Groundwater High-Resolution Site Characterization

United States
Environmental Protection
Agency

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Course Objectives

- **After taking this course, participants will be better able to:**
  - » Define High Resolution Site Characterization (HRSC)
  - » Explain the need for, and benefits of, HRSC
  - » Describe the contaminant hydrogeology context for HRSC
  - » Plan for and use strategies, methods and tools for groundwater HRSC:
    - › Smart scoping best practices
    - › Data management, visualization, and analysis
    - › HRSC checklist

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Course Overview

Learn and Integrate Foundational Concepts

- ♦ Module 1 (Webinar): Introduction and Background
- ♦ Module 2 (Webinar): Hydrogeology and the Impacts of Subsurface Heterogeneity

Practice Using HRSC Strategies, Methods, and Tools

- ♦ Module 3 (In-person): Scale-Appropriate Measurement and Data Density
- ♦ Module 4 (In-person): Potentially Applicable Tools
- ♦ Module 5 (In-person): Planning for High-Resolution Site Characterization
- ♦ Module 6 (In-person): Data Analysis and Decision-Making for HRSC
- ♦ Module 7 (In-person): Wrap Up

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Instructor Introductions

- ♦ **Matt Jefferson, U.S. Environmental Protection Agency, Headquarters**
  - » B.S. in Environmental Engineering; M.S. in Environmental Engineering
  - » 20+ years in environmental characterization and remediation
    - › Former EPA Remedial Project Manager (RPM) in Regions 7 and 9
    - › OSRTI’s Technology Innovation and Field Services Division; Technology Integration & Information Branch
  - » Focus on site characterization, conceptual site models (CSM), optimization, and soil/groundwater sampling strategies
- ♦ **Cindy Frickle, U.S. Environmental Protection Agency, Headquarters**
  - » B.S in Geology, MS in Biogeology
  - » Physical scientist with EPA's Superfund program where she reviews and propagates technical information to site cleanup professionals through Clu-In, EPA forums, and interagency channels.
  - » Prior to joining EPA, she spent time characterizing contaminated sites, coring sediments, studying microbes, and teaching.

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Instructor Introductions

- **Ben Bentkowski, U.S. Environmental Protection Agency, Region 4**
  - B.S. in Geology; M.S. in Geology
  - Senior Hydrogeologist
  - Board member – Georgia Professional Geologist Registration Board
  - 40-year experience focused on fractured bedrock, downhole geophysics and direct push site characterization
- **Jim Rice, ICF**
  - B.S., Geology
  - M.S., Geology, New Mexico Institute of Mining and Technology
  - 30-year site investigation and remediation
  - Contractor for US EPA OSRTI Technology Integration & Information Branch
  - Focus on innovative techniques and tools to understand and remediate Superfund and Brownfields sites

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Let's Practice: Q&A Polls

- **We will be asking various questions during the delivery.**
- **You will either use the Q&A window to answer or participate in the multiple-choice polls in Zoom.**

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Participant Welcome

- **I am from**
  - EPA Region
  - EPA Headquarters
  - State
  - Tribe
  - Consulting
- **What is your experience/project role? Type in the Q&A window.**
  - Manager, risk assessor, hydrogeologist, engineer, etc.
- **What is your experience with HRSC? Type in the Q&A window.**

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Module 1 – Introduction and Background

- CSM Refresher
- What is HRSC
- Why do HRSC
- How to implement HRSC

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CSM Refresher
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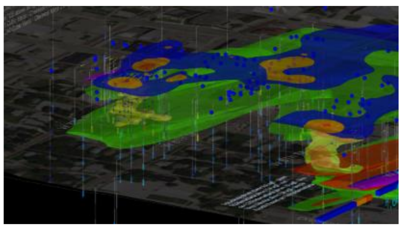
Conceptual Site Model (CSM)

- Written and graphical (2-D and 3-D) expression of site knowledge
- Primary basis for project design and execution
- Effective platform for maintaining stakeholder consensus
- Updated throughout project life cycle
- *Essential* to successful projects



Conceptual Site Model Worksheet

CSM Component	Summary of Key Points	Uncertainties and Data Gaps
Past Use	•	•
Previous Investigations and Actions	•	•
Media and Transport	•	•
Intended Reuse	•	•
Decision Criteria	•	•
Pathway Receptor Network	•	•
Technologies and Approaches	•	•
Completion Strategy	•	•

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Notes

- **Written and graphical expression of site knowledge:** A CSM is a functional description about what is known about a site and the contamination present. The CSM organizes known information and working site hypotheses and provides the basis for designing a Dynamic Work Strategy (DWS – to be discussed later in this module). A CSM is a flexible platform for updating and communicating site understanding and provides stakeholders with a unified understanding of site conditions. It can be presented in text or graphically in two or three dimensions. The objective is to get the concept of the site to match the reality of the site. Many difficulties with projects are the result of differences between the CSM and reality or with differing stakeholder interpretation of existing CSM information.

- **Primary basis for project design and execution:** A CSM is the essential starting point for an HRSC investigation. If the CSM is incomplete or misinterpreted, the investigation may be flawed. It is essential that a complete list of site-related elements be considered for the Baseline CSM to provide the basis for an effective DWS. The CSM not only defines what we know, but also identifies data gaps and areas of uncertainty among stakeholders.

- **Updated throughout project life cycle:** Development of the CSM is not a one-time exercise conducted during project scoping and then set aside. A CSM should be used to guide the entire cleanup process. It should be updated at critical junctures as applicable with new information to reflect the revised understanding of site conditions.

- **Essential to successful projects:** The CSM is a planning tool captured and described in many planning efforts; it is not a “Triad” invention. However, Triad places a heavy emphasis on the active and continuous use of the CSM.

Project Life Cycle CSM Supports Project Phases

- **Preliminary CSM**
  - Developed prior to systematic planning
- **Baseline CSM**
  - Product of systematic planning; documents stakeholder consensus
- **Characterization Stage**
  - Guides investigation efforts and supports decision-making
- **Design Stage**
  - Supports basis for remedy and redevelopment design
- **Remediation/Mitigation Stage**
  - Guides efforts, meet objectives, and supports optimization
- **Post Remedy(s) Stage**
  - Documents attainment of remediation objectives and goals

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IdeaMain

- *The life cycle of a CSM is composed of two milestone deliverables and four evolutionary stages. New information obtained during the project is used to update the CSM.*

Notes

The Preliminary and Baseline CSMs are milestone deliverables that are typically presented in different formats because of their primarily developmental nature. The remaining CSM stages represent evolutionary stages of the CSM aligned with the major phases of a typical environmental cleanup project.

- **Preliminary CSM:** The Preliminary CSM is developed as a fundamental element of preparations for a systematic planning effort. Diligence in gathering and evaluating key data from previous investigations is essential to preparing a thorough and effective Preliminary CSM. A Preliminary CSM is developed after an initial assessment but prior to systematic planning.

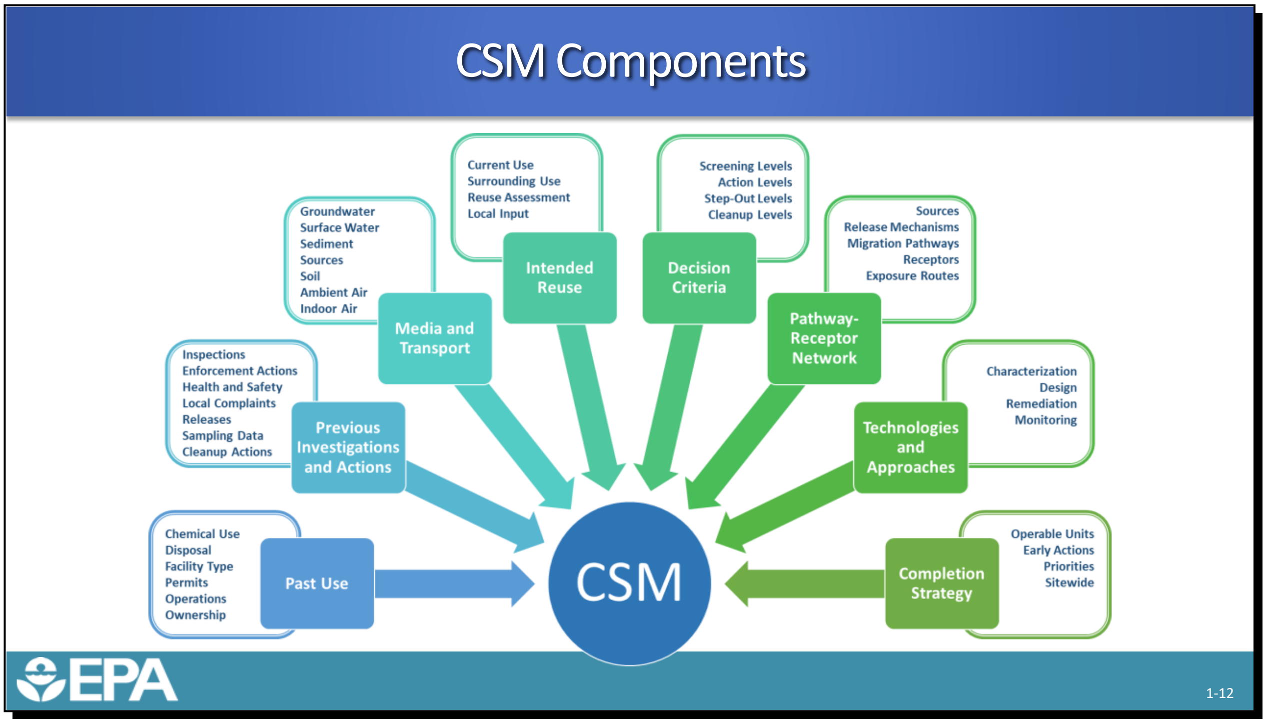
- **Baseline CSM:** The primary goal of the Baseline CSM is to establish stakeholder consensus on the state of site knowledge, identify information needs and plan data collection efforts. If consensus is not achieved during initial project planning, it is possible to develop CSMs that articulate different interpretations of the Baseline CSM. Together these Baseline CSMs become the basis for future information and data collection as the Characterization CSM is refined to resolve these discrepancies.

