March 1, 2024 – MassDEP is issuing **Draft Guidance Chapters 1 through 5 of the Risk Characterization Guidance in support of the Massachusetts Contingency Plan (MCP), 310 CMR 40.0000,** for a 60-day public review period at the conclusion of which it intends to consider comments received and issue a final guidance. This Draft Risk Characterization Guidance supersedes the 1995 Risk Characterization Guidance (#WSC/ORS-95-141).

Additional chapters of the Risk Characterization Guidance will be released for external comment and review in additional phases to provide an opportunity for the public to provide feedback prior to finalizing the guidance.

This portion of the draft Risk Characterization Guidance incorporates the 2024 MCP amendments, incorporates current risk characterization practices and provides clarifications based on program experience and frequently asked questions.

Please send written comments on this portion of the draft Risk Characterization Guidance by May 1, 2024 to Greg Braun by email to Greg. Braun@mass.gov or by mail to Greg Braun, MassDEP/ORS, 100 Cambridge Street, Suite 900, Boston, MA 02114. You may also reach Greg Braun by telephone at (781) 697-4843.

MassDEP Guidance for Disposal Site Risk Characterization

Part 1 – General Site Characterization to Support Assessment

Chapter 1
Introduction

1.0 Introduction

1.1 Risk Assessment Requirements under the MCP

The Massachusetts Contingency Plan (MCP) comprises the regulations (310 CMR 40.0000) for assessing and managing hazardous waste disposal sites in the Commonwealth. Risk characterization is used under the MCP to determine whether a remedial response action is necessary and to document that a level of No Significant Risk[1] of harm to health, safety, public welfare and the environment exists or has been achieved for a site. In this context, the site risk characterization is a decision tool for making remedial decisions in a manner which is both protective of public health and the environment and consistent from site to site. A risk characterization must be performed at each site seeking a Permanent or Temporary Solution, because determining whether a condition of "*No Significant Risk*" or *"No Substantial Hazard"* exists is a basic requirement of a regulatory endpoint.

MCP Risk Assessments are not Health Assessments

MCP risk characterizations are designed to support cleanup decisions that will protect people from harmful Exposure in the future. The results do not support conclusions about the cause of past illnesses that may be experienced by people who have been exposed to contamination at the site. MCP risk characterizations are used to make protective site management decisions, not to predict effects on health or the environment.

While risk characterizations may be performed at any point during the site assessment and remediation process (assuming that sufficient information about the site and the contamination has been gathered), they are typically conducted at two points in the process: (1) as part of a site assessment, to determine whether or not remediation is necessary, and/or (2) following a remedial response action to determine whether the action achieved a condition of No Significant Risk (NSR).

Regardless of when the risk assessment is conducted, it is an essential component in documenting the achievement of a temporary or permanent solution. There is only one exception to the requirement that a risk assessment must be completed prior to achieving a permanent solution: If the Comprehensive Site Assessment shows that site conditions are entirely consistent with background conditions, it can be concluded that a condition of NSR exists at the site. The MCP defines Background as those levels of oil and hazardous material that would exist in the absence of the disposal site of concern (310 CMR 40.0006. A disposal site where background conditions exist is therefore deemed to have achieved NSR (310 CMR 40.1020(2)) for the purpose of attaining a Permanent Solution.

[1]In this document, the capitalized term "*No Significant Risk*" is often used in lieu of the longer "*no significant risk of harm to health, safety, public welfare and the environment*." Reference to single measures, such as "*no significant risk to the environment*," will not use the capitalized form.

***No further response actions are required at any disposal site where the concentrations of oil and hazardous material in the environment have been reduced to Background levels* (40.1020(2)).**

While the terms "Risk Characterization" and "Risk Assessment" are often used synonymously, there is a subtle difference in their meaning in the regulations. A risk assessment describes, often quantitatively, the potential risks, answering the question, "*What are the risks associated with the contamination at this site?*" An MCP Risk Characterization takes the process one step further: using criteria promulgated in the regulations, the risk characterization answers the question, "*Are those risks significant (important)?*" The standards used to answer that question may be expressed qualitatively, as concentration-based standards or as limits on Cumulative Receptor Risk, depending upon the nature of the risks being evaluated and the risk characterization approach used. Each report presenting an MCP Subpart I Risk Characterization must contain both the documentation of the risk assessment and a clear statement whether or not a condition of NSR of harm to health, safety, public welfare and the environment exists or has been achieved.

However, under certain circumstances adequate assessment performed as part of Preliminary Response Actions may demonstrate that background conditions have been met that supports a Permanent Solution Statement (PSS).

Thus, under the MCP, *Risk Characterization* is a process which links assessment to risk management.

1.2 Implementation of the Guidance for Disposal Site Risk Characterization

This document provides guidance for conducting and documenting risk characterizations and related investigatory activities pursuant to Subpart I (310 CMR 40.0900) of the MCP. The MCP is a set of regulations for the notification, assessment and remediation of contaminated sites promulgated pursuant to M.G.L. Chapter 21E (c.21E), the Massachusetts Oil and Hazardous Materials Release Prevention and Response Act. In addition to persons conducting risk characterizations at sites, this material may also be of use to persons *reviewing* MCP risk characterizations, persons conducting a risk assessment for other (non-MCP) purposes, and to the interested public.

This guidance provides risk assessment approaches the Department considers acceptable for meeting the general requirements set forth in the regulations and is intended solely as guidance. It does not create any substantive or procedural rights and is not enforceable by any party in any administrative proceeding with the Commonwealth. Parties using this guidance should be aware that other acceptable alternatives may be available for achieving compliance with general regulatory requirements. Risk assessors opting to employ different methods than those recommended in this guidance are expected to provide documentation that the alternative approach provides equivalent risk characterization with regard to risk estimates, level of protection and completeness.

While some parts of this guidance are highly detailed, it is not a “how to” manual. Risk assessors are expected to be familiar with current practice and the technical literature. Further, this document is not meant to provide a complete list of all the regulatory requirements pertaining to risk characterization. Parties undertaking a risk characterization for a site should consult the MCP (310 CMR 40.0000) for applicable requirements.

MassDEP’s Waste Site Cleanup program is semi-privatized. A key feature of the program is its reliance on Hazardous Waste Site Cleanup Professionals (also called "Licensed Site Professionals", or "LSPs") to manage assessment and cleanup actions and to ensure that such actions are performed in compliance with the MCP. LSPs oversee and manage response actions and render opinions on behalf of Responsible Parties (RPs), Potentially Responsible Parties (PRPs), and Other Persons conducting response actions to ensure response actions,

including the risk characterization portion of the response action, meet the MCP's requirements. LSPs are licensed by the Commonwealth and employed by people conducting response actions.

1.3 Contents of the Guidance for Disposal Site Risk Characterization

The general data gathering and interpretation which must precede the risk characterization is described in the regulations at 310 CMR 40.0835 and 310 CMR 40.0904 – 40.0933. These activities include investigation of the physical characteristics of the site; identification of the source and extent of the release; characterization of the type, volume, nature, and spatial distribution of the released oil or hazardous materials (OHM); identification of applicable soil and groundwater categories; identification of exposure points and the concentration of OHM at these exposure points; and identification of background levels of OHM. While it is beyond the scope of this document to provide detailed guidance on all site investigation activities, **Part 1** (Chapters 2 through 7) discusses the general site assessment topics that have the greatest potential impact on the risk characterization process:

- Chapter 2: Conceptual Site Model
- Chapter 3: Site Activities and Uses
- Chapter 4: Sample Collection
- Chapter 5: Sample Analysis
- Chapter 6: Identification of Contaminants of Concern
- Chapter 7: Background Evaluation

Part 2 provides guidance for evaluating the risks of harm to human health, safety and public welfare. As described in 310 CMR 40.0940 of the MCP, risks of harm to human health must be characterized by one of three methods. This document includes guidance for all three approaches. *In general, only one method should be used for a given disposal site*, although there are circumstances when a combined approach is appropriate. Correct choice of the appropriate method is extremely important.

When Method 1 is applied, it is assumed to cover risks of harm to human health, public welfare and the environment.

Method 2 assessments (310 CMR 40.0980) allow for limited modification of the Method 1 standards based upon site and chemical-specific fate and transport factors. In addition, if MassDEP has not promulgated a Method 1 soil or groundwater standard for a chemical, Method 2 may be used to develop values analogous to Method 1 Standards. The use of Method 2 is described in Chapter 9.

The scope and level of effort of the risk characterization depends upon the complexity of the disposal site and the response action being performed. A Licensed Site Professional may provide ***technical justification*** *(310 CMR 40.0193) for forgoing specific site investigation activities if, in the LSP's professional judgment, any particular requirement is unnecessary or inappropriate based upon the conditions and characteristics of the site. The LSP must employ* ***RAPS*** *(Response Action Performance Standard, 310 CMR 40.0191) in determining whether any such activity is unnecessary or inappropriate.*

Guidance for selecting and applying the appropriate risk characterization method is provided in Chapters 8 through 10. Method selection is explained ed in Chapter 8 and guidance for employing each method follows in Sections 9 and 10, and 11. Section 12 covers Imminent Hazard and Substantial Hazard assessments, and Public Safety and Welfare are addressed in Chapter 13. These are listed below.

- Chapter 8 Selection of the Risk Characterization Method
- Chapter 9: Applying Method 1 to assess risks to human health and the environment
- Chapter 10: Applying Method 2 to assess risks to human health and the environment
- Chapter 11: Method 3 Site-specific Human Health Risk Assessment
- Chapter 12: Imminent Hazards and Substantial Hazards
- Chapter 13: Safety and Public Welfare

Finally, **Part 3** contains guidance for ecological risk assessment

Additional guidance is provided in the Appendices. Appendix 1-A presents a glossary of terms and acronyms used in the MCP and this guidance document. Appendix 1-B provides references for potentially Applicable or Suitably Analogous Standards. Additional Appendices are referenced in other chapters.

1.4 Objectives of Risk Characterization at MCP Disposal Sites

As described in Subpart I of the MCP, risk characterization is used in the Waste Site Cleanup Program to determine whether a remedial response action is necessary at disposal sites, to identify target cleanup levels in the event that a remedial action is required and to document that a level of NSR of harm to health, safety, public welfare and the environment[1] exists or has been achieved for a site. Risk characterizations may also be used to determine if an Imminent Hazard exists or to establish No Substantial Hazard. In other words, risk characterization is used to answer the question *"How Clean is Clean Enough?"*

In this context, the site risk characterization is a decision-making tool with which remedial decisions may be made in a manner which is both protective of public health and the environment and consistent from site to site. A risk characterization must be performed at each site seeking a Permanent or Temporary Solution: a condition of "*No Significant Risk*" is a basic requirement of a Permanent Solution. While risk characterizations may be performed at any point during the site assessment and remediation process (assuming that sufficient information about the site and the contamination has been gathered), they are typically conducted at two points in the process: (1) following a comprehensive site assessment to determine whether or not remediation is necessary, and (2) following a remedial response action to determine whether the action effectively eliminated significant risk.

1.4.1 Risk Characterization to Demonstrate the Need for a Response Action

Risk characterization is used under the MCP to evaluate the need for response actions under a wide range of conditions - from fuel released as a result of roadway tanker truck accidents to mixtures of chemicals released to soil and groundwater over the years at historically industrial locations. Many MCP sites result from the sudden release of OHM where Emergency Response teams are called in immediately to clean up the spill, often to "background" levels. Others result from years of diverse and evolving waste and land management practices.

Decision about whether the conditions at a site are serious enough to require remediation requires evaluation of a number of factors such as the possible presence of ongoing releases, the use of the site, the location of the contamination and the concentrations of the OHM. The MCP establishes a consistent set of procedures by which decisions can be made regarding the need for remedial actions at a disposal site. Risk Characterization is one of the tools incorporated into the regulations to assist site managers in making decisions that are both consistent from site to site and protective of health, safety, public welfare and the environment. This risk characterization guidance document aims to promote consistent compliance with the MCP requirements through procedures that can be tailored to fit a wide range sites and conditions.

1.4.2 Risk Characterization to Assess Baseline Risk

A "*baseline*" is a measure used as a standard for comparison. In environmental regulation, a baseline measure describes the conditions which would exist in the absence of any controls or remedial measures - in other words, the baseline measure describes the "No Action" alternative. Thus, a baseline Risk Characterization describes the health, safety, public welfare and environmental risks which would exist if no remedial actions were taken to address the contamination at a disposal site. Because a baseline risk characterization assumes that no remedial action will take place, the assessment includes an evaluation of both current and future exposures to the contamination that has not been remediated.

At most sites, however, a true baseline risk characterization may never be carried out. The 1993-1994 revisions to the MCP allow preliminary response actions and risk reduction measures to be taken without a formal determination that the contamination concentrations at the site exceed concentrations that indicate NSR. This change was made to the regulations in response to comments that the need for action (and the appropriate type of action) at a site is often evident, and resources should be spent on cleaning up sites and reducing risk rather than documenting the need to take such actions. Thus, the first, and only, risk characterization performed for a c.21E site may be to demonstrate that the remedial actions already implemented have achieved a condition of No Significant Risk[2]. While this approach can greatly streamline the assessment/remediation process, there are potential problems as well. Without an adequate understanding of the site, chemical concentrations and exposure pathways, the initial remedial measures may not be sufficient to achieve a level of NSR, and further response actions may be necessary. Risk characterizations conducted *before* a remedial measure is carried out can be used to plan cost effective remedial strategies, such as targeting for cleanup those chemicals or exposure media contributing the most risk.

1.4.3 Risk Characterizations to Identify Imminent Hazards

Imminent Hazard Evaluations are a specific type of MCP risk characterization which answers the question, ***"Is a remedial action required NOW?***". It is a form of baseline risk assessment which typically evaluates the potential risks associated with short-term exposures at a site under current conditions. Imminent Hazard Evaluations are not required at all sites. They are triggered by the presence of conditions indicating the potential for short term exposures to pose a risk. An Imminent Hazard Evaluation should be conducted whenever information indicating a potential imminent hazard comes to light, which could be at any point in the site assessment/remediation process. Chapter 11 of this document describes when and how such evaluations are conducted.

1.4.4 Risk Characterization to Identify Target Cleanup Levels

When a risk characterization indicates that remediation is needed (i.e., a condition of NSR has not been achieved) the question "*Is a response action necessary?*" becomes "*When can the response action stop?*" In much the same way that the question is turned around, the risk characterization can be reversed and used to identify target cleanup levels. To obtain cleanup levels protective of human health, the equations used to estimate exposure and risk (Chapter 11) can be rearranged to solve for the highest concentration that would not pose a significant risk. The standards promulgated in Method 1 (310 CMR 40.0970), which indicate the need for remediation when exceeded, can also be used as target cleanup levels during remediation, as can Method 2 Standards.

Using risk assessment procedures to obtain cleanup levels protective of environmental receptors can be more

[2]This type of post-remedial action assessment could be thought of as a modified Baseline Risk Characterization, "*modified*" because the remedial measure has altered the initial conditions (changed the baseline.)

challenging. Some measures commonly relied upon for environmental risk characterization, such as sediment toxicity tests and benthic community assessment are not amenable to estimation of cleanup levels. Often, the use of published effects-based benchmarks is the best option for identifying cleanup goals to protect environmental receptors.

1.4.5 Risk Characterization to Evaluate Remedial Action Alternatives

When remedial action alternatives utilizing known technologies are proposed, it is often possible to project the effectiveness of those technologies in reducing contaminant concentrations (and thus exposure point concentrations.) When the capabilities of a given technology are described in terms of likely residual concentrations, then a risk characterization can be performed to determine if that technology is capable of achieving a condition of NSR or No Substantial Hazard at the site. If there is more than one remedial alternative being considered, then the relative effectiveness (particularly the cost effectiveness) of the technologies in reducing risk may be an important factor in choosing among the alternatives.

1.5 Caution Against Using Reportable Concentrations in Risk Assessment

It is important at this point to note that comparison of site concentrations to Reportable Concentrations is ***not*** a valid risk assessment procedure.

> **Reportable Concentrations are <u>ONLY</u> triggers for notification** under the MCP and any other use of those numbers is not sanctioned by the Massachusetts Department of Environmental Protection.

> **Reportable Concentrations are <u>NOT</u> cleanup standards.** The MCP Method 1 Standards are a distinct and separate list of numbers and their use is described in detail in Subpart I of the MCP and Chapter 9.0 of this document.

> **Reportable Concentrations are <u>NOT</u> "No Risk" levels.** Sites with concentrations of oil or hazardous material below RCs do not trigger notification to MassDEP *at that time* but may pose significant risk and require remediation. Information gathered at a later date may result in the need for notification and/or remediation (310 CMR 40.0370).

> **Reportable Concentrations are <u>NOT</u> screens to eliminate Contaminants of Concern from a risk assessment.** The acceptable approach for eliminating chemicals from further consideration is discussed in Chapter 11 of this document.

Chapter 2
The Conceptual Site Model

2.0 The Conceptual Site Model (CSM)

The 2024 Massachusetts Contingency Plan defines the CSM at 310 CMR 40.0006 as follows:

> *Conceptual Site Model or CSM means a site-specific description of how contaminants entered the environment, how contaminants have been and may be transported within the environment, and routes of exposure to human and environmental receptors that provides a dynamic framework for assessing current and foreseeable future site characteristics and risk, identifying and addressing data gaps and managing uncertainty, eliminating or controlling contaminant sources, developing and conducting response action strategies, and evaluating whether those strategies have been effective in achieving desired endpoints. At sites at which NAPL is or may be present, this includes the body of fundamental scientific principles describing the behavior of fluid flow in porous media necessary to assess NAPL in subsurface strata.*

Simply put, the CSM is a site-specific description of what and how contaminants entered the environment, how they were transported within the system, and routes of exposure to and identification of human and environmental receptors as soon as any information on contaminant conditions becomes available, an initial CSM should be developed. The CSM represents a working understanding of environmental conditions and processes at a site. This understanding will evolve as more data and information are gathered and should serve as a guidepost for decision-making throughout the comprehensive site assessment process.

The CSM is a site-specific description of what and how contaminants entered the environment, how they were transported within the system, and routes of exposure to and identification of human and environmental receptors.

The CSM provides a framework for assessing risks from contaminants, controlling or eliminating sources, developing response action strategies, and determining whether those strategies have been effective in achieving the risk management requirements of the MCP as well as demonstrating that potential imminent hazard conditions have been considered. It serves multiple purposes, including:

- Identifying the sources and types of site contaminants and tracks them through environmental transport pathways and that lead to human and environmental receptors (i.e., people, wildlife and other resources that could be exposed to the contaminants).
- Identifying groups of people who are most susceptible to contamination.
- Forming the basis for the design of the site-specific risk characterization and provides the framework for quantifying exposure and risk.
- Serving as a communication tool to develop a common understanding among stakeholders of how data is collected and interpreted.

At a minimum a CSM is expressed as a comprehensive description of site conditions, including source areas and potentially affected resources. The narrative description may be accompanied by a graphic representation of the links between contaminant sources, transport pathways, and the locations and routes of exposure for people and wildlife. Various styles of graphic CSM representations are suitable for risk assessment practice, including diagrammatic, pictorial (Figures 2.1 and 2.2, respectively) as well as plan or overhead diagrams.

MassDEP recommends including diagrammatic presentations in MCP assessment reports because they can be used to clearly show the links between contaminant sources, environmental media and environmental receptors, facilitating a more detailed and comprehensive representation of exposure pathways. Pictorial models are simpler figurative depictions that are particularly useful for communicating site assessment and management decisions after the pathways of primary importance have been identified.

Box 2.1
Human Health
Conceptual Site Model Components

- **Sources** of contamination include waste materials or contaminated soil from which contaminants are migrating to other media and/or locations.
- An **exposure pathway** describes the course a chemical travels from a source to an exposed person.
- An environmental **medium** is soil, sediment, groundwater, surface water or air that receives contamination.
- An **exposure point** is the place where a person may come into contact with the contamination.
- An **exposure route** is the way a person contacts contaminants (by ingestion, inhalation or dermal contact).

(Adapted from U.S. EPA, 1989)

Depending on the complexity of the site, the CSMs for human health and ecological receptors may be either combined or presented separately. Throughout the assessment process the CSM should be reviewed and revised to accurately portray an increasingly refined understanding of exposure pathways at the site.

The CSM represents the understanding of the connections between contaminant sources, transport pathways and environmental receptors. It provides the framework for planning the risk assessment, designing sampling plans, assimilating new information and assessing exposure.

MassDEP's policy document *MCP Representativeness Evaluations and Data Usability Assessments* (REDUA) (MassDEP, 2002) emphasizes the central role of the CSM in documenting the adequacy of the data on which the risk characterization is based. Figure 1 from the REDUA document depicts the iterative nature of CSM

development and the interdependent relationship between the CSM, the sampling plan(s), data collection and data evaluation.

The following sections describe in greater detail the types of site information needed to fully develop a CSM
and the connections between the CSM and the site assessment.

Box 2.2
Fate and Transport Note

Biodegradation is a mechanism that may often be an important attenuating fate and transport factor. However, it is difficult to quantify for site-specific conditions. The application of degradation rates observed under controlled laboratory conditions to field conditions can lead to significant underestimation of future concentrations. For MCP risk assessment purposes, the assumption that the concentrations will decrease at a certain rate due to biodegradation is discouraged.

2.1 Conceptual Site Model: Source Identification

Source identification is a fundamental part of developing a comprehensive site assessment, but this step is often either insufficiently detailed or overlooked. Pursuant to 310 CMR 40.0904(2), "The documentation of the Risk Characterization shall contain a description of the source and extent of the release of the oil and/or hazardous material." In some instances, the source of contamination cannot be pinpointed. However, with a robust data set the site can be adequately assessed to characterize risks. The process of developing the CSM serves as a reminder to obtain this key information, which is necessary for describing both the current nature and extent and the future fate and transport of the contamination. Important information for identifying sources includes site use history, historical maps, aerial photography and reports from previous site investigations.

Typical contaminant sources include, but are not limited to:

- Former lagoons or other areas where waste has been deposited;
- Active or abandoned tanks, drains or pipes contributing to contamination;
- Non-aqueous phase liquid (NAPL) present in soil, groundwater or sediment;
- Soil or sediment that is contaminating surrounding media via a dissolution or volatilization process (310 CMR 40.0006); and
- Known chemical spills or releases.

Failure to identify the source(s) of contamination can lead to inadequate characterization of exposures under present and future conditions.

2.2 Conceptual Site Model: Nature of Contamination

The sampling plan must include all contaminants or groups of contaminants known or suspected to be present, along with other contaminants commonly associated with the primary contaminants as well as any tentatively identified contaminant. *See* section 5.4.1 of this Guidance. For example, groundwater contaminated with chlorinated solvents should be analyzed for 1,4-dioxane, which often co-occurs with solvents. Any contaminants whose presence is expected based on the site history should also be included. For example, dioxin at former burn dumps, perchlorate in groundwater where explosives have been used, or perfluorinated compounds where aqueous film forming firefighting foam (AFFF) may have been deployed. Any new contaminant(s) identified during the assessment process should initiate a revision of the CSM to incorporate the new contaminant(s).

2.3 Conceptual Site Model: Fate and Transport

Along with source characterization, fate and transport analysis is necessary to fully characterize both present and future site conditions. A transport pathway connects a contaminant source with a person or an environmental receptor (plants, animals and their habitats). Fate and transport analysis should also consider preferential pathways. The CSM must include:

- Historical transport pathways and conduits through which contaminants have or may have migrated from

the source;
- Existing transport pathways, which may increase concentrations at an exposure point or facilitate contaminant migration to new locations (e.g., preferential pathway); and
- Future transport pathways that may result from changes in site activities and uses.

2.4 Conceptual Site Model: Extent of Contamination

The CSM should include the delineation of the horizontal and vertical extent of the contaminated area (310 CMR 40.0904(2)). It is imperative to update this information in the CSM as the site investigation progresses and the understanding of the extent of contamination is refined. Final identification of all environmental media and Exposure Points of concern can only be accomplished after the full extent of site-related contamination is determined. *See* section 4.2.1 and Chapter 7 of this Guidance.

2.5 Conceptual Site Model: Characterizing Future Environmental Conditions

If changes in contaminant distribution are anticipated based on fate and transport evaluations, the extent of contamination under future environmental conditions may have to be evaluated. Future concentrations cannot be measured and must be modeled. Modeling will be discussed in somewhat greater detail in the chapter on Exposure Point Concentration Estimation. *See* section 4.2.5 of this Guidance.

