EPA ID# 542-F-18-005

Introduction

The purpose of this technical guide is to assist environmental professionals in identifying where strategic sampling approaches may benefit data collection activities at their project or site and what sampling approach may be most effective given site conditions.

Why is EPA Issuing this Technical Guide?

The U.S. Environmental Protection Agency (EPA) developed this guide to support achievement of the July 2017 Superfund Task Force goals. Two additional companion technical guides should be used in conjunction with this strategic sampling approaches technical guide:

- Smart Scoping for Environmental investigations
- Best Practices for Data Management

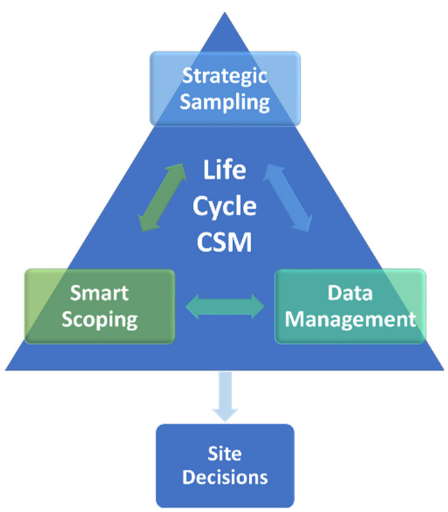
Section 1 of this guide defines the concept of strategic sampling approaches; describes the benefits of applying them; and explores opportunities for leveraging strategic sampling approaches during various phases of a project's life cycle.

Section 2 of this guide describes eight strategic sampling approaches that can be used to improve data collection activities' effectiveness.

EPA recognizes that other sampling approaches may be developed and has designed this technical guide to allow for the inclusion of new approaches as they are developed.

Section 1 - What Are Strategic Sampling Approaches?

As applied in this guide, strategic sampling is broadly defined as the application of focused data collection across targeted areas of the conceptual site model (CSM) to provide the appropriate amount and type of information needed for decision-making. Strategic sampling throughout a project's life cycle may help inform the evaluation of remedial alternatives or a selected remedy's design, improve remedy performance, conserve resources, and optimize project schedules. In addition, strategic sampling approaches assist with source definition and identify unique contaminant migration pathways, such as the vapor intrusion pathway.



Improving Site Decisions

Evolving life cycle CSMs improve the efficiency of site characterization and cleanup and, ultimately, result in better, more defensible site decisions and improved remedy performance. **Smart scoping, data management,** and **strategic sampling** include best management practices that ensure CSMs evolve and improve the understanding of site conditions throughout the site cleanup process life cycle.

EPA encourages smart scoping to effectively plan for data collection and has outlined smart scoping concepts in the companion technical guide, "Smart Scoping for Environmental Investigations."

Role of the Conceptual Site Model

The key to planning a strategic sampling approach is to ensure that a CSM is based on existing data and other assumptions. EPA promotes the use of the project life cycle CSM to assist Superfund project teams, hazardous waste site cleanup managers and decision-makers throughout the investigation and cleanup life cycle stages.[1] As discussed above, the existing CSM informs strategic sampling approaches. Strategic sampling results from throughout the project life cycle help to inform and continually update the CSM.

What are the Benefits of Using Strategic Sampling Approaches?

In general, the benefits of strategic sampling approaches, whether in the remedial investigation, design, action, or long-term remedy operation phase, include:

1. Closing identified data gaps, thereby reducing project uncertainty;
2. Aligning data collection efforts with data needs for critical site decision-making;
3. Generating collaborative data sets across the project life cycle phases; and
4. Developing multiple lines of evidence to provide confidence when making decisions.

Benefits During Remedial Investigation/Feasibility Studies

Consideration of strategic sampling approaches during scoping of the remedial investigation/feasibility study (RI/FS) benefits the three primary objectives of the RI/FS: defining the extent of contamination, assessing risks and evaluating remedial technologies. Strategic sampling approaches provide more certainty regarding the identification of contaminant fate and transport and can provide an accurate footprint of contaminant sources and migration pathways. The risk assessment conducted as part of the RI/FS benefits from strategic sampling approaches because the risk assessment's needs are a primary scoping effort consideration to ensure all potential migration pathways, exposure routes and receptors are identified. Strategic sampling approaches also target early action opportunities to mitigate potential threats as well as the data needs for technology applications over the longer term, including targeted pilot studies.

Key Concept: Critical Factors for Strategic Sampling

- Thorough scoping and planning to identify key decisions, decision-makers, and site uncertainties
- Baseline or up-to date CSM
- Maximum use of state-of-practice analytical tools and sampling approaches
- Well-planned communications and data management and visualization

Benefits During Remedial Design and Remedial Action

Frequently, data collection activities are necessary during the design phase to address uncertainty related to site characterization, such as subsurface characterization, contaminant nature and extent, or contaminant partitioning to support the remedial design. Collection of these data may result in changes in site understanding, such as increased or decreased material volumes to be handled or treated, media contaminated at levels different than those described in the RI/FS, new treatment processes that become necessary to address contamination, or access and permitting issues that affect the remedy

[1] EPA. 2011. Environmental Cleanup Best Management Practices: Effective Use of the Project Life Cycle Conceptual Site Model. EPA 542-F-011. July. https://www.epa.gov/sites/production/files/2015-04/documents/csm-life-cycle-fact-sheet-final.pdf

design. Identifying and addressing these changes before the remedy is designed will help ensure that the design can meet the requirements laid out in the record of decision (ROD).

Remedy decisions may select multiple technologies to address a problem, such as groundwater contamination. Each technology requires consideration of specific objectives to inform decisions regarding performance of the technology and when to transition from one technology to another. These performance objectives may include: mass discharge, diminishing return and others. Evaluating options and determining these goals early will facilitate strategic sampling decisions during the design and help establish data necessary for performance measurement during the remedy's implementation.

Finally, for some traditional source control remedies (such as soil or sediment excavation), confirmation sampling is critical to determining if a remedial action may be considered complete. In some instances, strategic sampling decisions may be made during the design investigation work to streamline or reduce the amount of sampling required at the remedial action's completion.

Benefits During Long-Term Remedy Operation

The benefits derived from the use of strategic sampling approaches during long-term remedy operation focus on evaluating how remedy implementation is moving the site toward completion in accordance with the site-specific completion strategy. It is recommended that the site-specific completion strategy be developed as early as possible in the Superfund process. There is intentional flexibility in how a site-specific strategy is developed and, depending on the cleanup stage when the strategy is first developed, it may be described in one or more site documents. A site-specific completion strategy's development can help a site team focus resources on gathering the most relevant data and other information to inform science-based site-specific decision-making. While a modest level of effort may be needed to create and maintain the remedy-specific strategy, an increased focus on gathering data to support cleanup decisions generally should improve the overall time- and cost-efficiency of remedy completion.[2]

Document Organization

This document presents key concepts in separate call-out boxes, as appropriate, and includes highlights important points. In addition, each strategic sampling approach has: (1) a tool box for implementing the approach and (2) suggested resources and training to advance the reader's knowledge.

[2] EPA. 2014. Groundwater Remedy Completion Strategy. OSWER No. 9200.2-144. May.

Section 2 – Strategic Sampling Approaches

This section describes eight strategic sampling approaches project managers and site teams can consider when conducting environmental investigations during any phase of a project's life cycle.

Section 2 is organized to provide a short description and resources for each of the following strategic sampling approaches:

- High-resolution site characterization in unconsolidated environments;
- High-resolution site characterization in fractured sedimentary rock environments;
- Incremental sampling;
- Contaminant source definition;
- Passive groundwater sampling;
- Passive sampling for surface water and sediment;
- Groundwater to surface water interaction; and
- Vapor intrusion.

New strategic sampling approaches will be added to this technical guide as they are developed.