- **Characterization CSM Stage:** The primary goals of the Characterization CSM are to guide field investigation efforts, maintain stakeholder consensus as new site information is generated through data collection and provide accurate and complete information as the basis for the remedy design. The Characterization CSM is “evolved” via real-time or near-real-time updates until site uncertainty is reduced to a point where stakeholders reach consensus that the site is adequately characterized for making decisions in support of subsequent project phases.

- **Design CSM Stage:** The Design CSM is used as the basis for remedial design. It is dependent on stakeholder agreement that the Characterization CSM was adequate for selecting a remedial action. If the site is not adequately characterized, the Design CSM will be insufficient for the design effort.

- **Remediation/Mitigation CSM Stage:** The Remediation/Mitigation CSM is used to guide field efforts, meet remedial goals and performance objectives and support remedial strategy and system optimization. Similar to the Characterization CSM, the Remediation/Mitigation CSM is evolved in real-time as a remedy is implemented and/or optimized.

- **Post-Remedy CSM Stage:** The Post Remedy CSM documents attainment of remediation objectives and goals can be used to support site completion or closure.



Notes

- **Past Use:** Evaluated to identify the contaminants of concern/contaminants of potential concern (COCs/COPCs) that may have been disposed of or released from the facility and the location and timing of historical disposal and releases. Critical to site characterization.

- **Previous Investigations and Actions:** Data from previous investigations, including inspections, enforcement actions, local complaints, current and former employee interviews, and releases and cleanup actions, are evaluated to estimate contaminant distributions in the environment and evaluate potentially complete pathway-receptor networks.

- **Media and Transport:** The CSM identifies all media impacted and the transport of contaminants in media and between media. EPA has identified eight strategic sampling approaches (Media/COC interactions, sources, soil, groundwater, surface water, sediment, ambient air, and indoor air) for various media and contaminants.

- **Intended Reuse:** A site's proposed reuse can dictate decision criteria, be used to focus sampling efforts, and can affect the nature and cost of the remedy.

- **Decision Criteria:** Include contaminant screening levels, action levels, site-specific field decision levels, and cleanup levels. Decision criteria are used to: (1) guide in-field decisions based on the real-time results of field methods, (2) characterize risk, and (3) determine the extent of cleanup.

- **Pathway Receptor Network (PRN):** This component synthesizes site information to identify actual potential risks and is essential to human health and ecological risk assessments.

- **Technologies and Approaches:** The CSM includes consideration of technologies and approaches that may exist to address the project's current phase, and upcoming phases, as appropriate. For example, the technologies and approaches focused on in the RI/FS phase include characterization technologies to understand contaminant movement in the environment as well as data for potential cleanup technologies.

- **Completion strategy:** This component focuses on the steps necessary to achieve site completion. A sitewide strategy identifies site objectives/priorities and the schedule.

Test Your Knowledge

- **True or False:** It is important to address each component of the CSM on a regular basis

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What is HRSC?

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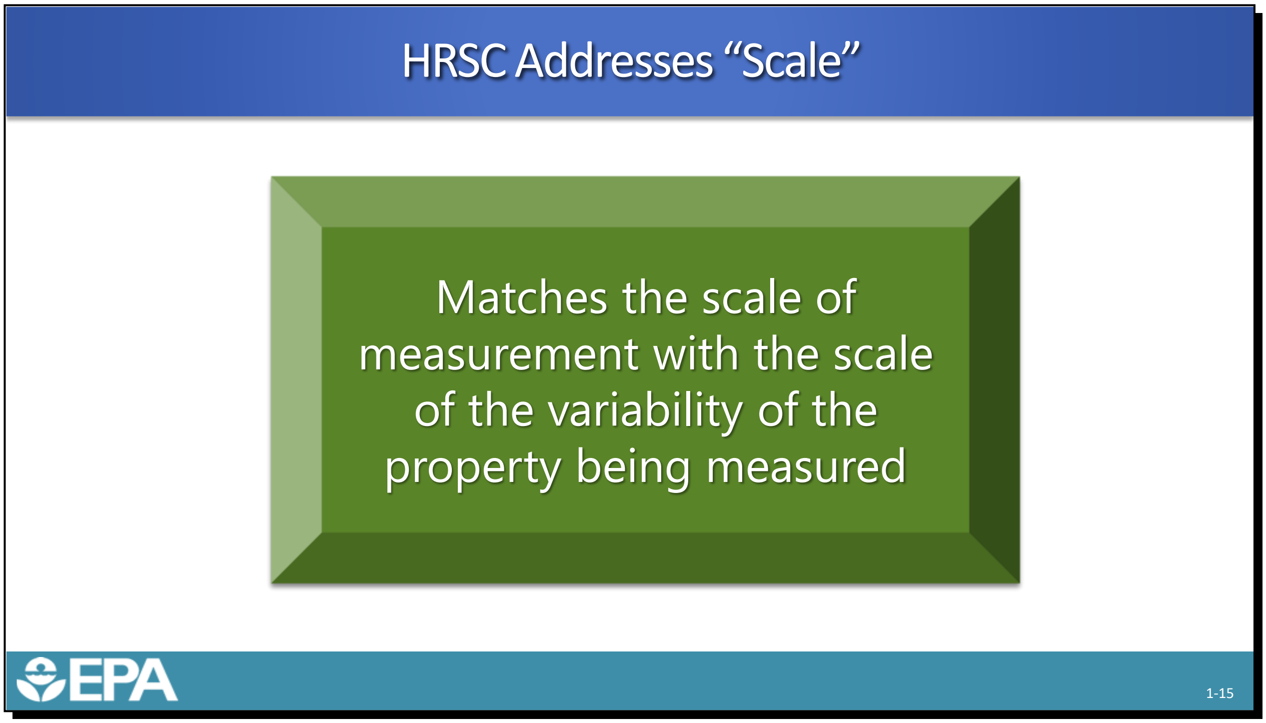
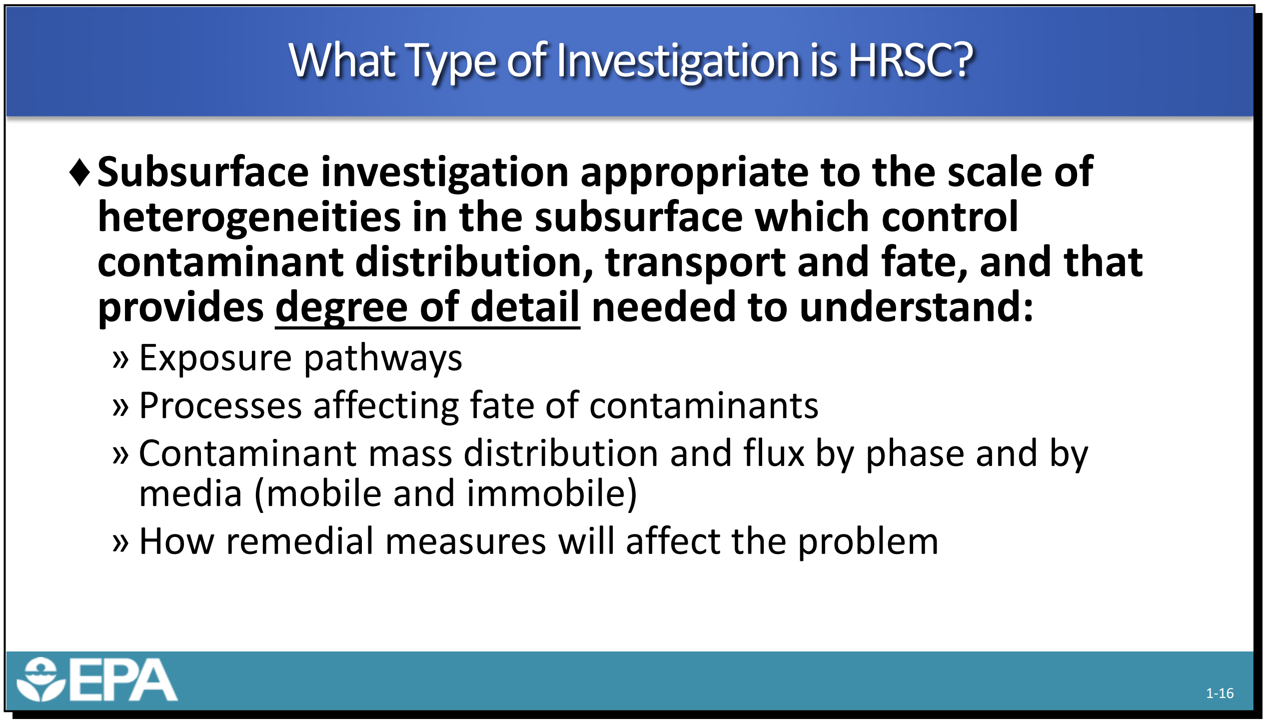


Notes

- HRSC strategies and techniques use scale-appropriate measurement and data density to define contaminant distributions in environmental media with greater certainty, supporting faster and more effective site cleanup.
- For example, when performing hydraulic testing to determine hydraulic conductivity, the testing interval will be influenced by the heterogeneity of the grain size distribution in the subsurface material.



Main Idea

- *The definition of HRSC is, by necessity, a functional definition. It depends not only on the objectives of the investigator but on the physical nature of the site as well.*

Notes

- There is no single sample size or a standard sample spacing that is appropriate for all sites. Spatial structures for key variables are dependent on the geological environment. In addition, the distribution of contaminant concentrations is dependent on the nature and architecture of the source.

- HRSC is designed and implemented to be appropriate to the scale of the heterogeneities in the subsurface which control contaminant distribution, transport and fate. These heterogeneities happen at a very small scale that traditional investigations miss.

How Is HRSC Data Collection Different?