Although biodegradation may be an important attenuation mechanism for some chemicals at some sites, predicting actual degradation rates in field conditions is difficult. Due to the uncertainty related to modeling future media concentrations, MassDEP generally expects fate and transport models to use conservative assumptions. The application of degradation rates observed under controlled laboratory conditions to field conditions can lead to significant underestimation of future concentrations. The assumption that the concentrations will be decreased at a certain rate by biodegradation is discouraged for risk assessment purposes.

2.6 Conceptual Site Model: Exposure Pathways

The CSM must identify all possible exposure pathways and the exposure routes that may result. *See* Box 2.1 for terminology. In other words, the CSM must draw connections between the contaminated media and the people and environmental receptors that may be exposed to each medium.

Exposures are identified based on the current and foreseeable uses of the site and the activities consistent with those uses. The terms "activity" and "use" are both employed to describe exposure settings. In this document, "use" refers to the general purposes for which a site is managed and developed. "Activity" is a more specific term used here to describe behaviors that involve contact with contaminants (exposures). Examples of some activities and uses considered at sites with contaminated soil are shown in Table 2.1.

Table 2.1: Examples of activities and uses

USES	ACTIVITIES
Residential	Playing, gardening, lawn mowing
Commercial	Landscaping, lawn mowing, taking lunch breaks outside
Industrial	Parking, walking, working in storage yards
Recreational	Playing, picnicking, walking, dirt-biking

The specific activities determine which exposures to a contaminated medium are likely. In the CSM, Exposure Points are not delineated, but the media of concern for human and environmental receptors are specified.

While the initial CSM should be all-encompassing, as site work progresses and more data are gathered and new information is discovered, it may be possible to rule out one or more potential exposure pathways as incomplete or insignificant. Each decision to eliminate a potential exposure medium, pathway from the risk assessment must be supported by data showing that the pathway is incomplete through a multiple line of evidence approach if necessary (e.g. indoor air).

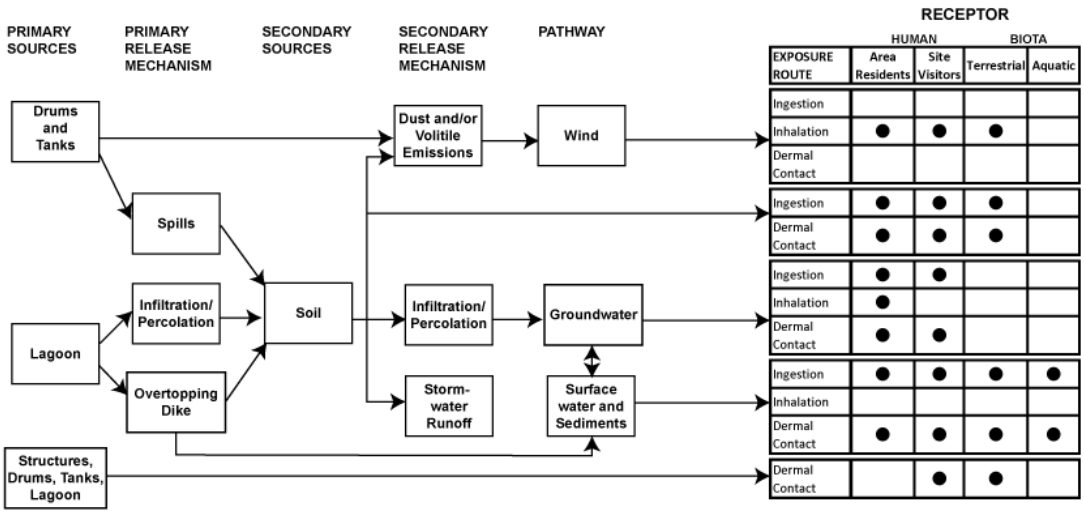
2.7 Linking the Conceptual Site Model with the Sampling Plan

The CSM provides the framework for planning sample collection and analysis and data evaluation procedures. Sampling and analysis for MCP risk assessments must be carefully planned and executed to accurately assess the specific exposures identified in the CSM and to fill any existing data gaps.

In addition to exposure points, the CSM may point to other areas of special concern. These may include areas where NAPL is present, locations where contaminated groundwater is discharging to surface water, and areas that could potentially be hotspots.

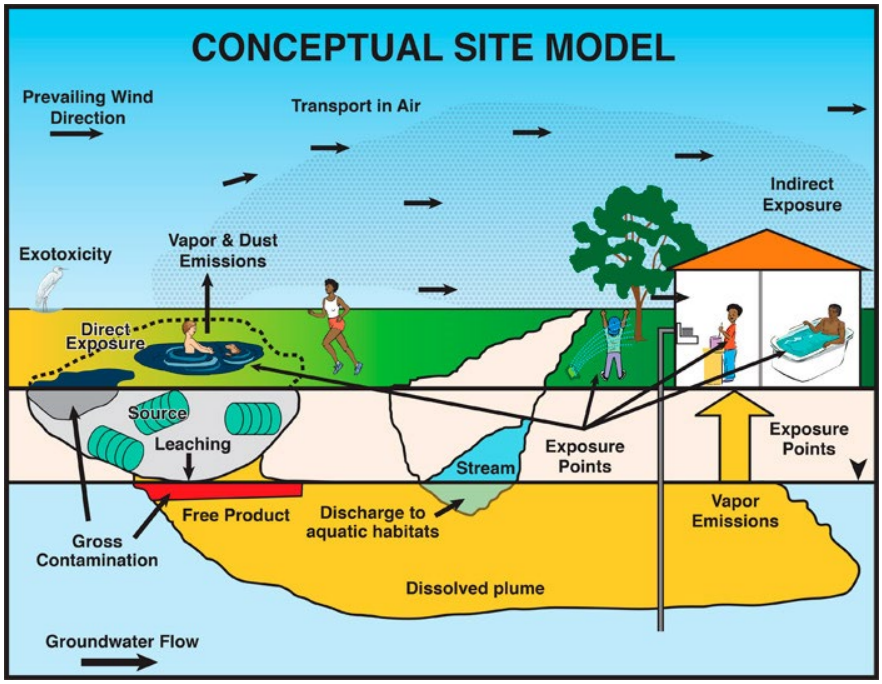
Sampling, analysis and data handling decisions must be firmly grounded in the conceptual site model to ensure the results answer the essential site and risk assessment questions.

Figure 2.1
Diagrammatic Conceptual Site Model



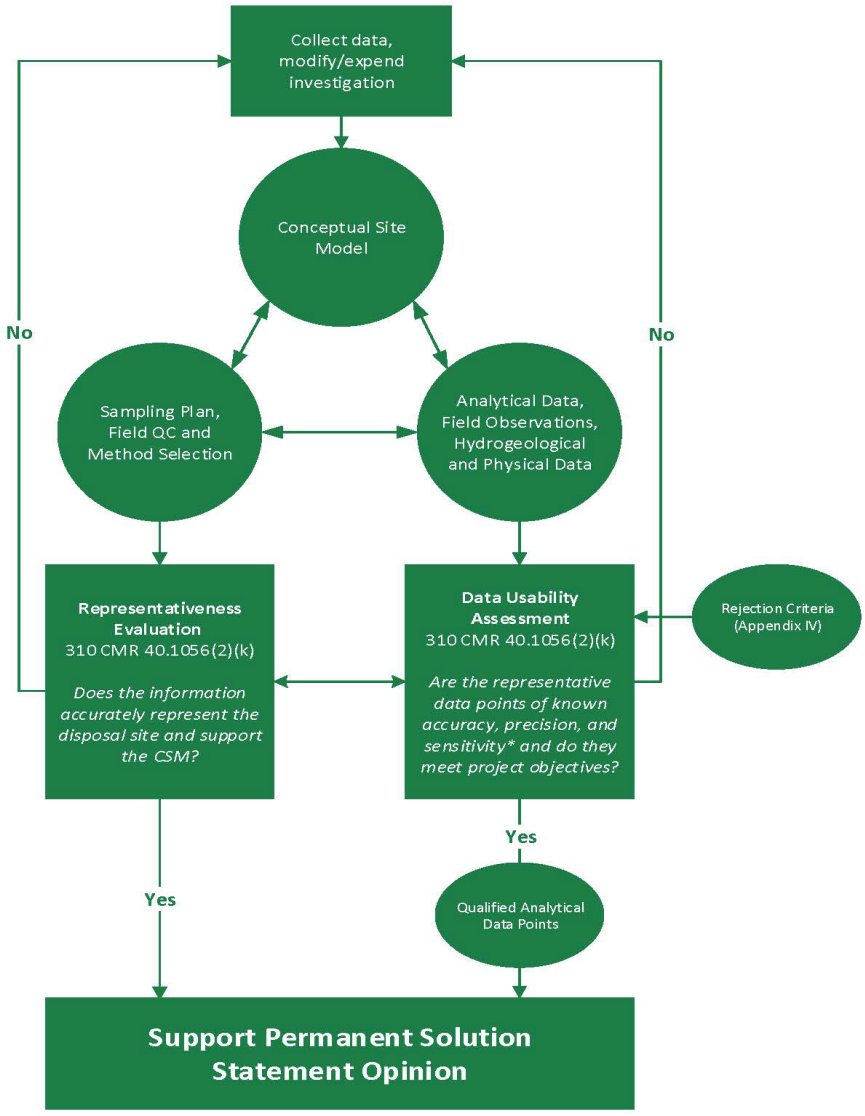
(U.S. EPA, 2011)

Figure 2.2
Pictorial Conceptual Site Model



(ITRC, 2018)

Figure 2.3
Representativeness Evaluation and
Data Usability Assessment Process Diagram



(Modified based on MassDEP, 2002)

*CAM Compliant Data is of known accuracy, precision and sensitivity; the adequacy of information establishing the accuracy and precision of other analytical data must be evaluated separately.

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MassDEP Guidance for Disposal Site Risk Characterization

Part 1 – General Site Characterization to Support Assessment (Contd.)

Chapter 3
Site Activities and Uses
and
Soil and Groundwater Categories

3.0 Site Activities and Uses and Soil and Groundwater Categorization

3.1 Activities and Uses - Introduction

The risk characterization methods described in the MCP are used to establish whether a level of No Significant Risk exists or has been achieved at a disposal site for all *current and reasonably foreseeable uses and activities* occurring at the disposal site or in the surrounding environment which could result in exposure to oil and/or hazardous material (OHM) by Human or Environmental Receptors (310 CMR 40.0923 (1)). The terms "activity" and "use" are both employed to describe human or environmental pursuits which could result in exposure to OHM. The term "use" is a broader description referring to how the site is purposed, while the term “activity” describes the actions by human and environmental receptors that could result in exposure to contaminants. Examples of uses and activities are given in Table 2-1.

The activities expected at a disposal site depend on site use. Any activities consistent with the site use must be covered by the risk assessment, including those that are actually occurring, and those that are not occurring at the time of the evaluation, but may reasonably be expected to occur because they are consistent with the current use of the site and the surrounding land use. For example, children playing outdoors must be included in the risk assessment for a residential property, whether or not young children currently reside at that location. This approach ensures that site management decisions will not result in a significant risk if future activities involve more frequent and intense exposure to contaminated media.

The MCP recognizes a distinction between the current use of the site and the foreseeable use. The term "current" means actual or possible given current circumstances, while "foreseeable" has not yet occurred, is hypothetical and may yet be changed or avoided. Current site uses and activities must be identified and evaluated to characterize risk under current conditions, and reasonably foreseeable uses and activities must be identified to characterize potential risk under future conditions. The implications of this distinction are discussed in more detail in the section that follows.

> ***The risk assessment should identify and describe all current and reasonably foreseeable uses and activities at the disposal site or in the surrounding environment which could result in exposure to OHM by human or environmental receptors*** (310 CMR 40.0923(1)).

Zoning terms, such as "residential," "commercial" and "industrial" are not reliable indicators of use, as zoning limitations may change or be violated. They are helpful in identifying current use but do not necessarily reflect all current or foreseeable uses or activities.

3.1.1 Current Site Activities and Uses

Any current site activities and uses that could result in exposure of human and/or environmental receptors (plants, animals and their habitats) to contamination must be considered in the risk assessment. The current use of the site may be consistent with a wide range of possible site activities, some of which may happen to be occurring at the time of the risk assessment, but all of which are possible considering the use. The risk assessment should be based on the possible activities associated with the most frequent and intense exposures. For example, if the site is currently used as residential property, the risk assessment should evaluate exposures to children, regardless of the age of the present residents. The MCP requires that activities that are not occurring at the time of the assessment but are consistent with the current use of the site must be evaluated (310 CMR 40.0923(2)).

3.1.2 Reasonably Foreseeable Site Activities and Uses

In the absence of an Activity and Use Limitation (AUL), described further below, reasonably foreseeable activities and uses include any possible future activity or use (310 CMR 40.0923(3)), with some important exceptions described below. These foreseeable uses must be evaluated in the risk assessment if they would result in greater human or environmental exposures than the current site use. However, since the current site use must be evaluated, there is little need to evaluate foreseeable uses which would result in less exposure. This is an important point in streamlining the risk assessment process since there are theoretically innumerable possible exposure scenarios. For a given site the risk assessor should quantify the risks only for the most sensitive receptors as well as the most exposed receptors because the risks for other receptors will likely be lower and are not likely to change the site management decisions.

. Uses and activities involving groundwater form a special case in the evaluation of uses and activities at a site. For example, it should NOT be assumed that all groundwater is a foreseeable source of drinking water. The MCP provides a list of criteria at 310 CMR 40.0932(4), developed for the purpose of protecting groundwater resources, to determine if the groundwater at the disposal site is a current or potential source of drinking water and must be protected for this use. Except as specifically provided in 310 CMR 40.0932(4), there are no site-specific exceptions, nor can professional judgment be used to overrule the criteria. The criteria are discussed in more detail in the section below titled “Categorization of Groundwater.”

As indicated above, some foreseeable site uses and activities may be eliminated from future consideration through the application of an AUL. When the disposal site conditions do not support unrestricted use, an AUL is required to identify the limitations on reasonably foreseeable future activities and uses that are assumed in the risk characterization. For example, if the current use of a disposal site is commercial, *current* receptor exposures would be evaluated based upon this commercial use and activity scenario. Exposures evaluated for the *reasonably foreseeable uses* of the property would include those consistent with foreseeable residential use and associated activities unless an AUL is implemented to restrict land use. The MCP requires that all reasonably foreseeable activities and uses of the property be evaluated in the risk characterization or restricted in an AUL unless the site can attain a condition of No Significant Risk for unrestricted use. AULs are discussed in more detail in section 3.3.

If the risk assessment is conducted prior to implementation of an AUL, but it assumes that certain exposures will be limited by the planned AUL, the risk assessment must clearly state the assumed exposure limitations, and that the results of the risk assessment will not be valid until the AULs is in place.

3.2 Soil and Groundwater Categorization - Introduction

The MCP establishes categories of groundwater and soil that reflect the nature of current and reasonably foreseeable uses, activities and anticipated exposures. These categories must be utilized in characterizing risk posed by a disposal site. Groundwater and soil must be categorized when conducting a risk assessment regardless of the method selected. When utilizing either Method 1 or Method 2 it is necessary to categorize the soil and groundwater so that the appropriate soil and groundwater standards will be used. The groundwater and soil standards for Methods 1 and 2 are listed in 310 CMR 40.0974(2), 310 CMR 40.0975(6)(a), (b) and (c), and 310 CMR 40.0985(6).

When conducting a Method 3 risk assessment the soil and groundwater categories should also be identified to aid in the development of exposure profiles and to identify applicable or suitably analogous standards as described in 310 CMR 40.0993(3).

Finally, it is necessary to have categorized soil and groundwater prior to placement of any AULs at the site. Specific guidance on the classification of soil and groundwater at a site is discussed below.

3.2.1 Categorization of Groundwater

The MCP identifies three types of applicable groundwater categories in 310 CMR 40.0932, which are described as GW-1, GW-2 and GW-3. These groundwater categories were established to identify groundwater associated with three distinct types of exposures: its use as drinking water, as a source of indoor air contamination, and as a source of surface water contamination. Because these exposures of concern are not necessarily related to each other, they are not mutually exclusive: Groundwater may, at the same time, be used as drinking water, be a threat to indoor air and discharge to surface water, in which case that groundwater would be considered categories GW-1, GW-2 *and* GW-3.

Note also that MassDEP assumes that all groundwater eventually discharges into surface water, and therefore may act as a source of contamination to that water body. Since the GW-3 Standards are based upon this assumption, the GW-3 Standards are applicable everywhere.

In addition, there may be disposal sites where groundwater in one area of a site is classified as one category and another area of the site is classified as a different category, even though the groundwater in both areas is part of the same aquifer.

At any disposal site more than one groundwater category may be applicable within the aquifer. All groundwater is considered GW-3.

Groundwater Category GW-1

Groundwater GW-1 is considered to be either a current or future source of drinking water, and the MCP describes six criteria (310 CMR 40.0006 and 310 CMR 40.0932(4)) that are used to identify aquifers that should be protected for this use. If it is determined that the groundwater at a site meets any one of these criteria, its current and foreseeable use must be described as being a source of drinking water. The criteria are:

(a) the groundwater is within a Zone II;

(b) the groundwater is within an Interim Wellhead Protection Area;
(c) the groundwater is within a Potentially Productive Aquifer;
(d) the groundwater is within the Zone A of a Class A Surface Water Body;
(e) the groundwater is located five hundred (500) feet or more from a public water system distribution pipeline; or
(f) the groundwater is located within five hundred (500) feet of a private water supply well that was in use at the time of notification pursuant to 310 CMR 40.0300 and was installed in conformance with any applicable laws, by-laws or regulations.

The terms used in the classification criteria above are defined at 310 CMR 40.0006(11) as follows:

- The Zone II is defined as: "that area of an aquifer which contributes water to a well under the most severe pumping recharge conditions that can be realistically anticipated, as approved by the Department's Division of Water Supply pursuant to 310 CMR 22.00.

- The Interim Wellhead Protection Area (IWPA) is defined as meaning:

  (1) with respect to public water supply wells and wellfields whose pumping rate is one hundred thousand (100,000) gallons per day or greater and for which the Department has not approved a hydrologically delineated Zone II, the one-half mile (2640 foot) radius surrounding such well or wellfield; and
  (2) with respect to public water supply wells and wellfields whose pumping rate is less than one hundred thousand (100,000) gallons per day and for which the Department has not approved a hydrologically delineated Zone II, the radius calculated by multiplying the maximum pumping rate in gallons per minute for such well or wellfield by thirty-two (32) and adding four hundred (400) feet thereto.

  (i.e. IWPA = (32) (y) + (400); where y = pumping rate in gallons per minute.)

- A Potentially Productive Aquifer (PPA) is defined as:
  (a) all aquifers delineated by U.S. Geological Survey (USGS) as a high or medium yield aquifer, except for any portion of a high or medium yield aquifer's surface area that is located in a municipality with a population density equal to or greater than 4,400 persons per square mile (based on the most recent U.S. Census); and

  (b) all aquifers located east of the Cape Cod Canal (Cape Cod), on the Elizabeth Islands, on Martha's Vineyard, or on Nantucket.

- A Public Water Supply is defined as "a source of water supply, including, but not limited to, primary, backup and emergency sources, utilized by a public water system. For the purposes of 310 CMR 40.0000, the terms "public water system", "primary source", “backup source” and "emergency source" shall have the meaning defined in 310 CMR 22.02: Public Water System, Primary Source, Backup Source, and Emergency Source.

- A Private Water Supply is defined as "a well which is utilized by a private water system". The system provides for "piped water for human consumption which has fifteen (15) or less service connections or does not regularly serve an average of at least twenty-five (25) individuals daily at least 60 days of the year".

Note that there is some flexibility in the regulations to consider site-specific factors, but this flexibility is limited. The MCP describes situations in which the groundwater which normally would be classified as GW-1 may be otherwise classified. These situations are described at 310 CMR 40.0932 (5)(a)(b)(c) and are summarized below.

- If the groundwater would be classified as GW-1 *solely* on the basis of the groundwater being located within an IWPA, and it can be demonstrated that the groundwater is hydrologically downgradient of the public supply well, or cross gradient and outside the zone of contribution for the public well, or that a hydrogeologic barrier exists between the site and the supply well, then the groundwater need not be classified as GW-1.

- If the groundwater would be classified as GW-1 *solely* on the basis that it is located within a PPA, it need not be classified as GW-1 if the regional or site characteristics meet MCP criteria for exclusion from GW-1.

- If the groundwater would be classified as GW-1 *solely* on the basis of the site being located greater than 500 feet from a public water supply distribution line, it need not be classified as such if any portion of the parcel or facility is within 500 feet of such a pipeline.

- Finally, if the groundwater at the site would be classified as GW-1 because the location is within 500 feet of a private well, it need not be so classified if specific requirements are met such as connecting the properties to a public water supply and registering an environmental restriction on the groundwater. See section 3.3 for discussion of limits on use of AULs.

Groundwater Category GW-2

Groundwater can also serve as a source of volatile contaminants to indoor air, and MassDEP established a groundwater category to identify circumstances under which such an impact may be likely. Groundwater will be classified as GW-2 when it is located within thirty (30) feet of an occupied building or structure and the average annual depth to groundwater in the area is fifteen (15) feet or less (310 CMR 40.0932(6)). Note that for certain chemicals (particularly chlorinated hydrocarbons) the GW-2 standards are more stringent than the GW-1 or GW-3 standards.

Groundwater Category GW-3

All groundwater in the Commonwealth is classified as GW-3. GW-3 standards are based upon discharge to surface water. All groundwater is deemed to ultimately discharge to surface water. Note that for certain chemicals (some metals and pesticides) the GW-3 standards are more stringent than the GW-1 or GW-2 standards.

3.2.2 Categorization of Soil

In accordance with 310 CMR 40.0933, soil at each disposal site must be categorized as either category S-1, S-2 or S-3. The soil categories are based upon current and foreseeable uses and activities, the location of the soil in question, and the associated potential for exposure. Category S-1 is associated with the highest potential for exposure and Category S-3 is associated with the lowest potential for exposure. Sites that meet applicable S-2 or S-3, but not S-1, soil standards must implement an AUL to ensure that the site uses and activities and associated exposures associated with that soil category do not change without further assessment and, if necessary, remediation.

When categorizing soil at a disposal site, it is important to note that the category is based upon several factors described below. Any disposal site may have more than one category of soil present at the same time.

The factors to be considered in categorizing the site soil include:

1) the type of **receptor** present at the disposal site;
2) the **frequency** of use;
3) the **intensity** of use; and
4) the **accessibility** of the soil.

Each of these factors is discussed briefly in the following paragraphs. Figure 3.1 depicts the relationships between these factors, soil depth and soil categories.

Receptor

The type of receptor at the disposal site must be considered when determining the appropriate soil category. The receptor should be identified as a child or an adult. If both children and adults are present at the site then the soil should be categorized based upon whichever would result in the most stringent soil category (e.g., if the adult's exposure is more intense, the soil should be categorized based upon the adult's exposures). The MCP defines a child at 310 CMR 40.0933(4)(a)(4) as an individual age 15 or under.

Frequency

Frequency of exposure describes how often a receptor has access to or use of the area where the soil is located on the site. The frequency of use is addressed in the MCP at 310 CMR 40.0933 (4)(a) and is classified as either "high" or "low". When evaluating frequency, the risk assessor should be considering how often a receptor comes to the disposal site, not how often the receptor comes into contact with contaminated soil. In other words, frequency term must not be reduced if the contamination is located at depth - the depth of the soil in question is considered separately under "accessibility".

Intensity

The intensity of use considers activities associated with that use that may, by their nature, result in more contact with contaminated soil. Intensity is described in 310 CMR 40.0933(4)(b) and is classified as “high” or “low”. High intensity activities, such as gardening, digging or recreational sports would result in a greater exposure to the soil. Low intensity activities, such as walking could still result in exposure to soil, but to a lesser degree.

Accessibility

The accessibility of the soil relates to the depth of the contaminated soil and whether there is any covering of the soil, by paving, a building or clean soil cover. Soil is classified as either "accessible", "potentially accessible" or "isolated". The criteria for determining which classification is applicable to the soil are identified at 310 CMR 40.0933(4)(c). Note that in determining whether soil is either "potentially accessible" or "isolated" it is assumed that the soil will not become accessible (e.g., it is assumed that the asphalt surface will remain intact), and these assumptions would be reinforced with an AUL.