The strategic sampling approaches described in this section address a variety of site complexities, such as heterogeneity associated with media and contaminant distributions, and interactions between contaminant phase and media. Several sampling techniques are highlighted, including high-resolution site characterization (HRSC), incremental sampling (IS) and passive methods. High-resolution site characterization and IS may address media and contaminant distribution heterogeneities whereas passive methods may provide valuable information on the groundwater to surface water interaction.

High-Resolution Site Characterization for Groundwater in Unconsolidated Environments

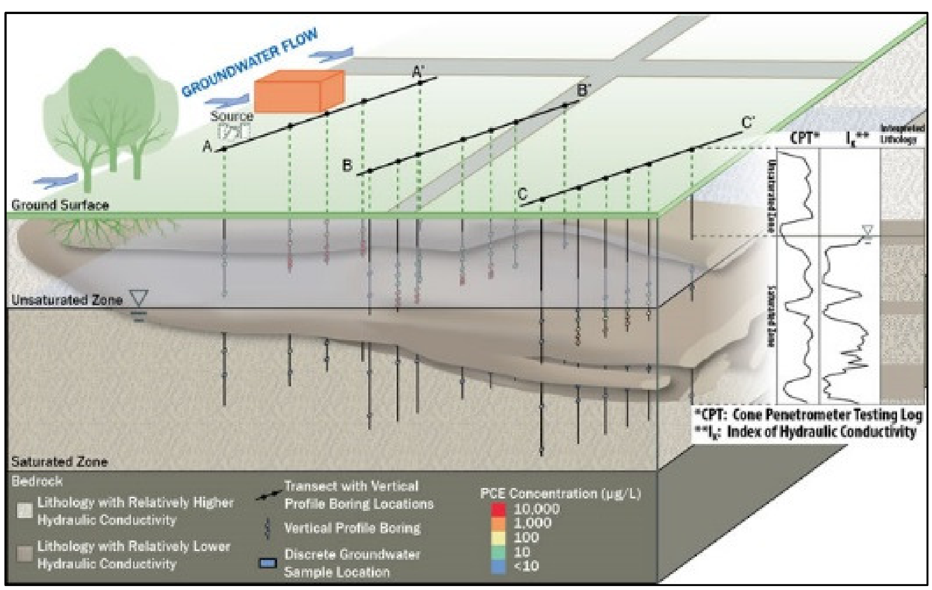
Consider this strategy if your site has:

- Contaminated groundwater in unconsolidated environments
- Stratified layers of varying soil type
- Non-aqueous phase liquids (LNAPL/DNAPL)
- Incomplete or generalized understanding of mass storage and transport in the CSM

Characterizing groundwater in unconsolidated environments can present challenges due to the high level of heterogeneity often found in sequences of gravel, sand, silt and clay. This heterogeneity not only creates uncertainty in the data and CSM when obtained with lower resolution techniques, but can often result in the existence of discrete zones of contaminant mass storage and transport. Heterogeneities that control contaminant storage and transport, such as thin layers of highly permeable sand and gravel, or thin silt and clay layers with low hydraulic conductivity, can be on the centimeter to meter scale and may be too small for conventional investigation strategies, such as monitoring wells, pump tests and slug tests to resolve. Detailed geologic, hydrogeologic and contaminant information is necessary to develop an accurate CSM to select and design remedial technologies matched to the scale of the spatial attributes of the subsurface problem. High-resolution site characterization offers an effective approach to resolve groundwater flow and contaminant concentrations at a detailed level.

Understanding the subsurface heterogeneity at a much higher resolution is critical for designing and implementing more effective and targeted remedial actions. Characterization activities that: (1) match the scale of the investigation to the scale of geologic heterogeneity expected in the subsurface and (2) define the three-dimensional (3D) structure through which groundwater and contaminants are moving can provide data necessary to evaluate and design a remedial strategy, possibly consisting of a combination of technologies. With sufficient resolution the site can be “compartmentalized” into areas of source treatment, plume management, and compliance monitoring to efficiently apply and monitor strategic and targeted remedial actions.

Highlight 1. Transect-based multi-level vertical profiling using direct push technology



High-resolution site characterization for groundwater in unconsolidated environments is comprised of a set of tools and approaches site managers can use to address the sample scale and sample spacing in 3D. Highlight 1 provides an example of transect-based, multi-level vertical profiling using direct push technology. Transects are oriented perpendicular to groundwater flow; vertical sampling for contaminant concentrations rely on direct sensing information for soil type and hydraulic conductivity to optimize sampling depth intervals. Data of this type can be collected over short, discrete intervals with specially designed tools that work with conventional drilling, direct sensing, direct push and hybrid techniques. Discrete samples can be analyzed in the field for contaminants in real time using handheld monitoring devices, field test kits or onsite laboratories. Continuous qualitative vertical contaminant profiles can be obtained using direct sensing tools, such as the membrane interface probe (MIP) or laser induced fluorescence (LIF) tools. A key component of the HRSC approach is dense data set integration and visualization to identify trends in aquifer material, physical and geochemical properties, contaminant phase and contaminant concentration, such as lower-concentration dissolved plumes and higher-concentration plume cores. Transects of vertical subsurface geologic, hydrologic and contaminant profiles oriented perpendicular to the hydraulic gradient's direction are used to generate two-dimensional (2D) cross-sections or more advanced 3D visualizations. Geostatistical data interpolation in 3D can further serve to estimate aquifer material properties like hydraulic conductivity and contaminant distribution in areas between data points.

While HRSC tools can provide valuable data for developing an accurate CSM, each has limitations on the subsurface conditions where it can be deployed and the type of data generated. For example, the MIP has delicate sensors that may be damaged in rocky, dense soils. Cone penetrometer testing (CPT) trucks are heavy, which may damage subsurface infrastructure. Subsurface sensors are subject to analytical detection limitations, and may provide relative concentration or permeability data that can be further verified by collaborative data and multiple lines of evidence. It is important to match the data gaps with the proper set of data collection tools to ensure the results will address the CSM data needs.

When using HRSC, the project team will need to consider each potential tool's applicability to site conditions and practical limitations. Planning and scoping field activities may require evaluation of site access and infrastructure, soil types, depth, and drilling platform and contingencies, in addition to the technical data needs to support an updated CSM.

Key Concept: Back Diffusion

The term "back diffusion" is the movement of contaminant mass out of low permeability units into higher permeability units by diffusion. In dual porosity systems, where low permeability units are in contact with higher permeability units, the low permeability units serve as sinks or storage areas for contaminant mass during the plume life's early stages. Large amounts of contaminant mass diffuse into the low permeability units when concentrations are high in the more permeable units. It is the diffusion of this mass stored in low permeability units back out into the higher permeability units that is referred to as back diffusion. This process serves as a long-term secondary source of contamination. These secondary sources are not limited to the original source area but are found throughout the plume's entire footprint. High-resolution site characterization defines areas where contaminant storage and back diffusion may be occurring.

EPA. 2016. Groundwater High-Resolution Site Characterization Course. CERCLA Education Center.

