Decision Unit Characterization

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Acronyms Used in This Directive

CSM	Conceptual Site Model
DEQ	Oregon Department of Environmental Quality
DU	Decision Unit
EDU	Exposure Decision Unit
EPC	Exposure Point Concentration
HDOH	Hawaii Department of Health
HDU	Habitat Decision Unit
IMD	Internal Management Directive
ISM	Incremental Sampling Methodology
ITRC	Interstate Technology and Regulatory Council
mm	Millimeter
PDU	Perimeter Decision Unit
RME	Reasonable Maximum Exposure
RSD	Relative Standard Deviation
SDU	Source Decision Unit
UCL	Upper Confidence Limit
EPA	US Environmental Protection Agency

1. Introduction

The scope and detail of a site characterization will vary from site to site, depending on the questions the investigation is intended to answer and the site complexity. The Oregon Department of Environmental Quality recommends a systematic planning approach to ensure that the data collected during the site investigation are of the type and quality needed to meet the overall site assessment objectives. A detailed discussion of systematic planning for site investigations is beyond the scope of this document and DEQ refers the reader to the U.S. Environmental Protection Agency's (EPA's) and Interstate Technology and Regulatory Council's (ITRC's) current and forthcoming guidance (ITRC, 2012, EPA, 2000, EPA 2006). Critical to systematic site investigation planning is developing a conceptual site model, which illustrates migration and exposure pathways. Guidance for developing conceptual site models (CSMs) is also provided in EPA and ASTM materials. (EPA, 1988 & 2000; ASTM, 2014). This Internal Management Directive (IMD) provides guidance on identifying and selecting decision units (DUs), characterizing DUs, and interpreting the data, including developing exposure point concentrations (EPCs) for use in risk assessments.

2. Decision Unit Selection

DEQ uses DU concepts to support decision making and standardize the use of data. DUs are the defined volume (area and depth) of sample media (such as soil) where a contaminant can be sampled and represented by a mean. DUs can be designed for surface soil or sediment and/or subsurface soil or sediment. DUs described in this document are most relevant to soil DUs. The general concepts described below may be applied to sediment DU. However, specific guidance on approaches and methods to be used in aquatic settings is beyond the scope of this IMD.

A key component in this approach is the designation of one or multiple DUs, and distinguishing between types of DUs to meet sampling objectives. Objectives include the characterization of source or transport features to support the remedial investigation, or to characterize exposure to people and plants and animals. DEQ uses a variety of types of DUs to make decisions, including exposure DUs (EDUs), source DUs (SDUs), and perimeter DUs (PDUs). The sampling approach and design used within a single DU should meet specific objectives. If the selection of decision units are designed to meet multiple objectives, such as a mix of EDUs and SDUs, consultation with DEQ staff is strongly recommended. The different types of DUs are described below.

Source Decision Units

SDUs, for purposes of this guidance, is an area of elevated concentrations relative to surrounding areas. SDUs may be of any size that occur from historical spills, waste disposal areas, or other historical operations. In this case, decision units are identified using site history and field observations as areas with distinct characteristics or soil types, such as stained soil or known releases. SDUs are characterized specifically to determine nature and extent of contamination for the purposes of targeted source control or remedial action.

Exposure Decision Units

EDUs correspond with areas of current and/or future exposure to people and plants and animals where the desired exposure estimate is a representative average concentration. Examples of EDUs are areas over which workers come in contact with soil during the course of their work, a residential backyard, or ecological habitat areas (forest, fields, wetlands, etc.) consistent with the home ranges of wildlife.

For **human health EDUs**, EDUs represent areas accessed by residents or workers, such as residential yards, parks, shorelines, and commercial or industrial properties.

For developing EPCs for soil, DEQ generally uses depth ranges of 0 to 3 feet for surface soil, and 0 to 15 feet for subsurface soil (for example, construction or excavation worker exposure). However, it will be important to understand where the highest chemical concentrations are present based on a conceptual understanding of release mechanisms at the site. For example, if a spill results in high chemical concentrations in the top few inches, an EPC calculated using data over a range of 3 feet will underestimate the current risk from exposure to surface soil. The vertical distribution of hazardous substances released to soil determined by pre-existing samples may be used to decide appropriate soil depth intervals for subsequent sampling using incremental sampling methodology (ISM) .