- **Provides a greater density of measurements**
- **Uses collaborative data sets**
- **Employs strict field QA/QC**
  - » Maximize usefulness of data
  - » Target confirmatory or collaborative sample analysis where needed
- **Often uses field-based action levels or response factors with a margin of safety**
- **Uses real-time data management and communication strategies**
  - » High volume of data gathered to capture, process, format for stakeholder decision-making

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Main Idea

- *HRSC data collection benefits from both higher quality and quantity of data.*

Notes

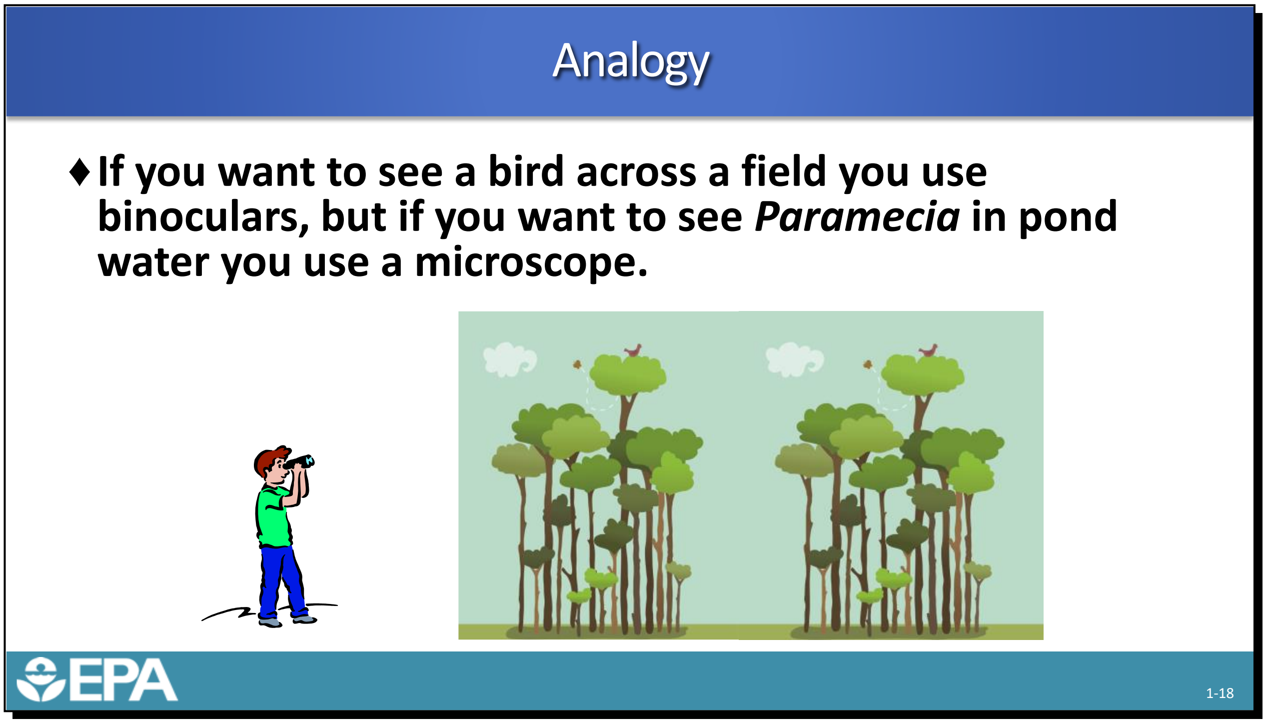
- **Provides a greater density of measurements:** An HRSC project follows the Triad approach and entails collecting a greater number of measurements, which provides a denser, and therefore, more confident estimation of the nature and extent of contamination. This more confident estimation is achieved using real-time measurement technologies that can generate many measurements in a short period of time and produce collaborative data sets.

- **Uses collaborative data sets:** The term “collaborative data sets” refers to the use of more than one analytical or measurement technique to shed light on the contamination status of a site or area of concern. “Collaborative” indicates that the combination of two sources of results, each with different strengths and weaknesses, produces a better decision-making result than used separately. The Triad Approach does not advocate replacing laboratory methods completely with cheaper, field-deployable technologies. In fact, it promotes just the opposite: that typically the most effective analytical program is one that judiciously blends real-time techniques with fixed-based laboratory methods to produce collaborative data sets. In addition, several field-deployable technologies can be used in combination to provide collaborative data sets of like or dissimilar data.

- **Employs strict field QA/QC to maximize usefulness of data and target confirmatory sample analysis where needed:** Uncertainty exists within any method, but QC programs can identify areas of variability or uncertainty and focus resources on those with the greatest potential impact to the project. Recognizing limitations and using the advantages of various methods allows data sets to be evaluated collaboratively to control different areas of uncertainty (such as laboratory methods to control analytical variability and high-density field measurement tools to control sample or spatial variability). Where needed, use of a Demonstration of Method Applicability (DMA) early in the project can help refine Quality Assurance (QA)/QC goals and processes for field deployments, support development of decision logic diagrams to enable effective DWS and provide a mechanism for adaptively managing uncertainties or variabilities that can have potentially significant impacts on the project.

- **Often uses field-based action levels or response factors with a margin of safety:** HRSC develops and uses field-based actions levels that consider site- and instrument-specific factors to guide decision-making in the field. These action levels may be adjusted in response to QA/QC of the field method.

- **Uses real-time data management and communication strategies:** Like Triad, HRSC project data collection depends on real-time management and communication. For many projects, large amounts of data must be managed, validated, displayed, incorporated into the CSM and communicated to decision-makers and stakeholders as they are generated, or soon thereafter. Automated and semi-automated data management and visualization tools make this effort easier.



Main Idea

- *HRSC addresses scale first, then addresses measurement spacing, density, and placement second*

Notes

- If measurements are made at the wrong scale it is very hard to understand what is being measured no matter how many measurements are made. The scale at which measurements are made is a separate (but related) issue from the frequency or spacing or quantity of measurements.
- However, even if measurements are made at the right scale it will not help unless enough measurements are made at the right spacing and in the right places. The amount of data is a second issue (scale of measurement being the first). Once the scale to measure at (and what tool to do it with) has been properly determined, the number and placement of measurements can be evaluated.
- With the analogy: Even when binoculars are used (instead of a microscope) to look at the cardinal in the tree line, the overall health of the bird population cannot be assessed until many birds are observed in enough trees in enough tree lines. No matter how many times someone looks through the microscope at the birds, nothing will be learned about the birds.

Characterization versus Monitoring: Apples and Oranges

- **Site Characterization**
  - » Objectives
  - » Tools
  - » Approaches
- **Site Monitoring**
  - » Objectives
  - » Tools
  - » Approaches

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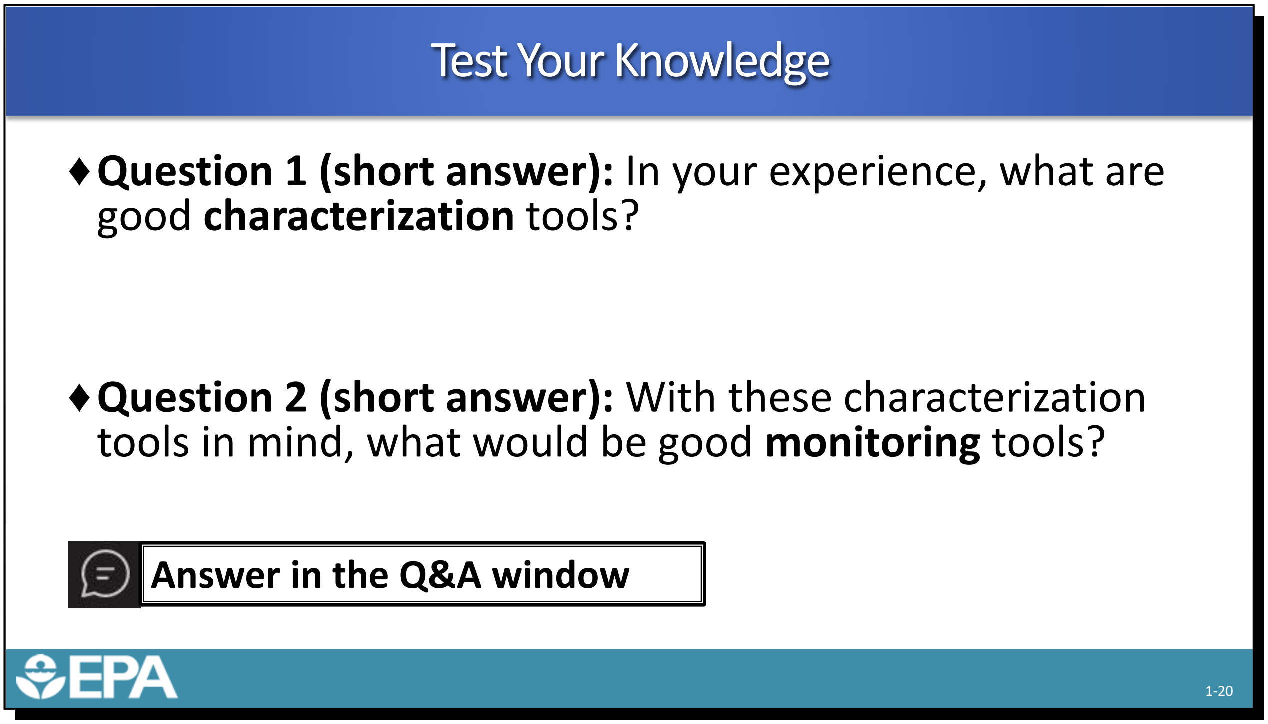
Main Idea

- *The objectives of site characterization are different from the objectives of site monitoring.*

Notes

- The tools and approaches for site characterization are different from the tools and approaches for site monitoring: The investigation of sites by installing monitoring wells is done with good intentions and is required by state regulations but may not be the best tool for the job of characterization.
- The objective for site characterization is to identify the nature and extent of contamination in areas where there are significant data gaps. The objective is based on the needs for decision making related to risk and clean up. Tools selected for investigation should provide a comprehensive understanding of the geology, hydrogeology, and contaminant chemistry. Wells that screen multiple layers or long intervals are not good characterization tools. Detailed information at a high resolution is needed during the characterization phase.
- The objective for site monitoring is to have a data monitoring point that investigators can collect data from over time. The monitoring point should be representative of the site conditions identified during site characterization. Properly screened wells in key area of the plume and aquifer can be good monitoring tools.


