9 Sampling

A well-designed sampling program is critical when conducting a study to determine default or site-specific soil background or obtaining soil samples from an investigative site that is being evaluated to compare to default or site-specific soil background. This section provides an overview of important considerations when designing a soil background sampling program, including:

- areas for collecting representative soil samples
- sample depth
- sample size
- sampling methods (discrete, composite, incremental sampling methodology (ISM))
- sampling design
- sample collection methods
- sample handling

Whenever possible, existing guidance will be referenced because this section is not intended to be a detailed description of soil sampling procedures but is intended to provide an overview of how the procedures relate to soil background. Field sampling practices are a source of variability in reported results. This variability can be minimized, but not eliminated, by using a high-quality sampling plan and experienced personnel to perform the field work.

9.1 Background Reference Areas

When selecting areas to collect soil background samples, it is very important that locations should be as similar as possible to the site that is being evaluated in physical, chemical, geological, biological, and ecological characteristics; the rationale for this is discussed further in Section 9.1.3. Land use of the background reference area, compared to the site, should also be considered. The background reference areas selected should not be affected by site releases or site activities. Additionally, where transport processes are likely to deposit new soils on the site (such as floodplains, alluvial fans, or areas with high dust creation and deposition), the background reference location should be located upgradient or upwind of the site to avoid contamination from the site and to provide information on contaminants that may be transported to the site. Multiple background reference areas could be required for the collection of sufficient background samples to determine representative background concentrations if the site exhibits a wide range of physical, chemical, geological, and biological characteristics.

Typically, background reference areas are located off site. In some cases, it may be difficult to find a suitable background reference area in an industrialized area. In these cases, an on-site area may be used as a background reference area if the area has not been affected by site releases or site activities (USEPA 2002). Thus, background reference areas are not limited to natural areas or undeveloped lands.

Review of the history of the site and surrounding areas, as well as current and historical aerial photographs, geological maps, soil maps, and vegetation maps, can assist in selecting candidate background reference areas. Soils maps, available geotechnical and environmental drilling borehole data, and satellite imagery can also provide useful insights. Areas that generally should be avoided when collecting background samples include industrial areas, roadways, stormwater ditches, areas of local anthropogenic releases, and areas with fill. Areas with fill are generally unsuitable to use as a soil background reference area; however, some jurisdictions may allow for the exclusion of contaminants in fill materials if these contaminants are not site-related. Before considering the use of fill in a background study, the regulatory agency should be consulted.

Alternatively, existing background studies from sites located adjacent to the cleanup site being evaluated, with similar soil properties, and collected using similar sampling methods, can often be used for representative background values with high confidence (USEPA 1995); however, use of the adjacent site as a background reference area still needs to be evaluated and technically justified.

Once preliminary background reference area sampling locations have been chosen, it is important to compare these locations to available remediation site databases (for example, USEPA’s Cleanups in My Community or state websites such as California’s CalEnviroScreen) to ensure that sample locations are not close to known potential contamination sources. The data resulting from samples taken from the background reference area could be evaluated using statistical (Section 11), geochemical evaluation (Section 5), or forensic (Section 7) methodologies to ensure that the background reference area has not been impacted by localized contamination sources (sometimes referred to as “hot spots”). Some complex situations, such as the presence of anthropogenic influences and variable site geology, can make it challenging to identify background reference areas not impacted by on- or off-site activities. In such situations, it might be appropriate to establish site-specific background data by extracting it from an on-site dataset (Section 3.8).

9.1.1 Natural soil background

When selecting samples to determine natural soil background, sample locations should be chosen from areas that generally share similar physical, chemical, geological, and biological characteristics and are unlikely to have been impacted by human activities. Public lands, such as state or national forests, are often good candidate areas for obtaining background samples, assuming such areas have not been previously impacted by anthropogenic activities (including agricultural activities).

Practitioners should document the technical rationale for choosing each of the sample locations.