TOOL BOX
HIGH-RESOLUTION SITE CHARACTERIZATION FOR UNCONSOLIDATED ENVIRONMENTS

Field Analysis and Vertical Profiling

Geology and Hydrogeology Data
- Soil coring
- Cone penetrometer testing
- Electrical conductivity meter
- Hydraulic profiling tool
- Borehole flow meters
- Flow velocity sensor
- Point velocity probes
- Mini-piezometers
- Push-point samplers
- Thermal imaging with FLIR and DST

Qualitative Contaminant Data
- Membrane interface probe
- Laser induced fluorescence

Quantitative Contaminant Data
- Passive flux meters
- Polyethylene diffusion bags
- Mobile laboratory
- Fixed-based laboratory

Data Interpretation and Management
- Electronic lithologic logs
- Real-time instrumentation transfer
- Data base, such as Scribe
- QA/QC
- Decision logic to guide investigation
- CSM updates and distribution
- X, Y, and Z locational coordinates
- Data visualization, 2D and integrated 3DVA
- Data storage, EQuIS and WQX/STORET

Advancing Your Knowledge: Resources and Training

Resources:

- EPA's CLU-IN website contains a comprehensive set of HRSC resources in unconsolidated aquifers. www.clu-in.org/characterization/technologies/hrsc/
- This website contains references, case studies, and other resources for an investigation using the Triad Approach. HRSC is best implemented using the Triad Approach. www.triadcentral.org
- Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) are the Department of Defense's (DoD) environmental research programs, harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities. https://www.serdp-estcp.org/
- Highlight 1. See www.clu-in.org/characterization/technologies/hrsc/

Training:

- Groundwater High-Resolution Site Characterization, https://trainex.org/offeringslist.cfm?courseid=1389
- Best Management and Technical Practices for Site Assessment and Remediation, March 2015, CLU-IN Archived Webinar, https://clu-in.org/conf/tio/bmp/
- National Association of Remedial Project Managers Presents…Practical Applications and Methods of Optimization across the Superfund Pipeline, Parts 1 and 2, Spring 2013, https://clu-in.org/conf/tio/NARPMPresents18_050813/
- Triad Month, Sessions 1 – 7, August 2009, CLU-IN Archived Webinar, https://clu-in.org/conf/tio/triad1_080409/

High-Resolution Site Characterization for Fractured Sedimentary Rock Environments

Consider this strategy if your site has:

- Fractured sedimentary bedrock
- Fracture dominated flow
- LNAPL/DNAPL
- Plume stability concerns
- Incomplete CSM for fracture/matrix interaction flow

Fractured sedimentary rocks, such as sandstone and limestone, contain primary porosity created by the pore spaces between grains, and secondary porosity created by fractures that also allow fluids to move through the rock. Shale and siltstone are moderately impermeable to water flow through the matrix but may convey water through permeable fractures and along horizontal bedding planes. Finer grained sedimentary rocks, including shale and siltstone, have sufficient porosity to allow for contaminant diffusion into the matrix. Like back diffusion often encountered in unconsolidated heterogeneous media, dissolved contaminants that diffuse into the porous rock matrix can become a contaminant source zone if the concentration in the fractures falls below the contaminant concentrations in the rock matrix.

Investigations at fractured sedimentary rock sites must consider the interrelationship of the matrix and fractures in the CSM. To address these concerns, an integrated approach to characterizing the matrix and the fractures may be required. Rock-core material can be examined using a variety of visual logging and field examination techniques along with laboratory chemical, mineralogical and biological measurements. The borehole itself also provides opportunities for measurements during drilling and short- and long-term measurements within a completed unlined or lined borehole.

The HRSC strategy for fractured sedimentary rock focuses on identifying the permeable fractures and their associated flow characteristics, and determining contaminant phase and concentration in the fracture flow as well as the amount of sorbed contaminant in the rock matrix that may act as a long-term source. Packer testing, groundwater sampling, geophysics, acoustic and optical viewers, caliper logs, borehole flowmeters, and temperature logging are commonly used in fractured media; however, lining boreholes and limiting the time the boreholes are open in these settings are key strategies to limiting potential cross-contamination impacts that could be caused by the open borehole. Installation of borehole liners not only serve to limit potential connection of previously unconnected fractures but provide valuable fracture flow and contaminant distribution information during and after installation. Subsequently, within lined boreholes a variety of geophysics, temperature logging and vertical profiling techniques can be applied.

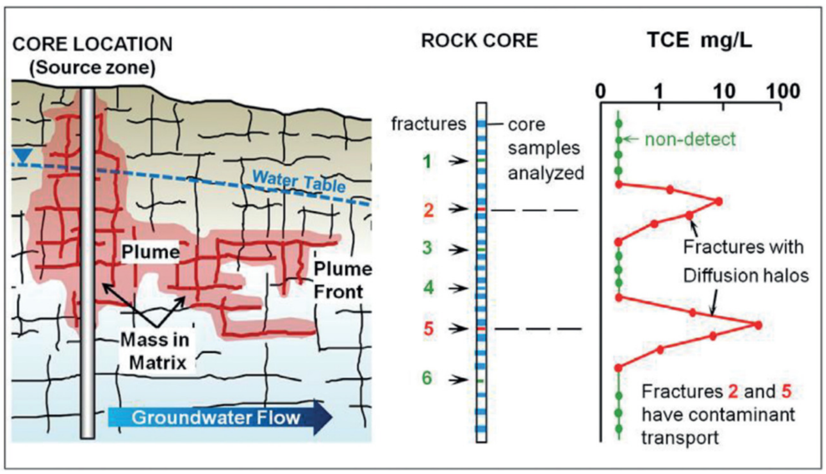
TOOL BOX
HIGH-RESOLUTION SITE CHARACTERIZATION FOR FRACTURED SEDIMENTARY ROCK ENVIRONMENTS

- Packer testing
- Borehole liners
- Groundwater sampling
- Multi-level groundwater sampling
- Geophysics
- Acoustic and optical viewers
- Caliper logs
- Borehole flowmeters
- Temperature logs
- Rock core sampling using microwave assisted extraction

The discrete fracture network (DFN) approach, described in the University of Guelph's G360 Centre for Applied Groundwater Research publication,[3] is one example of a comprehensive set of investigation tools used to delineate contaminant distributions and to understand contaminant transport and fate in both fracture networks and the rock matrix blocks between the fractures. The primary data collection components include comprehensive sampling of continuous rock core from strategically located holes for contaminant analysis, and open borehole tests, such as flexible liner hydraulic conductivity profiling, geophysical logging, hydraulic testing and use of multilevel monitoring systems to characterize fracture flow. These data are used to improve the CSM to reflect the source and plume characteristics. The CSM is then used as input to numerical groundwater flow and transport models to predict contaminant behavior. Remedial design is based on the contaminants' predicted behavior over the short- and long-term.

This type of approach is applicable to sites where contaminants are transported through fractures and are capable of diffusing into the rock matrix (see Highlight 2). Generally, this circumstance includes sites with sedimentary rocks (sandstone, limestone, dolomite) having rock matrix porosity generally in the range of 5-20 percent, not crystalline rocks, such as igneous or metamorphic rocks. Organic contaminants have been the most commonly studied species in DFN applications, but consideration may also be given to other contaminant types with the capacity of diffusing into pore spaces and becoming trapped. Sites with a history of releases of LNAPL and DNAPL are particularly well suited to sampling strategies that provide collaborative data and multiple lines of evidence because the complexities of NAPL fate and transport make reliance on a single line of evidence ill advised.

Highlight 2. Using Borehole, Fractures, and Rock Core



The limitations of a non-traditional approach to fractured sedimentary rock investigations are related to the site conditions described above, and the availability of project teams and vendors capable of delivering the high level of specialized services required to conduct the field work and analysis. Forming and using a comprehensive team is a best practice discussed in EPA's companion technical guide "Smart Scoping for Environmental Investigations," and an interdisciplinary team of geologist, geophysicists, hydrologists, engineers, and numerical modelers is required to develop and execute the plans. Specialty vendors, including diamond core drillers, labs capable of analyzing rock chips/cores, borehole geophysical services, and flexible borehole liner vendors, are necessary to execute the complex sampling strategy.