Test Your Knowledge
♦ Question 1 (short answer): In your experience, what are good characterization tools?
♦ Question 2 (short answer): With these characterization tools in mind, what would be good monitoring tools?
Answer in the Q&A window
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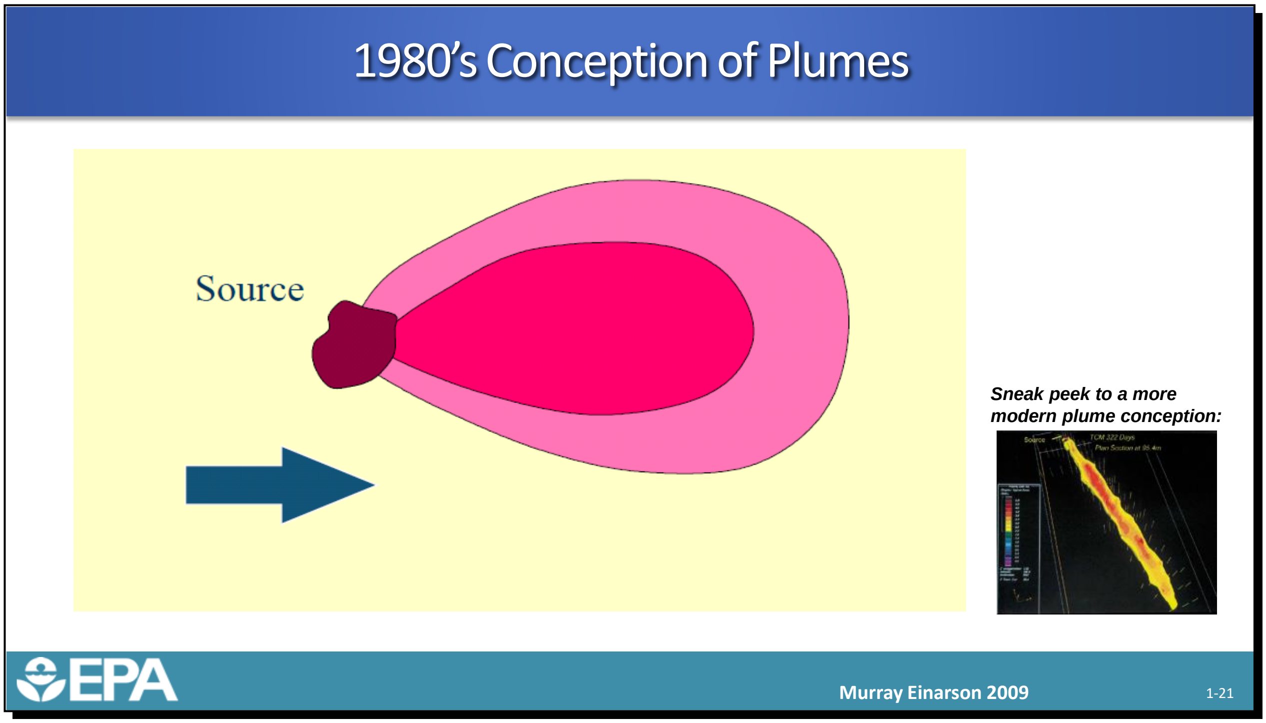


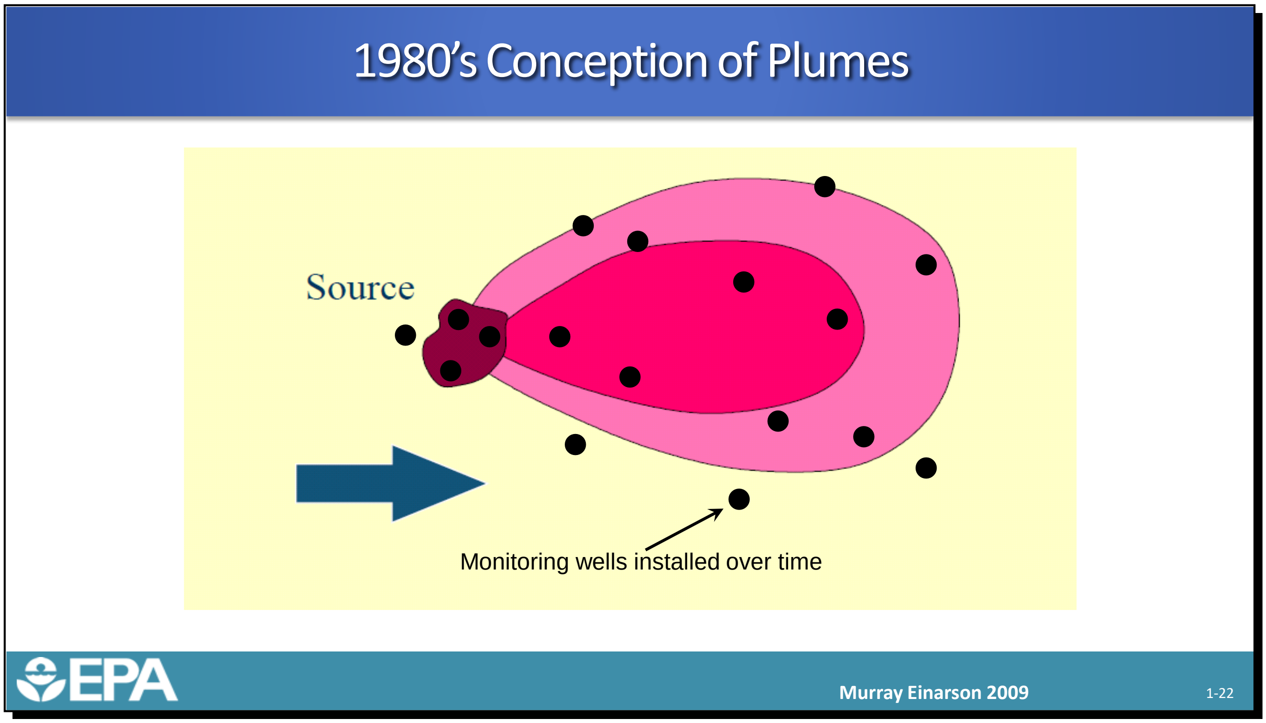
Main Idea

- *We do NOT use the 1980's conception of plumes. Our thinking has evolved because of research and more sophisticated understanding of the subsurface.*

Notes

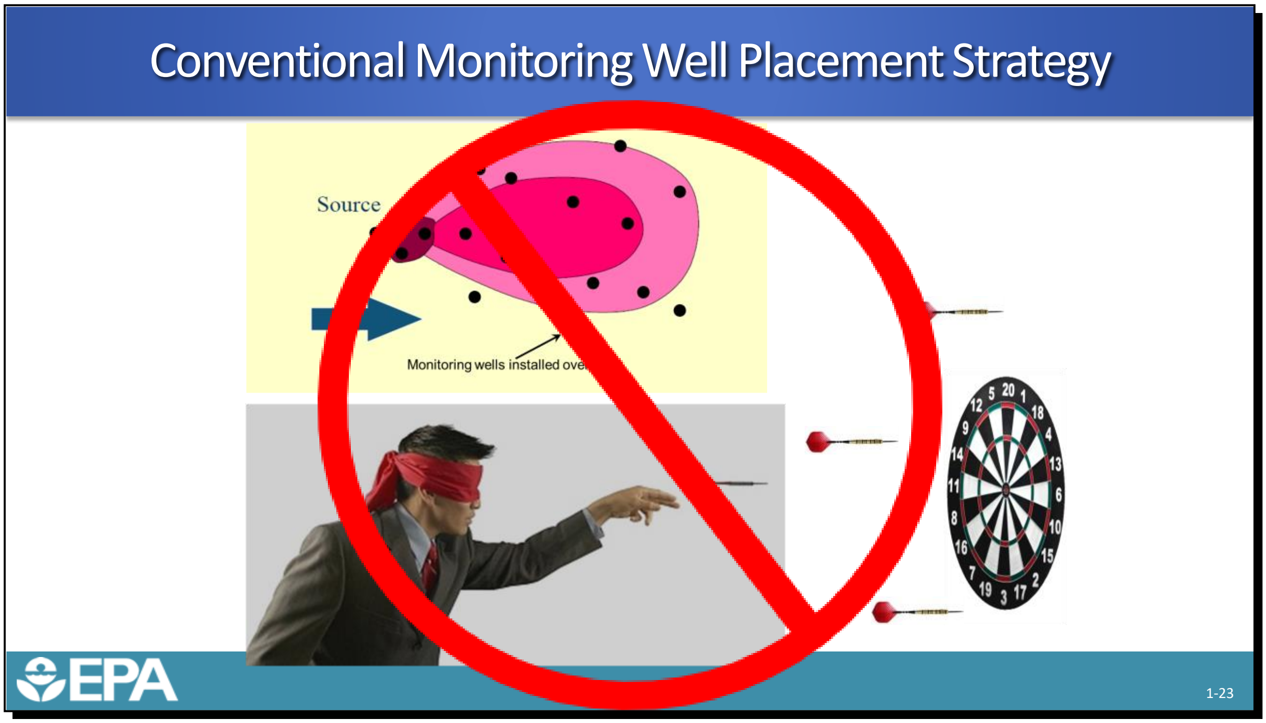
◆ This cartoon, prepared by Murray Einarson, summarizes old thinking about groundwater contaminant plumes, specifically that plumes were broad, fan-shaped objects with relatively uniform contaminant concentrations throughout. This thinking probably originated from plumes observed at landfills where groundwater mounding caused semi-radial flow away from the landfill. It is also a product of the numerical dispersion that was a feature of earl numerical models used to simulate plumes. Such plumes fit with the notion of powerful transverse hydrodynamic dispersion which was debunked in the late 1980's.

Source: http://www.solinst.com/onthelevel/symposium2009/high-resolution-subsurface-monitoring-presentation.pdf



Notes

- Einarson's cartoon illustrates how conventional investigations are done. Monitoring wells are installed in phases over time in a seemingly random distribution as specific "data gaps" are identified after each field phase.



Main Idea

Monitoring wells should be avoided as investigation tools.