9.1.2 Anthropogenic ambient soil background

When selecting samples to determine anthropogenic ambient soil background as defined by this document, sample locations should be chosen from areas that generally share similar physical, chemical, geological, and biological characteristics and are unlikely to be impacted by local releases. These soil background reference areas could be affected by anthropogenic nonpoint sources of chemicals that are present in soil (often, but not always at lower concentrations)—not because of local anthropogenic sources, but because of their persistence, ubiquity, and/or ability to be transported long distances. Examples include PAHs, polychlorinated dibenzo-p-dioxins (PCDDs), persistent pesticides (such as DDT), and mercury.

What is included in anthropogenic ambient soil background depends on what the lead regulatory agency allows and the goals of the project or the site-specific situation. In some cases, the lead regulatory agency allows the inclusion of local releases that are not a result of releases from the site that is being evaluated to be included in anthropogenic ambient soil background (for example, the release of metals related to local mining or smelting operations). In some jurisdictions, metals might be included as a widespread urban source related to the historical association of lead with vehicle emissions (the contribution of this source has decreased over time, as leaded automotive gasoline use has been phased out). In these cases, the level of urbanization and intensity of anthropogenic land use are very relevant. Sample locations should be selected from an area with a similar level of urbanization to the site and as proximate to the site as possible.

Practitioners should document the technical rationale for choosing each of the sample locations.

9.1.3 Geological and other considerations

Naturally occurring concentrations of elements are an important consideration in soil background studies. Naturally occurring elements detected in soil are derived from parent material (bedrock) that was chemically and physically weathered. Climate, physical and chemical erosion processes, and the composition of the parent material determine the minerals that occur. Additional detail on the elements commonly found, their parent material, and effects of weathering and climate on chemical composition can be found in the reference *Chemistry of Soils* (Sposito 2016). Additional discussion of geochemical considerations is provided in Section 5.

Geotechnical sampling and testing procedures (for example, grain-size distribution) should be included as part of the SAP ((Winegardner 2019), (ITRC 2020)), along with the COPC. Mineralogy and biotic and abiotic weathering are important factors in determining grain-size distribution and are underlying factors that can contribute to environmental availability of naturally occurring elements. In addition, soil texture can have a substantial effect on the distribution of COPC in soil. For example, fine-grained soils can have a greater sorption capacity for some COPC (for example volatile organic compounds (VOCs), semivolatile organic compounds, and metals) due to greater surface area. Laboratory analysis to ensure comparable grain-size distributions between site datasets and background datasets should be conducted to ensure any COPC concentration differences between the datasets are not just a result of differing grain-size distributions.

In some soils, vegetation can affect the distribution of elements. Some metals (for example, arsenic, cadmium, copper, mercury, lead) can be taken up by plants or adsorbed to organic matter. When the plant dies, these elements can be concentrated in the surface soil. Information regarding plant communities and differences in vegetation density should be considered as part of background study design (Kabata-Pendias 2010).

9.2 Sample Depth

Soil sample depth should be considered when conducting background studies to ensure that datasets from the site and the background reference area are comparable. The soil sample depths chosen for both the site and background reference areas should be consistent with the receptors (as described in the CSM) that are expected to have contact with the soil. As noted above, background and site sample locations should be similar in physical, chemical, geological, biological, and ecological characteristics, which can be affected by depth. For example, surface soil can be affected by atmospheric influences, so the use of variable sample depths to define surface soil (for example, 0–15 cm versus 0–60 cm) can yield quite different results for contaminants that are deposited from the atmosphere. It should be noted that the definition of surface soil can vary by jurisdiction, with depths ranging from surface to 2, 15, 30, or 60 cm. For example, the USEPA's Soil Screening Guidance (USEPA 1996) defines surface soil as the top 2 cm.

Sample depth should also take into account other site-specific factors that may vary with depth. These factors include the depth to the water table, perched water zones, or soil stratigraphy (for example, sand lenses and fracturing).

For risk assessment, the selected sample depth needs to reflect the type of exposures and receptors expected. Surface soil samples generally target the data needed to evaluate human health exposures via direct ingestion, dermal contact or inhalation (via dust) pathways, as well as some ecological exposures. Subsurface soil sampling generally targets the data needed to evaluate human health exposure to soil during construction or utility work and migration to groundwater or animals burrowing at depth.