[3] Parker, et al. 2012. Discrete Fracture Network Approach for Studying Contamination in Fractured Rock. AQUA mundi (2012) – AM06052: 101 – 116. December. http://www.acquesotterranee.it/sites/default/files/Am06052.pdf

The benefits of using the non-traditional approach over conventional fractured rock investigation methods are that the detailed knowledge of fracture and matrix interactions results in better prediction of flow and transport for remedial designs. The approach focuses on identifying and mapping fractures potentially storing or moving contaminant mass, nearby rock matrices with the potential for matrix diffusion, and the phase/flux of contaminant mass. A CSM constructed in this manner, for a site in remedial design for example, can focus on specific fractures that are most likely to transport contaminants and drive site risk, or may indicate that the plume is stationary and a combination of limited and targeted active remediation in conjunction with passive techniques may be most appropriate.

Contaminant flow in fractured sedimentary rock can be complicated and HRSC may employ many different tools, strategies, and visualization and modeling techniques. When planning and scoping, project managers are best served by expanded project teams, extensive stakeholder outreach, and taking the time required for integrating multiple data sets.

Advancing Your Knowledge: Resources and Training

Resources:

- EPA's CLU-IN website contains focused case studies classified under "Fractured Sedimentary Rock" and the "DFN Approach." www.clu-in.org
- DoD's SERDP and ESTCP are the Department's environmental research programs, harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities. https://www.serdp-estcp.org/
- Highlight 2. EPA. Groundwater High-Resolution Site Characterization Course. CERCLA Education Center. 2016.

Training:

- Groundwater High-Resolution Site Characterization, https://trainex.org/offeringslist.cfm?courseid=1389

Incremental Sampling

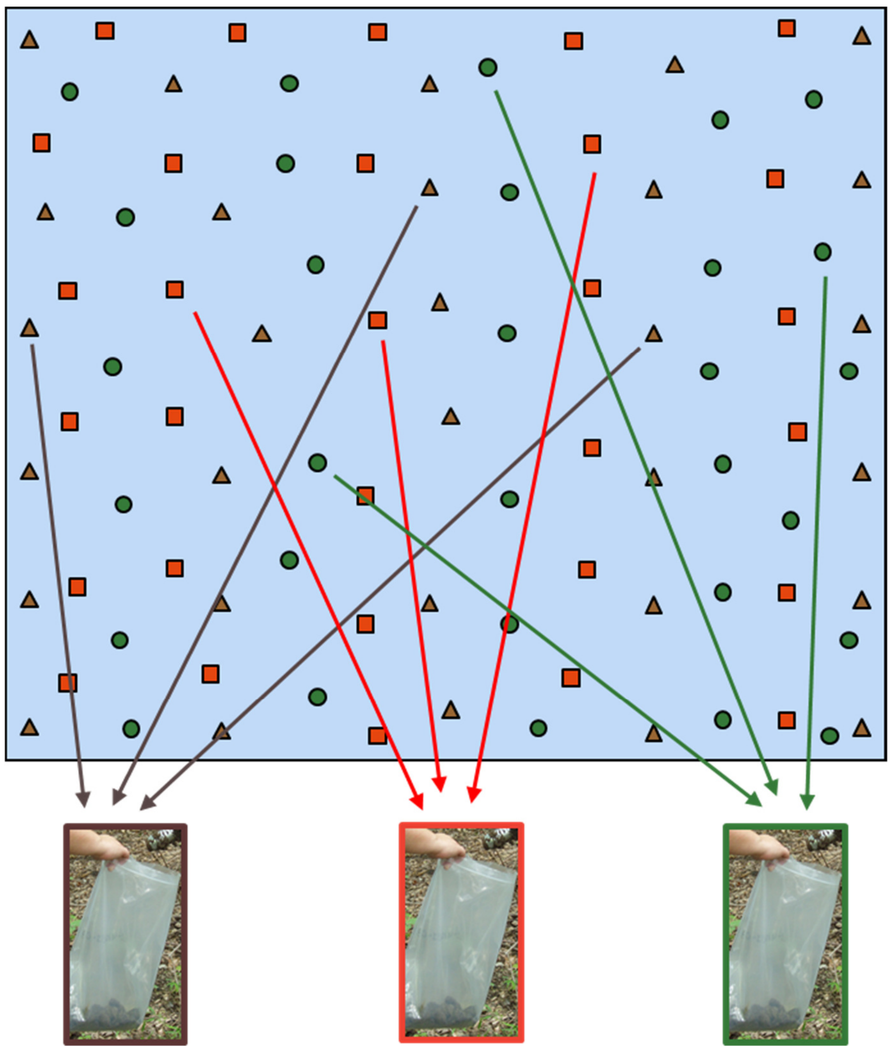
> **Consider this strategy if your site has:**
>
> - Contaminated shallow soil over large area
> - Heterogeneous soil concentrations
> - Release mechanisms with lower spatial correlation (aerial deposition versus a spill)
> - Stable, non-volatile contaminants (such as metals, energetics and PAHs)
> - High analytical costs expected due to known chemicals of concern

Traditional soil sampling methods do not always provide the accurate, reproducible and defensible data needed to make decisions about the volume and extent of cleanup because they do not account for contaminant heterogeneity in soil. Incremental sampling techniques include processing protocols that reduce variability, provide sampling results more representative of exposure scenarios, and provide higher density spatial coverage to reasonably assure adequate representation of the contamination present within a defined soil area or volume. To address the inherent variability due to matrix heterogeneity, IS involves collecting multiple soil increments of equal mass from locations throughout a defined soil sampling area and depth interval (known as a decision unit, DU) and combining the increments into a single field sample. The resulting field sample may be homogenized and processed such that it is representative of the defined DU and exposure mechanisms or assumptions. The IS strategy reduces data uncertainty from sample variability and soil heterogeneity, resulting in a more accurate delineation of the DU's volume of contaminated soil.

> **Key Concept: Compositing and Dilution**
>
> Some project stakeholders are concerned that potential areas of higher concentration within a DU (i.e., hot spots) will be diluted out when combined through the incremental sampling methodology (ISM) with increments of soil from less-contaminated portions of the DU. There are two concerns regarding hot spots: sampling density and defining the DU. Incremental sampling methodology effectively addresses compliance when action levels are based on the mean concentration within a DU. Concerns related to spatial resolution can be addressed only by changing the scale of the DU so that the it equals the hot spot's size. The chance that any single sampling event will include subareas of high and low concentration in the proper proportion is directly related to the number of samples collected within a DU. Incremental sampling methodology offers an advantage over other sampling designs because it accommodates large sample sizes. For this reason, while any individual sample collected in a hot spot is diluted within the larger group of samples, we are more likely to achieve an estimate of the mean that is representative of the true mean within the DU. This advantage of ISM addresses the concern of compliance with action levels but not the concern about spatial resolution. If the data quality objective includes the identification and delineation of small areas of elevated concentrations, ISM sampling can address this objective only by changing the scale of the DU so that it equals the size of the hot spot of concern.
>
> http://www.itrcweb.org/ISM-1/8_5_1_2_Sampling_objectives_and_developing_the_decision_unit.html

Smart scoping is required to develop a site-specific sampling strategy for IS implementation. Project teams, including data users (risk assessors and design engineers), data quality managers, and sampling teams, identify the DU selection rationale and the increment volume and number to be collected. Decision unit size and volume are typically driven by applicable remediation strategies in source areas where contamination above cleanup standards is likely (smaller DUs) and exposure scenarios in areas where exceedances are less likely but risk management requires sampling to evaluate potential exposure (larger DUs). While there is no DU- required size and volume, DUs can range from smaller 10’x10’ grids with a depth of a few inches to larger ¼- 1-acre size with a 6-inch depth for some residential settings. Decision units can be regular in shape, such as a rectangle or square, or irregularly shaped, and those that are larger than one acre are typically only used for agricultural, recreational and industrial exposure scenarios.