To assist in categorizing soil, a matrix showing the relationship between exposure frequency, exposure intensity, soil depth and accessibility is illustrated in a matrix provided in the MCP at 310 CMR 40.0933(9) and included here as Figure 3.1. Note that for unrestricted future site use, all soil within 15 feet of the ground surface must be categorized as S-1 unless it is under the footprint of a building or permanent

structure. This is because children are presumed receptors under residential use and their frequency and intensity of use are both assumed to be high.

Figure 3.1

SOIL CATEGORY SELECTION MATRIX - HUMAN EXPOSURE POTENTIAL

<table>
<tr><td rowspan="4">Accessibility
↓ of Soil ↓</td><td colspan="8">RECEPTOR CHARACTERISTICS</td></tr>
<tr><td colspan="4">CHILDREN PRESENT</td><td colspan="4">ADULTS ONLY PRESENT</td></tr>
<tr><td colspan="2">HIGH FREQUENCY</td><td colspan="2">LOW FREQUENCY</td><td colspan="2">HIGH FREQUENCY</td><td colspan="2">LOW FREQUENCY</td></tr>
<tr><td>High Intensity</td><td>Low Intensity</td><td>High Intensity</td><td>Low Intensity</td><td>High Intensity</td><td>Low Intensity</td><td>High Intensity</td><td>Low Intensity</td></tr>
<tr><td>ACCESSIBLE (SURFICIAL) SOIL
0 <= 3'
(unpaved)</td><td colspan="3">CATEGORY S-1</td><td>S-2</td><td>S-1</td><td colspan="3">CATEGORY S-2</td></tr>
<tr><td>POTENTIALLY ACCESSIBLE SOIL
3<=15' (unpaved)
or
0 <= 15' (paved)</td><td colspan="2">CATEGORY S-2</td><td>S-3</td><td>S-2</td><td colspan="4">CATEGORY S-3</td></tr>
<tr><td>ISOLATED SUB-SURFACE SOILS
>15'
or under the footprint of a building or permanent structure</td><td colspan="4">CATEGORY S-3</td><td colspan="4"></td></tr>
<tr><td colspan="9">* - Category S-1 also applies to any accessible soil where the current or reasonably foreseeable use of the soil is for growing fruits and vegetables for human consumption.</td></tr>
</table>

3.3 Activity and Use Limitations (AULs)

An AUL is a legal document recorded with the Registry of Deeds (or filed with the Land Court, in the case of registered land)[3] that identifies activities and uses that are consistent or inconsistent with a Permanent or Temporary Solution and any ongoing obligations and conditions that are necessary to maintain a level of No Significant Risk or No Substantial Hazard. An AUL may be used as part of either a Temporary or Permanent Solution. The standard for a Temporary Solution is "No Substantial Hazard" and the standard for a Permanent Solution is "No Significant Risk," as M.G.L. c.21E and the MCP define those terms (310 CRM 40.0006). Unless otherwise specified, the term "No

[3] For ease of reading, this Guidance henceforth assumes that the property that is subject to an AUL is not registered land, and that the AUL is recorded with the relevant Registry of Deeds. See MassDEP's *Guidance on Implementing Activity and Use Limitations,* – Policy #WSC24-300, for more information about registered land.

Significant Risk" is used for the purpose of readability throughout this guidance to refer to the disposal site cleanup standard related to the implementation on an AUL.

An AUL serves several purposes (310 CMR 40.1012(1)). First, an AUL provides property owners, other interest holders in the property and others who review property records at the Registry of Deeds with notice of the presence and location of contamination remaining at the disposal site. In addition to identifying the site uses and activities that are *consistent and inconsistent* with *maintaining a Permanent Solution and a condition of No Significant Risk,* the AUL establishes the property owner's obligations that ensure that the objectives of the AUL continue to be met (e.g., maintaining caps or other barriers, monitoring the areas subject to the AUL), including a duty to evaluate any proposed changes to site activities and uses within the AUL area prior to such changes occurring (310 CMR 40.1080).

An AUL may apply to an entire property, multiple properties, or to some portion of a property, and therefore may apply to an entire site, multiple sites or a portion of a site. AULs may be used to eliminate site uses and/or activities and entire exposure pathways which would otherwise need to be considered in the evaluation of future site use.

The most common application of an AUL would be to limit the site uses and activities to those which are currently occurring. Remediation goals which would achieve a level of No Significant Risk for the current site use would then be acceptable for the foreseeable future. When foreseeable exposures are excluded from a risk assessment because of an AUL, documentation and description of the AUL is a fundamental component of the risk assessment. In such cases the risk assessment is only valid when an adequate and appropriate AUL is in place (i.e., recorded or registered with the Registry of Deeds).

An AUL must be used anytime the risk characterization assumes that some site uses or activities would be inconsistent with maintaining a level of No Significant risk. Conversely, an AUL is not necessary when No Significant Risk has been demonstrated for unrestricted site use.

3.3.1 Roles and Responsibilities:

The property owner is generally the only individual who can limit site activities and uses through the use of an AUL. In addition, MassDEP may impose an "Environmental Restriction" at disposal sites where it has conducted response actions or at sites where the property owner fails to record an AUL (see 310 CMR 40.1073).

Although a property owner is responsible for placing an AUL on the site, the decision to use an AUL should be made in consultation with the Licensed Site Professional (LSP), the risk assessor and the owner's attorney, all of whom can help evaluate the costs and benefits of using this tool as opposed to engaging in additional site remediation.

3.3.2 AUL Contents

The contents of the AUL are specified in 310 CMR 40.1074(2) of the MCP. In 40.1074(2)(h) through (j) and 40.1074(2)(l), the regulations describe the risk-related information contained in an AUL, including a description of the site activities and uses that are consistent and inconsistent with a condition of No Significant Risk on the property, and the obligations and conditions necessary to maintain a level of No Significant Risk. The AUL must specify the portion of the disposal site subject to the activity use restrictions.

3.3.3 Referencing the AUL in the Risk Assessment

The results of the risk assessment are based upon the exposure assumptions used. The exposure assumptions in turn are based upon the current and foreseeable uses of the site. The conclusions of the risk assessment must therefore discuss all limitations in detail. When an AUL is placed on the disposal site, the risk assessment is only valid and applicable in conjunction with the AUL.

3.3.4 When an AUL is required

Except as otherwise provided in 310 CMR 40.1012(3) and 40.1013, Activity and Use Limitations shall be required in the following circumstance:

- At all disposal sites or portions of disposal sites for which the risk characterization used to support the Permanent Solution is based upon the restriction or limitation of Site Activities and Uses to achieve or maintain a level of No Significant Risk, including:
    - Any disposal site or portion of a disposal site for which a Permanent Solution is based on MCP Method 1 or 2 Soil Standards and the Exposure Point Concentrations of OHM exceed the S-1 standards but meet applicable S-2 or S-3 standards;
    - Any disposal site or portion of a disposal site where a Method 3 Risk Characterization performed pursuant to 310 CMR 40.0990 relies on reduced exposure potential due to the assumption of limited site use;
    - Any disposal site or portion of a disposal site at which the OHM in soil located at a depth greater than fifteen feet from the ground surface exceeds an applicable Method 3 Ceiling Limits in Soil listed at 310 CMR 40.0996(6) or determined at 310 CMR 40.0996(7); and
    - Any disposal site or portion of a disposal site where visible coal tar deposits are located at a depth greater than 15 feet from the ground surface or are located beneath an Engineered Barrier pursuant to 310 CMR 40.0997(3).

- at all disposal sites for which a Permanent Solution relies upon an Exposure Pathway Mitigation Measure to prevent exposure to levels of OHM that would otherwise pose a significant risk of harm to health, safety, public welfare or the environment, including:
    1. one or more Passive Exposure Pathway Mitigation Measures; or
    2. one or more Active Exposure Pathway Mitigation Measures implemented pursuant to the requirements at 310 CMR 40.1025;

- at all disposal sites where an existing private water supply well(s) is removed from service as a source of drinking water and maintained for uses other than as a private water supply in accordance with the provisions of 310 CMR 40.0932(5)(d);

- at disposal sites for which a Permanent Solution is achieved and NAPL with Micro-scale Mobility is present; and

- at disposal sites that are not licensed by the Massachusetts Department of Public Health pursuant to 310 CMR 40.0115 where a Permanent Solution or Temporary Solution is achieved and Radioactive Material emitting Radiation above background level is present.

3.3.5 When an AUL is Not Required, but May Be Used

The MCP (310 CMR 40.1012(3) and 310 CMR 40.1013)) describes several situations where an AUL is not required but may be implemented to provide notice to future interest holders of residual contamination left at the site. Every AUL implemented in conjunction with work done under the MCP, even if not specifically

required by the MCP, must still comply with procedures established in 310 CMR 40.1070 through 310 CMR 40.1099. Examples of scenarios where an AUL may be used are described in section 3.3.5.1 and section 3.3.5.2, below.

3.3.5.1 Sites with Permanent Solution with No Conditions, Temporary Solution or Remedy Operation Status at which an AUL may be used [310 CMR 40.1012(3)(a)-(j)]

Situations where an AUL is not required but may be used to provide notice of residual contamination include:

- Disposal sites or portions of disposal sites where the concentrations of OHM have been reduced to natural background as defined at 310 CMR 40.0006, or where the requirements described in 310 CMR 40.0923(3)(b) have been met;

- Soil that is located at a depth greater than 15 feet from the ground surface in which residual contamination levels are equal to or below the applicable Method 3 Ceiling Limits for soil listed or determined in 310 CMR 40.0996.

- Disposal sites or portions of a disposal site for which Method 1 or Method 2 has been used to characterize risk and levels of OHM in soil are (or have been reduced to) below the applicable category S-1 soil standards listed in 310 CMR 40.0975(6);

- Disposal sites or portions of a disposal site for which Method 3 has been used to characterize risk and levels of OHM in soil pose No Significant Risk pursuant to 310 CMR 40.0990, including comparison to any applicable or suitably analogous standards, and no limitations on site use were assumed or implied in the Risk Characterization;

- Except as provided at 310 CMR 40.1012(2)(e), any disposal site or portion of a disposal site where all substantial hazards have been eliminated and where all applicable requirements for a Temporary Solution have been met pursuant to 310 CMR 40.1050;

- Any disposal site or portion of a disposal site where all substantial hazards have been eliminated and where all applicable requirements for Remedy Operation Status have been met pursuant to 310 CMR 40.0893;

- Any other disposal site or portion of a disposal site where an Activity and Use Limitation is not expressly prohibited by 310 CMR 40.1012(4);

3.3.5.2 Sites with Permanent Solution with Conditions that do not require an AUL [310 CMR 40.1013]

Except where otherwise required pursuant to 310 CMR 40.1012(2), an AUL is not required but may be used where a Permanent Solution with Conditions is based on one or more of the limitations, assumptions, or conditions at the site that are specified at 310 CMR 40.1013 and described below.

Residential Gardening [310 CMR 40.1013(1)(a)]

An AUL is not required but may be used to address residential gardening exposures in situations where the Risk Characterization demonstrates No Significant Risk for residential direct contact exposures to site soils. If No Significant Risk is demonstrated via Method 3 Risk Characterization,

Best Management Practices are recommended for non-commercial gardening in a residential setting to minimize and control potential risk, pursuant to 310 CMR 40.0923(3)(c). Best Management Practices recommendations are not required if No Significant Risk is demonstrated using a Method 1 Risk Characterization. More information on the use of Best Management Practices at disposal sites is available in Best Management Practices ("BMPs") for Non-Commercial Gardening at Disposal Sites, #WSC-14-910.

Anthropogenic Background [310 CMR 40.1013(1)(b)]

An AUL is not required but may be used to address residual contamination that meets the definition of Anthropogenic Background, in accordance with 310 CMR 40.0006. The MCP defines Anthropogenic Background as the level of OHM resulting from any of the following sources that would exist in the absence of the disposal site:

- atmospheric depositions of industrial process or engine emissions;
- Historic Fill, as defined at 310 CMR 40.0006;
- coal, coal ash, or wood ash, excluding ash landfills or wood ash resulting from combustion of lumber or wood products that have been treated with chemical preservatives;
- sources specifically exempt from the definition of disposal site or release;
- groundwater releases from a public water supply system; or
- petroleum residues incidental to normal operation of motor vehicles.

Public Ways or Rail Rights-of-Way [310 CMR 40.1013(1)(c)]

AULs are not required for areas within a public way or rail right-of-way, as those terms are defined at 310 CMR 40.0006(12). The reasons for not requiring AULs in these areas include the limited potential for future exposure to or excavation into contamination in these locations and the public oversight in place to maintain them. Note, while public ways and rail rights-of-way do not require AULs, all other cleanup requirements in these areas must be met. Further, the AUL exception for a public way or rail right-of-way is limited to publicly-owned lands within the transit corridor (e.g., road, highway, sidewalk, tree belt); it does not extend to ancillary land contiguous with the public way or rail right-of-way, such as garages or other maintenance facilities associated with the transit corridor, but not located within it.

GW-2 standards exceeded at the site with no occupied building [310 CMR 40.1013(1)(d)]

When OHM levels in groundwater exceed GW-2 standards at a disposal site that is not currently categorized as GW-2 (i.e., there are no occupied buildings on the property), the MCP does not require an AUL be implemented to address the potential for vapor intrusion if a building were constructed at the property in the future [see 310 CMR 40.1013(1)(d)]. However, an AUL may be used to provide future owners or developers with notice of the potential risks associated with site development and to establish limitations on site activities and uses related to the potential for vapor intrusion or conditions for the construction of future buildings to ensure that the plans incorporate measures that prevent vapor intrusion.

An AUL in such cases may be used to specify measures to be taken at the time of building construction to prevent vapor intrusion impacts. Such measures may include the installation of vapor barrier, SSD system, passive venting system, subsurface parking facility or limiting construction to locations outside of areas with groundwater VOC contamination.

More information related to AULs implemented to address vapor intrusion at future buildings can be

found in the Vapor Intrusion Guidance, #WSC-16-435.

3.3.6 When an AUL May Not be Used

Per 310 CMR 40.1012(4) Activity and Use Limitations may not be used:

- to change the groundwater category of groundwater categorized as GW-1 or GW-2 pursuant to 310 CMR 40.0932; or
- to justify a conclusion that a condition of No Significant Risk exists or has been achieved at sites characterized using Method 1 or Method 2 if an identified Exposure Point Concentration exceeds an applicable Method 1 or Method 2 standard.

3.3.7 AULs and Specific Environmental Media

The media in which contamination is present often determines the routes and likelihood of exposure, and thus there are several media-specific considerations for AULs. The MCP risk characterization process further requires that some media be categorized based on the likely receptors at the site (e.g., whether children might be using a site intensely and playing in soil). Medium-specific exposure assumptions are described in more detail below.

3.3.7.1 AULs and Soil Contamination

Under the MCP, soils are placed into one of three categories based on site activities and uses and the associated potential for exposure: S-1, S-2, and S-3. Regardless of the risk characterization method used, site soils must be categorized to evaluate exposure. The need for an AUL depends largely upon the soil category at the site or portion of a site.

Soil Category S-1

The Soil Category S-1 applies to land used for residential or active recreational purposes such as playgrounds where frequent and intense direct contact exposures are likely. A risk assessment for a site or portion of a site where soil is categorized as Method 1 must consider a receptor who comes into contact with contaminated soil while playing or gardening, activities that involve the highest frequency and intensity of soil contact considered under the MCP. Soil that is clean enough to support these activities is considered suitable for unrestricted use. Regardless of whether a Method 1, 2 or 3 risk assessment is used, the risk assessment for an S-1 area cannot assume limited exposures. Consequently, AULs are not applicable.

Soil Category S-2

The Soil Category S-2 includes land used for commercial and passive recreational uses, where a person could come into contact with contaminated soil in a work environment or during passive recreational activities such as walking, bird watching, or picnicking. These activities involve less frequent and less intense soil contact than the activities considered in S-1 areas. Soil category S-2 may also apply to certain residential developments with large multi-family dwellings and little or no potential for soils exposure on the property. Risk assessment in S-2 areas assume exposures that are limited in comparison to exposures in S-1 areas. Unless the soil concentrations remaining in an S-2 area after a Permanent Solution is achieved would not pose a risk for S-1 activities and uses, an AUL is required to ensure that the property use is not changed without reevaluating the risk and managing it appropriately.

Soil Category S-3

The Soil Category S-3 is based upon a person coming into contact with contaminated soil during a short but intense exposure, such as excavation work. The exposures considered in the Method 1 or Method 2 S-3 standards are incidental ingestion and dermal contact with contaminated soil during the warmer months as would be experienced in construction work. When conducting a Method 1 or 2 risk characterization at a site where S-3 standards are applicable, the disposal site exposure point concentrations (EPCs) are compared to those standards. Whenever the EPCs are equal to or less than the applicable S-3 standards, but exceed the S-1 standards, either remediation or an AUL is required. This is because like S-2, the S-3 soil category assumes limitations on receptor exposure.

3.3.7.2 AULs and Groundwater

The application of AULs to groundwater is somewhat restricted. A groundwater aquifer is a resource of the Commonwealth and therefore its foreseeable use is determined by the Commonwealth and not by the individual property owner. The determination of whether or not the groundwater is a current or potential source of drinking water (GW-1) is made in accordance with the criteria listed in 310 CMR 40.0932(4).

The only situation in which groundwater that has been classified as GW-1 and may be subjected to an AUL is when the groundwater is classified as GW-1 solely on the basis of the presence of private drinking water wells within 500 feet of the site (310 CMR 40.0932(5)(d)). In such a case, an AUL is specifically required for groundwater, as described in 310 CMR 40.0932(5)(d), to provide notice that an existing private water supply well is not suitable for future use as a potential drinking water supply. The Notice of AUL required in this case may only be used after the property supplied by the well is tied into a public drinking water supply. The groundwater, as a result, can be eliminated from consideration as a current drinking water source area, as detailed in 310 CMR 40.0932(5)(d). Provided these requirements are met, the well may be maintained for non-potable uses as long as those uses meet a level of No Significant Risk. Note that it is not the AUL that eliminates the GW-1 category, but the act of connecting the relevant property into a public water supply.

AULs are not required to prevent installation of future private drinking water wells in areas where groundwater exceeds the GW-1 standards. In the case of new private water supply wells, local Boards of Health have the authority to ensure that such supplies are potable and are not installed in or drawing upon contaminated groundwater. The MCP does not provide a separate regulatory check on potential exposure to groundwater contamination via new private water supply wells.

As is the case for soil, an AUL may not be used to change the category of groundwater categorized as GW-1 or GW-2, and may not be used to justify a conclusion that a condition of No Significant Risk exists at sites characterized using Method 1 or 2 if an identified EPC exceeds applicable standards (310 CMR 40.1012(4)(1)).

The limited application of AULs to groundwater rests on several considerations. Because contamination in groundwater migrates over time, providing an accurate description of the affected area of groundwater as part of an AUL is problematic because the boundaries can be expected to change. Further, because groundwater migration does not respect property boundaries, AULs for groundwater in many cases would entail the need for an AUL for each of the affected properties to restrict access and exposure to contamination in groundwater; implementing multiple AULs in such cases would be complex, difficult, and often impractical. The installation of new public and private drinking water supply wells is otherwise regulated on the state and local level to ensure that such wells provide safe drinking water. An AUL to prohibit well installation at a property without an existing water supply well is therefore deemed duplicative.

More fundamentally, the MCP embodies the assumption that areas that are categorized GW-1 must be cleaned up to drinking water standards to achieve a condition of No Significant Risk and a Permanent Solution. This represents a policy decision to safeguard the drinking water resources of the Commonwealth, and to prevent the use of AULs as a means by which persons performing response actions may permanently to eliminate such resources.

3.3.7.3 AULs and Indoor Air

AULs may be necessary to ensure the maintenance of Exposure Pathway Mitigation Measures that are installed and maintained to prevent exposure to the volatilization of OHM in the subsurface environment into the indoor air of a building [see 310 CMR 40.1012(2)(b)]. These measures include Passive Exposure Pathway Mitigation Measures, such as subslab venting systems and vapor barriers, and Active Exposure Pathway Mitigation Measures, such as subslab depressurization systems. In such instances, the AUL ensures that the system will remain in place, in good repair and operating in a manner so that it continues to function effectively in preventing exposure. See the Vapor Intrusion Guidance, #WSC-16-435 for guidance on implementing AULs when Exposure Pathway Mitigation Measures are relied up on to maintain a Permanent Solution and 310 CMR 40.1025 for the requirements applicable to Active Exposure Pathway Mitigation Measures implemented to support of a Permanent Solution.

More information related to AULs implemented to address vapor intrusion at future buildings can be found in the Vapor Intrusion Guidance, #WSC-16-435.

3.3.7.4 AULs and Sediment

AULs are used infrequently at sites where sediments have been contaminated. This is because sediment is an essential medium for ecological receptors, and an AUL cannot be used effectively to limit ecological exposure. Additionally, where public access rights exist to shores of a water body, exposures associated with that access must be evaluated under the current use scenario. For example, a river must be cleaned up to protect activities that are authorized by federal and Commonwealth statutes, such as navigation, swimming and fishing, including M.G.L. c. 91. An owner of land adjacent to a surface water body cannot use an AUL to restrict access to contaminated sediment if people could be exposed to it while exercising public rights such as navigation, swimming and fishing. As with any AUL, access can only be restricted by the property owner to the extent the property owner otherwise has that right; the property owner may not use an AUL to eliminate public rights.

In limited cases, an AUL may be appropriate for sites where a sediment cap is part of an implemented remedy. An AUL may be used to document the presence of the sediment cap, require that the cap remain in place, and specify obligations for the monitoring and maintenance of the cap. The AUL cannot, in such cases, restrict access. The appropriateness of an AUL for a sediment cap would be dependent upon site-specific conditions, including factors such as ownership of the sediments, other state permit requirements, access rights, and the responsible party's continued ability to monitor and maintain the cap.

Chapter 4
Sampling for Risk

4.0 Sampling for Risk Assessment

4.1 Introduction

Characterizing the nature and extent of contamination is a fundamental requirement for Comprehensive Site Assessment, as set forth in the Massachusetts Contingency Plan (MCP) at 310 CMR 40.0835(4)(e) and (f). The MCP definition of the word "site" includes "any place or area where oil or hazardous material has come to be located" (310 CMR 40.0006). The types and concentrations of contaminants at a site and the vertical and horizontal extent of contamination must be determined in order to complete the Comprehensive Site Assessment. The Comprehensive Site Assessment should include a map that depicts the boundaries of the disposal site in plain view, inclusive of areas where contamination has come to be located.

The MCP requires parties performing response actions, including sampling, to meet a general performance standard, referred to as the *Response Action Performance Standard* (RAPS) The MCP states that the Response Action Performance Standard is "the level of diligence reasonably necessary to obtain the quantity and quality of information adequate to assess a site and evaluate remedial action alternatives, and to design and implement specific remedial actions at a disposal site to achieve a level of No Significant Risk..." (310 CMR 40.0191(1)). The site investigation processes will vary from site to site, but in all cases the data must be sufficient to complete a Comprehensive Site Assessment and to reach a defensible conclusion about the risk of harm to human health and the environment.

This Chapter focuses on planning the sampling and analysis activities necessary to support a risk assessment. It covers decisions about the number, locations and types of samples needed to characterize exposure and risk. Guidance on the execution of sampling projects, including selecting appropriate sampling equipment and employing proper techniques, is provided in a number of U.S. EPA publications and is beyond the scope of this document. A more detailed discussion of sampling considerations related to Exposure Points and estimating Exposure Point Concentrations is provided in Chapter 11.

Ideally, the risk assessor will be involved in the development of the site sampling plan and will have significant input on where and when to collect samples to determine the nature and extent of contamination for the site risk characterization. There will, however, be situations where the site data have already been collected, in which case, the risk assessor should review this information and discuss its adequacy with the site or project manager and recommend additional data collection if necessary. The risk assessor must have confidence that the data collected are representative of the site and the site background conditions if this information is to be meaningfully used in the risk characterization process.

A comprehensive site assessment forms the foundation of a risk assessment and calls for a thoughtful and rigorous approach to sampling and analyzing contaminated media. As noted in the Conceptual Site Model (CSM) discussion in Chapter 2, human health and environmental exposure pathways begin with contamination in soil, groundwater, sediment and/or surface water, so the full scope of the risk assessment can be established only after the nature and extent of contamination have been characterized. Describing the nature and extent of contamination requires answering several basic questions:

- **What** contaminants have been released or deposited at or from the site?
- **Where** have those contaminants come to be located?
- **How much** contamination is present, and how do the concentrations vary?