Site-specific considerations must be taken into account when evaluating receptors and exposure pathways. For example, ecological receptors could be exposed to soils at depth while burrowing, depending on the species present at the site. Human health exposure to subsurface soils (as well as shallow soil) may need to be considered if there is soil disturbance at a site. Soil disturbance can be caused by construction (for example, basements, utility lines, or residential pool installation), landscaping, children digging while playing, gardening, soil erosion, or recreational activities (for example, ATVs).

As noted in Section 8, the CSM should document all relevant complete and potentially complete and complete exposure pathways for the receptors at the site, and that information should be used to help inform the relevant sampling depths for soil background.

9.3 Sample Size

Adequate background dataset sample size will need to be determined on a project-specific basis in accordance with the project's DQOs. For example, in the context of defining DQOs to support use of background in risk assessment, the DQOs for developing a site-specific background dataset would differ from DQOs for developing a default background dataset. The number of samples necessary to determine representative background, along with the rationale for the sampling locations and depths chosen, must be outlined in the SAP. The intended application, assumptions about the underlying distribution of the concentrations of the COPC, tolerable error rates (maximum acceptable error rate set by the decision maker), and sample design need to be considered when determining sample size. Inadequate background sample size can lead to unreliable or erroneous conclusions (ASTM E3242-20; (ASTM 2020)).

Size of the background reference area and expected variability should also be accounted for when determining adequate sample size to ensure the data are representative. A larger number of samples may be required to adequately represent a larger and more variable background reference area. This is discussed in more detail in Section 11.1.3.

Additional information on determining adequate sample size can be found in USEPA (2002) and USEPA (2002). Many software packages and tools can be used to determine an adequate sample size; two are discussed in detail here.

9.3.1 Sample size tools

Information on statistical software is also provided in Section 11.9.

9.3.1.1 Visual Sample Plan software

The free Visual Sample Plan software (VSP Development Team 2020) is a recommended tool for use in calculations to determine sample size. The VSP software is specifically designed to provide an output to support the project DQOs. The software selects "the number and location of samples so that the results of statistical tests performed on the data…have the required confidence for decision making" (Matzke et al. 2014). The software can also recommend a minimum number of samples taking into account budget and sample design. Using the DQO process and this software ensures that the background study goals are well defined up-front, while identifying and minimizing uncertainty. VSP calculates DQO-based sample sizes for a wide range of applications, including the estimation of the mean or median, calculation of confidence intervals on the mean, one-sample and two-sample hypothesis tests, and location of hot spot areas, among many other statistics. Site maps and aerial/satellite photographs can be imported, with the resulting sample locations displayed on the maps or photographs, accompanied by geographic information system (GIS) coordinates for precise sample placement in the field. VSP has the support of a wide range of government agencies, including the Department of Energy, Department of Defense, USEPA, and Department of Homeland Security, among others.

9.3.1.2 ProUCL

ProUCL is another free statistical tool that can be used to determine sample size (USEPA 2015). Its sample-size module allows the user to calculate DQO-based sample sizes to support estimations of the mean, as well as one-sample and two-sample hypothesis tests (for example, *t*-test or Wilcoxon rank sum test). The software can also be used for comparing background and site concentrations. ProUCL is easy to use and accepted by regulatory agencies. Its disadvantages include a limited number of scenarios for sample-size calculations, inability to import maps, and inability to depict sample placement.

9.4 Sample Methods

Sampling methods can consist of discrete, composite, or incremental sampling methodology (ISM). The sampling method chosen will depend on project goals.

Soil background samples should ideally be collected using the same, or similar, sampling methods as the samples from the site that are being evaluated to ensure comparability of the datasets. At a minimum, composited samples, which are a physical representation of “average” conditions, should not (except under select conditions) be directly compared to discrete sample data. If the same sampling methods cannot be used, a comparison of the methods should be conducted to ensure that substantively different results will not be obtained. For example, the comparison of data collected using ISM to data collected using a discrete sampling methodology should be done with an understanding of the potential error in the mean based on the ISM result (ITRC 2020). Note that comparing ISM and discrete datasets may be possible, but this should be done by a qualified statistician.