Exposure area DUs for residential properties typically encompass the entire yard, but could also focus on play areas or other areas of the yard that are most frequented. DUs for apartment complexes should focus on open common areas. For future redevelopment projects that involve single-family homes, the size of a hypothetical residential lot is generally assumed to be 5,000 ft^2 (see Subsection 3.5).

The location and size of exposure area DUs for commercial or industrial sites is necessarily site specific. DUs should be based on the location of exposed areas of soil and use of the site by workers. As a default and especially for undeveloped properties, exposure areas should be initially limited to half an acre or approximately 20,000 ft^2. When possible, designate DUs and investigate the site in a manner that allows future, unrestricted land use (i.e., residential land use, see Section 13). This will minimize the need for restrictions on future site use or delays in redevelopment.

For **ecological EDUs**, EDUs should represent one habitat type (e.g., grassland or forestland), and not blend habitat and non-habitat areas. Habitat size should correspond with the home ranges or habitat units for relevant wildlife. The default assumption for a screening level risk assessment is to assume that the home range of one or more animals is entirely within the contaminated area. In this case, the animals are exposed 100% of the time to the contaminated area.

DEQ has set the minimum size of a terrestrial habitat decision unit (HDU) at 0.5 acres to be representative of small home range wildlife such as ground feeding birds and mammals. The mean home range (0.55 acres) for the vagrant shrew (*Sorex vagrans*) sampled during the breeding season in British Columbia (Hawes 1977) was used to develop this default size. Therefore, the habitat area(s) in the locality of the facility should be broken into 0.5 acre DUs to characterize small home range exposure.

Decision units collected for characterizing exposure to small home range wildlife, such as ground feeding birds and mammals, may be combined in an exposure estimate of 90 percent upper confidence on the arithmetic mean to represent the exposure of large home range wildlife. These include representative larger home-range mammalian and avian predators such as weasels and hawks. In cases where DUs of different sizes may have been collected (e.g. SDUs), area weighted averaging of incremental samples can be used to calculate concentrations reflective of the EDU.

Perimeter Decision Units

"Perimeter DUs" are used to delineate the extent of later contamination and/or the extent of a remedial action area. The number and design of perimeter DUs is site-specific.

There may be other types of DUs that can be developed on a site-specific basis.

Note that selecting the size and location of the DU is an important component of the planning process and should be informed by what is known about sources of contamination at the site. For example, including a small area of high concentrations in a larger EDU with mostly lower concentrations could result in an EDU concentration that exceeds criteria. For this reason, areas known or suspected to have high concentrations should be characterized separately from areas anticipated to be lower in concentration. These different source area DUs can then be combined to represent an exposure area EDU.

3. Decision Unit Characterization

When the DUs are established, the next phase of the process is developing the sampling design (number, type, and exact locations of samples) required to represent the DU. The three types of samples typically used to characterize decision units including include 1) discrete samples; 2) conventional composite samples, and 3) incremental (composite) samples (ISM). For the purposes of this guidance, the term *conventional composite* refers to the combination of low-density discrete samples, or subsamples (3-5), for testing, originally developed to save on analytical cost. While incremental samples are a form of compositing, the methodology ensures the sample is representative by collecting sufficient mass / volume to represent heterogeneity in the DU spatially and compositionally (particle type and size).

For all sample types, the optimal DU characterization uses systematic planning to ensure data collected for generating a mean concentration is representative and unbiased. If judgmental (i.e., biased) sampling is used instead, then decision-making is vulnerable to disagreements about unquantified estimation errors (EPA, 2002 and ITRC, 2012). The following provides a hierarchy for recommended sample design:

1. Use ISM to characterize the DU with adequate increments (ITRC, 2012 and HDOH, 2016) for measuring mean contaminant concentrations.
2. Use systematic grid sampling (EPA 2002) to estimate a mean and confidence intervals (90% upper confidence limit of the mean [UCL]) based on at least 20 discrete or composite samples. If less than 20 (but at least 10) samples are used, and sample results exhibit variability, sample concentrations should be evaluated on a point-by-point basis.
3. For small-scale source areas or to characterize known site features, judgmental design may be used to represent a "high bias" using: a) incremental samples representing the source area sampling units or b) at least 10 randomly collected discrete or composite samples. Data should be evaluated on a point-by -point basis.