Highlight 3. IS Replicate Samples in a Decision Unit



Highlight 3 shows how a DU is sampled in triplicate under IS. Each IS sample is made up of 30 increments, with all triangle locations representing the increments combined for the first IS sample, all square locations representing the increments for the second IS sample, and all circle locations representing the third IS sample increments. The three IS samples will each yield separate contaminant values. Using triplicate values or any series of replicates greater than three allows project teams the ability to calculate confidence limits on the mean. EPA has been combining IS with use of the x-ray fluorescence (XRF) instrument to conduct soil sampling for metals. EPA uses a high level of quality assurance and quality control (QA/QC) for sample preparation and analysis with the XRF to ensure data are of sufficient quality for decision-making. Sampling plans and quality assurance project plans (QAPP) developed for IS programs include detailed procedures for field sample collection and detailed instructions to field crews or laboratories for sample processing. Sample collection considers the type of tools used to collect soil samples as well as the procedures for collecting subsamples. Sample processing is an important part of the sampling design and may have a significant influence on the data. For example, small soil particles tend to have higher contaminant concentrations than larger particles, so soil sieving, grinding and disaggregation may need to be considered dependent on the soil material's characteristics. Sample processing may be completed in the field, begin in the field and finish in the lab, or all be done in the lab. All these considerations need to be addressed in the systematic planning and documented in the QAPP.

TOOL BOX
INCREMENTAL SAMPLING

- Decision unit selection – knowledge of site conditions, data quality objectives, statistical assistance
- Sample support – shape, orientation, and size
- Sample processing – grinding, drying, sub-sampling
- Mobile laboratory or fixed-based laboratory
- XRF instrument for specific contaminants

Advancing Your Knowledge: Resources and Training

Resources:

- The Interstate Technology and Regulatory Council (ITRC) developed a technical and regulatory guidance document, Incremental Sampling Methodology (ISM-1) http://www.itrcweb.org/Team/Public?teamID=11. The document provides users with a practical working knowledge of the methodology's concepts and principles, emphasizes the critical importance of clearly articulated sampling objectives, and provides a sound basis for adapting ISM to meet project goals and site-specific objectives. EPA and ITRC resources include additional references and case studies.
- EPA. 2013. The Roles of Project Managers and Laboratories in Maintaining the Representativeness of Incremental and Composite Soil Samples. OSWER Directive No. 9200.1-117FS. June. https://clu-in.org/download/char/RolesofPMsandLabsinSubsampling.pdf
- Highlight 3. EPA. Incremental Composite Soil Sampling course. CERCLA Education Center. June 2016.

Training:

- Soil Sampling and Decision Making Using Incremental Sampling Methodology, Parts 1 and 2, February and March 2015, CLU-IN Archived Webinar, https://clu-in.org/conf/itrc/ISM_020515/
- Incremental Composite Sampling Designs for Surface Soil Analyses, Modules 1 – 4, CLU-IN Archived Webinar, https://clu-in.org/conf/tio/ISM1_021612/
- XRF Training, Sessions 1 – 8, August 2008, CLU-IN Archived Webinar, https://clu-in.org/conf/tio/xrf_080408/

Contaminant Source Definition

> **Consider this strategy if your site has:**
>
> - Complex source (LNAPL/DNAPL, dispersed waste or source area, vadose zone source)
> - Design that relies on source treatment or control
> - Uncertainty in source footprint and heterogeneous/anisotropic aquifer conditions
> - Incomplete CSM of the source – transport relationship

Strategic sampling designs for contaminant source definition focus on providing an accurate estimate of volumes and location in 3D space for application of both in situ and ex situ technologies. Two common reasons for cost or schedule challenges at many sites are the under-estimation of volume with related cost escalation in remedial action, and over- or under-estimation of the footprint for the application of in situ technologies. Both examples demonstrate the need for improved CSMs to ensure the design is appropriately sized to meet the remedial action objectives in the most cost effective and timely manner. Dense data sets help to focus treatment components.

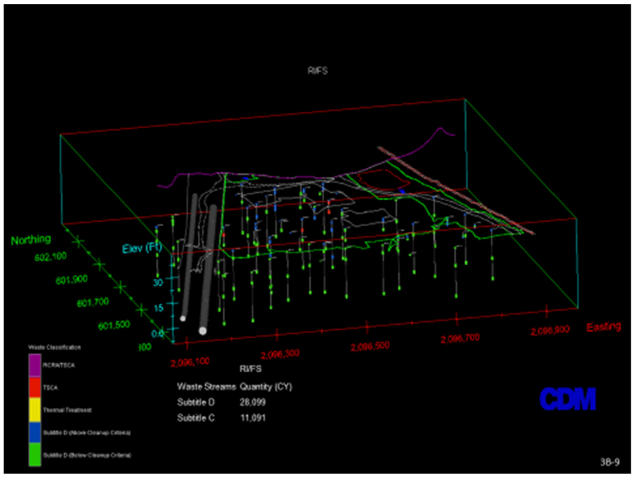
An accurate understanding of the CSM chemistry and hydrogeology is a critical factor in identifying cost-effective design alternatives and optimizing remedial design. Site managers can improve and expand the CSM by using collaborative data sets with a large volume of real-time data supported by a small volume of fixed lab data, and thoughtful development of DUs over which to measure contaminant levels. High-resolution site characterization techniques can be applied to source definition when the benefits outweigh the costs (return on investigation). Applying high-resolution tools can improve the delineation of the source footprint to optimize in situ remedies or to better segregate material for disposal. For LNAPL and DNAPL sources, high-resolution techniques aid in mapping mass storage versus transport zones so that more costly and aggressive methods are applied to the appropriate source areas, and plume management strategies effectively account for mass storage and transport zones.

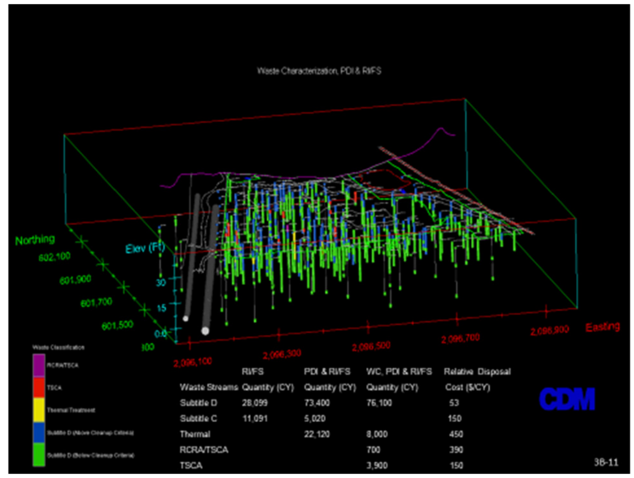
Source areas that contain dispersed waste, such as surface soils contaminated by airborne lead deposition or subsurface contamination from multiple subsurface waste pits, can present uncertainty in estimating waste location and volume. High-resolution characterization tools, such as geophysical surveys or passive soil gas grids, coupled with the IS approach, can significantly reduce uncertainty in defining the source areas. Decision units and sample design can be selected based on the geophysical or soil gas signatures.

Using 3DVA to visualize the source area can be beneficial for developing a more realistic CSM. The dense data sets from HRSC match well with visualization tools and reflect high quality characterization in support of remedy selection, design, and optimization. Applying 3DVA improves communication among the design and construction team members by providing a consistent understanding of the site conditions.

When planning and scoping remedial design tasks, site managers consider the uncertainties in delineation of the source and apply the appropriate high-resolution data collection and analysis tools to reduce uncertainty.

Highlight 4. Comparative sampling densities using traditional approach versus HRSC





Highlight 4 shows the value of HRSC for source definition at the Horseshoe Road Superfund site. The image on the left shows sampling density before HRSC and the image on the right shows sampling density using HRSC. The denser data set allowed better segregation of waste types and significantly reduced disposal costs.