Only after these questions have been answered can the risk assessor identify the transport pathways through which human and ecological receptors might come into contact with contaminants. For example:

- Volatile Organic Compounds (VOCs) can migrate in groundwater, in some cases for a long distance, resulting in drinking water and/or indoor air exposures at locations distant from the source.
- VOCs near the groundwater surface can contribute to vapor intrusion.
- PFAS are present in many common products and are highly persistent in the environment, leading to pervasive contamination well beyond sites where PFAS were directly manufactured or used.
- Soil contamination that extends or drifts as airborne particles from a source property onto a school or residential yard could be available for children to be exposed.
- Sediment contaminants in rivers and streams can be carried downstream, in some cases for miles, where human or ecological receptors can come into contact with contaminants.

As detailed in Chapter 2, the CSM describes contaminant transport pathways from sources to human and environmental receptors, thus drawing the connections between site contaminant conditions and the risk assessment. The CSM should be updated on a continuing basis as site conditions change or new information is discovered.

Site boundaries are not frozen in time; a site may expand after initial delineation due to contaminant transport. Identifying or estimating where contaminants may come to be located in the future is a basic component of the risk assessment.

4.2 Sampling Project Plans

Ideally, before collecting samples for waste site risk characterization, a detailed plan should be developed. This step will ensure that the sampling project will produce valid and reliable data and that the assessment goals will be met. Implementation of a thorough sampling plan and selection of appropriate analytical methods are both essential for site characterization that is adequate for risk assessment purposes.

To ensure that site sampling efforts provide adequate data for the risk assessment, the sampling and analysis plan should be developed in consultation with the risk assessor. Analytical data is collected during the site investigation to fully characterize the nature, extent, severity, and horizontal and vertical distribution of the oil and hazardous materials at the disposal site. Some or all of the data obtained may be used for the risk assessment. The data obtained or selected for the risk assessment must be representative of actual and foreseeable exposures, and they

must be compatible with the dose response value that will be used in the assessment.

MassDEP has not set general sampling plan requirements because the waste site cleanup program in Massachusetts is a semi-privatized system, and sampling plans are not routinely reviewed by the Bureau of Waste Site Cleanup prior to the execution of sampling projects. However, the absence of a requirement to submit plans in no way eliminates the necessity and value of methodical planning. Sampling data from a site without consideration for how that data will be used may result in a need for additional sampling in the future and additional costs for site characterization.

Over the past several decades U.S. EPA has published numerous guidance documents for comprehensive and systematic project planning oriented toward meeting specified objectives. These include Sampling and Analysis Plans (U.S. EPA, 2014), Quality Assurance Project Plans (U.S. EPA 2002a), Data Quality Objectives Process (U.S. EPA, 2006), and Field Sampling Plans (U.S. EPA, 1995a, 2020). The U.S. EPA guidance contains valuable information on planning and implementing logical, efficient and effective projects. Even though detailed plans for MCP site assessment work are not formally submitted to the Department, the investigators are advised to become familiar with U.S. EPA's recommended principles and practices, and to adopt them for use at specific MCP sites as appropriate.

Note: Although detailed sampling plans are not required submittals for all sites, general plans are required at two points in the MCP process:

- **Tier Classification** submittals must include:
  . . . .a conceptual Phase II Scope of Work that, at a minimum, includes:
  1. a general plan for assessing contaminants of concern, potential receptors and potential exposure pathways, identifying the likely technical approach(es) to be used... (310 CMR 40.0510(2)(f)1.).

- **Phase II Comprehensive Site Assessment** submittals include:
  (1) A Scope of Work, as described in 310 CMR 40.0834, shall be developed and submitted to the Department in accordance with 310 CMR 40.0510 prior to the initiation of Comprehensive Site Assessment activities at any disposal site that has been classified as Tier I or Tier II under the provisions of 310 CMR 40.0500, unless the Phase II fieldwork has been implemented prior to Tier Classification (310 CMR 40.0832(1)).

This Chapter describes some key decision points and sampling project components that control (or limit) data representativeness and useability and must be considered when planning a sampling project. It is MassDEP's expectation that the decisions described in this chapter will be documented, as applicable, in site assessment reports submitted to the Department.

4.2.1 Sampling Objectives

The objectives of the sampling should be considered in the sampling plan and discussed in the subsequent site investigation report(s). This Chapter covers sampling approaches and methods as well as collecting data needed for estimating Exposure Point Concentrations (EPCs) for a risk assessment. Additional details on collecting data for EPCs and risk assessments are covered in Chapter 11 (Method 3 Risk Characterization). Sampling to achieve other objectives may require

additional information not addressed in this guidance (e.g., performing a Comprehensive Site Assessment).

To highlight the importance of fitting a sampling plan to a specific purpose, brief descriptions of different objectives follow.

- **Conducting exploratory sampling to identify the source, nature and possible extent of contamination**
  In the initial phase of site assessment, when very little information on contaminant levels and distribution is available, a preliminary sampling effort may be necessary to begin characterizing the nature and extent of contaminants across the site. Data from preliminary sampling can provide an initial picture of contaminant sources, identify contaminants of concern, indicate where exposures may occur, detect the possible presence of hotspots, and guide further sampling efforts (including sampling approaches).

- **Defining the extent and distribution of site-related contamination**
  Because the MCP defines a disposal site as a location "where uncontrolled OHM has come to be located"; the vertical and lateral limits of contamination define the site. The determination of where contamination is present and absent (delineating the extent of contamination) is a basic component of the exposure assessment. The validity of the risk assessment depends in part upon correctly identifying and delineating the extent of the contamination. It is important to note that property boundaries are not physical impediments to migration of OHM and therefore do not delineate the extent of contamination.

- **Evaluating Background Conditions**
  Determining the nature and extent of contamination often requires characterization of background conditions (310 CMR 40.0835(4)(f)) and an effort to delineate the area of the site where concentrations are elevated above background levels. Where concentrations of site-related contaminants are indistinguishable from background levels, those areas need not be included in the risk assessment (310 CMR 40.0902(3)). Guidance on evaluating background and local conditions is provided in Chapter 6.

- **Delineating Hot Spots**
  Defining the distribution of contaminants may also include delineating sub-areas or "Hot Spots" where people might be exposed to concentrations averaging 10 to 100 times higher than the concentrations in surrounding area. See Section 4.8 for details.

- **Trend analysis**
  Trend analysis is the evaluation of directional concentration changes over time or space. Examples include, but are not limited to, characterizing the decrease in groundwater concentrations with distance from a source and evaluating the decrease in indoor air concentrations after remediation. Trend analysis requires sufficient sampling frequency and/or density to distinguish a real trend from the underlying spatial and/or temporal variation in concentrations.

- **Identifying the site-related contaminants to which people might be exposed** (Contaminants of Concern)
  This objective may require chemical analysis for both: (a) the broad suites of substances (for example, those listed as target analytes for a standard U.S. EPA method) and (b) specific OHM indicated by site history information. In many cases, identifying site-related contaminants will also involve comparing the concentrations of chemicals detected at the site to concentrations at a background location (Chapter 6), and eliminating those that are consistent with background from further consideration as contaminants of concern.

- **Estimating Exposure Point Concentrations for human and ecological receptors**
  For MCP risk assessments, a conservative estimate of the mean concentration of contamination within a human or ecological Exposure Point (area) is used to estimate the EPC. Representative sampling is needed for a reliable estimate of the arithmetic mean. See Section 4.2.5 for a discussion of representative sampling.

- **Preliminary assessment of concentration variability**
  Data variability at an Exposure Point can be used to determine the size of the data set needed for reliable estimates of the arithmetic mean. This will require some preliminary data collection (e.g., a pilot study) to discern the variability of the media being sampled. Highly variable concentrations call for larger data sets. An early assessment of data needs can support efficient sampling efforts and can ultimately lead to more reliable EPC estimates.

- **Delineating areas that must be remediated to achieve a condition of "No Significant Risk"**
  Areas where contaminant levels are above concentrations associated with "No Significant Risk" must be remediated. Identifying these areas requires data sets that are sufficient to (a) provide reliable estimates of mean concentrations and (b) distinguish variation prevalent throughout the site from significant differences between areas that require remediation and those identified as posing "No Significant Risk." For example, soil concentrations can vary widely within very short differences (on the order of one foot), so removal strategies and confirmatory sampling must take this variability into account. Concentrations detected in a discrete sample from a cell in a soil or sediment sampling grid may not be a reliable representation of the levels present throughout that grid cell.

- **Conducting confirmatory sampling to evaluate remedy effectiveness**
  Situations that call for re-sampling after remediation include evaluating residual levels of contamination remaining after soil or sediment removal from a site or portion of a site and checking for groundwater "re-bound" following in-situ treatment operations. Each situation calls for a different kind of sampling plan as well as a different approach to data collection and analysis:

  - For road spills and tank pulls where the lateral and vertical extent of the release is known from field screening and historical knowledge to be limited, confirmatory sampling at the periphery of the removal may suffice in many cases.

  - In contrast, re-sampling after surface soil or sediment removal from a portion of a site requires ascertaining that the final EPC(s) throughout the Exposure Point (or area) have been reduced and no longer pose a significant risk. This may involve comparing final concentrations within the removal area to risk-based standards or to background levels. In the latter case the data sets should be similar in size and must be generated from the same type of sampling design (i.e., discrete, composite, or incremental sampling – See Section 4.2.3). In both cases, a pre-remedial baseline data set is essential to delineate the extent of contamination for removal. A robust baseline data set is a worthwhile investment, as it cannot be improved upon after remedial activities have begun.

Estimating EPCs is commonly thought of as the decision point that relates site investigation activities to the risk assessment. In principle it is no more important than determining the presence or absence, or delineating the extent of contamination. Nevertheless, the data quality requirements for estimating EPCs are generally more stringent than for some of the other site assessment decisions.

Often, the data needs of the risk assessment are overlooked in the early stages of the site investigation process. As a consequence, site sampling efforts often do not produce sufficient data to adequately characterize exposures at a disposal site. The sampling plan should ensure the collection of data which can adequately characterize exposures at the disposal site. To that end, potential Exposure Points and the activity patterns of potential receptors at the site in question should be identified when the sampling plan is being developed for current and potential future exposure. If exposure patterns are considered only after sampling has been completed, the data collected may not provide sufficiently accurate or representative EPC estimates, and further sampling may be needed. Ideally, the risk assessor's involvement in a project should begin with the sampling plan development stage. If not, the risk assessor must retrospectively evaluate the representativeness of the samples for exposure assessment purposes. This may add time, cost, and complexity to the risk characterization process.

4.2.2 Sampling Approach

Throughout this guidance document, the term "sampling approach" refers to the way specific sampling locations are selected. The sampling approach determines the spatial pattern of sampling locations. The optimum sampling approach at a site or portion of a site depends upon the sampling objective (See Section 4.2.1) and the existing information on the nature, extent and distribution of contamination in the area(s) to be sampled. Examples of sampling approaches that have been used to estimate exposure point concentrations follow:

- ***Judgmental Sampling***

  In judgmental sampling (sometimes referred to as biased sampling), sample locations are selected based on professional judgment and knowledge of the site (or release) history (U.S. EPA, 2002b). In some cases, observational evidence such as soil staining may also be considered. Typically, when judgmental sampling is used for MCP assessments, samples are collected from locations known to be most contaminated to ensure conservative exposure estimates. In general, this type of sampling is appropriate only for situations where the contamination is known to be limited to a defined area, for example, for verifying the removal of contamination after road spills or tank leaks or for delineating hotspots. Judgmental sampling is referenced generally in 310 CMR 40.0903(1)(c), as well as in the context of soil and sediment sampling at 310 CMR 40.0904(4) and 310 CMR 40.0904(5), respectively.

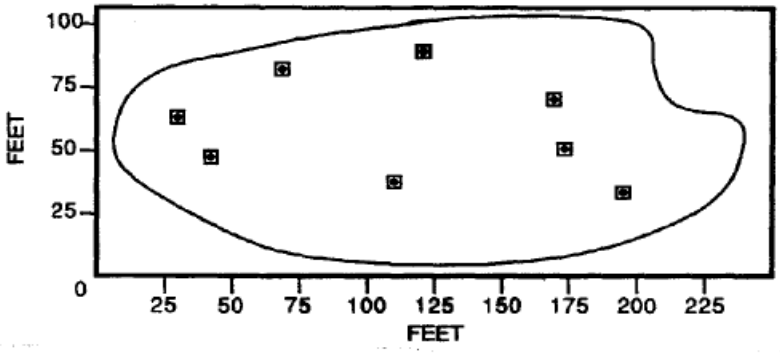
  Because data collected using judgmental sampling are inherently biased, certain statistical analyses or inferences, such as calculating an upper confidence limit of the mean, are not appropriate for judgmental data.

- ***Simple Random Sampling***

  In theory, random sampling is ideal for statistical analysis because it guards against bias. Some references contend that samples should always be collected randomly to avoid bias,

particularly when statistical analysis of the data is anticipated. However, randomly selected sampling locations may not always provide adequate coverage throughout the Exposure Point (Figure 4.1), and so this approach generally requires a larger data set than systematic sampling. To achieve a given level of precision, random sampling generally requires a larger number of discrete samples than other approaches (U.S. EPA, 2002a, 2002b). For this reason, random sampling is not recommended for MCP risk assessment purposes and is not mentioned in the MCP.

Figure 4.1 – Simple Random Sampling

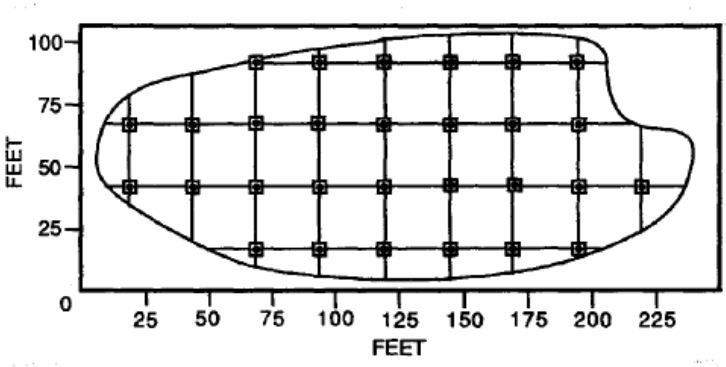


(U.S. EPA, 1991)

- ***Systematic Grid Sampling***

Under this approach, a sampling grid is laid out over the area of concern, or Exposure Point, and discrete samples are collected from the grid nodes or from consistent locations within the grid cells (Figure 4.2). In other words, samples are collected at regularly spaced intervals (U.S. EPA, 2002b). This provides even coverage throughout the Exposure Point (exposure area). The spacing of sampling locations depends on the size of the target area and the number of samples to be collected. Each discrete sample is analyzed individually, and results from all cells combined are used to calculate an estimate of the mean concentration for the area. Systematic grid sampling may be useful in the exploratory stage of the site assessment as well as for estimating EPCs.

Figure 4.2 – Systematic Grid Sampling



(U.S. EPA 1991)

"Systematic sampling is used to ensure that the target [area] is fully and uniformly represented in the set of n samples collected." (U.S. EPA, 2002b)

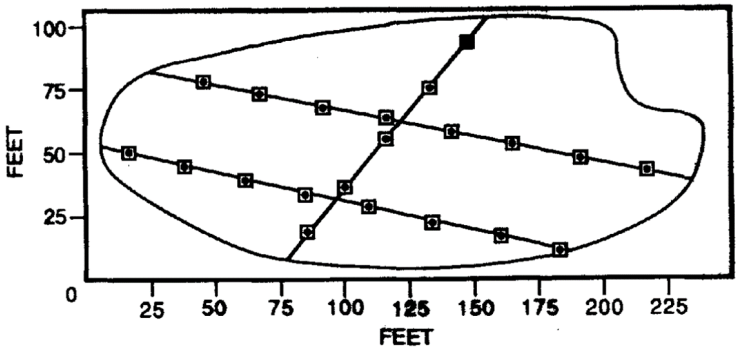
The more samples collected, the more representative the data set, and the less likely that there will be large sampling errors. If nothing is known about the spatial characteristics of the target area, grid sampling is efficient in finding patterns, assuming the patterns occur at the scale of the grid spacing (U.S. EPA, 2002a). Sample sizes needed for a reliable estimate of the mean are discussed in Section 4.3.2.1. As applied to sediments, 310 CMR 40.0904(5) refers explicitly to both systematic grid sampling and systematic transect sampling, which is discussed below.

"Samples taken at regular intervals, such as at every node of an area defined by a grid, are useful when the goal is to… identify a pattern."

- ***Transect Sampling***

In transect sampling, samples are collected along a line across the area of concern (Figure 4.3). Transect sampling is often used to delineate the extent of contamination or to define a concentration gradient in a specific direction (U.S. EPA, 1995a). Depending upon the sampling objective and what is known about contaminant distribution, sample locations may be laid out along a single transect line or multiple parallel transect lines. The MCP references transect sampling in connection with sediments (310 CMR 40.0904(5)) and is described in more detail in Section 4.4.

Figure 4.3 – Transect Sampling



(U.S. EPA 1991)

Whatever sampling approaches are employed, clear and consistent documentation is required to demonstrate that the data are adequately representative and defensible for the intended use

with reference to relevant MCP provisions, including 310 CMR 40.0904. Data for risk characterization must provide a conservative estimate of the mean concentration at the Exposure Point. In all cases, the number and locations of samples should be clearly depicted on site-plan figures, documented in text, and listed in corresponding tables.

4.2.3 Sampling Methods

Throughout this guidance document, the term "sampling method" refers to the specific way in which samples are collected. Three sampling methods are commonly employed at waste sites: discrete sampling, composite sampling, and incremental sampling.

- ***Discrete Samples***
  A discrete sample is an individual grab sample taken from a single sampling point. In contrast to the other two methods, discrete samples can be used to characterize variability of contaminant concentrations in the media of interest.

- ***Composite Samples***
  A composite sample is composed of more than one discrete sample taken from different sampling points
  and physically combined to form a single sample to be submitted to a laboratory for analysis. Compositing reduces the number of chemical analyses needed to characterize the area(s) being sampled and can be more cost effective when each analysis is expensive. Information on variability among sampling points is sacrificed when samples are composited. For soil sampling, U.S. EPA has recommended using from four to six samples per composite, stating that composites with more than six samples could be difficult to homogenize (U.S. EPA, 1996).

- ***Incremental Samples***
  An incremental sample is a structured kind of composite sample most often used to provide a representative sample of a specific volume of soil. Each incremental sample is composed of thirty or more individual samples (increments) collected using a particular technique from a systematic sampling grid and then combined. They are collected and processed in a very specific way with specialized equipment. This sampling procedure has been developed to maximize representativeness and minimize sampling error.

The applicability and limitations of different sampling methods are discussed in more detail in the media-specific sampling sections of this chapter (4.3 – 4.9).

4.2.4 Sampling Depth – General Considerations

Sampling depth is relevant to two separate MCP requirements: (1) Determining the nature and extent (horizontal and vertical) of contamination at the site; and (2) assessing exposure. Samples collected for one of these purposes often will not suffice for the other, so both need to be addressed in the project planning stage. This guidance document will focus on sampling at depth to evaluate exposure for human and ecological receptors. Because the optimum sampling depth differs among various environmental receptors, exposures, and habitats, the depth question will be addressed separately in the subsections on soil, sediment, and surface water (Sections 4.3, 4.4, and 4.5).

4.2.5 Representative Sampling for Exposure Point Concentrations

The representativeness of a data set is the degree to which it accurately and precisely represents the concentrations within the Exposure Point (exposure area). From a risk analysis perspective, the representativeness determines whether a data set provides a reliable basis for estimating EPCs. Analytical results from representative samples capture the variation in pollutant presence and concentrations throughout a site or a specific exposure area (Exposure Point).

As previously noted, the representativeness of an EPC data set is affected by decisions and actions at several points in the sample collection and handling process. These include:

- The size (n) of the data set;
- The locations, depths, and volume of individual samples collected from the exposure point;
- The density of sampling locations;
- The sampling frequency for media in which concentrations change over time (groundwater, indoor air, surface water);
- The sampling method, including whether samples are (a) collected and processed as discrete samples, (b) collected as discrete samples and composited in the field, or (c) collected as incremental samples;
- The sample processing, including soil sample sieving and water sample filtering;
- The method of subsampling in the laboratory to obtain an aliquot for analysis; and
- The accuracy and precision achieved by the laboratory analytical procedures.

Box 4-1
A Note on Terminology

In this document, the word "**sample**" is generally used to mean an individual discrete sample, consistent with common usage. The term **"data set**" is used to mean a set of discrete samples collected from an area of concern and used calculate the mean. However, readers should be aware that in technical documents describing statistical procedures, the word "sample" may refer to the entire data set used to calculate a mean.

The sampling decisions listed above must take into account the concentration variability of the media of concern in order to obtain data that are representative of an Exposure Point. In most MCP risk assessments, EPCs are based on a conservative estimate of the mean of contaminant concentrations within the Exposure Point (exposure area) over the time period of interest. Depending on site-specific circumstances, the mean may simply be estimated by the sum of the values divided by the number of values (the arithmetic mean) or by a statistical metric such as an upper confidence limit of the mean. Either way, a spatially and temporally representative data set is needed for a reliable estimate of the mean. Table 4-1 outlines effects of sampling decisions on the error in estimating the mean.

The greatest challenge in obtaining a representative sample is posed by concentration variability over space and time. Variability refers to the differences in concentration observed among samples in a data set. It is an inherent and pervasive characteristic of contaminated media at waste sites. Spatial variability in soil and sediment can be surprisingly high within short distances (ITRC, 2012), even among co-located samples (Brewer et al., 2017a, 2017b). This complicates the task of obtaining representative samples. Surface water concentrations can also vary substantially. The higher the variability, the larger the data set needed for sufficiently representative results. Data set size considerations are discussed in more detail in later sections of this document.

Table 4-1
Decisions Affecting Representativeness

Sampling Stage	Decisions	Considerations
Sampling project planning	• Select sampling approach • Identify sample volume, depth, number of samples collected, and locations • Choose discrete or incremental sampling • Decide sample volume (mass or sample size)	• Under-sampling can produce a large error in the mean • Incremental sampling can increase representativeness and decrease error without increasing analytical costs • Larger sample size increases representativeness and decreases error
Sample handling	• Sieving • Compositing • Conduct field subsampling	• Sieving reduces under-estimation of exposure • Compositing can increase representativeness, but only if subsampling is done correctly • Correct subsampling in the field may decrease error if lab subsampling is not possible.
Laboratory procedures	• Laboratory subsampling	• Correct subsampling ensures that the aliquot of sample that is analyzed is representative of the sample submitted to the lab

The MCP requires a representativeness analysis to be conducted and documented to support a Permanent Solution (310 CMR 90.1056 (2)(k)). In accordance with MassDEP's Representativeness Evaluation and Data Usability Assessment (REDUA) Guidance (MassDEP, 2002a), the representativeness analysis involves an evaluation and demonstration of the adequacy of the spatial and temporal data sets used to support risk assessment decisions. However, an investigator cannot wait until the documentation is required at the end of the assessment and cleanup process to carry out the representativeness analysis. As highlighted in Chapter 2, data evaluation and revision of the CSM are iterative and interdependent processes that should be revisited at every step of the site assessment/site management process.

"Representative… sampling ensures that a sample or group of samples accurately reflects the concentration of the contaminant(s) of concern at a given time and location. Analytical results from representative samples reflect the variation in pollutant presence and concentration throughout a site." (U.S. EPA, 1995b, p.3)

4.2.6 Laboratory Data Quality

Data quality depends upon procedures used for collecting samples and conducting laboratory analysis. Investigators planning a sampling project should coordinate with the lab to ensure that the samples provided to the laboratory will support a level of analytical sensitivity, precision, and accuracy, as specifically required by the MCP at 310 CMR 40.0191, sufficient to meet the project's objectives. MassDEP's REDUA Guidance (MassDEP, 2002a) identifies precision, accuracy and sensitivity as data quality metrics that determine the usability of the analytical data for MCP site assessment and risk characterization. The REDUA Guidance states that the analytical results will have "presumptive certainty," and the data will be acceptable to MassDEP, if the analytical methods and quality assurance protocols recommended in MassDEP's *Compendium of Quality Control Requirements and Performance Standards for Selected Analytical Protocols* (MassDEP, 2010) are employed. That document is commonly referred to as the *Compendium of Analytical Methods* (CAM). Laboratory data quality issues are discussed further in Chapter 5 (Chemical Analysis). U.S. EPA has published extensive guidance on laboratory quality control and quality assurance procedures, and investigators are advised to consult U.S. EPA guidance as well as the CAM.