DEQ strongly encourages practitioners to develop an ISM-based program to characterize DUs. Studies conducted by the Hawaii Department of Health (HDOH, 2016) demonstrate that ISM addresses significant deficiencies of discrete sampling methods and is a significant improvement in generating scientifically defensible and representative data. For this reason, DEQ expects sampling plans to either incorporate ISM, or provide a rationale for why ISM is not applied at a site.

For any of the methods described above, the assumptions and limitations of the method should be described, along with how the data quality objectives and data usability goals are addressed. If data usability goals are not met, then additional sampling may be required.

3.1 Incremental Sampling Methodology

ISM is a structured composite sampling and processing protocol that reduces data variability and provides a reasonably unbiased estimate of mean contaminant concentrations in a volume of soil targeted for sampling (ITRC, 2012). This approach is an improvement on conventional composite sampling by increasing representativeness of the mean over areas of interest. Theory and application of ISM has been documented in multiple documents (ITRC, 2012 and HDOH, 2016) and is not repeated here; practitioners should familiarize themselves with these and any forthcoming ISM documents. Specific expectations associated with implementing ISM in Oregon are described below.

3.1.1 Number of Increments

The number of increments should be at least 30, but may be over 75, depending on the size of the area and expected variability. As the size of the DU increases and/or expected contaminant heterogeneity increases (i.e., the standard deviation increases), the number of increments needed to measure (or capture) the true mean may increase. It is worth noting that in particularly heterogeneous soils, 30 increments is often not sufficient to characterize a mean with adequate precision. Generally, contaminant heterogeneity at cleanup sites can be high due to the range of sources and release mechanisms. The collection of a minimum of 50 increments is recommended to increase the certainty that the results are representative, achieve appropriate precision (defined as a relative standard deviation (RSD) of <35%), and a normal distribution (Jenkins et al, 2005, Hawaii, 2016). If fewer than 50 increments are proposed, three independent field triplicates should be collected to determine the standard deviation. For exposure DUs, the range of values within the triplicates are used to calculate 90th percentile upper confidence level on the arithmetic mean (ITRC, 2012). Triplicate results are also often used to assess the effectiveness of sampling in controlling the RSD to acceptable levels.

If the sampling of many DU samples is anticipated, or logistical considerations (e.g. subsurface sampling) limit the number of increments, site-specific sampling plans should include proposals for sampling a representative subset of samples using triplicate analysis for RSD determinations, which could then be used to develop confidence limits for application to the results of single (<50 increments) DUs.

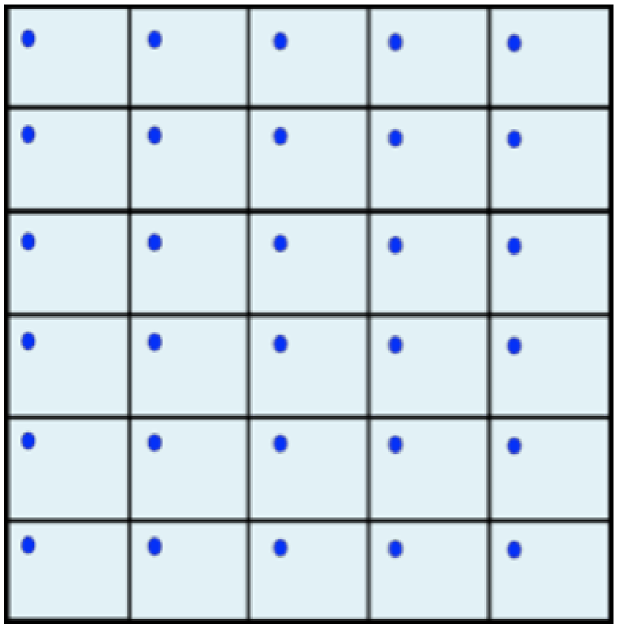
3.1.2 Target Mass

One important component of incremental sampling is the collection of adequate mass (grams) from the field to control compositional heterogeneity (particle composition). ITRC 2012 provides a table and online calculator to determine incremental soil mass (500 grams – 2500 grams) needed depending on the tool size and substrate density. Based on these considerations, it is recommended that at least 1000 grams be collected from each decision unit considering the number of increments needed to achieve the ISM mass. For example, if your design included 100 increments you would need to collect 10 grams from each to reach 1000 grams. If there are fewer increments in the design, the mass taken from each increment proportionally should likely increase (e.g. 50 increments = 20 grams from each).