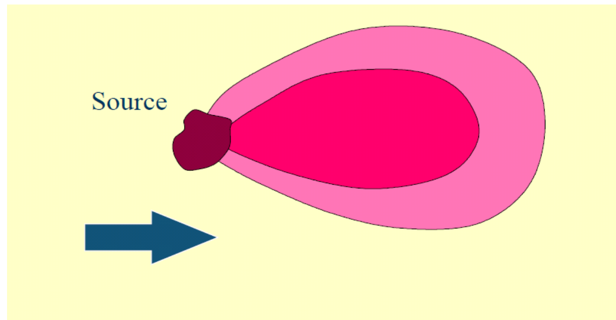
Notes

- This approach to site characterization is slow, **expensive**, wasteful and leads to erroneous understandings of the plume. This approach to investigation has come to be known as "poke and hope" or "hunt and peck." The investigator assumes that they know what the 3-dimensional distribution of contamination is and tests this "knowledge" by installing a well at a specific location. One may as well throw darts at a map with a blindfold on.

Test Your Knowledge

♦ **What influences the size and shape of a plume map?**

A. Contaminant Properties
B. Aquifer properties
C. Location of measurement points, such as wells
D. All the above



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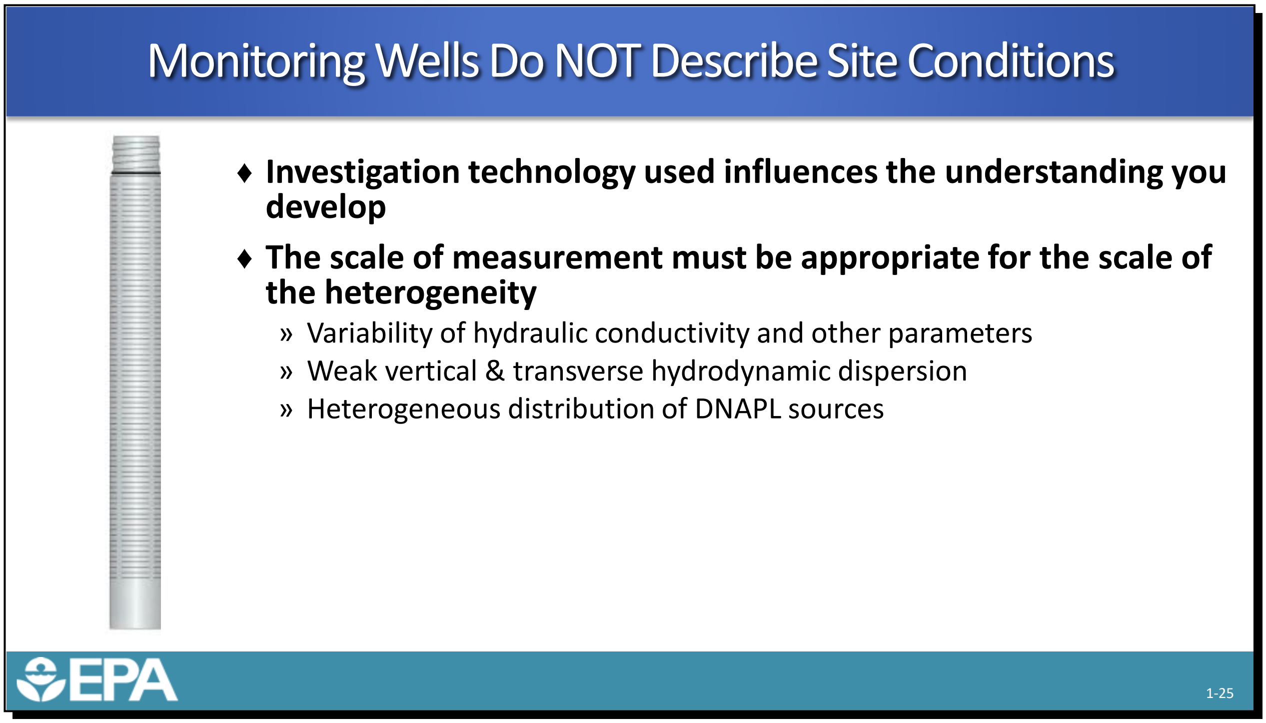


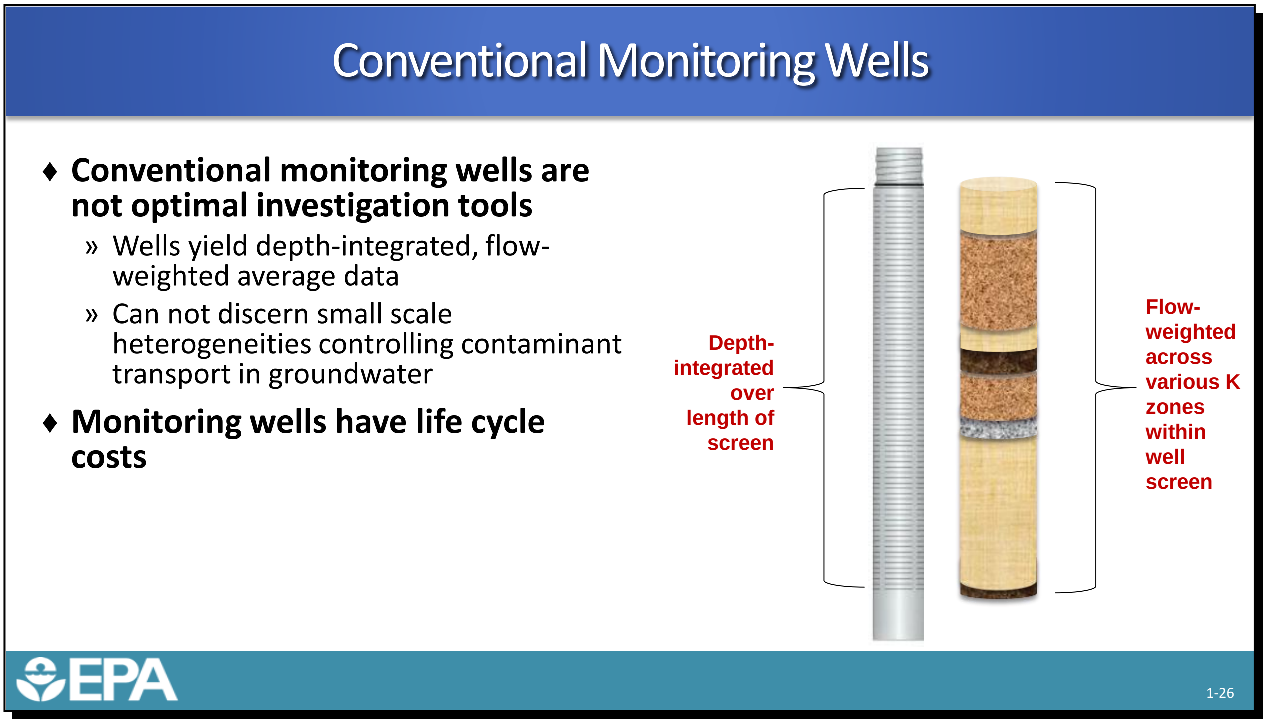
Main Idea

- *You will understand site conditions only as well as the characterization technology used allows.*

Notes

- **Characterization technology used influences the understanding you develop:** Sites investigated using monitoring wells typically have many of the wells in the wrong location and screened over the wrong intervals. The CSM that results from wells that are in the wrong location and screened over the wrong interval does not reflect reality. The construction of wells involves the use of materials that are costly, and the installation process is time consuming and expensive. Wells also require maintenance over time. The wells often must be monitored on a frequent basis for expensive suites of analyses. These costs contribute little to the understanding of the site.

- **The scale of measurement must be appropriate for the scale of heterogeneity:** Wells do not provide the appropriate scale of measurement for the variability that exists in hydraulic conductivity, contaminant concentrations and other important hydrogeological parameters. Well installation patterns do not take advantage of the fact that there is weak transverse hydrodynamic dispersion. In addition, wells do not provide the appropriate scale of measurement for a site's heterogeneous distribution of DNAPL sources.



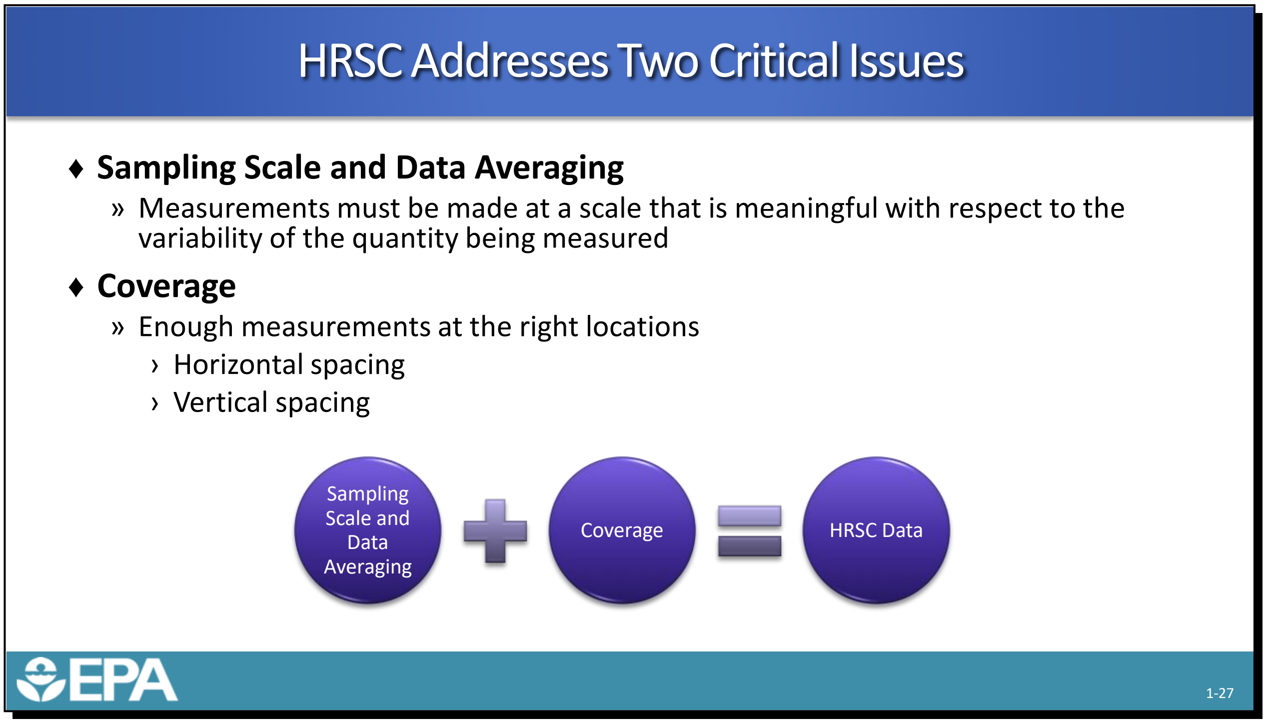
Main Idea

- *Conventional monitoring wells are not optimal investigation tools*

Notes

- **Conventional monitoring wells are not optimal investigation tools:** Perhaps the biggest drawback of using monitoring wells as investigation tools is that they typically provide depth-integrated, flow-weighted average data which are not helpful in understanding the spatial structure of the problem. There will be much more on this topic later.