Representativeness and data usability depend upon both appropriate field sampling methods and proper laboratory analysis procedures.

In the past, concerns about the reliability of sampling results have focused largely on laboratory analysis, but in recent years, it has been widely recognized that sampling practices are likely to be a larger source of measurement errors. Thus, the remainder of this chapter focuses on sampling procedures and practices.

4.3 Soil Sampling and Data Analysis

When evaluating medium and long-term exposures, the EPC should represent the arithmetic mean of the concentrations to which an individual may be exposed over the exposure period at the Exposure Point. Due to the nature of soil and the variability typical of soil contaminant concentrations, estimates of the arithmetic mean are inherently uncertain and can be highly erroneous. An understanding of the concentration variability that is characteristic of contaminated soil is essential to planning a sampling project that will yield representative samples.

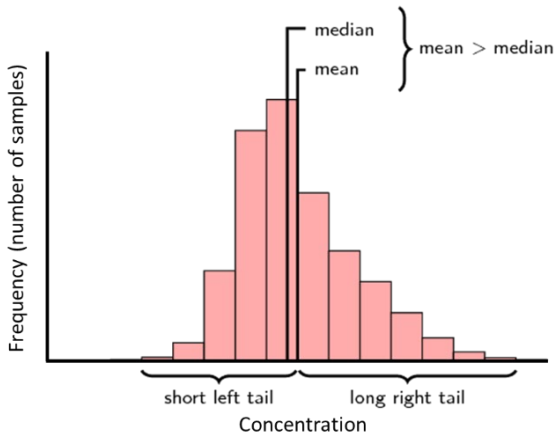
Characterizing the variability of contaminant concentrations over large areas is typically one of the main goals of environmental investigations, and the prevalence of this large-scale variability has been well documented. There is less awareness of the significant soil heterogeneity and concentration variability that can be present at smaller spatial scales. Surface soil concentrations at sites can vary by over an order of magnitude within a space of a square foot (ITRC, 2012). Even within a soil sample submitted to a laboratory, the variability can be substantial, and failure to collect a representative aliquot for analysis can lead to a significant error in estimating the mean concentration (ITRC, 2012).

A key characteristic of concentration variability in soils and sediments is the **frequency distribution of concentrations**. This refers to the proportion of samples with concentrations at different levels or within different concentration intervals. The frequency distribution of contaminants at waste sites is almost always right-skewed, as depicted in Figure 4.4. Even the concentration distribution of metals in natural soils (i.e., background levels) is often right-skewed,

which is to say that the majority of data fall to the right side of the contaminant concentration with the highest frequency (the peak of the distribution). The histogram shown in Figure 4.4 depicts a right-skewed distribution, with a right-side "tail" longer than the left.

To obtain a representative data set for soil (or sediment) in which the contaminant concentrations fall into a right-skewed distribution, the number of discrete samples must be large enough to capture the rare high values in the same proportion as they exist in the environment. Any one discrete sample is more likely to have a concentration nearer the median, simply because they occur more often, by definition. With fewer data points, the high values in the right-side tail are less likely to be captured. Thus, for right-skewed distributions, a data set that is too small is more likely to result in an underestimate of the true mean concentration than an overestimate.

Figure 4.4 – Histogram Representing a Right-Skewed Frequency Distribution



(Adapted from Siyavula Education)

4.3.1 Soil Sampling Approaches and Data Analysis

Section 4.2.2 described several different sampling approaches. Knowledge of the location and likely extent of the release is the starting point for choosing a sampling approach. The two sampling approaches most commonly used to sample soil at waste sites are **judgmental sampling** and **systematic sampling.** In general terms, these approaches are best suited to simple and complex sites respectively. The 2024 revision of the MCP details the types of sites to which each approach is appropriately applied:

1. *A judgmental sampling approach is appropriate for characterizing the soil Exposure Point Concentration, pursuant to 310 CMR 40.0926, where the contamination has originated from a known source or sources; there is evidence that the contamination is limited to a defined area; the area with the highest concentrations within the Exposure Point can be clearly identified; and there is no evidence, including site history, that the soil has been significantly disturbed since the release.* (310 CMR 40.0904(4)(a))

2. *[In general], a systematic sampling approach is required for characterizing the soil Exposure Point Concentrations where the soil contamination has not been attributed to a known source; the contamination may not be limited to a defined area; it is not possible to identify the area with the highest concentration within the Exposure Point; or the soil may have been significantly disturbed since the release.* (310 CMR 40.0904(4)(b)).

While judgmental sampling is appropriate for a majority of the releases and sites assessed under the MCP, sites that call for systematic sampling are often situations with a greater potential for exposure and risk. As a consequence, this guidance document places a greater emphasis on sites that call for systematic sampling.

Corresponding to the approaches recommended for different types of sites, the MCP prescribes specific EPC calculation procedures (310 CMR 40.0926(8)):

1. *For Exposure Points where judgmental sampling has been implemented in accordance with 310 CMR 40.0904(4), the arithmetic mean of data from the Exposure Point may be used as an Exposure Point Concentration, provided that 75% of the data points used in the averaging procedure are equal to or less than the applicable standard or risk-based concentration limit, and no data point used in the averaging is ten times greater than the applicable standard or risk-based concentration limit; Otherwise,*
    a. the maximum concentration from the Exposure Point may be used as the Exposure Point Concentration; or
    b. the arithmetic mean may be used to determine the Exposure Point Concentration, supported by a technical justification that considers the size of the data set, density and potential biases of the sampling, and other relevant factors.

2. *For Exposure Points where systematic sampling has been implemented in accordance with 310 CMR 40.09204(4), the 90th percentile Chebyshev non-parametric upper confidence limit on the mean of the concentrations within the Exposure Point may be used as the Exposure Point Concentration.*
    a. *If the 90th percentile Chebyshev non-parametric upper confidence limit on the mean is determined not to provide a suitable estimate of the Exposure Point Concentration, an alternative conservative estimate of the arithmetic mean may be used to determine the Exposure Point Concentration, supported by technical justification. Such technical justification shall document the determination that the 90th percentile Chebyshev non-parametric upper confidence limit on the mean is not suitable, and the suitability of the alternative approach, considering the size of the data set, density and potential biases of the sampling, applicable statistical analyses of the data, and other relevant factors.*

Examples of technical justification for using an alternative to a 90th percentile confidence limit on the mean include:

a. The data set is large (> 60 – 90 samples)
b. The data are parametric, and an appropriate 95th percentile parametric upper confidence limit on the mean is used; or
c. Sampling was conducted using incremental sampling methodology.

Matching the Sampling Approach and the EPC Calculation Method

- **For sites where the areal limits and distribution of contaminants are predictable, a judgmental sampling approach may be used. In these cases, an EPC based on the arithmetic mean is acceptable.**
- **For sites with an unpredictable distribution of contaminants, a systematic sampling approach is appropriate. In these cases, the EPC should be based an upper confidence limit of the mean.**

4.3.1.1 Linking Soil Sampling Objectives with Sampling Approaches

As previously mentioned, sampling objectives should drive soil sampling project design decisions. Table 4-2 provides examples of appropriate designs for some of the specific sampling objectives discussed in Section 4.2.1. These are not hard-and-fast rules but rather guidelines for considering the strengths and weaknesses of different designs for meeting each objective.

Table 4-2
Sampling Objectives and Approaches

Objective	Sampling Approach
Initial Nature and Extent Survey*	Systematic
Potential Source Area Evaluation	Judgmental
Defining the Distribution and Extent	Judgmental combined with Focused Systematic
Evaluating Background Conditions	Systematic (At both Site and Background Locations)
Hot Spot Evaluation	Judgmental
Estimating Exposure Point Concentrations	Systematic, Incremental Sampling

* Assuming incomplete knowledge of chemical use and historical operations

4.3.2 Soil Sampling Methods

A major consideration in selecting a soil sampling method is the goal of the sampling project. More specifically, the choice of method depends upon whether the concentration variability has to be characterized or whether the objective is to estimate the arithmetic mean and variability is not of concern. Concentration variability can only be evaluated by discrete sampling. Information on variability is completely lost when composite or incremental samples are collected. However, in many cases, incremental sampling may be a more efficient and effective way of collecting data to estimate an arithmetic mean for the EPC. Depending on the data needs for the site, multiple sampling projects using different methods may be called for. The three sections that follow describe sampling methods in more detail.

4.3.2.1 Discrete Soil Sampling Methods for Judgmental and Systematic Sampling

Discrete sampling is the conventional way of sampling soil (or sediment) at waste sites. As described in Section 4.2.3, a discrete sample is an individual grab sample taken from a single sampling point at a specified depth. Both judgmental and systematic sampling approaches can employ discrete sampling to estimate the mean for the EPC. Discrete samples are usually needed for initial characterization of the concentration variability and identification of potential Hot Spots. This method is also generally used to delineate the extent of site-related contaminants and often used to estimate EPCs.

Interpreting Data from Judgmental Discrete Sampling

In accordance with 310 CMR 40.0904(4), judgmental sampling shall only be performed in situations where the area with the highest concentrations within the Exposure Point can be clearly identified. While a judgmental sampling program may include samples from outside the area with the highest concentrations, only the data for the samples from the contaminated area should be included in the calculation of the arithmetic mean for the EPC. Non-detect results from the margins of the site or release should not be included in the calculation of the

EPC.

Data Set Size for Judgmental Discrete Sampling

The number of samples needed to estimate an EPC based on judgmental sampling depends upon the spatial contaminant distribution from the release in question. Considerations include the size of the affected area, the depth of the affected soil column, the transport mechanisms, and the direction(s) of transport from the source area. Evaluating exposure to residual contamination from a spill that is confined to a very small area of soil and has not been subject to significant transport mechanisms may require as few as five samples. Other situations may require a significantly larger data set. As the name suggests, judgment is the basis for identifying an appropriate data set size. In view of the subjective nature of judgmental sampling, technical justification and documentation are crucial components of the assessment process.

Interpreting Data from Systematic Discrete Sampling

When a systematic grid sampling approach is used, and a single discrete sample is taken from each cell of the grid, the mean of all of the results taken together is representative of the mean concentration in the grid *as a whole*. However, an individual result is not necessarily representative of concentrations in the grid cell from which it was collected. The concentrations of samples collected from locations in close proximity, even within several feet, can vary widely. A high (or low) detected concentration from a particular grid square could be happenstance – a reflection of high variability throughout the sampling grid as a whole and not a representation of the average or typical concentrations within the cell.

Therefore, certain caveats apply to the interpretation of analytical results for samples collected from a sampling grid:

- A high result for one sample location from a particular cell does not necessarily indicate the cell contains a "Hot Spot." A single sample with significantly elevated OHM concentrations may suggest the presence of a Hot Spot and should compel further characterization of the area. However, a Hot Spot is not a single sampling location; it is an area that must be identified by a sampling project specifically aimed at confirming the area where concentrations meet the definition of a Hot Spot and defining its boundaries. Sampling to identify or delineate Hot Spots is discussed further in Section 4.8.

When a high result from an individual discrete sample is observed, further work is needed to evaluate the presence of a Hot Spot.

- When an elevated concentration is detected at one or more sampling points within a sampling grid, the appropriate response depends upon whether that result (a) represents an area throughout which contaminant levels are elevated or (b) simply reflects the concentration variability throughout the grid. Additional targeted sampling in the vicinity of an elevated result can show which of these is true. If an area of elevated concentrations is apparent and the soil in that area is removed from the site, the initial elevated result may simply be eliminated from the data set to recalculate the mean concentration. However, if soil is removed from the vicinity of an elevated concentration result without first determining whether that concentration is a reflection of variability throughout the grid, it is inappropriate to simply eliminate the elevated concentration from the data set to re-calculate the mean concentration for the grid.

- Sampling is often an iterative process that combines multiple approaches and evolves as additional knowledge of site conditions is obtained.

"Surgical removal of hot spots can lead to erroneous conclusions regarding the magnitude of remaining contamination." (Brewer et al., 2017b, Abstract)

Concentration Variability and Data Set Size for Systematic Discrete Sampling

The number of discrete samples necessary to estimate the mean with a given level of confidence depends upon the variability in site concentrations. Soil contaminant concentrations can vary widely among different locations within a waste site due to past chemical handling practices, chemical-specific fate and transport characteristics, and the heterogeneous nature of soil.

Differences in physical and chemical characteristics among the particles that make up soil result in differing affinities for contaminants. For example, it has been shown that smaller particles adsorb greater amounts of contaminants per gram of soil than larger particles, and clay absorbs greater amounts than other soil types (ITRC, 2012). An understanding of soil heterogeneity and the variability in concentrations typically present at sites is key to developing a sampling plan that is likely to produce representative samples and reliable results.

The number of discrete samples required to obtain a representative average depends upon the variability in contaminant concentrations, not the size of the area being sampled. The greater the variability, the more samples required.

The size of the data set needed for a reliable estimate of the mean depends upon the tolerance for error and the variability in the data. Statistical calculations can be used to estimate the size of the data set needed for a specified level of certainty. Two widely available software packages that simplify the calculation task of estimating the size are U.S. EPA's "Visual Sampling Plan" (VSP) and U.S. EPA's ProUCL software, which has a tool called "DQO-based sample size." However, calculating the sample size presents certain practical challenges:

- Methods of estimating the data set size require an estimate of the concentration variance.
- Most of the methods rest on an assumption that the concentrations present at the site fit a particular concentration distribution (i.e. normal, lognormal).
- The resulting data set size can be quite large.

A realistic estimate of variance generally requires a pilot study to collect a preliminary data set. However, a proper pilot study may be impractical for many soil sampling projects. For one Exposure Point, it would involve sampling twice – first to obtain the variance for calculating the size of the data set needed and again to obtain a data set of the necessary size. Project managers may deem the cost of collecting a statistically determined number of samples to be beyond what the project budget allows. Nevertheless, the data set must be large enough to provide

a representative sample of the Exposure Point and a reasonably reliable estimate of the mean.

To an extent, sampling error can be mitigated by estimating the mean using an upper confidence limit (UCL, see Box 4-3, Section 4.3.6.1). However, if the sample size is small and the data set does not include the exceptionally high concentrations present in the tail of the concentration distribution, even the UCL can significantly underestimate the actual mean.

In the *Supplemental Guidance to RAGS: Calculating the Concentration Term*, U.S. EPA has provided a qualitative indication of the level of confidence associated with a range of data set sizes (U.S. EPA, 1992):

> *Sampling data from Superfund sites have shown that data sets with fewer than 10 samples per exposure area provide poor estimates of the mean concentration (i.e., there is a large difference between the sample mean and the 95 percent UCL), while data sets with 10 to 20 samples per exposure area provide somewhat better estimates of the mean, and data sets with 20 to 30 samples provide fairly consistent estimates of the mean (i.e., the 95 percent UCL is close to the sample mean).*

As a general guideline, based on a combination of practical and technical considerations, MassDEP will generally deem 20 to 30 discrete samples sufficient to estimate an exposure point concentration using an upper confidence limit as described in Section 4.3.6.1.

4.3.2.2 Composite Soil Sampling

Composite sampling involves collecting discrete samples from several different locations and physically combining them to form a single sample to be submitted to a laboratory for analysis. Strictly speaking this is more a sample preparation procedure than a sampling methodology. Compositing reduces the number of chemical analyses needed to characterize the area(s) from which discrete samples are collected and can be more cost effective than collecting and analyzing a larger number of discrete samples when information on variability is not needed. In theory, the contaminant concentration reported for a composite sample represents the arithmetic mean of the concentrations present in the discrete samples making up the composite, but information on concentration variability among discrete sample locations is lost.

The reliability of a mean estimated by composite sampling depends upon obtaining a representative subsample for laboratory analysis. Obtaining a representative subsample is crucial, but technically challenging. Sub-sampling must be done in a manner that does not preferentially obtain lager-sized particles, because the bulk of contamination is associated with the smallest particles (see Section 4.3.3.2). Failure to obtain a representative subsample for analysis could result in substantial underestimation of the true average concentration in the composite sample. While particle size discrimination is a problem for discrete samples as well, improper sub-sampling of larger composite samples may lead to even larger sampling errors. Laboratory sub-sampling is discussed in more detail in Section 4.3.3.2.

Composite sampling can be an economical way to obtain analytical data, but information on concentration variability and distribution will be lost.

4.3.2.3 Incremental Soil Sampling Methodology

Incremental Sampling Methodology (ISM) is a soil sample collection and processing protocol aimed at increasing sample representativeness and reducing data variability. ISM is a type of composite sampling that is compatible with systematic sampling approaches. The methodology is designed to obtain a single aliquot of soil for analysis that has all of the constituents in the same proportion as the volume of soil (in the area of concern) being sampled. The goal is to provide reliable, reproducible estimates of the mean concentrations of analytes present in the volume of soil being analyzed (ITRC, 2012).

The two main processes through which ISM controls data variability are: (1) field collection of soil samples and (2) laboratory processing and subsampling procedures. Both are critical for obtaining representative results.

Field collection involves these steps:

- Identify the area to be sampled, referred to as a **decision unit**.
- Lay out a sampling grid over the decision unit to guide the systematic collection of soil from 30 to 60 locations within the decision unit.
- Employ a soil sampling tool appropriate for the site and sampling purpose to collect the soil from each of the locations. The soil taken from each individual location is referred to as an **increment.**
- Combine the increments into a single larger volume of soil (typically 1 to 3 kg) from which a smaller aliquot (a few grams) will be taken for laboratory analysis. The volume of soil containing 30 to 60 increments combined is called an "**incremental soil sample**."
- Repeat the process two more times to obtain two **replicate incremental soil samples**. The increments for these replicate samples are taken from points within the sampling grid that are consistent in their spatial relation to those original increments.

The objective of ISM field sampling procedure is to obtain an ISM sample that is representative of the contaminant concentrations present in the decision unit as a whole. The objective of laboratory subsampling procedures is to obtain an aliquot for analysis in which the concentrations of a contaminant are approximately the same as the concentration that would be measured **if** the entire incremental sample could be analyzed at once (which is not possible). Laboratory subsampling is discussed in more detail in Section 4.3.3.

To illustrate the ISM field sampling process, Figure 4.5 depicts a rectangular decision unit with 60 increments, with triangles representing the first set of increments and Os and Xs representing the increments for two replicate samples. The sampling design represented in Figure 4.5 would result in three samples to be submitted for analysis, but all together those three samples would comprise 180 increments of soil (essentially 180 discrete samples).

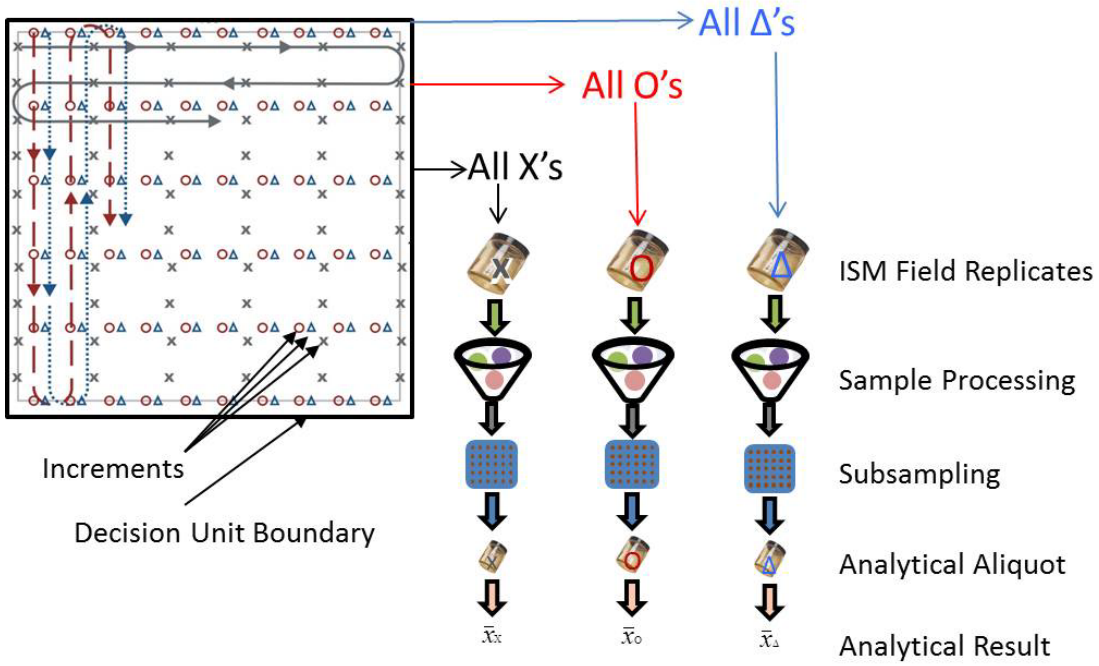
Box 4-2
Evolution of ISM Principles and Practices

Current ISM sampling guidelines are based on well-established principles and on computer simulation tests.

- ISM is rooted in Gy Sampling Theory, originally developed by Dr. Pierre Gy for mineral exploration (Gy, 1998).
- Multi Increment® Sampling, a Gy-theory based approach, has been developed for waste site investigation applications in the U.S. by Charles Ramsey of Envirostat. The underlying principles for ISM are similar to those for Multi Increment® Sampling.
- In 2012, the Interstate Technical and Regulatory Commission (ITRC) published "Incremental Sampling Methodology" to provide practical written guidance for obtaining representative sampling results for contaminated soil (ITRC, 2012). It relies on an extensive simplification of Gy Theory. The 2012 ITRC document continues to provide a foundation for understanding and applying ISM at waste sites.
- In 2020, ITRC published a "Clarification" (includes corrections) of selected aspects of the 2012 guidance and an updated on-line version of the guidance (ITRC, 2020a, 2020b).

Several sections of the 2012 ITRC document provide foundational information and sampling principles that apply to soil sampling decisions in general, whether or not ISM is being used. In particular, the sections on the nature of soil and contaminant adsorption should be taken into account when undertaking any soil sampling project, whether or not ISM is employed. MassDEP strongly recommends that all environmental professionals who work on sites under the MCP familiarize themselves with the 2012 ITRC document.

Figure 4.5 – Schematic of ISM Process



(ITRC, 2012)

Incremental sampling is most practical where the contamination and exposures of concern both occur near the soil surface, as the specialized equipment typically used to obtain soil increments only reaches soil a few inches beneath the surface. Subsurface incremental soil sampling has been done, but it involves collecting soil increments from coring equipment and is resource intensive.

One special application where incremental sampling can be very efficient and effective is characterizing stockpiled soil. This characterization can be performed as the stockpile is being formed or moved, or if the stockpile is small, by first spreading it out and then sampling using an incremental sampling grid. Incremental sampling allows accurate characterization of the average concentration of contaminants in the stockpile, which is usually the sampling goal.

4.3.3 Representative Soil Subsampling for Laboratory Analysis

In recent years, laboratory subsampling procedures have most often been discussed in conjunction with ISM, but proper subsampling is important regardless of how samples have been collected from the field. Both the aliquot size and the soil particle size can have significant impacts on analytical results. These issues are discussed in more detail in the following subsections.

4.3.3.1 Aliquot Size and Representative Analytical Results

When a soil sample is submitted to a laboratory, only a very small fraction of it (an aliquot) is actually analyzed. The mass of the soil (i.e., the subsample from the field sample that is submitted to the laboratory for analysis) can have a significant effect on precision. In one study

that compared the variability in soil americium concentration measurements for soil samples ranging from 1 to 100 g, the investigators found significant reductions in variability as the aliquot size was increased, with the largest reductions occurring as the aliquot size increased from 1 to 10 g (Gilbert & Doctor, 1985). In planning sampling projects, the opportunity to reduce sampling error by increasing the aliquot size should not be overlooked.

4.3.3.2 Soil Particle Size Considerations

People who come into contact with contaminated soil are mainly exposed to very small particles. Smaller particles adhere more readily to the skin surface and are more available for incidental ingestion (U.S. EPA, 2000). In most cases, a high percentage of the contamination present in a bulk soil sample is associated with the smallest particles (See Table 4-3). Therefore, it is very important to ensure that the aliquot taken for analysis contains smaller particles in the same proportion as the original sample. This will ensure that the contaminant concentrations in that aliquot are approximately the same as the concentrations in the soil sample as a whole.