9.4.1 Discrete samples

Discrete soil sampling is “the process of collecting a single soil sample from a specific location and depth interval” (OhioEPA 2013).

9.4.1.1 Advantages

- Discrete soil sampling allows for less labor-intensive collection of representative data for volatile organic compounds than other sampling methods that involve some form of sample compositing.
- This method can be used to understand the distribution of background concentrations and to aid in identifying localized areas of elevated concentrations if microscale heterogeneity is sufficiently managed (information may be masked with composite samples if they represent a larger area and ISM samples if the decision units selected are too large).
- Data can be used to calculate representative point BTVs (a measure of the upper threshold of “point” background concentrations). In this context, “point” implies a discrete sample, as opposed to an area-average composite or ISM sample.
- Discrete soil samples allow the examination of data via geochemical evaluation (Section 5).
- Discrete samples are relatively easy to collect and do not require any specialized equipment or sampling skills.

9.4.1.2 Disadvantages

- Discrete soil sampling can bring potential increased effort and cost, as a larger number (relative to composite or ISM) of discrete samples may be needed to adequately characterize an area. This especially true in the case where soils are very heterogeneous.
- Discrete samples may represent a small mass compared to area or volume of the target population being analyzed, so the sample may miss contamination or may not be representative (ITRC 2012). The DQO process should be followed to ensure that discrete samples are representative.

9.4.2 Composite samples

A composite soil sample is a sample composed of several smaller subsamples that are physically mixed to create a single homogenous sample. The subsamples must be the same volume. The composite sample should be representative of the entire composite area or volume.

9.4.2.1 Advantages

- Composite soil sampling can produce an estimate of the mean, with fewer analyses and lower cost compared to discrete sampling (USEPA 2002).

- This method can reduce errors due to soil heterogeneity, because a single composite sample can be more representative of a defined area than a single discrete sample—when the goal is to characterize the mean (ITRC 2020). Note that not all composite samples are equally effective in their ability to reduce variability.

9.4.2.2 Disadvantages

- Composite samples can be prepared for analyzing volatile compounds. To minimize contaminant losses from volatilization when preparing the composite sample, methodologies must be used that are more time-consuming than those used for discrete samples.
- Composite sampling can introduce additional error related to weighing than with discrete samples (more weights are being taken, so there is more error). Soils that are mostly clay are difficult to homogenize and tend to be poor candidates for composite sampling.
- Composite sampling yields a reduced amount of information on variability, and information on spatial trends can be masked and diluted.
- Summary statistics from discrete sample results (for example, individual site measurements from historical sampling programs) are not directly comparable to summary statistics from composite sample results; comparison is only possible using statistical methods. While discrete samples are analogous to point values, composite and ISM measurements are representative of area averages.
- Information on the upper tail of the distribution may be lost; elevated concentrations might not be identified, because the data represent a physical average. Since composite samples usually represent larger areal extents, their data are typically not used to calculate a BTV or in geochemical evaluations.

9.4.3 Incremental sampling methodology (ISM)

ISM is a structured sampling and processing protocol that reduces data variability and is a superior methodology to provide an estimate of mean contaminant concentrations in a defined volume of soil. ISM provides representative contaminant concentrations in samples from specific soil volumes, defined as decision units or sampling units), by collecting numerous increments of soil that are combined, processed, and subsampled for laboratory analysis (ITRC 2020). ISM was developed by mining corporations because standard sampling methods often missed ore bodies that were indicative of profitable levels of metallic ore present in rock formations. Since then, these sampling concepts have been applied to agricultural, food, drug, and environmental sampling. In environmental investigations, incremental sampling was originally intended for clearing large tracts of land at former bombing ranges to determine whether more focused sampling was required, but its use has since been expanded (ITRC 2020). Use of ISM during background studies, as with any sampling design, should be carefully considered and justified.