3.1.3 Increment Distribution

DEQ recommends collecting increments in a systematic random sampling scheme (see Figure below), i.e., in a grid fashion at a fixed spacing to ensure all portions of the population are represented. A random start should be used for the selection of the increment location within each grid cell, and this location is then repeated across all cells. This sampling approach has a lower error rate in the measured average and therefore is more reproducible than other approaches. When implemented, other approaches such as simple random or stratified random, can result in significant holes within a DU.

Figure: Systematic Random Sampling Grid (ITRC, 2012)



3.1.4 Field Sample Collection

Sampling Tools. The tool selected to collect the increments should be able to scoop to the bottom of the sample depth while getting all the particles in the sampling tool. The use of a square tool or cylindrical core ensures no bias toward any of the particles present, while rounded or flat scoops introduce a bias in the particle sizes collected. The tool size is typically selected as representing a diameter of a minimum of three times the diameter of the largest particle present (d≥3 millimeter [mm] coarse particles, 3d + 10 mm for fine) (see ITRC, 2012 for more information). As discussed above, the tool should be selected to support the collection of the target mass, which generally ranges from 20 to 60 grams of soil from each increment.

Sieving. Soil or sediment for the purposes of exposure characterizations is typically defined as particle sizes <2 mm. Sieving after collection is designed to remove vegetation debris, gravel and pebbles. However, this process can remove a portion of the target mass, which should be accounted for when planning the mass needed from each increment. In order to avoid sticking and clumping, sieving should be conducted on dry soils. Therefore, the laboratory may need to do the sieving after air-drying has been completed.

Replicate Samples. Replicates should be taken from a subset of DUs in order to evaluate data quality and ensure the mean is adequately representative of a 90^{th} percentile upper confidence level on the arithmetic mean. Underestimates of the mean using incremental samples are most likely to occur where heterogeneity is high or the number of increments are low relative to the spatial coverage size of the DU. Variability (relative standard deviation or RSD) is appropriately reduced by either 1) collecting an adequate number of increments (>50) as discussed in Section 3.1.1, or 2) collecting triplicates and calculating a 90th percentile upper confidence level on the mean. Since the RSD is controlled by several sampling design factors including the DU size, heterogeneity, and number of increments, site specific information is needed to determine the number of replicates. The sampling design should be developed in conjunction with DEQ prior to sampling, and should consider the following:

- If a sufficient number of increments are collected for each sample (>50), the RSD decreases and field replicates can be collected at a lower frequency (e.g. one per batch).
- If fewer than 50 increments are collected per ISM sample the RSD increases, and there is less confidence that the sample captured the 90th percentile upper confidence level on the mean. Therefore, replicates should be taken in triplicate at a higher frequency equating to most if not all DUs. In some cases, site history may indicate similar heterogeneity (e.g. contaminant release mechanism, soil type), and replicates collected from one DU may be used to assess the expected variability in other DUs by extrapolating the RSD. In this case, replicates should be taken from the DU suspected to contain the highest concentration based on the CSM.

Field replicates should be collected using the same sampling methodology as the primary ISM sample, i.e., the same number, depth, and mass in systematic random fashion.

3.1.5 Laboratory Subsampling

The goal of subsampling in the laboratory is to select a representative sample for analytical testing from the total mass collected from the field. This is to avoid error that occurs when the range of particles collected in the field are not represented in the laboratory sample (compositional heterogeneity). Examples include collecting only a few grams of sample media off the top of the sample, or only targeting the fines at the bottom. The following steps are recommended to ensure representative laboratory subsampling, which are presented in more detail in ITRC, 2012.