Table 4-3
Relationship between particle size and lead concentration for a firing range site

Particle Size (mm)	Standard Sieve Mesh Size	Soil Fraction (Percent)	Lead Concentration in Fraction (mg/kg)	Percent of Total Lead
>9.53	>3/8 inch	18.85	10	0.2
9.53 – 4.76	Between 3/8 and 4 mesh	5.53	50	0.24
4.76 – 2.0	Between 4 and 10 mesh	3.65	108	0.43
2.00 – 0.297	Between 10 and 50 mesh	11.25	165	2.00
0.297 – 0.074	Between 50 and 200 mesh	27.8	836	25.06
<0.074	Less than 200 mesh	33.92	1970	72.02

(ITRC, 2012)

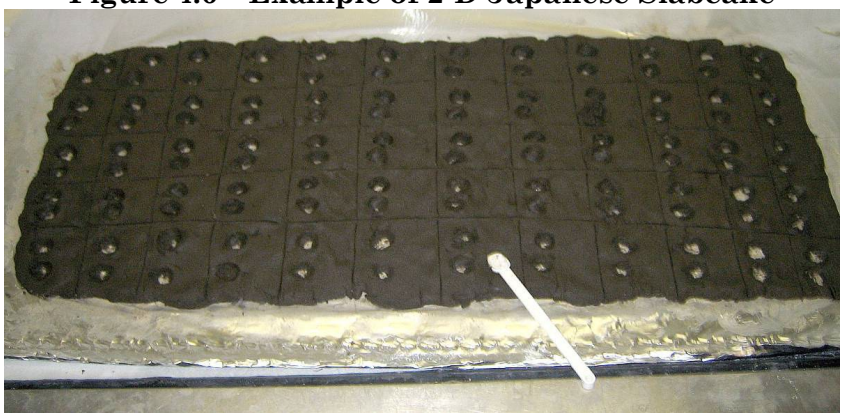
Sampling and subsampling practices generally favor larger particles. One reason for this is "particle size segregation", which occurs when smaller particles fall to the bottom of the sample container. If the subsampling method discriminates against smaller particles, the analysis is likely to significantly underestimate the sample concentration, as demonstrated in Table 4-3 above.

In order to overcome particle size segregation, specific subsampling procedures are necessary. Common laboratory subsampling procedures (mix well, then take a scoop) do not eliminate the problem and may exacerbate it (ITRC, 2012). Given that few laboratories are prepared to conduct representative subsampling, investigators may choose to conduct subsampling in the field. A practical and reasonably reliable procedure is the "slabcake" method. The procedure involves sieving the soil sample to 2mm, spreading it on an aluminum pan, and collecting subsamples in a grid pattern. In essence this is a small-scale incremental sample collection project. The basic set-up is shown in Figure 4.6. Section 5.4 of the ITRC guidance (ITRC, 2012) provides an extensive discussion of field sub-sampling.

Representative subsampling is important regardless of whether discrete, composite, or incremental sampling procedures are used. It is particularly important for incremental samples and composite samples because the larger sample volumes may exacerbate particle size segregation within the sample, thereby increasing underestimation of contaminant

concentrations. Proper sub-sampling of incremental samples is imperative in order to realize the potential improvement in representativeness that the method offers.

Figure 4.6 – Example of 2-D Japanese Slabcake



(ITRC, 2012)

4.3.4 Soil Particulate Inhalation Exposures

Another challenge related to contaminants preferentially adsorbing to smaller soil particles is obtaining a conservative estimate of the EPC for the soil particle (dust) inhalation exposure route. Basing the EPC on the concentrations measured in bulk soil samples containing a range of particle sizes is likely to underestimate the EPC significantly. One way to minimize this source of error is to sample inhalable airborne particulates directly rather than estimate particulate concentrations from bulk soil concentrations.

4.3.5 Soil Sampling Depth

For both human health and ecological risk assessment, soil sampling depth decisions should account for both (a) the vertical distribution of the contaminants of concern; and (b) the depth intervals over which the receptors of concern may be exposed based on the CSM (Chapter 2). The depth intervals of concern are identified in different ways for human and ecological receptors, and so these are discussed separately in the two subsections that follow.

4.3.5.1 Soil Sampling Depth for Human Health Risk Assessment

When evaluating *current* soil exposures for human health risk assessment, the relevant sampling depth depends upon the vertical extent of contamination *and* the Exposure Point definitions presented in 310 CMR 40.0924(7). For example, that section states that the zero to 3-foot depth interval *shall be considered* for exposures associated with surficial activity, but it does not say that concentrations must always be averaged over the top 3 feet of soil. In cases where contaminant levels are high in the top several inches of soil but taper off significantly below that depth, averaging concentrations over the whole 3-foot depth interval could substantially underestimate actual exposures. The risk assessor should consider the depth profile of contamination in conjunction with the depth interval specified for particular types of exposures in accordance with the CSM.

4.3.5.2 Soil Sampling Depths for Ecological Risk Assessment

The appropriate soil sampling depths for ecological risk assessment depend in part upon the depths at which the organisms of concern come into contact with subsurface soil contamination. Organisms exposed to subsurface soil that are most commonly evaluated in ecological risk assessments include invertebrates and burrowing mammals. This section describes the soil depth intervals where these organisms experience the highest levels of exposure to soil contamination.

"In essence, spatial and vertical co-occurrence of contamination and ecological receptors need to be considered to estimate risk."
(U.S. EPA, 2015)

The interval with the highest biological activity is the layer of soil that begins just below the surface litter layer of partially decomposed organic material and extends to a depth of about one foot. This layer is rich in organic material and is characterized by high microbial activity and the presence of soil invertebrates. This layer is often referred to as the "A horizon," and it should be sampled for ecological risk assessment purposes because this is where soil organisms are most likely to come into contact with any contaminants present.

While the A horizon is an important exposure point for soil invertebrates, other organisms of concern may be exposed to contamination in deeper soil, including trees with deep roots and burrowing mammals. It has been reported that 65% of the root mass in temperate forests is present in the top foot (Suter et al., 2000), which indicates that 35% of the root mass is extends to deeper soil.

Burrowing mammals can be exposed to soil well below the A horizon and should also be considered in the risk assessment. Examples of burrowing mammals in Massachusetts include the following:

Woodchuck (*Marmota monax)*

- Distribution: Statewide except Dukes and Nantucket counties (MassDFW, 2022).
- Burrowing behavior: Woodchucks live in burrows from two to six feet deep and up to 40 feet long (Mass Audubon, 2022a).

Meadow Jumping Mouse (*Zapus Hudsonius)*

- Distribution: Statewide (MassDFW, 2022).
- Burrowing Behavior: Meadow jumping mice hibernate in nests located 0.5 meters underground (Virginia DWR, 2022).

Hairy-tailed Mole (*Parascalops breweri*)

- Distribution: Northeastern, central, and western Massachusetts. Absent from the three southeastern mainland counties, and Dukes and Nantucket counties (MassDFW, 2022).
- Burrowing behavior: Hairy-tailed moles dig deep tunnels and are active below the frostline during the winter (SUNY College of Environmental Science and Forestry, 2022).

Eastern Chipmunk (*Tamias striatus*)

- Distribution: Statewide except Nantucket County (MassDFW, 2022).
- Burrowing behavior: Eastern Chipmunks excavate a burrow entrance that reaches down to a depth of two feet. They then tunnel parallel to the soil surface for up to 10 feet and build a sleeping chamber at the end of it. They excavate side chambers off the tunnel to store food, defecate, and give birth (Mass Audubon, 2022b).

River Otter (*Lontra Canadensis*)

- Distribution: Statewide except Nantucket and Suffolk counties (MassDFW, 2022).
- Burrowing behavior: Otters do not excavate their own den, but they do sometimes use the abandoned burrows of other animals (Mass DFW, 2022).

Muskrat (*Ondatra zibethicus*)

- Distribution: Statewide except Nantucket County (MassDFW, 2022).
- Burrowing behavior: A muskrat occupying a stream habitat will burrow into banks to build a den above the water line and then dig an additional entrance tunnel (NY DEC, 2020).

4.3.6 Soil Data Analysis

The appropriate way to estimate the exposure point concentration from the soil analysis results is purpose-dependent. Considerations include, but are not limited to:

- **The source and extent of release**. As specified in the Massachusetts Contingency Plan (310 CMR 40.0904), at sites where the source of contamination is known, the lateral and vertical extent of contamination is well defined, and the concentration distribution is well-characterized, it may be appropriate to simply use the arithmetic mean of concentrations detected in the most highly contaminated area, which is most likely to be found in the vicinity of the source. The arithmetic mean is appropriate if the data meet the criteria set forth in Section 310 CMR 40.0926(8), often referred to as the 75/10 rule. This rule is described above in Section 4.3.1. The most typical situation in this category is to verify removal of contaminated soil from the excavation of a leaking underground fuel tank and ascertain that all of the contaminated soil that could pose a risk has been removed.

- **The exposure scenario and exposure period being considered**.
  When the goal is to obtain an exposure point concentration for a contaminant known to have acute effects at levels that can be present at sites, the highest detected concentration should be used to estimate potential one-time exposures. For example, when cyanide is present, an acute (one-time) exposure should be evaluated in the risk assessment. There may be exceptional situations where an arithmetic mean may be acceptable to characterize acute exposures, but the onus is on the investigator to demonstrate what would be conservative and appropriate.

- **The size of the data set on which the exposure point concentration is based.**
  As discussed in Section 4.3.1, for large data sets from systematic discrete sampling, MassDEP will generally accept the use of the unadjusted arithmetic mean of the data set. In other words, if the data set is large enough, the use of an upper confidence limit (UCL) of the mean may not be required. MassDEP will consider data sets of 60 samples or more to be adequate, depending on the variability and the size of the Exposure Point being evaluated.

- **Sampling procedure.**
  To date, MassDEP has not required the use of a UCL for data acquired by ISM. In other words, we do not require the calculation of a UCL from the ISM sample and replicate results. The arithmetic mean of the three results (one ISM sample with two replicates) is considered a reasonably conservative estimate of the mean concentration for use as an EPC.

EPCs for contaminants known to have acute effects at levels that could be present at a site should be estimated using the highest detected concentration to account for risks from one-time exposures.

4.3.6.1 Exposure Point Concentration for Medium- and Long-Term Exposures Based on Data from Discrete Sampling Procedures

When the goal is to calculate an exposure point concentration for assessing subchronic, chronic, or lifetime risks, an estimate of the arithmetic mean (average) concentration is used. The MCP requires a "conservative estimate of the mean." Given the level of variability typical of soil concentrations, the error associated with the (measured) mean can be significant. For a conservative estimate of the mean for Exposure Points where systematic sampling has been implemented, MassDEP specifies the use of the 90th percentile Chebyshev nonparametric upper confidence limit (310 CMR 40.0926(8)).

A UCL within the context of EPC calculations refers to the upper confidence limit of a mean. The percentage in front of a UCL refers to the likelihood that the value of the UCL is greater than or equal to the mean, so the 90% UCL referred to in Section 310 CMR 40.0926(8) will be greater than or equal to the mean 90% of the time.

Box 4-3
The UCL Abbreviation

Versions of the MCP prior to the 2024 revisions used the "UCL" abbreviation to refer to the Method 3 Upper Concentration Limits in Section 310 CMR 40.0996. This terminology has changed to "Method 3 Ceiling Limits" or "M3CLs" to avoid confusion with upper confidence limits.

The equation for calculating the 90% UCL of a mean using the nonparametric Chebyshev method is given in U.S. EPA's guidance for calculating upper confidence limits (U.S. EPA, 2002c, Exhibit 12):

$$UCL_{(1-\alpha)\ x\,100\%} = X + \left(\sqrt{\frac{1}{\alpha} - 1}\right) \times \frac{S_x}{\sqrt{n}}$$

Where:
X = sample mean
α = 0.1 to compute the 90% UCL
S_x = standard deviation
n = number of samples (number of values in the data set)

As discussed above, the risk assessor may opt to provide a technical justification for using an alternative method to calculate the UCL. For example, if justified and documented, a parametric UCL may be used in lieu of the non-parametric UCL to estimate the EPC.

4.3.6.2 Considering "Outliers" in soil data sets

An exceptionally high concentration detected at a waste site is not likely a sampling or analytical error. It is a concentration that is actually present, and it represents a data point that lies in the right tail in the concentration distribution at the Exposure Point being evaluated. As such, it contributes to exposure, and it is inappropriate to eliminate it from the data set on which the EPC is based.

4.4 Sediment Sampling

4.4.1 Temporal Variability in Sediment Concentrations

Sediment contaminant concentrations vary spatially in much the same way as contaminants in soils. However, unlike soils, sediment concentrations in any one place will vary over time, due to meteorologic and hydrologic forces that continually move sediment within a water body. This ongoing redistribution of contaminated sediment increases the challenge of obtaining representative samples, especially when changes over time are of interest.

> **"Representative surface water and sediment sampling ensures that a sample or group of samples accurately reflects the concentration of the contaminant(s) of concern at a given time and location." (U.S. EPA, 1995b)**

4.4.1.1 Spatial Variability of Sediment Contamination

A number of factors contribute to spatial variation of contaminant concentrations in sediment. These include, but are not limited to:

- **Grain size** - Contaminant concentrations are higher in fine grained sediments due to the higher surface area to volume ratio. To aid in interpreting data, sediments collected for chemical analysis should also be subjected to grain size analysis.

- **Organic carbon content** - A higher organic carbon content also enhances the sediment's binding capacity.

- **Depositional patterns** - Contaminant concentrations are generally higher in depositional areas where grain size is smaller than in erosional areas dominated by coarser grained sediment. Deposition is greater in sections of rivers and streams where current speed changes from fast to slow. Typical depositional areas include wider stretches of stream channels, the inside bend of a river, downstream of islands or obstructions, estuarine areas, and the central area of impoundments.

- **Mixing tendencies –** As discussed below in Section 4.5, surface water is generally not well mixed, and the associated sediments are even less so. The forces that move and deposit sediment tend to separate material with different physical characteristics, which may lead to separation of more contaminated material from less contaminated material. Sediments just below a confluence are often not well mixed, so those locations are generally poor locations for collecting representative samples.

An understanding of the how each of these factors affects sediment concentration variability is necessary when designing a sampling project to obtain representative samples.

4.4.2 Habitat Considerations

4.4.2.1 The transition zone of lakes, ponds, streams, and rivers

The transition zone represents a unique and important ecosystem that exists between surface water and the underlying groundwater, receiving water from both of these sources. Biota inhabiting or dependent on the transition zone may be adversely impacted by contaminated groundwater discharging through the transition zone into overlying surface waters.

4.4.3 Sediment Sampling Objectives

Sediment sampling projects may be undertaken for a range of reasons. For example:

- To assess the nature and extent of sediment contamination
- To characterize human health and environmental risk from sediment exposure
- To delineate areas requiring remediation
- To monitor changes in sediment concentrations over time
- To verify cleanup goals have been met after remediation is complete

Each objective calls for a different sampling approach or sampling design. Although it may be possible to collect samples for different purposes during one sampling event, this is likely to require a combination of approaches; no one design will address all objectives.

4.4.4 Sediment Sampling Approaches

The optimum sampling approach depends on the setting, the available site information, and the sampling objective. Sediment sampling depth is a site-specific consideration that should correspond to the depth of exposure likely to occur to human or ecological receptors. U.S. EPA has described a number of approaches to sampling sediment and surface water (U.S. EPA, 1995b). Brief descriptions of those most applicable to sediment sampling follow:

- **Judgmental** sampling involves selecting locations based on site history information, visual or olfactory evidence, and professional judgment. The applicability of judgmental sampling is more limited for sediment than for soil. For sediment, its use should be restricted to situations where there is clear evidence that the target area is the most contaminated area, such as locations identified as depositional areas.

- **Systematic grid** sampling requires marking out a square or triangular grid over the area of concern to guide the collection of samples from the intersection of grid lines. The more closely spaced the sampling points are, the more reliable the results will be. In still water bodies, this approach is useful for both EPC estimation and nature and extent assessment. In riverine systems, systematic grid sampling is most useful for assessing the nature and extent of contamination.

- **Transect** sampling entails setting out transect lines across the surface of a water body and collecting samples at regular intervals along each line (see Figure 4.7). Samples may also be collected at depth along each line. Transect sampling is a conventional method for rivers and streams. Discrete samples collected along a transect line provide information on the distribution of contamination across the width of a river. Comparison of sample results between successive transect lines can provide information on downstream transport and the extent of contamination.

"Transect sampling is applicable to characterizing water flow… contaminant characteristics and contaminant depositional characteristics in sediments, such as distinguishing erosional versus depositional zones."
(U.S. EPA, 1995a)

- **Stratified** sampling requires dividing the area of interest into mutually exclusive sub-areas (strata) where different sampling strategies may be employed in each stratum (e.g., silty area versus cobbles). Strata may be chosen based on areas where separate cleanup decisions will be made or where different contamination constituents or levels are expected. This sampling approach requires fairly extensive prior knowledge of sediment conditions based on previously collected data. To the extent that different conclusions are to be drawn for different sub-areas, the data representativeness for each area must be justified separately.

For more detailed descriptions of these and other methods, the reader is referred to U.S. EPA's guidance on representative sampling for soil (U.S. EPA, 1995b).

Figure 4.7 – Example of Transect Sampling for Sediment

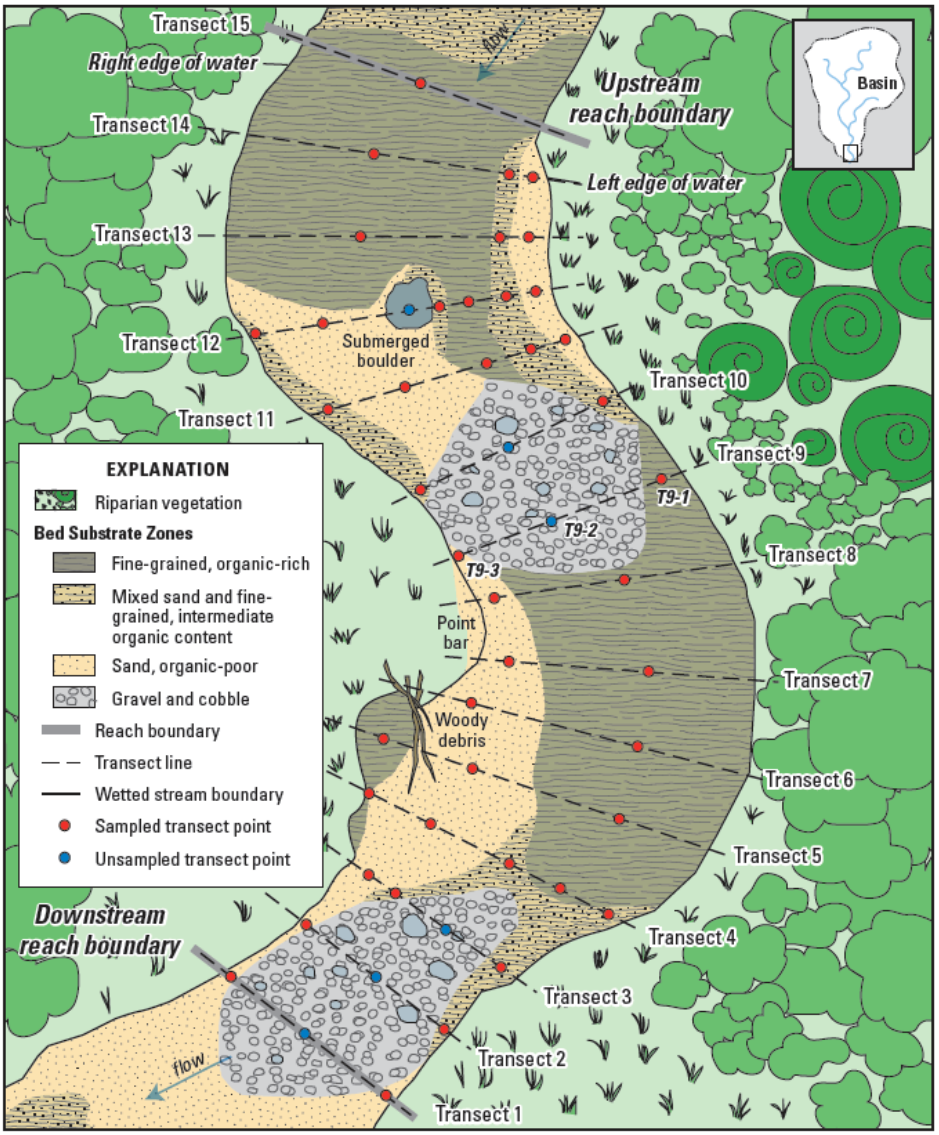


Figure 4. Diagram of simplified reach and point-sampling locations for transect sampling performed in association with reach characterization. Transect-point locations are at the cross-sectional midpoint of bed-substrate zones. Point numbering is indicated for transect 9 only; numbering strategy is identical for each transect. [T, transect number; left-most point is always 1]

(USGS, 2008)

4.4.5 Sediment Sampling Methods

The two most common sample types used for sediment sampling are discrete (grab) samples and composite samples. Composite sampling involves physically combining several grab samples. To ensure that the composite represents an average of the discrete samples comprising it, each of the discrete samples must be similar in terms of water content and volume. Note that composite sampling should not be used where the samples will be analyzed for volatile organic compounds.

A composite sample from a sub-area or along a transect provides no information on concentration variability within the area from which the samples were taken. Further, a composite result

contains no information about sampling precision or accuracy. Replicate composites at a subgroup of the transects or areas sampled can provide a qualitative indication of precision. Similarly, replicate discrete samples collected at a few transects along with the subsamples that are composited can provide an indication of concentration variability.

4.5 Surface Water Sampling

In surface water, particularly in rivers and streams, concentrations of contaminants from sites are generally quite low. Nevertheless, human or ecological exposures to low concentrations over an extended period of time may pose a significant risk in certain cases. For example:

- If the surface water in question is used as a drinking water source, low concentrations of toxic chemicals could pose a risk of harm to health.
- If the contaminants are bioaccumulative toxins such as mercury or PCBs, fish and shellfish may accumulate enough to result in tissue concentrations that may be harmful to the fish/shellfish itself or to piscivorous wildlife or people who eat the fish or shellfish.
- Where groundwater is discharging to sediment, contaminants may pose a risk of harm to benthic organisms or other organisms exposed at that location, for example fish eggs or amphibians.

4.5.1 Surface Water Heterogeneity

Surface water samples are often collected as though the water body is assumed to be well-mixed. In general, this is not a valid assumption. Concentrations of metals and other chemicals in surface water vary substantially over both time and space (U.S. EPA, 1982, 1995b; Cowgill, 1996). Neither flowing nor still water is perfectly mixed, although variability tends to be greater in streams and rivers than in lakes and ponds (Allan, 1995). An understanding of the potential variability in surface water constituent levels is crucial for designing surface water sampling plans to obtain representative samples and valid concentration estimates for risk assessment purposes.

"In most natural waters there is considerable heterogeneity, in both time and space, in the concentrations of constituents in the water column." (U.S. EPA, 1982, p. 2-1)

Sample collection, preparation, and analysis can also contribute to sampling error. However, these potential errors relate to sampling protocols, which as noted earlier, are beyond the scope of this document. Nevertheless, it is important to keep in mind that the very low levels of contaminants that may be of concern in surface water heighten the importance of taking precautions to avoid sample loss or cross-contamination.

In the guidance on representative soil sampling (U.S. EPA, 1995b), the Agency has identified a number of factors that affect both temporal and spatial variability including:

- Stratification, which can be thermally or chemically induced;
- Current, which can distribute contaminants over a larger area;
- Storm events, which can either increase contaminant concentrations from runoff and/or decrease concentrations by dilution;
- Time of year, which can increase mixing by thermal inversion in lakes and ponds. In rivers and streams, seasonal changes in precipitation control the volume and flow;

- Circulation, which may result from either wind or density gradients. Shallow lakes are most susceptible to mixing by wind;
- Varying flow velocity (across or within the cross-section of the water body), which can lead to non-homogenous mixing;
- Turbidity, which transports contaminants adsorbed onto fine sediments; and
- Salinity and tidal influence, which affect the distribution of contamination in estuaries.

Different water bodies are affected in different ways by these forces, and the magnitude and spatial scale of variation is unique to each. A general understanding of how each condition listed above affects different water bodies is the key to planning site-specific sampling projects that take variability into account and produce representative results.