9.4.3.1 Advantages

- ISM yields more consistent and reproducible results when characterizing the mean than that which is obtained by discrete or composite sampling approaches (ITRC 2012).
- ISM reduces data variability and increases sample representativeness when calculating mean values for a specified volume of soil by designing and accounting for soil heterogeneity, so fewer samples are typically needed to obtain the same statistical power (ITRC 2012).
- This method provides less biased and more precise estimates of the mean than discrete sampling plans, which typically have much lower sample density (ITRC 2012).
- ISM is more cost-effective (for shallow soil sampling programs) than moderate- to high-density discrete sampling plans that provide a comparable level of decision quality when the goal is to characterize the mean (ITRC 2012).
- Samples can be collected for analyses of VOC compounds, but refinements to the procedures are required. These may include the use of special bottle ware, not drying or milling samples before laboratory analysis, and direct preservation of soil in increments in methanol or collections of increments by specialized samplers for processing in the lab (ITRC 2020).

9.4.3.2 Disadvantages

- Although regulatory acceptance of ISM is growing, some regulatory agencies may still not accept ISM.
- Although the methanol preservation approach for VOC analyses is effective at minimizing the loss of volatile contaminants from a soil sample, methanol preservation can result in lower analytical sensitivity. “The methanol dilution step causes elevated analytical detection limits compared to the direct soil purge-and-trap and low concentration method techniques. Analytical detection limits could be elevated above relevant screening levels

for certain targeted contaminants" (ITRC 2020).

- Summary statistics from discrete sample results (for example, individual site measurements from historical sampling programs) are not directly comparable to summary statistics from ISM sample results. A more reliable comparison is obtained when both the site and background datasets are collected and analyzed using the same methodologies (ITRC 2012).
- Information on the upper tail of the distribution is lost because the goal of ISM is to characterize the mean (elevated concentrations might not be identified, depending on the size of the decision unit chosen).
- Because the data represent a physical average, a BTV calculated from the data will likely not be representative of the upper tail of the background data distribution.
- ISM prevents the use of geochemical evaluation, because the compositing of incremental sampling obscures the natural variability in element concentrations and will diminish the ability to distinguish anomalously high elemental ratios relative to background elemental ratios. Note that geochemical evaluation data could be collected by concurrently taking discrete samples during an ISM sampling program.

9.5 Sampling Design

There are two main types of sampling designs: judgmental (also known as targeted biased sampling) and probability-based (or statistical). Probability-based sampling design includes simple random sampling, systematic sampling/grid sampling, and stratified systematic sampling.

The selection of (and rationale for) the sampling design should be determined in accordance with the project's DQOs, as outlined in the SAP. A robust sampling design is required to develop representative and defensible soil background concentrations. For example, DQOs could include determining the presence/absence of a given chemical; determining soil background levels; and evaluating the human health risks associated with site-related chemicals (for example, is the incremental risk greater than background).

An overview of various sampling designs, as well as advantages and disadvantages of each, is available in the USEPA Guidance for Choosing a Sampling Design for Environmental Data Collection (USEPA 2002).

9.5.1 Judgmental (targeted or biased) sampling design

With judgmental sampling design, the number of samples and locations are selected at the discretion of a qualified person, based on their judgment/expertise. Judgmental sampling plans do not allow for a full characterization of uncertainty. Statistical analysis of data collected using judgmental sampling design cannot be used to make any type of scientifically defensible probabilistic statements about the target population. Conclusions drawn about the data are made solely based on judgment and depend entirely on the validity and accuracy of this judgment (USEPA 2006). Because judgmental sampling design is based on nonrandom sampling, this results in datasets that can be biased, clustered, and correlated, so conclusions based on the dataset cannot be extrapolated to the whole site (USEPA 2002). Since judgmental sampling is not amenable to statistical analysis, it is not recommended for establishing a soil background dataset.

