Introduction

Incremental Sampling Methodology Update

Incremental Sampling Methodology (ISM) is a statistically supported technique for assessing the mean contaminant concentration in soil, sediment, and other environmental media. Environmental investigators have demonstrated that the methodology can be a useful tool to accurately represent site conditions when applied to bulk particulate materials such as soil, sediment, or waste. For clarity, this document uses the term soil, understanding that other solid particulate media can also be assessed using this methodology. This guidance, developed by the Interstate Technology Regulatory Council (ITRC), reflects recent advances in the technique, shares case studies that provide insight into potential applications, and helps those considering ISM for their sites determine whether to pursue an ISM approach, and if so, how to implement it. It serves as an update to the ISM guidance released in 2012 and represents the current state of ISM that should be adapted for use at contaminated and potentially contaminated sites.

1.1 Sampling to Accurately Inform Environmental Cleanup

The assessment of contaminated sites and areas of potential concern relies on the collection and analysis of samples of environmental media. Analytical data from samples provide a *representation* of site conditions, showing what contaminants are present and at what concentrations. Decision-makers can then utilize this data to assess risk, determine the need for cleanup action, and guide remediation to protect human health and the environment. As part of this process, representative sample data are either compared with decision criteria, such as numerical regulatory cleanup standards for a given contaminant or are used in a baseline risk assessment. An example of such decision criteria would be a state-specific cleanup goal for a contaminant in soil.

To ensure effective decision-making, it is critical that the data compared with the criteria or used to calculate risks accurately represent the conditions at a site in terms of a mean contaminant concentration that meets the data quality objectives (DQOs). Both risk-based screening levels and cleanup levels apply to the mean concentration of a contaminant for a designated volume/mass of soil.

In particular, the characterization of contamination in soil and sediment poses unique challenges due to the heterogeneity of contaminant distribution in these media. As discussed in Section 2, *heterogeneity* refers to the condition where components of a matrix differ from each other between individual soil particles and in the nonuniform distribution of the constituents across the site. Heterogeneity is present at all scales and results in spatial variation of contaminant concentrations.

Historically, soil sampling approaches have relied on the collection of a number of discrete samples at randomly selected or biased locations and depths, providing a patchwork of data across a given site. Composite sampling, one such historically used method, is the collection of multiple increments (MIs) mixed together and then analyzed to provide a sample that is intended to represent a larger area or multiple depths at one location. While this can provide an improvement over discrete sampling methods, the basis behind the selection of a number of increments, total bulk sample mass, and processing and subsampling requirements can limit the reliability of resulting data.

Moreover, contaminant data can vary substantially between locations, even in near proximity to each other. Attempts to confirm data quality through the use of field duplicate samples may not provide the desired level of confidence that data are reproducible.

ISM addresses the problems associated with the reproducibility and reliability of discrete sample data by presenting a structured approach to historically termed “composite” sampling modified with the collection of many increments (30 to 100) and standardized processing. The methodology has gained acceptance and attention due to its robust statistical basis, the reproducibility of data gained from ISM, and the growth in understanding of its applications in the regulatory and environmental practice communities.

1.2 What Is ISM?

ISM is a structured sampling and processing protocol that reduces data variability and provides an estimate of mean contaminant concentrations in a defined volume of soil. Essentially, the methodology provides representative contaminant concentrations in samples from specific soil volumes, defined as decision units (DUs) or sampling units (SUs), by collecting numerous increments of soil that are combined, processed, and subsampled for laboratory analysis according to specific field and laboratory protocols. Analytical data for small subsamples of soil tested by a laboratory represent the mean for the volume of soil included in the subsample. ISM includes specific planning, sampling, and processing aspects that have historically been underutilized or not performed, including:

- establishing DU or SU boundaries that define the scale of decision-making and/or scale of data to spatially structure the assessment
- verifying the laboratory's ability to perform ISM processing and analysis
- reviewing ISM procedures with the sampling team
- reviewing field sampling protocols for ISM
    - collecting a sufficient quantity of increments for each DU (typically 30 to 100)
    - collecting equal mass per each increment
    - collecting increments throughout DUs in an unbiased manner
    - compensating for media heterogeneity by collecting a sufficient mass of sample (typically 1 to 2 kg dry weight)
- verifying laboratory sample processing techniques
    - for non-volatile compounds, air-drying the entire field sample and sieving and/or milling
    - subsampling from the entire processed sample

The goal of ISM is to obtain and analyze a sample that contains analytes in the same proportions as the soil throughout a given DU. To achieve this goal, many increments are obtained from a single DU. Another key element of the sampling approach is that replicate samples (typically three, each with the same coverage and representativeness) are collected from the same DU. Traditional discrete soil sampling approaches often employ the collection and analysis of duplicate samples to obtain a percentage of the samples and evaluate data reproducibility. However, in practice, the results for soil duplicate samples, which are intended to represent the concentration at a single location, can often vary widely, even when proper soil sampling procedures are followed. Due to the challenges of addressing unsatisfactory duplicate soil sample results, duplicates are not even collected for some traditional applications. With ISM, replicates are typically collected for each DU, providing much greater insight into the reproducibility of the data, as well as the degree of heterogeneity.

The statistical basis and terminology for ISM is attributed to Pierre Gy, who used the term *incremental sampling* to describe an improved method for obtaining representative samples from heterogeneous media. His work, based in the mining industry, was prompted by the highly variable distribution of minerals within a rock formation. Misleading data were often obtained from a limited number of samples and yielded poor decisions about mine development. His analysis led to a statistically defensible method for sample collection and sample processing (Gy 1953, 1988) The U.S. Environmental Protection Agency (USEPA) documented improvements in site soil data that could be achieved by applying Gy's sampling theory (USEPA 1999a). USEPA continued to refine the description of ISM procedures in SW846 Method 8330B, published in 2006 (USEPA 2006c), and in 2019, issued "Incremental Sampling Methodology (ISM) at Polychlorinated Biphenyl (PCB) Cleanup Sites" (USEPA 2019). The U.S. Army Corps of Engineers (USACE) issued guidance in 2009 for munitions sampling in surface soil using ISM (USACE 2009). As more environmental practitioners grappling with how to obtain better representative soil data became aware of this theory, ISM began to be used in multiple states. It gained early acceptance in Hawaii and Alaska, which issued guidance in 2008 and 2009, respectively, as well as in Ohio and Michigan, and has now been used at sites in many states across the U.S. (see Section 7).

1.3 Why Should ISM Be Considered for My Site?

The overall efficiency and effectiveness of environmental investigation and cleanup actions can be assessed based on three criteria: time, cost, and reliability of results. ISM investigation methods can improve each of these criteria. Environmental cleanup activities in the U.S. has cost approximately $2 billion annually over the past two decades, just for Superfund sites alone (*Washington Post*, "Taxpayer dollars fund most oversight and cleanup costs at Superfund sites,") (Anderson 2017). Cleanup costs at privately funded industrial facilities are typically not shared with the public but are likely many times higher than costs incurred under the Superfund program. Even modest improvements in the accuracy of delineating target areas for cleanup can have significant cost savings. On the other hand, if areas that pose significant risk are not properly identified, contamination may be allowed to persist, potentially migrate further, and impact human and environmental receptors, posing risks that are not acceptable. One key goal of ISM is to reduce the potential for such "decision errors," such as when deciding that cleanup is needed when it is not or missing cleanup that is warranted.