Another aspect of variation that deserves more attention than it usually receives is the variation in habitat features within water bodies. Aquatic organisms use different areas and/or depths of a water body in very different ways. Some regions of the water column harbor a greater diversity and density of organisms than others. Some provide habitat for organisms of special concern, such as freshwater mussels. Such areas may warrant separate sampling and data analysis procedures.

The three sections that follow discuss temporal and spatial variability in contaminant concentrations and variation in habitat features in more detail.

4.5.1.1 Surface Water Spatial Variability

Given that both flowing, and still surface water are subject to changes likely to alter constituent concentrations at any one location over time, it would be difficult in practice to quantify spatial and temporal variability separately. Concentrations at any one location are changing constantly. As described in the preceding section, spatial variability in surface water concentrations is a result of a combination of spatial and temporal factors.

U.S. EPA has suggested two ways of dealing with the surface water heterogeneity when characterizing surface water concentrations (U.S. EPA, 1982):

- *Take a number of grab samples from the area or cross section of interest (See Box 4-4).*
- *Take areal composite samples to represent the average concentration within the area cross section of interest.*

More detailed guidance on collecting composite samples is provided in U.S. EPA guidance (U.S. EPA, 1995b).

Box 4-4
Surface Water
Grab vs. Composite Samples

A *grab* sample is a discrete sample from one specific sampling location at a specific point in time.

A *composite* sample is a non-discrete sample composed of two or more grab samples (of equal volume) collected at various sampling points or times.

The concentration of a chemical constituent in a composite sample is essentially the average of concentrations in the grab samples that make up the composite.

Spatial variability of surface water contaminant concentrations is observed over depth as well as area. In practice, spatial variability is often overlooked, and surface water is typically treated as though it were completely mixed (i.e., a single grab sample is taken to represent a stream segment). However, the concentration measured in a single sample is unlikely to prove a reliable estimate of concentrations present in the area of concern. Any surface water sampling effort should be designed to account for spatial variations in surface water.

The concentrations of contaminants in samples collected from different depths in the water column can vary appreciably. Often the highest concentrations are detected just above the sediment bed, where higher levels of contaminants associated with particulate matter are likely to be present. However, this may not always be the case, as some chemicals may concentrate preferentially in other distinct areas. A decision about sampling depth is required when samples are being collected to compute the average concentration for a river or stream segment or for a lake or pond.

4.5.1.2 Surface Water Temporal Variability

Surface water quality variation over different time scales can be significant. While chemicals in surface water vary continuously over time, most research has focused on variations measured over a 24-hour period (diel variation) and over a year (seasonal variation). Over a 24 hour period, concentration differences of two- to three-fold have been reported (Sherrell & Ross, 1999). Seasonal concentration differences of up to two orders of magnitude have been observed in streams. If the sampling project is focused on estimating an average concentration over time or identifying trends, samples should be collected from the same locations over time.

4.5.1.3 Habitat and Biological Variability

Within a lake, pond or river, there are a number of different zones providing different ecological services and calling for separate consideration in the sampling plan. Two examples are highlighted below:

The littoral zone of lakes, ponds, and oceans

The littoral zone is the area between the shore and the limit of the depth where sunlight and warm, well-mixed surface water reach down to the lakebed. This zone is characterized by high levels of biological diversity, density, and productivity. The shallow waters of the littoral zone are inhabited by most types of insects, snails, worms, crustaceans, and fish (Horne & Goldman, 1994). When surface water samples are collected for ecological risk assessment purposes, the littoral zone should be evaluated separately from the deeper, more sparsely populated water further from shore in the pelagic zone.

The Transition Zone Between Groundwater and Surface Water

The transition zone consists of the interface between groundwater and surface water. Where a surface water body receives recharge from groundwater, transition zone groundwater begins to mix with surface water in some cases beneath the surface of the sediment. In this zone, undiluted groundwater mixes with partially diluted groundwater, and groundwater contaminants are more concentrated in the transition zone than in the surface water. Physical, chemical, and biological conditions in this transition zone have implications for characterizing fate and transport, the nature and extent of contamination and ecological risk. Organisms exposed to transition zone groundwater include invertebrates, worms, bivalves, and fish larvae. As a consequence, where a groundwater plume is discharging to a surface water body, sampling sediment pore water and surface water just above the sediment can be a crucial component of the ecological risk

assessment. U.S. EPA has provided an overview of assessment considerations in an Eco Update (U.S. EPA, 2008).

4.5.2 Surface Water Sampling Objectives and Strategies

In the course of conducting site assessment and remediation to meet the requirements of the MCP, surface water samples may be collected for one or more purposes. Examples of surface water sampling objectives include, but are not limited to:

- To compare the concentration of surface water contaminants attributed to the site with background or local conditions (Chapter 6);
- To estimate current exposure point concentrations for site-specific risk assessment;
- To identify concentration gradients with distance from the site in question;
- To identify a temporal trend, for example to evaluate the efficacy of a remedial action; and/or
- To determine whether the concentrations exceed surface water standards.

The optimal approach to accounting for temporal and/or spatial variability depends in part upon the sampling objective, as well as hydrological, physical, chemical, and biological conditions within the water body in question (UNESCO/WHO/UNEP, 1996). The following are some of the basic principles to keep in mind when designing a sampling plan:

- To obtain a representative average concentration in an area of contaminated surface water, samples must be taken in a way that accounts for spatial variability within the area of interest and temporal variability within the time period of interest (310 CMR 40.0926(11)).
- If a focus of the study is the spatial distribution of contaminants, the number of sampling points is crucial.

- The samples must be sufficient to capture the temporal variability over the period being assessed.

  - If conditions during a particular season are of interest, sampling should be conducted to capture the potential variability of conditions across the season of concern.
  - If long-term exposure conditions are of interest, sampling must account for both daily and seasonal variation.

- When the purpose of a sampling project is to determine whether contaminant concentrations are trending downward, the frequency and duration of sample collection is key to detecting a trend despite daily and/or seasonal variations. Trend-monitoring data are useful for assessing the efficacy of clean-up activities in surface waters. Discerning a trend in surface water contaminant concentrations will usually require at least ten years of monitoring. The errors inherent in estimates of average concentrations are substantial, so only large changes in water quality can be detected over short time periods.

- Whether or not grab samples can be composited depends upon the site conditions and the sampling objective.

- Decisions about sampling location and depth, sample type (i.e., discrete or composite), and data averaging must consider the life history and feeding guilds of aquatic organisms.

Some examples of surface water sampling approaches for different objectives are provided below in Table 4-4. For a more detailed discussion of sampling decisions, please refer to the United Nations Guidance on surface water sampling (UNESCO/WHO/UNEP, 1996).

Table 4-4
Some Examples of Surface Water Sampling Approaches for Different Objectives

Objective	Possible Surface Water Sampling Approach
To estimate the average concentration of contaminants in a pond or lake -	Establish a sampling grid to guide sample collection in the affected area. Samples from within the area known to be affected can be composited prior to analysis to obtain an average. For deeper bodies of water that may undergo stratification, corresponding samples from different depths should be collected and analyzed. Samples collected from the littoral zone (near shore), which is generally characterized by higher biological activity, should be analyzed separately.
To characterize the distribution of contaminants in a lake or pond -	Establish a sampling grid to guide sample collection in the area of interest. To distinguish between more and less contaminated areas, and to identify areas that may not be contaminated, do not composite the grab samples.
To estimate the average concentration of a contaminant in a segment of a river -	Establish at least 5 parallel transect lines across the river or stream segment known to be affected by the site. Collect 4 to 6 grab samples from equidistant points along each transect. Combine the grab samples collected along each transect to obtain a total of 5 composite samples for analysis. Calculate the arithmetic mean from the 5 results.
To compare surface water contaminant concentrations in flowing water to background levels -	Establish at least 5 parallel transect lines upstream of the site (i.e., background or local conditions) and 5 across the river or stream segment suspected to be affected by the site. Collect a composite sample from each transect, each consisting of three to five grab samples taken from equidistant points along each transect.
To assess the potential effects of the contamination on fish passage in a stream or river -	Establish a at least 5 parallel transect lines across the river in the affected area. Collect 4 to 6 grab samples from each transect.
To assess potential effects on aquatic organisms in the transition zone, where contaminated groundwater is discharging through the sediment into the surface water -	Discrete surface water samples should be collected in the discharge area as near to the sediment bed as possible. The results should not be averaged with samples further away from the transition zone or further above the sediment bed.
To compare surface water in the vicinity of the site to the Applicable and Suitably Analogous Standard(s) (e.g., surface water quality standards)	The sampling strategy should aim to estimate the average concentrations of constituents in the affected area of the lake, pond, river, or stream. The average concentration should be compared to the applicable standard.

4.5.3 Filtering Surface Water Samples

In some cases, it is appropriate to filter water samples prior to analysis. For example, surface water samples intended for comparison to standards for dissolved constituents should be filtered. However, samples collected to estimate exposures for ecological risk assessment should not be filtered because aquatic organisms are exposed to surface water containing sediment particles that are associated with adsorbed contaminants.

4.6 Groundwater Sampling

4.6.1 Sampling to Evaluate Contaminant Impacts on Private Water Supply Wells

Within a GW-1 area, the risk assessment should address the risks associated with any well in use, existing wells not in use, and the foreseeable risks from the installation of a private supply well anywhere within the contaminated area. Thus, groundwater sampling projects should include both existing wells and the groundwater at any location where a well could potentially be installed based on the CSM (Chapter 2).

Drinking water and potential drinking water should be sampled at least quarterly for at least one year to characterize seasonal variation and to obtain data that can be used to estimate average daily dose over time.

4.6.2 Sampling to Evaluate Contaminant Impacts on Public Water Supply Wells

Where groundwater contamination from a site is impacting or could impact a public water supply well, the groundwater itself is the Exposure Point for both Method 1 and Method 3 Risk Characterization calculations (310 CMR 40.0924(6)(a) and (b)2.). While the concentrations of contaminants at drinking water supply wells are important, the MCP risk assessment should focus on protecting the groundwater as a drinking water resource. Therefore, when calculating the risk, the EPCs are measured groundwater concentrations. One exception to this rule is for petroleum contamination in an area that is designated as GW-1 to protect a public water supply (i.e., a Zone II). In such cases, the Exposure Point is the existing Public Water Supply well (see 310 CMR 40.0924(6)(c) for additional requirements).

Where groundwater petroleum contamination in a Zone II has not yet reached the Public Water Supply well, the future EPCs must be estimated. In some cases, a computational model may be needed to estimate future concentrations at a public supply well. In any case, the groundwater sampling plan should be designed to ensure that drinking water exposures are not underestimated. Groundwater modeling guidance is beyond the scope of this document, but Chapter 10 briefly discusses guidance on models published by the National Academy of Science and U.S. EPA (NAS, 2007; U.S. EPA, 2009).

Drinking water EPCs should not be based on existing or assumed water supply system management actions undertaken by the supplier to reduce concentrations in the distributed water. In other words, under the MCP, EPCs for baseline risk assessment purposes should represent pre-mixing, pre-treatment conditions (i.e. raw water, not treated water). Neither mixing nor well head treatment is considered a component of a Permanent Solution under the MCP.

4.6.3 Groundwater Sampling to Evaluate Impacts on Surface Water

All groundwater is classified as GW-3, so potential discharge of contaminants to surface water must be addressed wherever site-related contamination has reached or is likely to reach groundwater. Depending on the site setting, two points about contaminated groundwater transport to surface water may have to be addressed:

- Where site-related groundwater contamination is present at a considerable distance from a surface water body, is it likely to reach the surface water eventually? Answering this question may call for mathematical modeling. In such cases, groundwater sampling at the site must be sufficiently rigorous to obtain valid source term(s) for the model and must be documented.

- Where site related groundwater contamination could be present in the vicinity of the surface water, sampling must be sufficiently rigorous to support decisions about whether the surface water and/or sediment must be sampled in accordance with 310 CMR 40.0904(2)(c), which states:

> *Concentrations of oil and hazardous material in the sediment and/or surface water must be measured in any of the following circumstances to determine whether such material at or from the site has been or is being transported in a manner that would result in surface water or sediment concentrations of potential ecological significance, unless the need for such measurements is obviated by a technical justification consistent with 310 CMR 40.0193:*
>
> *1. Hazardous materials at or from the site, excluding VOCs, are present in groundwater within 200 feet of a surface water body;*
> *2. Hazardous materials at or from the site, excluding VOCs, are present in the groundwater at concentrations higher than the GW-3 standard(s) within 500 feet of a surface water body;*
> *3. Nonaqueous Phase Liquid (NAPL) at or from the site is present within 200 feet of a surface water body;*
> *4. Historical evidence indicates past discharge or dumping of oil or hazardous material from the site to the surface water body, unless such discharges were permitted;*
> *5. Evidence indicates current or past runoff of oil or hazardous material from or with site soil into the surface water body; and*
> *6. Site-specific conditions indicate that oil or hazardous material from the site may reasonably be expected to be present in the sediment or surface water at concentrations of potential ecological significance.*

To justify *not* sampling surface water or sediment in the vicinity of a site, groundwater samples for relevant contaminants must be collected from locations consistent with the criteria at 310 CMR 40.0904(2).

4.6.4 Minimizing Turbidity in Groundwater Samples

The nature of the samples analyzed to obtain EPCs at private water supplies should represent, as closely as possible, the nature of the water drawn from the wells in question. Often the water drawn from a private supply well is unfiltered, so, in theory, unfiltered groundwater samples from monitoring wells should be used to estimate potential EPCs. However, monitoring wells, especially newly developed monitoring wells, can produce samples that are quite turbid, and are not representative of water that would be drawn from a supply well.

To minimize turbidity, proper construction and development of wells along with low-flow/low stress sampling techniques are necessary. If turbidity issues persist, split filtered/non-filtered samples should be obtained, and the risk assessor must explain when filtered data is sufficiently protective. Simply filtering the samples is not recommended, as it can introduce a negative bias, especially in bedrock wells where colloidal/particulate transport is possible.

4.7 Indoor Air Sampling

In 2016, MassDEP published *Vapor Intrusion Guidance: Site Assessment, Mitigation and Closure* (MassDEP, 2016a). This document outlines MassDEP's recommendations for acceptable sampling practices that meet regulatory requirements. It provides guidance for evaluating the vapor intrusion pathway, assessing indoor air exposure and risk, and mitigating vapor intrusion conditions. This section focuses on indoor air sampling considerations related to assessing exposure and risk.

Key recommendations on sampling to assess exposure provided in the 2016 guidance include:

- A 24-hour sampling time for residential buildings to capture the fluctuations in indoor air concentrations due to changing conditions throughout the day and night, recognizing that longer sampling periods provide more representative data but are sometimes not practical.
- An 8-hour sampling period for commercial buildings during regular business hours, unless business activities could contribute VOCs to the indoor air.
- Multiple rounds of indoor air sampling across several seasons in order to address the considerable temporal variability associated with vapor intrusion with at least one sampling round during worst-case conditions, which typically occurs in late winter or early spring.
- Greater sampling frequency for more sensitive receptors in places like daycares, schools, and residences, with at least two to four rounds of indoor air samples before determining that a vapor intrusion pathway does not exist.
- At least two indoor air sampling rounds for commercial and industrial buildings to obtain sufficient information to make decisions about the presence of a vapor intrusion pathway. The sampling rounds should be obtained over at least two different seasons, one of which is winter, to obtain an estimate of long-term conditions and chronic exposure.
- In residential buildings, as applicable, assessment of concentrations and levels of risk in different exposure locations.

Previously, in 2002, MassDEP published an indoor air sampling guidance prepared by MassDEP's Office of Research and Standards (MassDEP, 2002b). That document lays out ideal sampling durations to obtain representative concentrations for estimating chronic, sub-chronic, and acute exposures. It also emphasized the importance of sampling duration and frequency in covering changes in conditions and concentrations that might occur on a seasonal, daily, or hourly basis. The 2002 guidance remains a useful reference for evaluating the sources of uncertainty inherent in indoor air data. Additionally, the Wisconsin Department of Natural Resources (WI DNR) has published guidance on the investigation of preferential pathways for vapor intrusion (WI DNR, 2021).

4.8 Sampling to Identify or Delineate Hot Spots in Soil or Sediment

Hot Spots are a special case of non-randomly distributed concentrations. They are usually small areas with relatively high contaminant concentrations. The potential for Hot Spots to exist at the site should be considered in planning the sampling locations and sampling density. In the risk assessment, Hot Spots should be evaluated separately as distinct exposure points (310 CMR 40.0924(11)(a)).

The MCP (310 CMR 40.0006) defines a Hot Spot as follows:

> *Hot Spot means a discrete area where the concentrations of oil or hazardous*

material are substantially higher than those present in the surrounding area. A Hot Spot shall be identified based on consideration of both the concentration of an oil or hazardous material within a contaminated area and the spatial pattern of that contamination. The areal extent and spatial pattern of a hot spot may be determined through the analytical results from multiple samples taken within the area, or the results of limited sampling in combination with other knowledge about the release, such as the presence of discoloration, odors or a defined source area. Discrete areas where the average concentration within the area is greater than ten but less than one hundred times the average concentration in the immediate surrounding area is a Hot Spot unless there is no evidence that the discrete area would be associated with greater exposure potential than the surrounding area. In all cases, a discrete area where the concentration of an oil or hazardous material is greater than one hundred times the concentration in the surrounding area shall be considered a Hot Spot. In no case shall concentrations of oil or hazardous material equal to or less than an applicable Method 1 standard be considered indicative of a Hot Spot.

An elevated concentration at a single sample location does not necessarily constitute a Hot Spot. However, an elevated concentration in a single sample may indicate the presence of a Hot Spot and the need for further sampling in that area. In deciding whether an exceptionally high result should trigger additional sampling, the investigator should consider: (1) the density of the existing sampling locations; (2) the magnitude of the spike relative to the concentration variability in the nearby samples; and (3) the site history.

Samples collected to identify or define a potential Hot Spot should be located such that a Hot Spot will not be missed if present. Where a cluster of high concentrations has been identified as a potential Hot Spot, the data set used to calculate the average Hot Spot concentration should be limited to the area exhibiting clearly elevated concentrations. The average concentration of the potential Hot Spot should not be artificially reduced by the inclusion of lower concentrations from the wider surrounding area.

It is important to remember that a Hot Spot is an area, not a sampling point. For example, detection of an elevated level at one point in a sampling grid does not necessarily mean that the grid square is a Hot Spot. When an elevated concentration is detected at a sampling location and suggests the possible presence of a Hot Spot, further sampling is necessary. Contaminant concentrations at waste sites are highly variable, and the detection of an elevated concentration may simply reflect that variability, and not the presence of a Hot Spot. As a consequence, removal of soil from a location where a high concentration was detected in a single sample may be unnecessary. Worse, simply dropping a single high concentration from a data set is likely to lead to an underestimate of the mean concentration in the area.

4.9 Nonaqueous Phase Liquid Sampling

Nonaqueous phase liquid (NAPL) has been found to be present in groundwater, soil, and/or sediment at numerous waste disposal sites in Massachusetts. The types of NAPL most often present and the exposures of greatest concern are media-dependent. For example:

- In soil and sediment, the most common types of NAPL are petroleum products and coal tar wastes.

- In sediment, risk of harm to aquatic organisms, specifically benthic (sediment-dwelling) organisms, mainly by habitat degradation or smothering is the primary concern.

- In soil, the risk of harm to human health posed by direct contact and/or inhalation exposures is typically the major concern.

- In groundwater, two categories of NAPL may be present: light nonaqueous phase liquids (LNAPL) and dense nonaqueous phase liquids (DNAPL).

    - The types of LNAPL found in groundwater are typically petroleum products. In 2016, MassDEP published comprehensive guidance on assessing LNAPL (MassDEP, 2016b).

    - The most common kinds of DNAPL found in groundwater are chlorinated organic solvents, which tend to sink to bedrock (or an impermeable soil layer, such as clay) and then spread laterally following the topography of that layer. DNAPL in an aquifer can be extremely difficult to assess and remediate.

Wherever NAPL is present at a site subject to the MCP, the nature, distribution, extent, and mobility of the free product must be fully characterized.

4.10 Characterizing Future Environmental Conditions

If changes in contaminant distribution are anticipated based on fate and transport evaluations, and if concentrations are likely to increase at the exposure point, contaminant concentrations under future environmental conditions may have to be evaluated in addition to present conditions. Future concentrations cannot be measured and must be modeled or estimated.

Biodegradation may be an important attenuation mechanism at some sites, although predicting degradation rates that will actually occur in the field at a specific site is complex and depends on several geochemical and hydrologic factors. The application of degradation rates observed under controlled laboratory conditions to field conditions can lead to significant underestimation of future concentrations. For risk assessment purposes, the assumption that the concentrations will be decreased at a certain rate by biodegradation is discouraged.

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MassDEP Guidance for Disposal Site Risk Characterization

Part 1 – General Site Characterization to Support Assessment (Contd.)

Chapter 5
Chemical Analysis

5.0 Chemical Analysis

5.1 Introduction

Assessment of exposures and risks at a waste site begins with identifying and quantifying contaminants present in areas where people or wildlife are exposed to contaminated media. The validity of the exposure assessment and its utility in managing risk depends in part upon the reliability of the chemical analysis data. As discussed in Chapter 2, data quality should be evaluated using the conceptual site model. While Chapter 4 focused on the data quality aspects of sample collection, Chapter 5 provides information that will assist in planning chemical analysis and evaluating the resulting data.

This section focuses on contaminant concentrations in environmental media such as soil and groundwater that may pose a risk to human health or the environment. Supplementary data often used in risk assessments include the hardness of surface water and the organic carbon content of sediment. Such supplementary parameters will be described in more detail elsewhere in this document, primarily in Part 3 (Ecological Risk Assessment).

5.2 Analytical Data Quality

Data quality is a crucial consideration at two points in the assessment process:

- When analytical methods are being selected, the ability of a candidate method to produce data that is fit for the purpose of the assessment must be considered in order for the method to be applied.
- After analytical results are reported by the lab, the data must be evaluated to determine the reliability of the results and the level of uncertainty associated with them.

Only if data quality is considered carefully at *both* points, will the resulting analytical data fully meet the objectives of the sampling project. While final MCP site assessment reports almost always include information on the quality of the analytical data being used, consideration of data quality in the planning process is not usually discussed because MassDEP does not require submittal of project plans. Nevertheless, careful planning is necessary to ensure that sample collection and analysis will provide defensible data.

"Unless some form of planning is conducted prior to investing the necessary time and resources to collect data; the chances can be unacceptably high that these data will not meet specific project needs." (U.S. EPA, 2006)

5.2.1 MCP Data Quality Requirements

The Massachusetts Contingency Plan (MCP) contains general performance standards referred to as Response Action Performance Standard (RAPS). The MCP (310 CMR 40.0191(1)) states:

> *The Response Action Performance Standard is the level of diligence reasonably necessary to obtain the quantity and quality of information adequate to assess a site and evaluate remedial action alternatives, and to design and implement specific remedial actions at a disposal site to achieve a level of No Significant Risk....and, where feasible, to reduce to the extent possible the level of oil and/or hazardous material in the environment to background levels.*

Accordingly, the investigation and cleanup measures may vary from site to site, but in each case, they must be sufficient to meet the goal of determining and achieving a condition of "No Significant Risk". Through the application of the performance standard, the MCP supports the use of professional judgment in selecting the analytical method most appropriate for a specific purpose.

Requirements for the acquisition, analysis, and reporting of the analytical and environmental monitoring data used to support MCP response actions are provided in two sections of the MCP:

310 CMR 40.0017

Procedures and methodologies employed for the collection and analysis of soil, sediment, water, vapor, air, and/or waste samples shall consist of:

> *(a) methods published by the Department, EPA, the American Society for Testing and Materials (ASTM), the American Public Health Association (APHA), the National Institute for Occupational Safety and Health (NIOSH), the American Water Works Association (AWWA), and other organizations with expertise in the development of standardized analytical testing methods;*
> *(b) modification of published methods, provided that all modifications are completely documented; or*
> *(c) unpublished methods, including analytical screening methods, provided that such methods are scientifically valid, are of a known and demonstrated level of precision and accuracy, and are completely described and documented in response action submittals.*

310 CMR 40.0191(2)

RAPS shall be employed during the performance of all response actions conducted pursuant to 310 CMR 40.0000, and shall include, without limitation, the following:

> (*a) consideration of relevant policies and guidelines issued by the Department and EPA;*
> *(b) use of accurate and up-to-date methods, standards and practices, equipment and technologies which are appropriate, available and generally accepted by the professional and trade communities conducting response actions in accordance with M.G.L. c. 21E and 310 CMR 40.0000 under similar circumstances; and*
> *(c) investigative practices which are scientifically defensible, and of a level of precision and accuracy commensurate with the intended use of the results of such investigations*.