TOOL BOX
CONTAMINANT SOURCE DEFINITION

- Direct push technologies
- Geophysics
- XRF
- Membrane interface probe
- Laser induced fluorescence
- Mobile laboratory or fixed-based laboratory
- High-resolution sampling strategy
- IS
- 3DVA

Advancing Your Knowledge: Resources and Training

Resources:

- EPA's CLU-IN website contains a comprehensive set of resources for HRSC in unconsolidated aquifers. High-resolution site characterization techniques are recommended for characterizing NAPL sources in the subsurface. www.clu-in.org/hrsc
- This ITRC document synthesizes the knowledge of DNAPL site characterization and remediation and provides guidance on characterization of contaminant distributions, hydrogeology, and attenuation processes. http://www.itrcweb.org/DNAPL-ISC_tools-selection/Content/1%20Introduction.htm
- SERDP and ESTCP are DoD's environmental research programs, harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities.
  https://www.serdp-estcp.org/
- Highlight 4. Horseshoe Road Superfund Site information:
  https://cumulis.epa.gov/supercpad/cursites/csitinfo.cfm?id=0200781

Training:

- Remedial Design/Remedial Action Training, https://trainex.org/offeringslist.cfm?courseid=47
- Best Practices for Site Characterization Throughout the Remediation Process, https://trainex.org/offeringslist.cfm?courseid=1515
- Groundwater High-Resolution Site Characterization, https://trainex.org/offeringslist.cfm?courseid=1389
- ICS training webinar, https://clu-in.org/conf/tio/ISM1_021612/

Passive Groundwater Sampling

A passive groundwater sampler acquires a water sample from a discrete depth in a monitoring well or borehole without active pumping or purge techniques. Passive samplers use one of three different mechanisms to obtain concentration data:

- Direct well water sampling is performed using instantaneous grab sample devices.
- Diffusion samplers rely on the diffusion of analytes between the sampler fluid and groundwater or surface water to reach equilibrium.
- Integrating samplers sequester chemicals through trapping in a suitable medium, which can be a solvent, chemical reagent or a porous adsorbent.

Consider this strategy if your site has:

- Contaminated groundwater in thin zones;
- Monitoring wells with long screen intervals and well-defined borehole flow dynamics
- Shallow groundwater adjacent to surface water
- Incomplete or generalized understanding of transport in the CSM

All passive technologies rely on the sampling device being exposed to groundwater in ambient equilibrium during the sampler deployment period or the monitoring well water being in equilibrium with the formation water.

Passive sampling is a cost-effective HRSC method that can be used to collect contaminant data from multiple intervals in an existing well or borehole for shallow groundwater or groundwater and surface water interfaces. Monitoring wells with long-screen intervals (10 feet or greater), and wells screened in heterogeneous materials may have multiple flow zones that transport different amounts of contaminants at different hydraulic conductivities. Most passive samplers can be stacked to obtain samples at multiple depths, which allows vertical zones within a screened well interval to be sampled individually to give a better understanding of the contaminant concentrations at various depths. However, monitoring well or borehole flow dynamics must be well understood to successfully use passive sampling devices to define contaminant differences in distinct vertical flow zones. If vertical flow regimes in boreholes or depth integrated flow weighted averages across well screens exist then care must be taken to isolate specific zones using packers in open boreholes or other technologies for passive sampling techniques. The increased resolution of contaminant flow paths in aquifers supports a detailed CSM and leads to more efficient remedial design by identifying zones where contamination is greatest. Highlight 5 shows passive diffusion bags installed in series in a screened monitoring well whose borehole dynamics have been confirmed.

Highlight 5. Passive samplers in series

While each passive sampling method has unique advantages and limitations, one common consideration is that passive samplers must be exposed to the host environment for a time, and the resulting sample may represent the most recent exposure conditions if groundwater conditions fluctuate dramatically. Equilibrium may be reached within a few days or a few weeks depending on the nature of the contaminant and the sampling device. One advantage of passive samplers is that minimal equipment is required and little to no purge water is generated.

Passive groundwater samplers are relatively simple to deploy, and they are cost effective tools for groundwater monitoring in remote conditions. They can be used at any point in the process with proper planning to ensure quality controls and by conducting a method demonstration as necessary. In addition, there are many new passive samplers under development.

TOOL BOX
PASSIVE GROUNDWATER SAMPLING

- Devices that recover a grab sample
  - Two proprietary options are discussed
- Devices that rely on diffusion of the analytes to reach equilibrium between sampler and well water
  - Regenerated-Cellulose Dialysis Membrane Sampler
  - Nylon-Screen Passive Diffusion Samplers (NPSPDS)
  - Passive Vapor Diffusion Samplers (PVDs)
  - Peeper Samplers
  - Polyethylene Diffusion Bag Samplers (PDBs)
  - Rigid Porous Polyethylene Samplers (RPPS)
- Devices that rely on diffusion and sorption to accumulate analytes in the sampler
  - Semi-Permeable Membrane Devices (SPMDs)
  - Polar Organic Chemical Integrative Sampler (POCIS)
  - Passive In Situ Concentration Extraction Sampler (PISCES)
  - One proprietary option is discussed

http://www.itrcweb.org/GuidanceDocuments/DSP_4.pdf

Advancing Your Knowledge: Resources and Training

Resources:

- The Characterization and Monitoring section of EPA's CLU-IN website contains a discussion of the three generic forms of passive (no purge) samplers, and provides links to other references. The site also includes a table describing common analytes addressed by 15 different technologies. https://clu-in.org/characterization/
- ITRC developed a Technology Overview of Passive Sampler Technologies, which includes a comprehensive table of advantages, limitations, availability and cost of 13 different passive sampler technologies. https://www.itrcweb.org/GuidanceDocuments/DSP_4.pdf
- SERDP and ESTCP are the DoD's environmental research programs, harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities. https://www.serdp-estcp.org/
- Highlight 5. ITRC. Technical Overview of Passive Sampler Technologies. March 2006.

Training:

- Best Practices for Site Characterization Throughout the Remediation Process, https://trainex.org/offeringslist.cfm?courseid=1515
- Groundwater High-Resolution Site Characterization, https://trainex.org/offeringslist.cfm?courseid=1389

Passive Sampling for Surface Water and Sediment

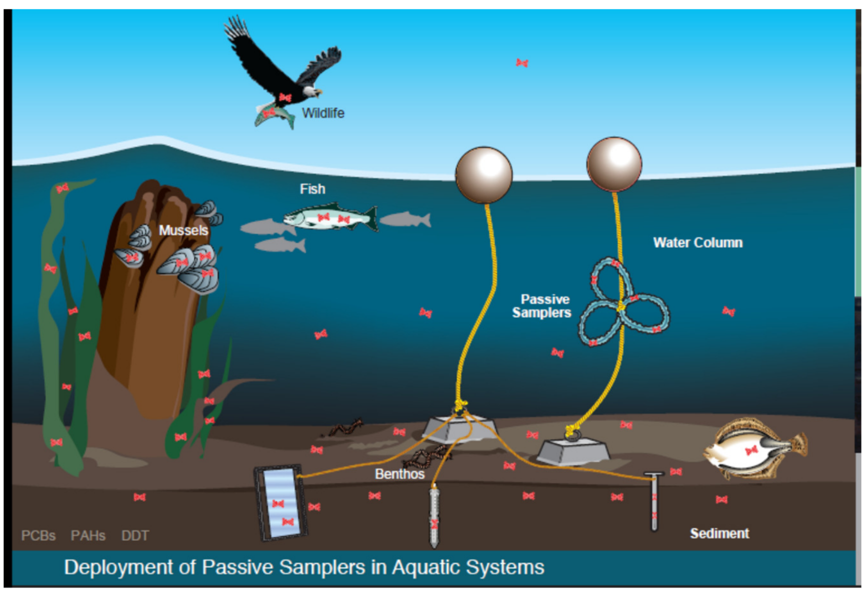
Consider this strategy if your site has:

- Sediment contamination
- Hydrophobic non-ionic contaminants (PCB, PAH, dioxins)
- CSM that includes sediment-surface water interaction
- Uncertainty regarding the bioavailability of contaminants
- Poor correlation between toxicity and bulk sediment chemistry

Sediment contamination is traditionally evaluated at Superfund sites using direct sampling of the sediment, pore water, and the adjacent surface water column. The underlying assumption of direct sample results is that all the contaminant is bioavailable. If the sediment concentrations indicate there may be a problem, then further bioavailability studies are sometimes conducted. Passive sampling methods for surface water and sediment can be used to quantify bioavailability based on the diffusion and subsequent partitioning of contaminants from sediment to a reference sampling media (pore water and surface water), which can reduce uncertainty in ecological risk assessment.