1. Air dry the sample. This is often necessary to conduct sieving or particle size reduction (grinding) to obtain a compositionally representative sample. If the sample is dried, subsample original sample for moisture using incremental methods described below.
2. Sieve to remove portions of the sample not defined as “soil” or “sediment” (e.g., sticks, pebbles, gravel)
3. Grind the sample so that all the particles represent the same size and mass (concentration), such that there is no bias in the selection of smaller test amounts for extraction. Select a larger mass for the analytical subsample so a more complete range of particles is included. Generally, the smaller a sample is ground the more likely a smaller analytical sample will be representative and control particle size variability. If particle size reduction is not completed, the following is recommended:
    a. Increase the analytical aliquot mass to at least 10 grams (ITRC, 2012) so a more complete range of particle sizes are included in the analytical subsample.

b. Create the analytical subsample by splitting or taking increments from a slab cake in order to select a representative range of particles present.
    i. Spread out the entire field sample in thin layer (or slab cake) such that all of the material has the potential for collection
    ii. Use rectangular tools to collect increments designed to sample all particle sizes.
    iii. Take approximately 30 stratified random increments of equal volume to comprise the analytical aliquot, ensuring all particles sizes are represented (e.g. sand, fines). For example, if 30 grams are required for extraction and analysis, 30 increments of 1 gram each would be collected.

In addition to standard general laboratory QA/QC requirements, independent laboratory replicates utilizing the laboratory subsampling procedures is recommended to assess precision.

3.2 Discrete Sampling

Discrete sampling of individual sampling points have a long history of use in site characterization activities and the calculation of human health and ecological exposure point concentrations.hese small-scale samples can have a high degree of uncertainty in representing heterogeneity over larger scales (e.g. residential lots, ecological habitat areas). In order to account for this uncertainty, discrete samples are typically combined statistically in the calculation of a 90% UCL on the mean. However, statistical analysis on limited data cannot correct the fundamental inadequacy of these data to represent the population of interest. Therefore, discrete sampling has resulted in highly variable estimates of the population mean (EPA, 2015, Singh et al., 1999).

DEQ recommends incremental sampling approaches for measuring the mean concentration (see hierarchy presented in Section 3), but recognizes discrete samples are widely used to help make a range of different environmental decisions. Therefore, if discrete sampling is conducted to characterize a DU, DEQ recommends unbiased selection of sample locations, where each sample is equally likely to be selected (probabilistic sampling). Unbiased sampling allows the user to make statistical inferences from the data collected to the entire area of interest, and reliably evaluate the precision of the estimates. In addition, there are procedures that may be used to reduce the variability in discrete samples. Examples include particle size reduction (grinding) and representative sub-sampling of discrete samples, which will reduce the compositional heterogeneity and intra-sample heterogeneity of individual samples. This variability reduction can be helpful in situations where ISM samples cannot be used.

DEQ does not recommend relying on professional judgment to identify sample locations. This approach may be used under select circumstances for characterizing small-scale site features, such as known source areas, or visual observations of discolored soil. The potential for small-scale heterogeneity is still significant, which should be accounted for using high-density discrete sampling or appropriate field duplicates/replicates.

3.3 Conventional Composite Sampling

Conventional composite samples typically combine subsamples (i.e., increments) without the consideration of the sampling errors, and typically collect fewer increments (low density), with unspecified mixing and processing procedures. Unlike incremental sampling, dilution of the sample is an issue, which requires selection of subsample locations and appropriate interpretation of the results when compared to a screening level value.

Similar to discrete samples, these conventional composites are potentially useful in small-scale contaminant delineation and can be used in the calculation of a 90% UCL on the mean to represent DU exposure. However, individual low-density subsample composites should not be used to represent large-scale mean concentrations for use as exposure point concentrations.