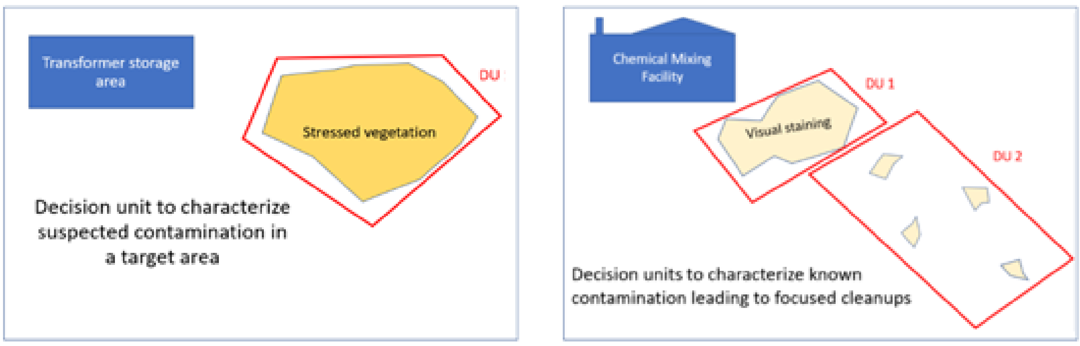
Significant attention to quality assurance (QA) and quality control (QC) for laboratory analytical methods has resulted in accurate, reproducible methods for analyzing small subsamples, or *aliquots*, of media such as soil. While laboratory methods continue to improve, much of the technological advances in recent decades have resulted in lowering detection limits or in detecting more contaminants, rather than in large improvements in accuracy. However, the limitations for obtaining a representative value for a soil concentration are driven far more by sample collection and processing protocols than by subsample analysis techniques. It is estimated that the errors introduced during sample collection and subsampling are at least 10 times greater than errors resulting from laboratory analytical inaccuracies. To improve decision-making for site cleanup, there is much more opportunity for gains in the sample collection and processing realm than in analytical improvements.

Because of the fundamental heterogeneity of contaminant distribution in soil and sediment at most sites, the collection of a small number of traditional discrete or composite samples can underestimate or overestimate the actual mean concentration. ISM, through preparation of a sample by combining increments (small masses) of soil from a large number of points within a well-defined area/volume, provides a more robust picture of the mean contaminant concentration for that volume. This allows a site to be reliably characterized with the collection of a relatively small number of analytical samples. Overall site characterization/remediation costs – and in many cases, time to project completion – can be reduced while providing data that are more statistically robust and reliable than discrete sampling approaches. To the extent that ISM can reduce the need for multiple mobilizations, "step out" the removal of contaminated media, or reduce unnecessary cleanup costs, even greater cost reductions may be recognized.

The potential costs and time efficiencies that can be attained using ISM are demonstrated in the case studies summarized in Section 3.4 and Appendix A. To help evaluate whether ISM may be appropriate for a given site, many key questions should be addressed:

- How variable is contaminant distribution at the site? The more variable the distribution, the greater the potential to obtain a better estimate of the mean using ISM.
- Is the goal of sampling to obtain an accurate mean or upper bound estimate of the mean concentration for a given DU? If so, ISM will yield superior results, but it will not provide information about the distribution of contaminants within a DU. If that is the goal, the DU may need to be defined on a smaller scale.
- How easy is it to collect samples? Because more increments are collected from a given DU with ISM than with discrete or traditional composite approaches, the ease with which samples can be collected affects the time and cost necessary to conduct soil assessment. For subsurface samples at deeper depths in formations that require slower drilling techniques, more time may be required to collect the necessary increments for a given DU. The user will have to balance potential higher costs in deeper DUs with the much lower confidence in decision-making using other methods.
- Is ISM restricted to specific contaminants? Initially, ISM was used for munitions and metals, and procedures have since been developed for all categories of contaminants. Specific refinements to procedures are required for some contaminants, such as not drying or milling samples in the laboratory for volatile organic compounds (VOCs), or based on state or territory regulatory agencies' guidance/requirements.
- How quickly are analytical results available? Does the additional laboratory processing time for ISM samples meet the schedule? Laboratory processing of ISM samples requires additional time (typically one to three days) compared to traditional approaches.
- Do site conditions limit the ability to safely or efficiently collect a number of increments from a given DU (for example, are there hazards such as subsurface utilities throughout the target area or a developed, paved property where access to underlying soil is restricted)?