Passive sampling is a scientifically sound and cost-effective approach for monitoring contaminant concentrations in the water column and sediment interstitial waters, and it can provide information about the contaminant gradients between the sediment and the water. Passive samplers provide information on dissolved and bioavailable contaminant concentrations because the samplers serve as surrogates for organism bioaccumulation. The most common sediment contaminants are hydrophobic non-ionic contaminants including pesticides, polychlorinated biphenyls (PCBs), PAHs, and, to a lesser extent, dissolved-phase chlorinated hydrocarbons. Passive sampling methods for metals are not as advanced or established as methods for hydrophobic organic contaminants. Highlight 6 shows the deployment of passive samplers in an aquatic system.

Highlight 6. Deployment of passive samplers in aquatic systems



Passive samplers are commonly made of plastic polymer that is similar in hydrophobicity to many hydrophobic contaminants. Hydrophobic contaminants present in the dissolved phase will partition into the polymer, moving out of the water and dissolving into the polymer. Over time, the contaminants will accumulate in the sampler until they reach a state of concentration equilibrium with adjacent media. Passive samplers can be used for determining contaminant sources released from sediments to the water column in support of the CSM, and monitoring water column and interstitial water concentrations before, during and after remediation.

Sediment characterization is often complicated by the relatively rapid changes that can occur in sediment composition due to short-term temporal events (such as storms) that can cause sediment resuspension and movement. These changes can either result in an elevated or a reduced dissolved concentration in the water column that does not accurately reflect the site's long-term average concentration. Passive samplers provide time-averaged measurements, which more accurately reflect representative concentrations at a site rather than a snap-shot of conditions represented by traditional sampling. One disadvantage of passive samplers is that they are limited to only those compounds that can be captured in the sampling media, which may not include all site contaminants of concern. Additionally, regulators may require comparability tests prior to the use of passive samplers for certain sampling objectives.

When assessing sediment sites, site managers may consider the use of passive sediment and surface water samplers to better delineate the source areas, as well as to measure remedy effectiveness. Planning and scoping investigations with passive samplers typically require ecologists, chemists, and field staff input to ensure data collection can address CSM uncertainties.

TOOL BOX
PASSIVE SAMPLING FOR SURFACE WATER AND SEDIMENT

- Polyethylene samplers
- Polyoxymethylene samplers
- Solid phase micro-extraction samplers
- Methodology for translating measured concentrations in the passive sampler into dissolved concentrations around the passive sampler

Advancing Your Knowledge: Resources and Training

Resources:

- EPA has developed a guideline for using passive samplers to monitor organic contaminants at Superfund sediment sites https://clu-in.org/download/contaminantfocus/sediments/Sediments-Passive-Sampler-SAMS_3.pdf
- The SERDP and ESTCP are the DoD's environmental research programs, harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities. https://www.serdp-estcp.org/
- Highlight 6. EPA. https://clu-in.org/download/contaminantfocus/sediments/Sediments-Passive-Sampler-SAMS_3.pdf

Training:

- The Use of Passive Samplers to Monitor Organic Contaminants at Superfund Sediment Sites, August 2013, CLU-IN Archived Webinar, https://clu-in.org/conf/tio/passsamp_082613/
- RPM 201, Sediment Module, https://trainex.org/offeringslist.cfm?courseid=1374

Groundwater to Surface Water Interactions

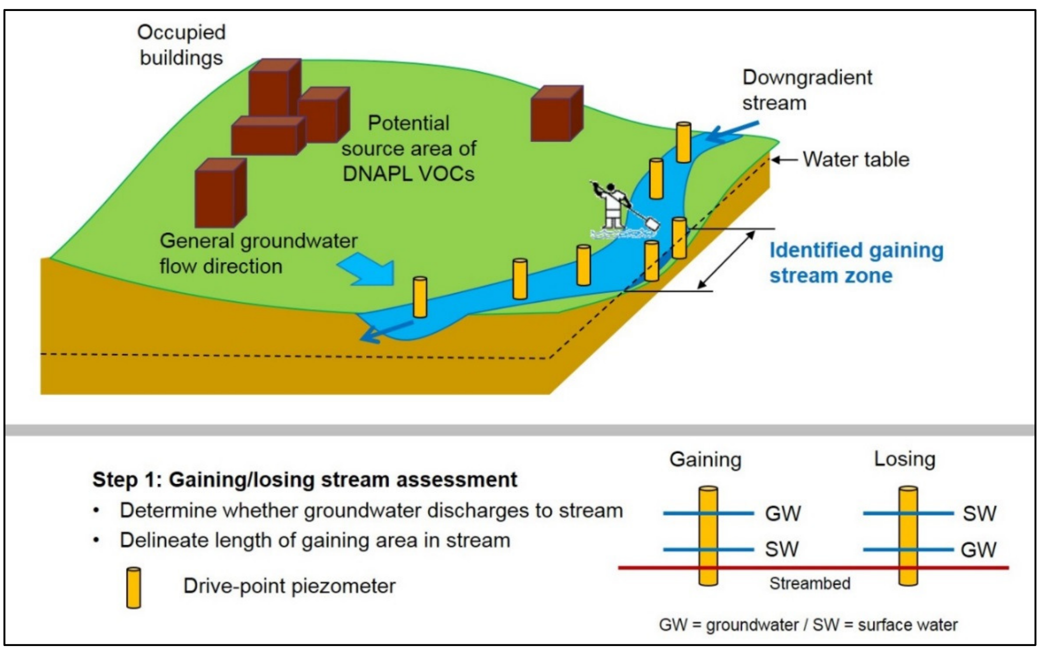
Consider this strategy if your site has:

- Surface water and groundwater present
- Potential for transport of contaminants from one media to the other
- Uncertainty in location of groundwater discharge points in surface water
- Incomplete CSM of the groundwater to surface water interaction

In hydrologic systems where groundwater and surface water are present, these media are connected by the groundwater and surface water transition zone. In some cases, groundwater discharges into the surface water, or the surface water may recharge the groundwater system. Understanding contaminant fate and transport in this zone is important because it represents the exchange of contaminants between media and the potential for ecological and human exposure. EPA is particularly interested in understanding the groundwater to surface water interaction because almost half of all Superfund sites have affected surface water.

Investigations of groundwater to surface water interactions are designed to evaluate both flow and chemical characteristics; specifically, understanding the location and magnitude of contaminant discharges to surface waters from groundwater plumes or from surface water to groundwater. The investigative and sampling strategy starts with a general reconnaissance of the area to identify groundwater discharge locations and evolves into a detailed and focused sampling of hydraulics, chemistry and biology. Highlight 7 depicts an example of an investigative strategy for evaluating groundwater to surface water interactions using groundwater and surface water elevations.

Highlight 7. Example of investigative strategy for groundwater – surface water interface



Potentiometric surface maps, developed from surface water- and groundwater-level data, are typically used to delineate discharge areas' general location. More specific methods, including seepage meters, thermal imaging, geophysical tools and quantitative dye tracer tests, may also be used to identify specific discharge locations. Temperature has been effectively used to map locations of groundwater to surface water discharge locations. Forward looking infrared cameras and distributed temperature sensors using fiber optic cables are techniques that can be used to map discharge at a variety of scales and optimize sediment, pore water and surface water sampling locations. This high-resolution, finer-scale analysis is important because recent studies have shown that significant discharge areas can be spatially complex, small and easily missed. Once the flow patterns have been established, the contaminants' flux can be evaluated.