- **Monitoring wells have life cycle cost:** The cost of a monitoring well is not just the installation cost; monitoring wells have a life cycle cost which some practitioners estimate to be as much as $50,000 on average. This includes maintenance and sampling (even when the well is in the wrong place and does not provide particularly useful data). Life-cycle analysis of environmental liabilities at some Federal Facilities require consideration of closure costs of wells, which can be significant if many well are present.

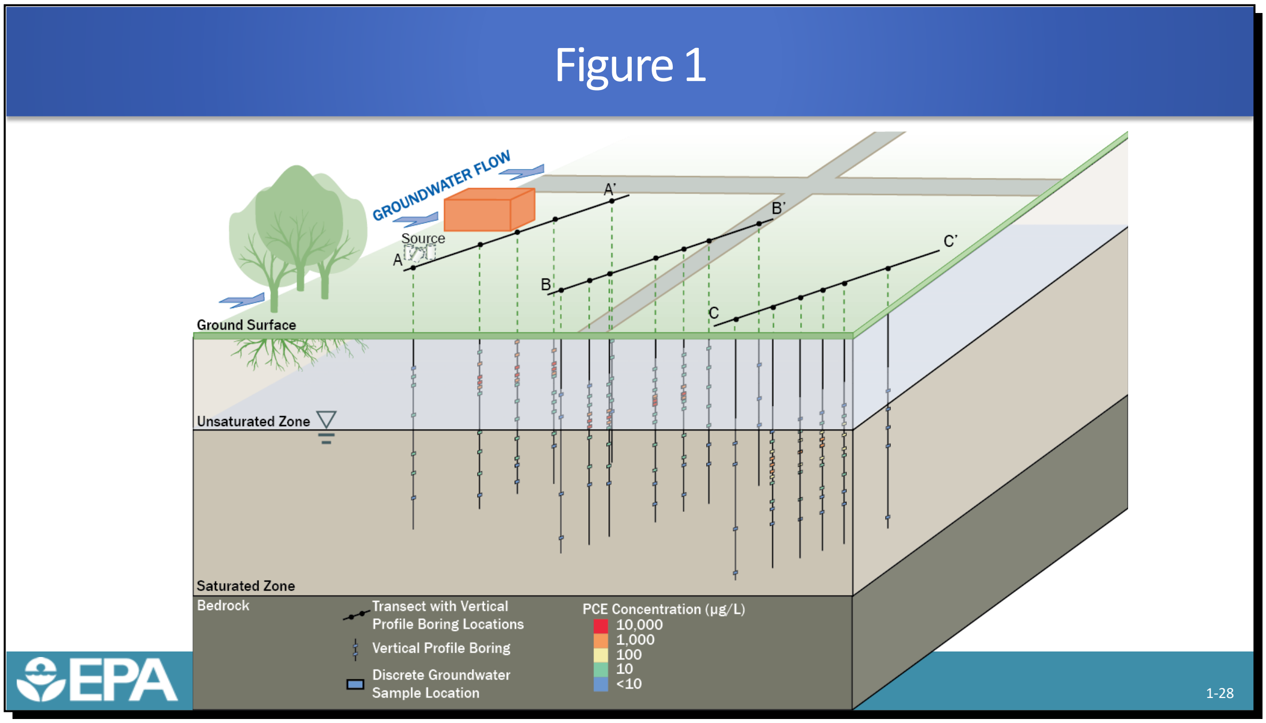


Notes

- "High resolution" is achieved by addressing these two key issues: (1) sample scale/data averaging and (2) having the samples be spaced appropriately in three dimensions. Sample scale and data averaging and coverage are discussed further in Module 3.

- Sample size must be such that averaging of properties over the scale of the sample does not obscure important information that resides in the region being sampled. Subsurface geologic heterogeneity is such that the values of most key variables change profoundly over very short distance scales. For a groundwater sample, key sample size issues include the length of the vertical sample interval as well as how much water is pumped to obtain the sample. Increasing the volume of water pumped increases the volume of aquifer sampled and results in decreased resolution.

- Horizontal and vertical spacing of sampling points must be small enough that important information (such as high concentration zones) are not missed, but not so small that the cost increases beyond the value obtained from it.



Main Idea

- *A primary HRSC strategy for groundwater contamination in unconsolidated aquifers uses transects of vertical subsurface profiles oriented perpendicular to the direction of the hydraulic gradient.*

Notes

- Profiles are advanced to depth along each transect and used to collect detailed geologic and hydrogeologic information. These data are then combined with groundwater contaminant data obtained from discrete-interval groundwater sampling to generate 2-dimensional (2-D) cross-sections, or more advanced 3-D visualizations, to identify lower concentration dissolved plumes and higher concentration plume cores correlated with site geology and hydrogeology.
- Figures 1 through 5 that follow illustrate a hypothetical application of HRSC to investigate perchloroethene (PCE)-contaminated groundwater in an unconsolidated aquifer at a manufacturing facility. A bedrock formation that is not a drinking water concern underlies the unconsolidated aquifer at the site.
- Figure 1 above shows the location of three transects used to investigate the release of PCE from a suspected source at the facility. Each transect is oriented perpendicular to groundwater flow and consists of vertical profiles advanced to depth in the overburden using direct push technology (DPT). Continuous geologic and hydrogeologic data are collected at a high density over the vertical extent of each profile boring using direct sensing technologies. In addition, a direct sensing tool such as the membrane interface probe (MIP) can be used to evaluate the distribution of contamination between higher hydraulic conductivity (K) and lower K zones. These data are used to target higher K zones for groundwater sample collection using a discrete interval groundwater sampling technology. More information on direct sensing and discrete interval sampling technologies can be found at http://www.brownfieldstsc.org/roadmap/contByInvTech.cfm.