The determination of sizes and arrangement of DUs or SUs is always project-specific and dependent upon the conceptual site model (CSM) and end use of the data. Figure 1-1 demonstrates just a few simplified examples of the diversity of DU and SU sizes and uses (see Section 3.1.6).



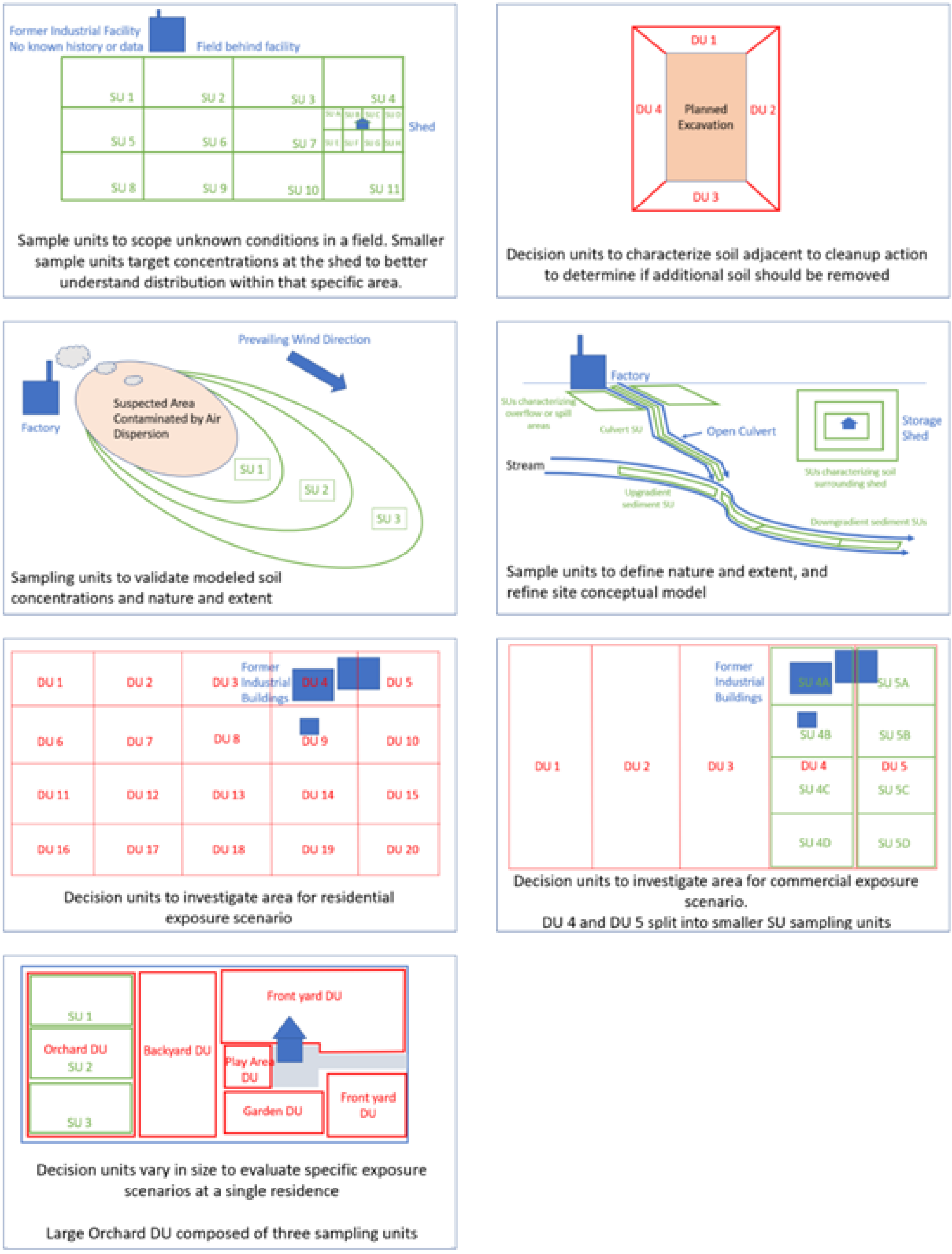


Figure 1-1. Examples of diversity of DU and SU sizes and uses.