While traditional investigation approaches using monitoring wells and depth-discrete surface water sampling are useful tools, HRSC techniques are also applicable for defining contaminant flux along the flow paths and at the suspected discharge points. High-resolution site characterization is critical in areas where contaminant flow may be at a very fine scale, such as in fractured rock or heterogeneous sediments. A large passive sampler network can be cost effectively deployed along stream banks and within the surface water body sediment to rapidly delineate the location and relative concentrations of contaminants discharging into surface water bodies.

TOOL BOX
GROUNDWATER TO SURFACE WATER INTERACTIONS

- HRSC techniques for groundwater component
- Passive flux meter
- Passive samplers
- Mini-piezometers
- Push point sampler
- Forward looking infrared camera
- Distributed temperature sensor
- Multi-level bundle piezometers
- Ground penetrating radar

The groundwater and surface water interface environment is complex, with flow across the sediment and water interface commonly changing direction and velocity, both temporally and spatially. The contaminant flux can change in magnitude and direction, with changes in both surface water temperature and stage; these changes require groundwater and surface water sample collections over time and during different flow conditions.

Developing an accurate and complete CSM of the groundwater and surface water interaction is a valuable tool when considering risk reduction options and remedial design. Discharge and flux information can aid in natural attenuation assessment, or the design and optimal placement of wall and curtain containment systems and engineered attenuation zones.

Advancing Your Knowledge: Resources and Training

Resources:

- EPA recommends the U.S. Geological Survey (USGS) document, Field techniques for estimating water fluxes between surface water and ground water, https://pubs.usgs.gov/tm/04d02/, as a practical compendium of methods for investigating the hydrologic characteristics of the groundwater/surface water zone.

- A joint publication EPA-USGS provides guidance on the application of passive samplers for delineating volatile organic compounds in groundwater discharge areas and nine case studies. https://pubs.usgs.gov/wri/wrir024186/pdf/wri024186.pdf
- The proceedings of EPA's Ground-Water/Surface-Water Interactions Workshop includes information on investigation methods and evaluation of the hydrological, chemical and ecological aspects of the zone. https://www.epa.gov/sites/production/files/2015-06/documents/gwsw_workshop.pdf
- Forward looking infrared camera, http://water.usgs.gov/ogw/bgas/thermal-cam/
- Distributed temperature sensor, http://water.usgs.gov/ogw/bgas/fiber-optics/
- The SERDP and ESTCP are the DoD's environmental research programs, harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities.
  https://www.serdp-estcp.org/
- Highlight 7. EPA. Best Practices for Site Characterization Throughout the Remediation Process course. CERCLA Education Center. 2016.
  https://trainex.org/offeringslist.cfm?courseid=1515&all=yes

Training:

- Best Practices for Site Characterization Throughout the Remediation Process, https://trainex.org/offeringslist.cfm?courseid=1515&all=yes
- A Rapid Multi-Scale Approach for Characterizing Groundwater/Surface Water Interactions and Evaluating Impacts on Contaminated Groundwater Discharge, NARPM 2014.

Vapor Intrusion

Consider this strategy if your site has:

- Subsurface source of vapor-forming chemicals underneath or near buildings
- Potential pathway for VOC inhalation exposure
- Incomplete analysis of vapor intrusion pathway in CSM

Vapor intrusion is the migration of hazardous vapor from a subsurface contaminant source (groundwater, soil or conduit) into an overlying structure. Contaminants that typically lead to vapor intrusion include chlorinated hydrocarbons, petroleum hydrocarbons, and both halogenated and non-halogenated volatile organic compounds. Vapor intrusion pathways are generally assessed by collecting and evaluating multiple lines of evidence through groundwater sampling, soil gas sampling, passive soil gas surveys, sub-slab sampling and indoor air sampling. A complete vapor intrusion pathway indicates that there is an opportunity for human exposure.

EPA recommends that the potential for human health risk from vapor intrusion be evaluated throughout the project life cycle. There are different scenarios for vapor intrusion depending on characteristics of the source, subsurface conditions and vapor migration, building susceptibility, lifestyle factors, and regional climate. For these reasons, every site (and every building) will not warrant the same vapor intrusion assessment approach. The best practice is to develop a strategic sampling program as early as possible in the cleanup life cycle to ensure the remedial design addresses the vapor intrusion pathway.

EPA recognizes two general levels of vapor intrusion assessments; each can be approached strategically:

- *Preliminary assessments* are conducted utilizing available and readily ascertainable information to develop an initial understanding of the human health risk potential
  - Typically performed as part of an initial site assessment
  - Strategy is to focus on data that help define inclusion zones
- *Detailed investigations* are generally recommended when the preliminary analysis indicates that subsurface contamination with vapor-forming chemicals may be present underlying or near buildings (buildings are within an inclusion zone)
  - Typically performed as part of the site investigation stage but can be done at any time
  - Strategy is to prioritize other lines of evidence necessary to complete detailed investigations
  - Account for spatial/temporal variations

Certain sites with long-term contaminated groundwater cleanups underway may be evaluated for vapor intrusion during periodic reviews.

Sampling programs for vapor intrusion can be invasive to structure occupants, and will require somewhat extensive community outreach efforts. Additionally, due to the highly site-specific nature of vapor risk, an accurate CSM that incorporates all aspects of the scenarios stated above is needed to successfully conduct the assessment. Temporal and spatial variability of sampling data can span at least an order-of-magnitude and often more, and individual lines of evidence may be inconsistent with other lines of evidence. Assessment of multiple lines of evidence may result in decisions based on professional judgement. A well-formulated strategic sampling approach should identify the buildings that will require mitigation, with mitigation strategies only implemented at the buildings that exceed risk thresholds.

TOOL BOX
VAPOR INTRUSION

- Building assessment
- Vapor source assessment
- Indoor air sampling
    - Evacuated canisters
    - Sorbent samplers – active and passive
- Outdoor air sampling
    - Use methods akin to indoor air sampling
- Sub-slab soil gas sampling
    - Sampling probe(s)
    - Evacuated canisters
- Groundwater characterization and monitoring
    - HRSC
    - Monitoring well network

Advancing Your Knowledge: Resources and Training

<u>Resources</u>:

- In June 2015, EPA released a final vapor intrusion technical guide that describes a recommended framework for assessing vapor intrusion. This comprehensive guide provides EPA's current technical recommendations based on the most current understanding of vapor intrusion into indoor air from subsurface vapor sources.
  https://clu-in.org/download/issues/vi/VI-Tech-Guide-2015.pdf
- The ITRC Vapor Intrusion Pathway Guidance is a practical, easy-to-read, how-to guideline for assessing the vapor intrusion pathway and includes a companion guide that describes six different, yet common, hypothetical vapor intrusion scenarios and the investigation approaches that might be followed. https://clu-in.org/download/contaminantfocus/vi/ITRC%20VI-1.pdf
- The SERDP and ESTCP are the DoD's environmental research programs, harnessing the latest science and technology to improve DoD's environmental performance, reduce costs, and enhance and sustain mission capabilities.
  https://www.serdp-estcp.org/
- Additional resources may be found on the CLU-IN Issues: Vapor Intrusion (provides many links/guidance documents):
  https://clu-in.org/issues/default.focus/sec/Vapor_Intrusion/cat/Overview/

<u>Training</u>:

- RPM 201, Vapor Intrusion module, https://trainex.org/offeringslist.cfm?courseid=1374
- Vapor Intrusion 2014 Update, NARPM 2014.

Disclaimer