Source: www.clu-in.org/characterization/technologies/hrsc/

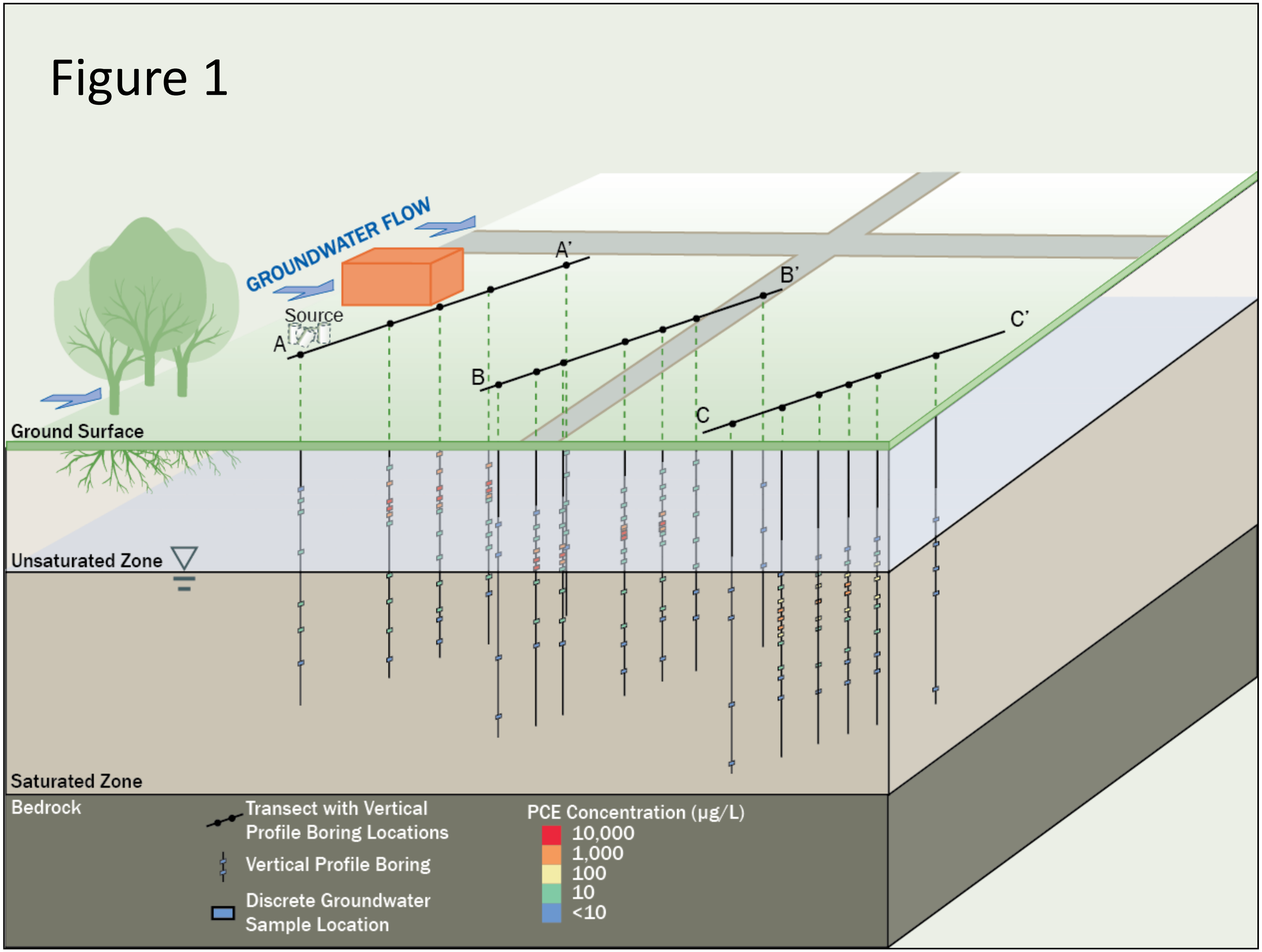
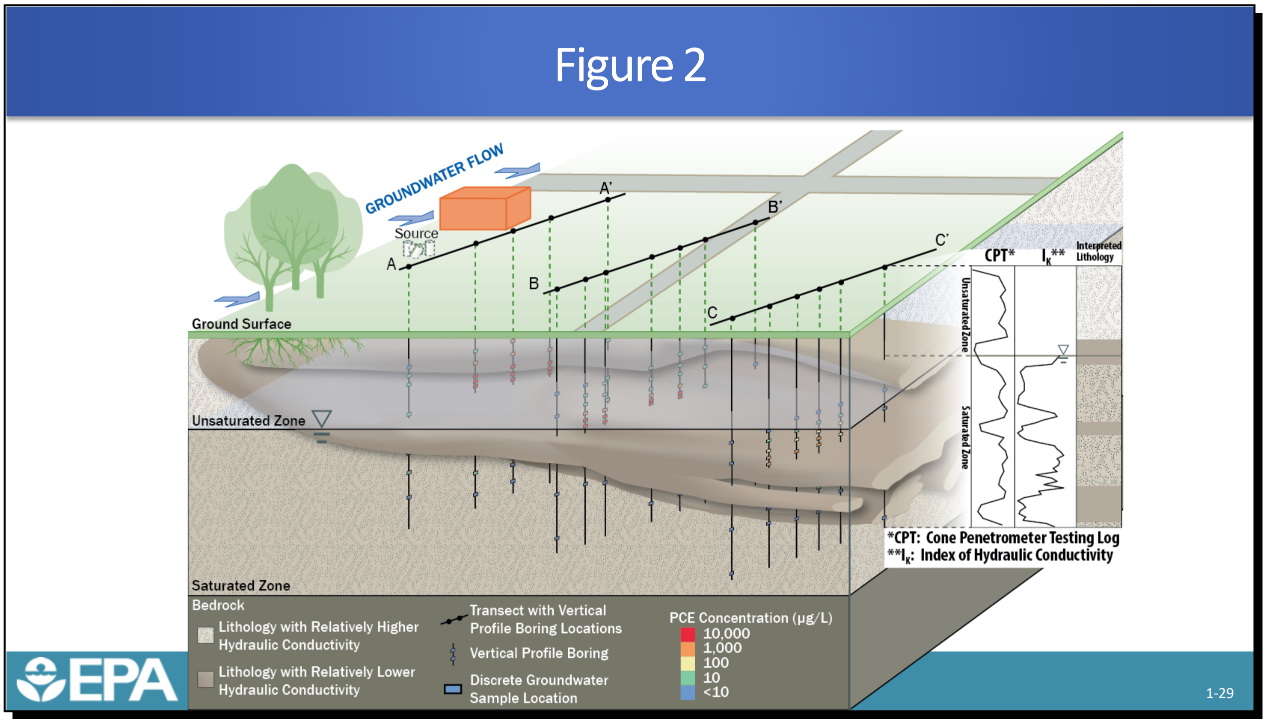


Figure 1
GROUNDWATER FLOW
Source
A
A'
B
B'
C
C'
Ground Surface
Unsaturated Zone
Saturated Zone
Bedrock
Transect with Vertical Profile Boring Locations
Vertical Profile Boring
Discrete Groundwater Sample Location
PCE Concentration (µg/L)
10,000
1,000
100
10
<10



Main Idea

- *Spatial assessment of other site data can improve site understanding*

Notes

◆ Figure 2 above shows the interpreted unconsolidated and bedrock lithology at the site based on 3-D visualization of the high-density, direct sensing geologic and hydrogeologic data and depth to bedrock information. Vertical data plots, similar to soil boring logs, show the heterogeneous distribution of lithologic zones of relatively high and low K that control contaminant fate and transport. Other site data could include data from a vertical profiling effort, such as hydraulic head, physiochemical parameters, qualitative (screening) contaminant levels and quantitative contaminant concentrations.

Source: www.clu-in.org/characterization/technologies/hrsc/

Figure 2

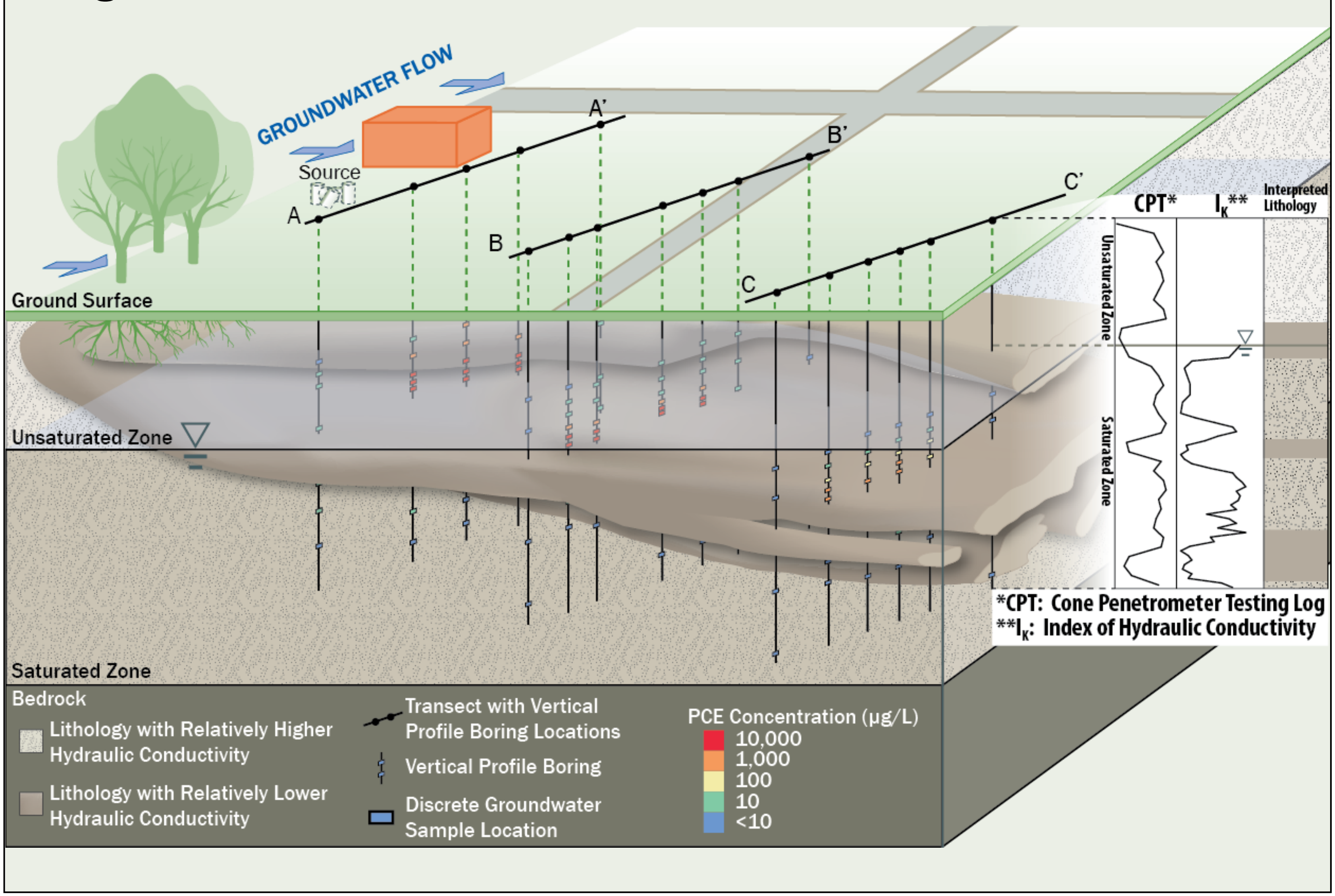
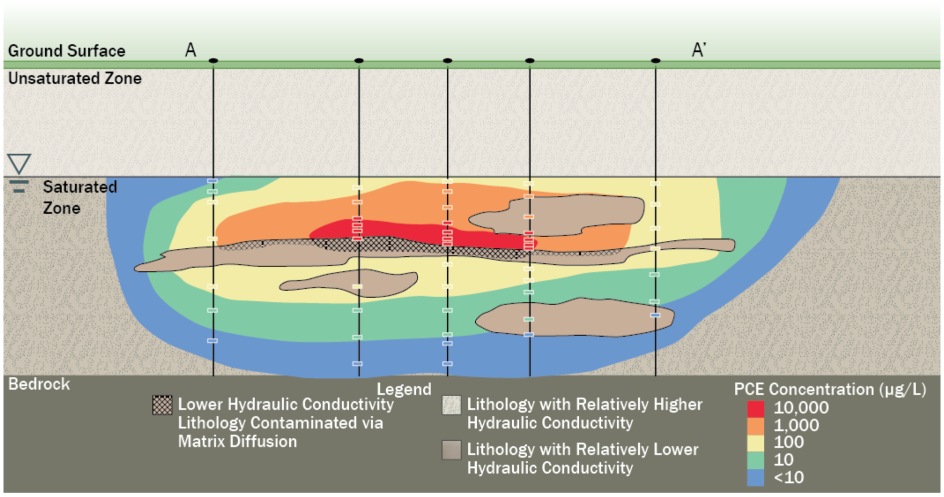