Source: Jason Brodersen, Tetra Tech, Inc., 2020. Used with permission.

1.4 How Is ISM Implemented for Environmental Sampling?

The application of ISM in environmental assessment has expanded from initial use for munitions and metals to a much broader range of contaminants and a wide range of site applications. While this guidance is not intended to be a detailed recipe for every application, it does provide key considerations to help decision-makers determine whether ISM makes sense for their site and, if so, how to tailor ISM to the conditions at a given site.

To begin, practitioners need to be familiar with several key concepts and terms associated with ISM. While many of these terms are described in more detail in subsequent sections, a general understanding is important for even starting a consideration of whether to use ISM:

- The CSM serves to define the relationship between contaminant sources, contaminated media, and receptors through consideration of potential or actual migration and exposure pathways. It presents the current understanding of the site, helps to identify data gaps, and helps to focus data collection efforts.

- A DU is the smallest volume of soil for which a decision will be made. It is the area and depth of soil from which mean analyte concentrations are obtained and is representative of a specifically defined population. A DU can be as small as a storm drain outlet or as large as a commercial parcel or agricultural field.
- An SU is a subdivision of a DU, or the volume of soil from which increments are collected to determine an estimate of the mean concentration. A DU may consist of one or more SUs. The use of SUs is project-specific and not always necessary.
- An increment is a specified volume of soil collected from a specific point within a DU. Multiple increments (typically 30 or more) are collected from a specified DU and combined into a single sample.
- The combined increments are referred to as a **multiple-increment**, **incremental soil sample**, or **ISM sample** that is representative of the mean contaminant level with in specified DU.
- An exposure point concentration (EPC) is a conservative estimate of the mean chemical concentration in an environmental medium. The EPC can be determined for an entire site or for an individual exposure unit (EU) – a location within a site where exposure potential may vary from the overall site, often where regular exposure is currently or anticipated to occur.
- A 95% upper confidence limit (95% UCL) of the arithmetic mean is a calculated value to ensure that the mean concentration is not underestimated, so a user can be 95% confident that the true mean (average) concentration of the population is below this value. Three or more ISM samples or replicates are required to calculate a 95% UCL, provided the appropriate statistical methods are used to calculate the 95% UCL.

The process for ISM is illustrated in Figure 1-2, which shows key steps through the three phases: planning, implementation, and data analysis and decision-making.