While MassDEP certifies laboratories for drinking water analysis, there is no certification process for soil, groundwater or EPH/VPH/APH analysis. Risk assessors using data for which a laboratory is not certified may want to consider conducting periodic detailed audits on lab work products to ensure sufficient quality. Such audits should be conducted by experienced validators.

5.2.2 Compendium of Analytical Methods

To facilitate compliance with the requirements of the MCP, MassDEP has published the *Compendium of Quality Control Requirements and Performance Standards for Selected Analytical Protocols* also referred to as the CAM (MassDEP, 2010). The CAM is a series of recommended protocols for the acquisition, analysis, and reporting of MCP-related analytical data (MassDEP, 2007). It provides the regulated community with a compilation of recommended laboratory protocols for generating analytical data used to support risk assessment and evaluation decisions at disposal sites regulated under M.G.L. c. 21E and the MCP. These laboratory protocols include recommended analytical methods, reporting limit requirements, method-specific Quality Control (QC) requirements and performance standards. Compliance with the QC requirements and performance standards for these protocols will result in analytical data that will be presumed to meet the performance standards of the MCP (presumptive certainty). If an alternative (non-CAM) analytical method is chosen to support MCP decisions, the data user is responsible for independently demonstrating the accuracy, precision, sensitivity, representativeness, and overall usability for all analytical data pursuant to the requirements of 310 CMR 40.0017, 310 CMR 40.0191(2), and 310 CMR 40.1056(2)(k).

5.2.3 MCP Representativeness Evaluations and Data Usability Assessments Guidance

All data (with or without presumptive certainty) must be assessed for usability and representativeness in comparison to project objectives as specified in 310 CMR 40.1056(2)(k) and further described in the MassDEP's *MCP Representativeness Evaluations and Data Usability Assessment*s (REDUA guidance) (MassDEP, 2007). The REDUA guidance may be used to prepare representativeness evaluations and data usability assessments required as part of Permanent Solution submittals made pursuant to 310 CMR 40.1056(2)(k) of the Massachusetts Contingency Plan (MCP):

310 CMR 40.1056(2)(k)
2. Except as provided in 310 CMR 40.1056(4), all documentation, plans and/or reports necessary to support the Permanent Solution shall be submitted to the Department with the Permanent Solution Statement, including, without limitation, the following:

> . . .
> *(k) a Data Usability Assessment documenting that the data relied upon is scientifically valid and defensible, and of a sufficient level of precision, accuracy, and completeness to support the Permanent Solution, and a Data Representativeness Evaluation, documenting the adequacy of the spatial and temporal data sets to support the Permanent Solution . . .*

The CAM and REDUA policy documents combined encompass the bulk of MassDEP's guidance on chemical analysis and the analytical data interpretation. For the most part, the content of those documents is not repeated in this guidance. The remaining sections of this chapter focus on additional technical considerations intended to help the investigator meet the requirements of the MCP.

5.2.4 U.S. EPA Data Quality Guidance

As noted previously in Chapter 4, over the past several decades U.S. EPA has published numerous guidance documents for comprehensive and systematic project planning that is oriented toward meeting specified objectives. The U.S. EPA guidance calls for extensive evaluation and detailed documentation that is not required under the MCP. Nevertheless, U.S. EPA guidance contains valuable information on planning and implementing logical, efficient, and effective projects. It is therefore recommended that site investigators become familiar with U.S. EPA's recommended principles and practices, and to adopt them for use at specific MCP sites as appropriate. Relevant aspects of the guidance documents are discussed herein.

To make data quality expectations clearer and to provide a resource for evaluating the quality and relevance of information, U.S. EPA has identified "General Assessment Factors" (GAFs) (U.S. EPA 2003, 2006). These factors encapsulate existing U.S. EPA data quality guidelines, and are defined as follows:

- Soundness - The extent to which the scientific and technical procedures, measures, methods or models employed to generate the information are reasonable for, and consistent with, the intended application.
- Applicability and Utility - The extent to which the information is relevant for the intended use.
- Clarity and Completeness - The degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations and analyses employed to generate the information are documented.
- Uncertainty and Variability - The extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, methods, or models are evaluated and characterized.
- Evaluation and Review - The extent of independent verification, validation, and peer review of the information or of the procedures, measures, methods, or models.

The GAFs were developed to assist in evaluating individual pieces of data. It was subsequently suggested that they may also be useful in a weight of evidence analysis. If used for that purpose, MassDEP believes they should be applied qualitatively to describe the strengths and weaknesses of different types of data.

Box 5-1
The Origin of EPA's General Assessment Factors (GAFs)

To comply with guidance and requirements published by OMB (OMB, 2002), U.S. EPA published the EPA Information Quality Guidelines (U.S. EPA, 2002).

The EPA 2002 IQG set forth an implementation plan, including general policies and procedures for ensuring the quality of information generated, used or published by EPA.

To complement the Information Quality Guidelines, U.S. EPA's Science Policy Council published *A Summary of General Assessment Factors* (GAFs) to make clear the Agency's data quality expectations for all information submitted to or published by the agency (U.S. EPA, 2003).

U.S. EPA has subsequently confirmed the adoption of GAFs by republishing them in other guidance (U.S. EPA, 2006).

Earlier data quality guidance published by U.S. EPA is more detailed and targeted to particular components of site assessment. The concepts described in such guidance still remains relevant. Of particular importance for chemical analysis is U.S. EPA's 1992 *Guidance for Data Useability in Risk Assessments* (Useability Guidance). The document contains a comprehensive discussion of data quality questions and criteria. Although that document was written for remedial investigations at Federal Superfund Sites, the principles of data quality evaluation contained in it are generally applicable to data produced for MCP site assessment purposes. The Useability Guidance provides an extensive discussion of quality assurance/quality control procedures for laboratory processes and data. This guidance includes the conventional data quality indicators, which are defined in Table 5.1.

"The General Assessment Factors are drawn from the Agency's [U.S. EPA's] existing information quality systems, practices and guidelines that describe the types of considerations EPA takes into account when evaluating the quality and relevance of scientific and technical information used in support of Agency actions." (U.S. EPA, 2003)

Table 5.1
Data Quality Indicators

Data Quality Indicator	Definition
Completeness	The amount of useable data resulting from a collection activity
Comparability	The confidence with which the data are considered to be equivalent.
Representativeness	The extent to which data define the true risk to human health and the environment.
Accuracy	A measure of the closeness of a reported value to the true value.
Precision	A quantitative measure of variability.

The REDUA guidance refers to these indicators as the PARCCS parameters. Appendix III of that document summarizes how the PARCSS parameters apply to the evaluation of data usability and any project-specific Data Quality Objectives (MassDEP, 2007).

5.3 Identifying Target Analytes

A basic question posed early in the site characterization process is, "What contaminants might be present?" Answering this question entails preparation of sampling and analysis project plans that are informed by knowledge of past and present chemical use in the vicinity of the site. A thorough review of site history, including ownership, operations, releases, use and storage of oil and hazardous materials, waste management and compliance history is required for Phase I Completion (310 CMR 40.0483(1)(c)) and is necessary to ensure that all potential site-related contaminants are included as target analytes.

Site history is an essential guide to the identification of target analytes.

It has been common practice to identify contaminants of potential concern for the risk assessment simply by focusing on the target analytes listed for standard methods (i.e. SW-846 methods for volatile and semi-volatile organic compounds and metals). While these broad-suite analyses are an important part of site characterization, this approach by itself may overlook pertinent site contaminants. Some contaminants, such as physiologically available cyanide, 1,4-dioxane, dioxin and furan congeners, total PCBs, perchlorate, and PFAS compounds will only be detected if deliberate decisions to target them are made in the early phases of site characterization.
The list of analytes targeted in chemical analyses may evolve as assessment activities progress and investigators accumulate information on what contaminants are present. Ultimately, contaminants to be included in the risk assessment are identified as Contaminants of Concern (COCs). Identification of COCs is discussed in Chapter 6.

5.3.1 Chemical Species

When identifying target analytes, it may be important to consider the form of the chemicals present. Different chemical forms are often associated with different health or environmental effects associated with the chemical. The absorption tendency and toxicity of a metal can differ significantly among oxidation states. For example, hexavalent chromium is more toxic than trivalent chromium, and methyl mercury is more toxic than inorganic mercury.

5.3.2 Impurities and Degradation Products

Many commercial and industrial chemical products contain additional compounds in considerable quantities. The presence of such compounds may appreciably increase the risk and could even pose a greater risk than the original compound of concern. Examples follow.

- Degradation products of tetrachloroethylene include trichloroethylene, cis-1,2-dichloroethene, and vinyl chloride.
- Dioxane is present in a number of chlorinated solvents. It is most prevalent in trichloroethylene.
- Polychlorinated dibenzodioxins are present in pentachlorophenol.
- Polychlorinated dibenzofurans can be formed by pyrolysis of some aroclors.
- Polychlorinated dibenzodioxins can be formed by pyrolysis of chlorobenzenenes.
- The dielectric fluids with the tradenames Pyranol and Inerten contained Aroclor 1260 (60 – 70%) mixed with trichlorobenzene (30-40%). These fluids may contain ppm levels of polychlorinated dibenzo furan. Pyrolysis of these fluids has been observed to produce 0.03% furan and 1.05 % dioxin.

The possible presence of impurities and degradation products should be considered in the sampling plan and in the selection of target analytes. If the data needed to evaluate the presence of potential co-contaminants are not available, additional sampling may be necessary.

5.4 Considering Uncertain and/or Qualified Data

5.4.1 Tentatively Identified Compounds (TICs)

Tentatively identified compounds (TICs) are compounds which are detected during sample analysis but are not target compounds. TICs are often reported when gas chromatography-mass spectrometry (GC-MS) is used to analyze organic compounds. Target compounds are those for which the instrument was calibrated, using a chemical standard, prior to analysis. The ability of the MS system to store mass spectra electronically in a "library" enables the analyst to compare the library spectra with the spectra produced by a non-target contaminant when one shows up in an environmental sample. Identification based on a "library" comparison is much more uncertain, however, than one based on calibration with a standard for the target compound. When compounds are identified in the sample, but the GC-MS instrument was not specifically calibrated for those compounds, they are designated as tentatively identified compounds (TICs).

All reported concentrations of TICs are, by definition, estimated values. The party conducting response actions may either accept the estimated TIC concentration without further qualification or improve the identification and the accuracy of the estimated concentration by post-calibration, re-sampling and/or re-analysis with a more appropriate analytical method. If the presence of the TIC at the concentration reported by the laboratory appreciably changes the overall risk posed by the site or the utility of the potential remedial measures under consideration, MassDEP recommends (and may require) the latter option be exercised.

There is no rule of thumb for whether TICs should be included in the risk assessment. Confidence in a TIC identification depends on a number of factors, including site history and the presence of similar compounds at the site. Many compounds that appear as TICs during broad spectrum analyses belong to compound classes. Examples of compound classes are saturated aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). The risk assessor may be able to make a preliminary judgment of toxicity at the compound class level without a definitive identification of each compound present.

The identification of a TIC can be confirmed definitively only by further analysis. However, depending on the analytical and historical information available, and the potential impact of the TIC on the results of the risk assessment, confirmatory analysis may not be warranted. The risk assessor should work with the project

manager and an analytical chemist to make a prudent decision about the need for follow-up analysis.

The following guidelines are offered in the Bureau of Waste Site Cleanup's *Compendium of Quality Control Requirements and Performance Standards for Selected Analytical Protocols* (CAM, MassDEP, 2010):

> *The evaluation of TICs in conjunction with GC/MS analyses (WSC-CAM-II A and WSC-CAM-II B) is a powerful and cost-effective analytical tool that can be particularly effective in assessing locations with suspect disposal practices, complex or uncertain site history, and/or sites that require detailed evaluation of critical exposure pathways. When GC/MS analytical methods are utilized in support of MCP decision-making, an analysis of TICs is:*
>
> ***Required** when drinking water samples are analyzed (Refer to WSC-CAM-VII A for a definition of "drinking water"),*
> ***Should be considered** in support of site characterization activities for releases at locations with complex and/or uncertain history,*
> ***Not usually expected at petroleum-only sites,***
> ***Not usually expected** when the contaminants of concern have been previously identified, and/or*
> ***Not usually expected** when used to determine the extent and magnitude of contamination associated with a "known" release of OHM.*

The data user (LSP) is responsible for determining when TICs must be reported and requesting that the laboratory include TIC analysis. The reader is referred to Appendix II A-3 of the CAM for more detailed requirements related to TICs.

5.4.2 Levels Below the Lower Analytical Limits

It is not uncommon for the risk assessor to be presented with analytical data for a chemical at the site which includes a number of samples reported to be present at levels below the lower limits of the analysis. Such results are commonly referred to as "non-detects." In some cases, the uncertainty carried into the risk assessment by non-detects can be mitigated by using a more sensitive analytical method. In others, the uncertainty can only be managed by the way non-detect results are handled in the risk characterization.

U.S. EPA has drawn a distinction between two kinds of analytical lower limits (U.S.EPA Region 3, 1991):

- A detection limit (DL) is "the lowest concentration that can be distinguished from zero, but is not quantifiable with acceptable precision."
- A quantitation limit (QL) is a level at which "the analyte is both proven present and measured reliably."

Over time, different governmental agencies have developed and applied different measures of analytical lower limits, giving rise to an alphabet soup of lower limits (See Box 5.2). For MCP purposes, MassDEP's Compendium of Analytical Methods (CAM) specifies the use of the reporting limits (RL), also referred to as lower limit of quantitation (LLOQ). The CAM describes the RL as being "empirically derived directly from the concentration of the lowest non-zero standard in the initial calibration, analyzed under identical conditions as the sample with adjustments for sample size, extraction concentration factor, percent solids, dilution factors, etc., as required." For each specific analytical method, the CAM provides the concentration (RL/LLOQ) that MassDEP deems acceptable for "presumptive certainty." The project manager should specify to the laboratory that the reporting limit must be achieved and reported with the results.

For each specific analytical method, the CAM provides the concentration (RL/LLOQ) that MassDEP deems acceptable for "presumptive certainty." The project manager should specify to the laboratory that the reporting limit must be achieved and reported with the results.

For risk assessment purposes, obtaining results that are below the analytical limit may be classified into two general situations.

- If a chemical is truly not present at the disposal site (virtually all the samples are reported as non- detects), and there is no history of a release of that chemical, then the risk assessor may conclude that the chemical should be dropped from the quantitative risk assessment.

- If the chemical is reported at the site at concentrations ranging from non-detect to some site maximum, the risk assessor may conclude that the reported non-detects actually represent a distribution of concentrations between zero and the quantitation limit. These non-detect results contribute to the information known about the disposal site and should be incorporated into the quantitative risk assessment in a meaningful way.

When the analytical result for a contaminant of potential concern is below the lower limit, data users should determine whether the sample was diluted. Samples may be diluted by a large factor if one or more constituents is known or expected to be very high. Sample dilution may cause contaminants that are present at the site at significant levels to be reported as below the quantitation or detection limit, leading to underestimation of exposures.

There are several options for the treatment of non-detects described in the literature, including the use of log-probit analysis, maximum likelihood estimation and probability plotting procedures. The level of effort and number of data points required to effectively employ these methods vary, and the risk assessor is encouraged to exercise professional judgment in the selection of a method to treat non-detect results.

Box 5-2
Examples of
Lower Analytical Limits

Reporting limit (RL) – Empirically derived directly from the concentration of the lowest non-zero standard in the initial calibration. The RL is a quantitation limit, below which the analytical result is considered unreliable. (MassDEP 2010).

Method detection limit (MDL) The minimum measured concentration of a substance that can be reported with 99% confidence that the measured concentration is distinguishable from method blank results (U.S. EPA 2017).

Limit of Detection (DL) – The minimum result, which can be reliably discriminated from a blank with a predetermined confidence level. The DL is similar to but less specific than the MDL. (NELAC, 2019).

Limit of quantitation (LOQ) - The level "at or above the lowest calibration standard (NELAC, 2019).

Instrument detection limit (IDL) includes only the instrument portion of detection, not sample preparation, concentration/dilution factors, or method-specific factors (U.S.EPA, 1992).

Sample quantitation limit (SQL) - The MDL adjusted to reflect sample-specific action such as dilution or use of a smaller sample aliquot for analysis (U.S.EPA, 1992).

Practical quantitation limit (PQL) - The lowest level that can be reliably achieved within specified limit of precision and accuracy during routine laboratory operations (U.S.EPA, 1992).

For estimating exposure point concentrations at most c.21E sites, the Department believes that a more straightforward approach is often appropriate. When a contaminant is detected or likely to be present in the area under investigation and the laboratory reports the concentration of an OHM in a sample taken from the area as below the lower limit of detection or quantitation, the concentration of the OHM in that sample may be assumed to be one-half of the lower limit. However, this method is not appropriate if a statistical test or estimation method is to be applied to the data set. The incorporation of non-detects into EPC estimates that use the 90th percentile Chebyshev non-parametric upper confidence limit (specified in 310 CMR 40.0926(8)(a)) is discussed in Appendix 4-B.

5.4.3 Modeled Concentrations

Concentrations estimated using a fate and transport model are inherently more uncertain than measured concentrations. Direct measurement of environmental concentrations is generally preferred, but estimation by a computational model may be acceptable when direct measurement is impossible or impractical. If a model is used, modeling methods, input parameters and assumptions, and model validation must be fully documented. The application of computational models is discussed in more detail in Chapter 10.

MassDEP strongly prefers measured concentrations to modeled concentrations, which should be used only when measurements are impossible or impractical.

5.5 Selecting Analytical Methods

When faced with a choice of potentially applicable analytical methods, project managers must exercise professional judgment consistent with the RAPS provisions of the MCP in selecting the appropriate method. Project managers must also use the CAM or justify alternate methods, as described in section 5.2.2. Above all, as discussed in Section 5.2, the quality of the data must be adequate for the specific purposes for which it will be used.

The remainder of this section focuses on two additional considerations when selecting the analytical method: sensitivity (detection limits) and type of method (field vs. fixed lab).

5.5.1 Considering Lower Limits when selecting Analytical Methods

A major consideration when selecting an analytical method is sufficient sensitivity to detect concentrations that would pose a risk. In other words, the analytical lower limit of the selected method must not be above concentrations of concern for the risk assessment.

The project manager must evaluate the relationship of the expected detection and quantitation limits to the lowest concentration that would pose a significant risk. This evaluation must be done before the samples are collected so that sampling and/or analysis plans can be adjusted if necessary. Analytical methods with detection limits well below concentrations of potential concern should be selected to ensure that the data are usable for the risk assessment.
When chemicals are reported at concentrations near the detection limit, the data have a greater possibility of containing false negative and false positive results. If detection limits of conventional methods are higher than or near concentrations of concern for the chemical(s) being evaluated, then an analytical chemist should be consulted to assist in identifying alternative methods.

5.5.2 Fixed Laboratory vs. Field Procedures

Data from various sources (different analytical procedures) may be used in a site investigation. The precision, accuracy and sensitivity of different analytical procedures can vary widely. Three main sources of analytical data are:

(1) **Fixed (stationary) laboratory analyses**, where procedures are conducted in commercial fixed (stationary) laboratories, under established quality assurance programs, with well documented QA/QC procedures, using published analytical protocols. In general, fixed laboratories can provide detailed information for a wide range of analytes and are fundamental sources of data for quantitative risk

assessment and site characterization.

(2) **Field laboratory analyses**, where procedures are conducted in field (mobile or temporary) laboratories located on or near the site, using equipment and protocols comparable to those employed in fixed laboratories. A field laboratory can provide defensible data for risk assessment if quality control procedures equivalent to those used in fixed laboratories are implemented.

(3) **Field screening techniques**, which are faster and less expensive than laboratory analysis, but generally entail compromises in overall data quality. They are usually done to provide a preliminary estimate of the type and concentration of chemicals of concern or to define the extent of contamination.

The differentiation of data sources outlined above is useful for the purposes of this document, but it is not a universally accepted categorization. Different fixed labs may also be considered different sources, as some laboratory settings are more amenable than others to implementing and documenting rigorous quality assurance/quality control (QA/QC) procedures. The key point is that data sources must be comparable for data to be combined for use in quantitative risk assessment, and evaluating comparability may require expertise in analytical chemistry.

Although there are exceptions, data from analyses done in commercial (fixed) laboratories are usually preferable to data from field labs because, in theory, fixed labs operate within an established quality assurance program. Comprehensive project-specific quality assurance documentation and review is needed to demonstrate equivalency of field lab data with fixed lab data. (Note that most of the gas chromatography work that is currently conducted in the field falls into the screening category, and it is not considered field analysis.)

Field screening procedures can produce data of acceptable quality for limited purposes. Compared with protocols carried out in fixed or field laboratories, screening methods involve some procedural compromises or shortcuts. While screening procedures may not meet all the data quality criteria that apply to definitive analyses conducted by a fixed lab, they can nevertheless be an efficient, cost-effective way to answer certain questions. One example of a useful screening shortcut is measuring concentrations in one medium to estimate concentrations in a different medium, as is done in headspace screening of contaminated groundwater or soil. Another is the use of sample preparation/extraction techniques that are less rigorous than those followed in a laboratory. One very common compromise is the use of simple instrumentation that does not produce substance-specific results, for example organic vapor analyzers. Such techniques save either time or money or both, but they impose some limitations on data applicability, as noted above.

The applicability of screening data at a particular decision point depends on the match between the data quality characteristics of the screening data in question and those that are relevant to the decision point of concern.

To decide whether a specific screening method is a technically sound approach at any point in a site assessment, the assessor must think about exactly what kind of information is needed to answer the specific question. The assessor must determine whether the data quality characteristics of the screening data match the data quality needs for the decision point in question. Every screening method has certain limitations relative to standard laboratory techniques. If the limitations of a proposed screening method are not relevant to the question at hand, then the screening data are *effectively equivalent to lab data for the purpose in question*.

For example, suppose that data were needed to determine the bounds of the area contaminated by specific substances. From a regulatory perspective, the most important data quality characteristics are analytical sensitivity to the contaminants of potential concern. The detection limit of the selected method should be lower than the lowest concentration of concern, so that the probability of false negatives is decreased. The precision should be good enough so that analytical variability does not produce false negatives for sampling locations where the concentration is actually substantially higher than the detection limit. A screening procedure that is sufficiently sensitive and precise should provide data essentially equivalent to commercial laboratory data *for the purpose of determining where the contamination is present and where it is absent*. The problem of delineating the extent of a release is similar to determining the presence or absence of contamination, and the same considerations apply.

From MassDEP's viewpoint, screening methods are frequently useful (supplementing fixed lab data) at decision points related to preliminary *delineation* of contamination, but seldom applicable for decisions related to *characterization* of contamination. MassDEP considers all of the data quality characteristics of CAM-compliant data relevant for characterizing contamination and estimating exposures, while a more limited subset of data quality characteristics may be relevant for delineating contaminated areas. Two of the decision points presented in Chapter 4, *estimating Exposure Point Concentrations* and *comparing site concentrations to background levels*, always require complete characterization of contamination; therefore these determinations usually cannot be accomplished using screening techniques.

5.6 Analytical Data Presentation

As specified in 310 CMR 40.0835, the documentation supporting the risk characterization should describe the nature and extent of contamination, including a characterization of sources, nature, and vertical and horizontal extent of contamination at the disposal site; presence and distribution of any non-aqueous phase liquids; tabulation of analytical testing results; and, where appropriate, characterization of background concentrations of oil and/or hazardous materials at the site. Further, the documentation of the risk assessment should contain summary tables which clearly indicate which oil or hazardous materials at or from the disposal site have been identified in each medium at the disposal site and in the surrounding environment. A separate table or set of tables should be presented for each environmental medium. These tables should also present the range of reported concentrations for each OHM detected at the disposal site and in the surrounding environment. Finally, laboratory data reports should be appended to the risk assessment and should include the chain of custody and any notes or narrative comments that were provided by the laboratory and are relevant top data interpretation and analysis.

Sampling and analysis procedures must be documented thoroughly and accurately in order to verify that the analysis was conducted as reported, and that the data are reliable.

References for Chapter 5

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