generally considered precise enough to make decisions. The number of replicates per DU and the frequency of replicate sampling should be clearly addressed in the DQO process and needs to consider contaminant variability, the existence of separate populations, and the precision desired. For sites with multiple similar DUs and where otherwise appropriate, replicates from one DU may be used to provide an estimate of variability that can then be extrapolated to other similar DUs. For multiple similar DUs, the DU expected to have the highest variability should be selected for replicates (MDEQ, 2018).

5.7 Regulatory Acceptance

Regulators are often concerned that potential areas of higher concentrations within a DU (i.e., hot spots) will be diluted out when combined with increments of soil from less-contaminated portions of the DU per ISM protocol. ISM effectively addresses compliance when action levels are based on the mean concentration within a DU. The chance that any single sampling event will include areas of high and low concentration in the proper proportion is directly related to the sampling density, i.e., the number of increments collected within a DU.

ISM offers an advantage over other sampling designs because it requires a large number of increments. For this reason, while any individual increment collected in a hot spot is diluted within the larger group of increments, points within the DU with high contaminant concentrations are more likely to be included in the sample. When low numbers of discrete samples are collected from a given area, the possibility of missing an area of high contamination is greater. Stated in another way, because of its physical composition, an ISM sample is more likely to generate an estimate of the mean that is representative of the true mean within the DU. This advantage of ISM addresses the concern of compliance with action levels but not the concern about spatial resolution.

Although an often-used term, the term hot spot is vaguely defined. How large does the area need to be, and how far above regulatory levels does it need to be to be considered a hot spot? Existence of a hot spot is greatly affected by the heterogeneity of contaminant concentrations in soil. Brewer et al. (2017a,b) conducted an extensive study of three contaminated sites, which showed apparent locations of hot and cold spots were quite different if samples located 0.5 m from the initial sample were evaluated. In the end, in order to obviate this issue, a project team must define the minimum spatial concentration resolution needed during project planning. In other words, the team must define “hot” and “spot” when deciding on the size of the DU. Once defined, further concern about dilution no longer has context.

5.8 ISM Application Challenges in the Field

Collection of ISM samples requires notable modifications from procedures used for discrete soil sampling. Because ISM sampling provides a dense coverage of increments across the entire DU, there may not be a need for surveying the location of each increment for smaller DUs. In this example, it is sufficient to survey the boundary of the DUs and a cornerstone increment. Subsequent distances between increments can then simply be measured and walked off. For large DUs, it may be advisable to obtain global positioning system (GPS) readings at the increment locations. To accommodate the larger sample mass of an ISM sample, the increments are typically collected in plastic bags. Because 30 to 100 increments are collected for each ISM sample, additional time is required in the field. If, for example, the potential presence of a threatened or endangered species might require that sampling be done in the summer, additional precautions in the field will be required due to health and safety concerns related to high temperatures. Use of core sampling devices is recommended for ISM to ensure that the entire depth of the DU is equally represented. Power tools cannot be used at some sites in summer due to potential fire hazard; hence, ISM sampling takes significantly more time in the field.

If ISM is employed for VOC-contaminated soils, then adaptations of sample collection will be needed. Collection of samples in methanol is often recommended to prevent loss of volatile constituents. Due to the larger sample mass of an ISM sample, larger containers and larger amounts of methanol are required. In addition, shipping of methanol may be a logistical challenge.

5.9 ISM Application Challenges in the Laboratory

Not all laboratories have the space or specialized equipment needed for ISM sample processing. The ISM protocol calls for air drying of the samples for 24 to 48 hours. This requires additional space and racks for spreading out and protecting the larger ISM samples. Sieving is recommended for non-volatile contaminants, and sieving is often not performed for discrete samples. Many laboratories are not set up to handle these larger samples and processing requirements. Grinding (or milling) of samples is a key step in ISM processing to reduce fundamental error caused by within-sample heterogeneity. Care must be exercised not to introduce metals from the mechanism during grinding. Many commercial puck mills use components that contain chrome, nickel, and other metals for hardening alloys used for the grinding tools, and contamination of samples during grinding has been reported (Clausen et al., 2013). Inclusion of grinding-blanks and using clean sand or soil will be necessary to evaluate the potential for cross-contamination. The sieving and grinding operations also require care in selection of personal protective equipment (PPE) to control dust and noise exposure to laboratory technicians.

The ISM protocol specifies that after sieving and/or grinding, the sample should be spread out in a uniform thin layer and then multiple increments should be taken in a systematic pattern to collect the subsample for analysis. This also requires additional space and time in the laboratory for full implementation of the ISM protocol.

Finally, the use of surrogates in organic methods is a notable challenge in the application of ISM. Surrogates are added to each sample prior to any sample preparation steps in order to evaluate the potential bias caused from the matrix and manipulation steps. Historically, surrogates have been added to 10 to 20 g subsamples just prior to extraction. However, as ISM includes sieving, drying, and milling steps, surrogates must be added to each as-received sample (1 to 2 kg). Therefore, surrogates should be fortified soils at higher concentrations to accommodate this need, but these commercial standards may not be available for all organic methods.

6.0 SUMMARY

As described in the sections above, ISM when applied appropriately, improves decision making by providing more representative data within the DU. The ISM approach helps to overcome sampling errors by accounting for significant variation in contaminant spatial distribution and in soil heterogeneity. The ISM approach is being used increasingly for sampling a wide variety of contaminants in soil. However, its applicability to a given Navy site should be carefully weighed along with the site investigation objectives in mind. If ISM is appropriate, it should be applied within a systematic planning framework that includes a protocol for the number of increments and replicates to be collected. The ISM approach is most useful when making risk-based decisions where a reproducible mean concentration is needed.

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