If this approach is used, DEQ recommends that each sample represent the same small spatial area (e.g., 4 point, each stepping out equidistant from center), and that increments taken from the subsamples are equal in volume. In any compositing scheme, DEQ recommends a rigorous laboratory processing approach to control compositional heterogeneity similar to that of ISM to ensure a representative sample for analysis. DEQ's general guidelines for composite sampling are as follows:

1. Composite areas of similar size and shape to represent the same volume of soil, and ensure subsamples do not overlap with other composite samples.
2. Subsamples are from evenly spaced adjacent sampling points in order to incorporate the same spatial heterogeneity within the average (e.g. 4 point composites).
3. When characterizing an EDU, composites should be collected from the same depth interval, which should correspond to equivalent exposure potential. Horizontal compositing should be limited to a habitat type where exposure is expected to be uniform. Composite over large vertical depth intervals is not recommended, since the probability of exposure varies by depth interval and receptor. Instead, composite samples should combine discrete samples within, but not between exposure intervals (e.g. 0-6, 6-12, 12-24 & 24-36 inches).
4. Each discrete subsample should contribute an equal amount of material to the composite sample such that the sample is not biased by larger or smaller subsamples.
5. Avoid mixing or "homogenizing" composite subsamples in the field, which can serve to further separate particles of different sizes. Sieving to <2mm helps control particle size error, with drying beforehand if necessary to avoid clumping of moist soil. Subsample using a simple slab cake or other method.
6. Absent laboratory particle size grinding as specified in ISM methodology, keep subsamples for the composite the same particle size and soil type. The goal is to obtain representative material from the area by preventing the bias of the physical average (e.g. avoid mixing sand with organic soil or the preferential selection of fine-grained material).
7. Use laboratory homogenization and subsampling (e.g. slab cake) to obtain representative smaller masses used in the analytical method.

4. Interpreting Decision Unit Data

Data quality of ISM, composite, and discrete samples should be evaluated using standard EPA and DEQ methods. In addition, data representativeness for ISM samples should be evaluated consistent with Section 4.2.7.3 of the HDOH Technical Guidance Manual. Significant disagreement between replicate ISM samples can indicate sampling error or the presence of an area with high concentrations within a larger DU with mostly lower concentrations. If this is the case, and the data are insufficient for decision making, the DU should be subdivided and re-characterized.

As described in other DEQ guidance, risk-based concentrations (RBCs) are intended to be compared with reasonable maximum exposure (RME) to receptors. As sample size increases and an EDU is properly and rigorously characterized, the variability around the mean is reduced such that the RME confidence interval (90 or 95%) becomes smaller and is closer to the true mean concentration. The best way to adequately reduce this variability is to increase the sample size using ISM with sufficient increments (>50 or >30 with replicates) to generate a highly certain mean concentrations in a DU. Sample size can also be increased using high-density discrete or composite sampling, but it is typically more expensive, less efficient, and more uncertain than ISM samples.

> To develop upper-bound or high-end exposure for both human health and ecological risk assessments, DEQ uses estimates of mean concentrations and reasonable maximum estimates of exposure, combining means and upper bounds. Specifically, Oregon Rule requires use of "the 90th percentile upper confidence limit on the arithmetic mean of concentrations of hazardous substances that would be contacted by an exposed receptor and reasonable maximum estimates of the exposure factors used in the risk calculations, ***unless a greater or lesser best estimate is acceptable to the Department***". OAR 340-122-0084(1)(f) (emphasis added). DEQ has determined that the mean concentration generated using ***ISM with adequate increments is a better estimate of exposure*** acceptable to the Department for the evaluation of chronic effects. The ISM mean estimate is also acceptable to assess the central tendency exposure for both human health and ecological risk assessments.
> For ecological risk, the assessment of acute effects would require the analysis of "decomposited" ISM subsamples in order to estimate variability. It would not be appropriate to compare an average EDU exposure concentration to acute levels (e.g., LC50).

If discrete or composite samples are used to estimate an EPC, the number of samples used to represent an exposure area is site-specific as described above. If both composite and discrete data are available at a site, the dataset used to calculate a 90% UCL on the mean concentration should use either all discrete or all composite samples (obtained using the same design, pattern, and number of increments) (EPA, 2015). While at least 10 samples are required, for characterization, typically approximately 20-30 are needed to characterize exposure areas with an appropriate degree of confidence. In cases where only 10 samples are available, unless data exhibit limited variability, data are evaluated point by point. On a practical basis, this means the maximum concentration will be used as the EPC for the DU.

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6. Record of Revisions to IMD

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