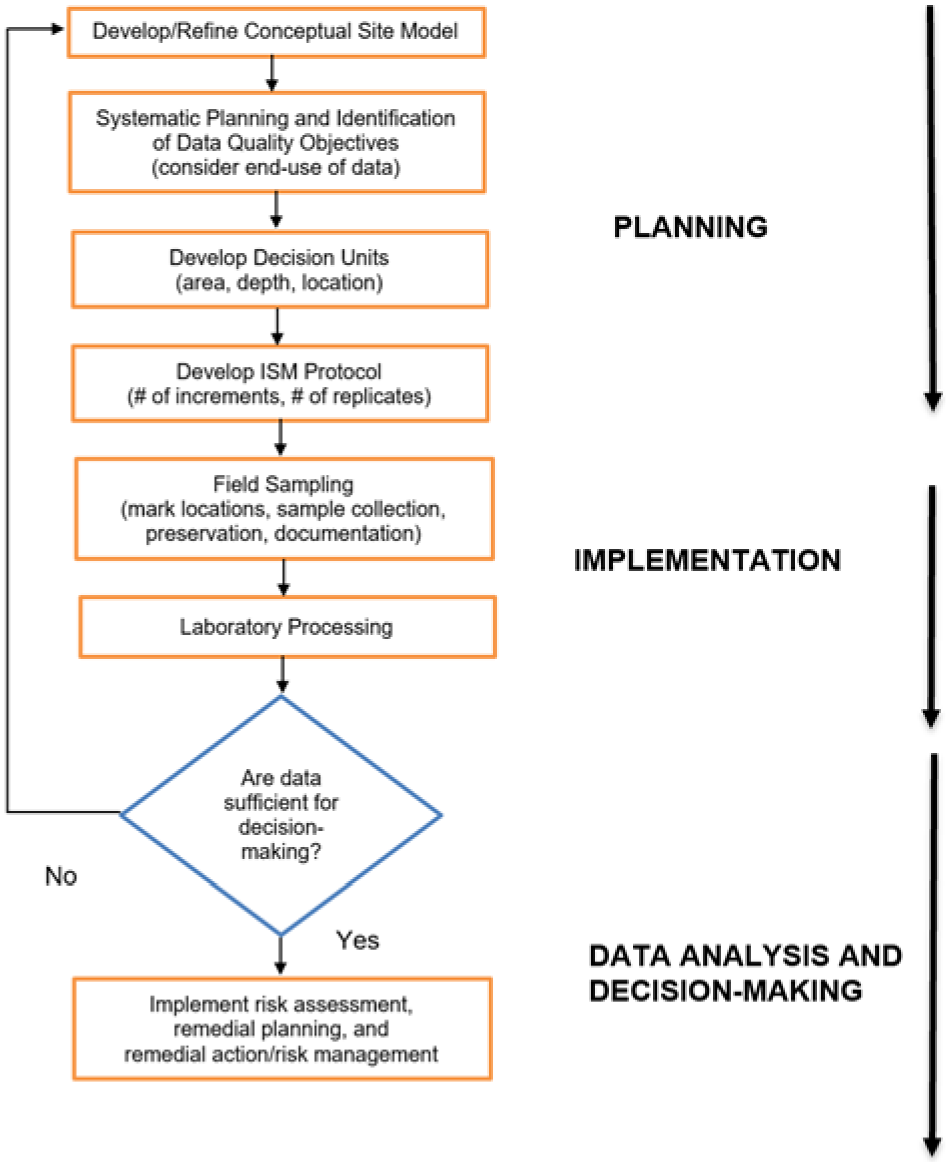


Figure 1-2. ISM flow chart.

Source: ITRC ISM Team, 2012.

Note that this guidance is intended to provide a high-level overview to help chart a path to plan and implement ISM – it is not a step-by-step detailed sampling and analysis plan or recipe that can be applied to any given site. The assessment of contaminated sites is a complex process that requires advanced planning, an understanding of contaminant fate and transport, and clear objectives for final site disposition. Any soil sampling approach, including ISM, is much more likely to be successful if there is an accurate CSM to guide planning (critical for knowing where to look and what to look for), the DQOs are clearly defined (so we understand what data is needed and how we will use it), and DUs are enumerated and geographically delineated prior to sample collection (to develop the scope and cost of assessment and reduce the potential need for multiple field mobilizations). A multi-disciplinary team experienced in planning, field implementation, laboratory analysis, risk assessment, and ultimate site cleanup is critical to that success.

1.5 Document Content – How to Use This Guidance

In 2009, ITRC created a working team to develop guidance for practitioners interested in utilizing ISM. The ISM Team published its first guidance document in 2012 to provide an overview of the concepts and principles of the methodology, emphasize the importance of clear objectives, and provide a basis for adapting ISM to meet project- and site-specific objectives. This 2020 ISM Guidance Document builds on the 2012 version to reflect advancements in technology and to share case studies that provide insight into potential applications, benefits, and challenges of the approach.