9.5.2 Probability-based (statistical) sampling design

With probability-based (or statistical) sampling design, each possible sampling location has a known probability of being selected, and only those sampling locations selected are sampled and used in the development of background concentrations. Advantages of probability-based design include the ability to account for uncertainty in the data, to draw conclusions about the target population, and to properly express uncertainty in these conclusions (USEPA 2006). Probability-based sampling designs are recommended for background studies because statistical analyses can be applied and bias is reduced.

9.6 Sample Collection Methods

Soil background samples should be collected using the same sampling methodologies as the site data, to the extent reasonable and appropriate, to ensure comparability of the datasets.

Considerations when determining the method for soil sample collection include:

- target depth for the soil samples (surface/shallow versus deep)
- whether discrete, composite, or ISM samples are required
- COPC (plus any additional analytes necessary for geochemical evaluation or forensic analysis)
- soil conditions

- site conditions for access of equipment (for example, space limitations, surface covering)

Various methods for soil sample collection are available and can be broken into the three main categories as outlined in Table 9-1. Additional information on soil sample collection methods can be found in the following references: ASTM D1452 (ASTM 2009), ASTM D4700-15 (ASTM 2015), ASTM D6151/D6151M-15 (ASTM 2015), ASTM D6169/D6169M-13 (ASTM 2013), ASTM D6282/D6282M-14 (ASTM 2014), ASTM D6286/D6286M-20 (ASTM 2020), ASTM D6914/D6914M-16 (ASTM 2016), (BC Environment 2020), (USEPA 2012), (USEPA 2014) and (ITRC 2020), as well as local, state, and USEPA regional guidance.

9.7 Sample Handling

Once soil samples have been obtained, they should be placed in the clean sample containers provided by the analytical laboratory and appropriate to the parameters being analyzed. During sample collection in the field, precautions must be taken to avoid cross contamination between samples (for example, the use of appropriate field decontamination procedures). Recommended sample containers and sample preservation for soil samples being submitted to the laboratory for different analytes or analyte groups are outlined in the appropriate USEPA reference method (see Section 10); these should be confirmed with the selected laboratory prior to sample collection. Proper sampling handling and quality controls, as outlined in the QAPP (Section 8.2.1), should be followed to maintain sample integrity.

Table 9-1. Soil sample collection methods

Source: (USEPA 2002).

Description	Equipment Examples	Advantages/When Appropriate to Use	Disadvantages/Precautions
Surface Soil Sampling Collect shallow/surface soil samples.	• Trier • Trowel • Shovel • Soil probe • Hand auger (manual or powered) • Core sampler	• Cost-effective • Rapid data collection • Relatively easy to use • Less intrusive and disruptive	• Limited depth range • Not ideal for rocky, dense, or hard soil conditions • Depending on method, soil type, and depth required, discrete soil samples can be difficult to collect due to sloughing
Test Pitting Collect shallow to intermediate soil samples. Samples are collected from the bucket of the equipment.	• Rubber-tire backhoe • Tracked excavator	• Cost-effective • Depth range up to 3–4 m with backhoe and 5–6 m with excavator • Provides good visualization of soil samples • Large sample volumes collected	• Disruptive, so not ideal for paved or developed sites • Difficult to collect discrete soil samples in unstable soil conditions (for example, sand) • More uncertainty in depth interval sample is being collected from than when drilling methods are used
Drilling Collect shallow to deep soil samples. Samples can be collected in all types of geologic material.	• Auger drilling (for example, solid stem augers and hollow stem augers) • Core sampling devices (for example, split spoons or Shelby tubes) • Direct push • Sonic drilling • Percussion drilling (for example, cable tool)	• Truck or tracked-mount rigs allow access to variety of sites • Collect samples at depths >100 m • Collect samples in any geologic conditions • Some methods allow for collection of discrete, undisturbed samples • Continuous, undisturbed samples can be collected	• Higher cost • Height and space requirements for rig can limit use • Waste (soil cuttings) is usually derived • Solid stem augers not preferred, as confidence in soil sample depth is lower • Use of drilling muds or fluids can introduce cross contamination • Sample volume potentially limited depending on method and soil conditions • Sample area per location is limited based on the diameter of auger/sampling device used (most common for hollow stem augers is 6–31 cm, inside diameter)