This document is arranged into the following sections:

- Section 2 – Nature of Soil Sampling provides the reader with an understanding of the unique challenges associated with sampling soil for the purpose of obtaining representative contaminant concentrations and how ISM is specifically designed to address these challenges. Contaminants in soil and other particulate media are often distributed unevenly at the scales of interest to decision-makers. Conventional soil sampling approaches that fail to address this heterogeneity can result in over- or underestimating contaminant concentrations, leading to decision errors. Section 2 provides the reader with a detailed understanding of why contaminants are heterogeneously distributed in soil, the consequences of that heterogeneity for soil sampling and decision-making, and how ISM is systematically designed to address this heterogeneity through the use of replicates of MIs. This section also discusses how data variability caused by soil heterogeneity is measured, as well as provides a simplified introduction to Gy theory, which is the basis for ISM procedures to increase the representativeness of soil data without breaking the budget.
- Section 3.1 – Systematic Planning and Decision Unit Designation provides a summary of the key aspects of systematic planning and DU design in relation to the collection of soil and sediment samples that have unique applicability or challenges using ISM sample collection. As with any sampling event, characterization must generate data in three dimensions so that data needs are met for a range of technical users who participate in the site investigation process. This means collecting data that inform each step of problem formulation: source area identification, fate and transport, and exposure/risk. Examples illustrate the key aspects of systematic planning and DU design.
- Section 3.2 – Statistical Concepts and Calculations for ISM answers the question, “Why use statistics?” Statistics can be used to answer important questions bearing on decision confidence:
    - Is the sampling and analysis design giving accurate information?
    - Are the data good enough to support confident decisions?
    - Are there enough data points to make decisions?
- Section 3.3 – Planning for the Use of ISM Data describes the application of statistical concepts to ISM work plans (WPs) for use in decision-making. Specifically, this section will discuss DQOs steps 5 and 6 as they apply to ISM. The intent is to provide a link between the DQOs, the sample plan, and the data quality evaluation (Section 6).
- Section 3.4 – Cost-Benefit Analysis provides a cost-benefit analysis of ISM sampling relative to more traditional sampling methodologies, including factors such as time to project completion, and shares example case studies to assist in the determination of how ISM may be appropriate for a specific site.
- Section 4 – Field Implementation, Sample Collection, and Processing describes practical methods for collecting consistently sized increments for surface soil, subsurface soil, and sediment from various environments. The sampling method includes guidance on field planning, locating samples, sampling tools, collection and field processing procedures, decontamination, sample handling, and sample shipping.
- Section 5 – Laboratory Sample Processing and Analysis presents current practices and options available to process and subsequently analyze field samples obtained via ISM. Incremental sampling has been successfully implemented at numerous sites for a variety of contaminants, and multiple options are available depending on contaminants such as metals, pesticides, dioxins/furans, semi-volatile organic compounds (SVOCs), VOCs, PCBs, perchlorate, white phosphorus, and energetics (propellants, explosives, and pyrotechnics).
- Section 6 – Data Quality Evaluation demonstrates how to determine if your ISM data are sufficient for your purpose(s) and provides guidance on using appropriate statistical methods for data evaluation and confident decision-making.
- Section 7 – Regulatory Acceptance describes the regulatory environment surrounding the use of ISM, including typical regulatory concerns, problems, or incentives that may apply. This section also presents the state of regulatory acceptance for ISM by comparing its use since 2009 as well as practical guidance for working with or within a regulatory agency to gain consensus for using ISM in investigations, risk assessments, and confirmation sampling.
- Section 8 – ISM for Risk Assessment provides guidance for use of ISM data in risk assessment and risk-based decision-making. Key concepts in this go-to resource include the importance of understanding the nature and extent of contamination when designing EUs, the necessity of ISM replicates for calculating EPCs (and how to calculate EPCs), background comparisons using ISM data, and communicating ISM-based risk assessment results.
- Section 9 – Stakeholder Input discusses applicable stakeholder concerns, points of view, and interaction with the remediation process or other issues discussed.
- Appendix A – Case Study Summaries provides information regarding ISM design, implementation, and assessment methodologies. The case studies presented were selected based on their relevance to the use and

application of ISM.

- Appendix B – Statistical Simulations
- Appendix C – Team Contacts
- Appendix D – Glossary
- Appendix E – Acronyms
- Appendix F – References

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