GROUNDWATER FLOW
Source
A
A'
B
B'
C
C'
Ground Surface
Unsaturated Zone
Saturated Zone
CPT*
I_K**
Interpreted Lithology
Unsaturated Zone
Saturated Zone
*CPT: Cone Penetrometer Testing Log
**I_K: Index of Hydraulic Conductivity
Bedrock
Lithology with Relatively Higher Hydraulic Conductivity
Lithology with Relatively Lower Hydraulic Conductivity
Transect with Vertical Profile Boring Locations
Vertical Profile Boring
Discrete Groundwater Sample Location
PCE Concentration (μg/L)
10,000
1,000
100
10
<10

Figure 3



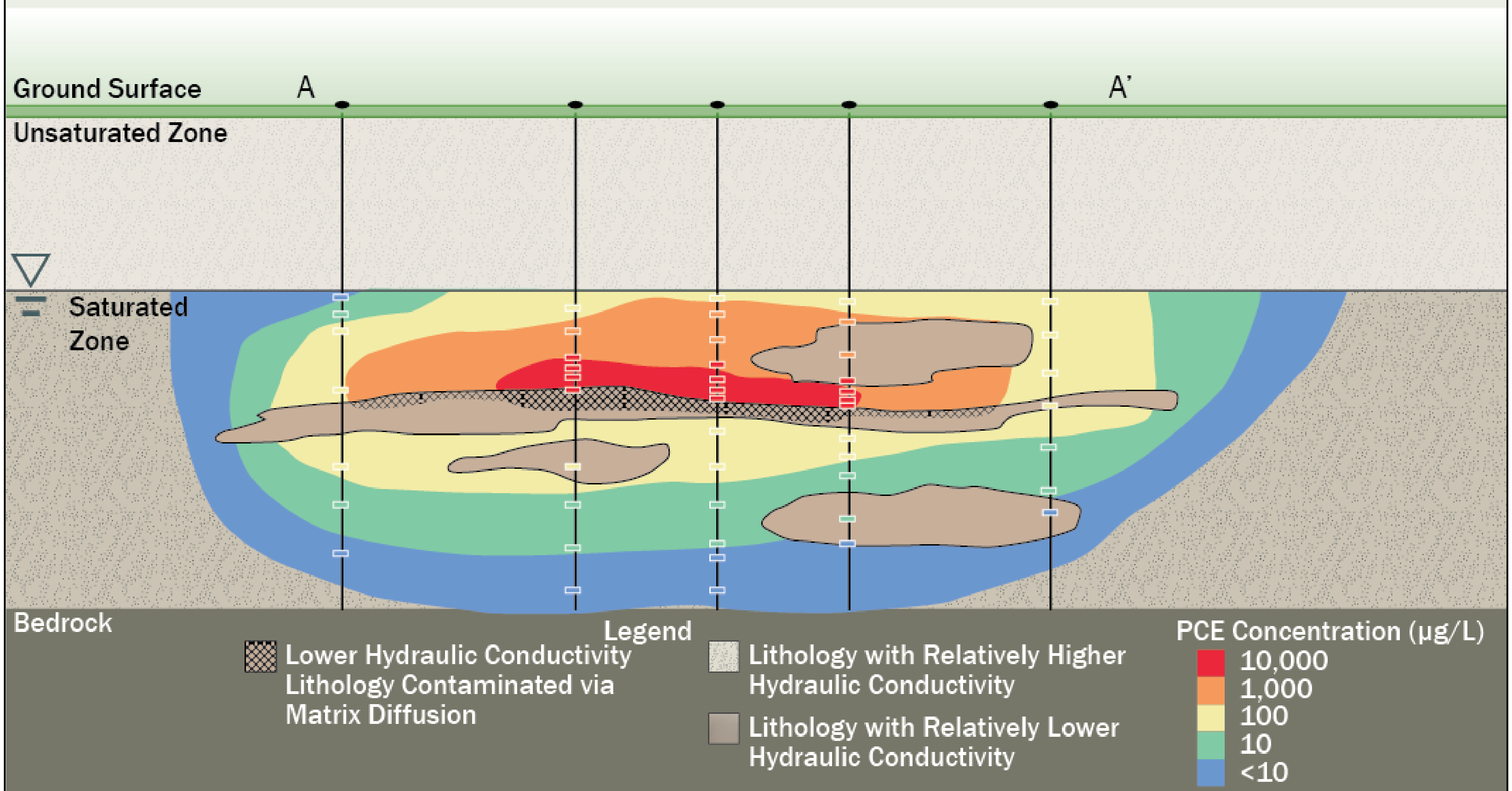
EPA 1-30

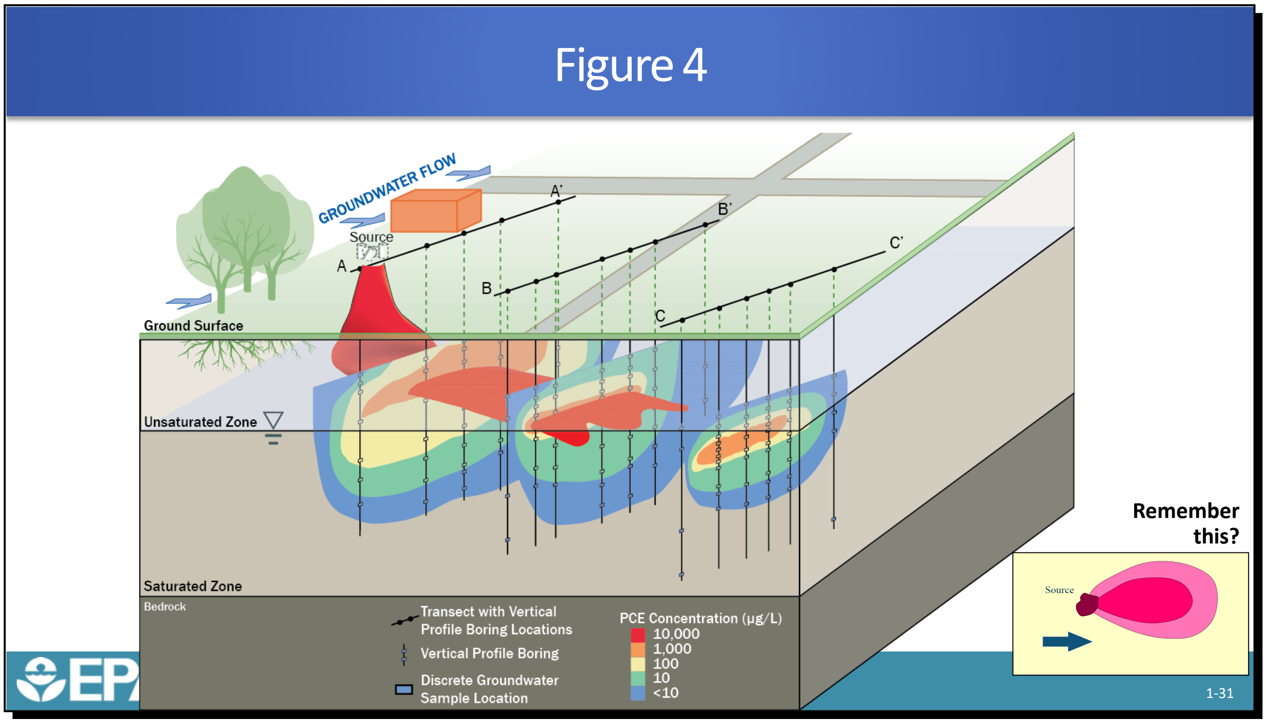
Notes

- Figure 3 is a 2-D visualization of the integrated geologic/hydrogeologic and contaminant concentration data for Transect A-A'. Contaminant concentrations detected in groundwater samples collected at discrete vertical intervals indicate a lower concentration plume and a higher concentration, higher mass per unit volume plume core (PCE concentrations exceeding 10,000 micrograms per liter [µg/L]), both in dissolved phase. [Note: on many sites, it is common for there to be multiple plume cores. This example assumes one plume core for presentation simplicity. However, the existence of multiple plume cores of various dimensions, positions and contaminant concentrations is a major driver behind the need to characterize sites using HRSC strategies.] The concentration distribution shown on Transect A-A' is consistent with established research which concludes that 75 percent of contaminant mass discharge occurs in only five to 10 percent of the plume cross sectional area (Gilbeault et al. 2005). Concentrations markedly decline away from the plume core over relatively short distances.
- The plume core is confined to a relatively thin interval of relatively higher K material, indicating that the bulk of the dissolved phase mass is moving through a comparatively small cross section of the aquifer. Potentially significant contaminant mass, however, is also likely stored in the adjacent lower K units through matrix diffusion. The length of time since the contaminant release and the scale of subsurface heterogeneity significantly impact the degree to which matrix diffusion has occurred. At this stage, additional field efforts may be warranted to better characterize the degree of matrix diffusion influence to support remedy selection and design.

  Source: www.clu-in.org/characterization/technologies/hrsc/

Figure 3


Ground Surface
A
A'
Unsaturated Zone
Saturated
Zone
Bedrock
Legend
Lower Hydraulic Conductivity Lithology Contaminated via Matrix Diffusion
Lithology with Relatively Higher Hydraulic Conductivity
Lithology with Relatively Lower Hydraulic Conductivity
PCE Concentration (µg/L)
10,000
1,000
100
10
<10



Main Idea • *This knowledge lowers site uncertainty and can significantly contribute to the design and success of any remedy or suite of technologies being considered for site cleanup.*

Notes

- Figure 4 above presents the three transects oriented in 3-D, showing the plume and plume core with respect to the source area and the prevailing groundwater flow direction. The visualization indicates that use of a HRSC strategy has effectively defined the higher K lithologic zones that serve as preferential pathways for both the dissolved plume and plume core. Similarly, HRSC has defined the lower K lithologic zones which commonly contain the majority of the contaminant mass and can serve as long-term secondary sources for the dissolved plume and plume core. The visualization also demonstrates, how in many instances, the plume information generated using HRSC transects can be used to locate or confirm specific source areas.

- The subsurface detail provided by HRSC can also support the design of targeted remedial approaches to remove mass from the plume core and low K lithologic zones and control the downgradient migration of the dissolved plume at its distal edge. In this case, HRSC identifies where contaminant mass is located spatially, and clarifies the hydrogeologic context in which the mass resides and behaves.

  Source: www.clu-in.org/characterization/technologies/hrsc/

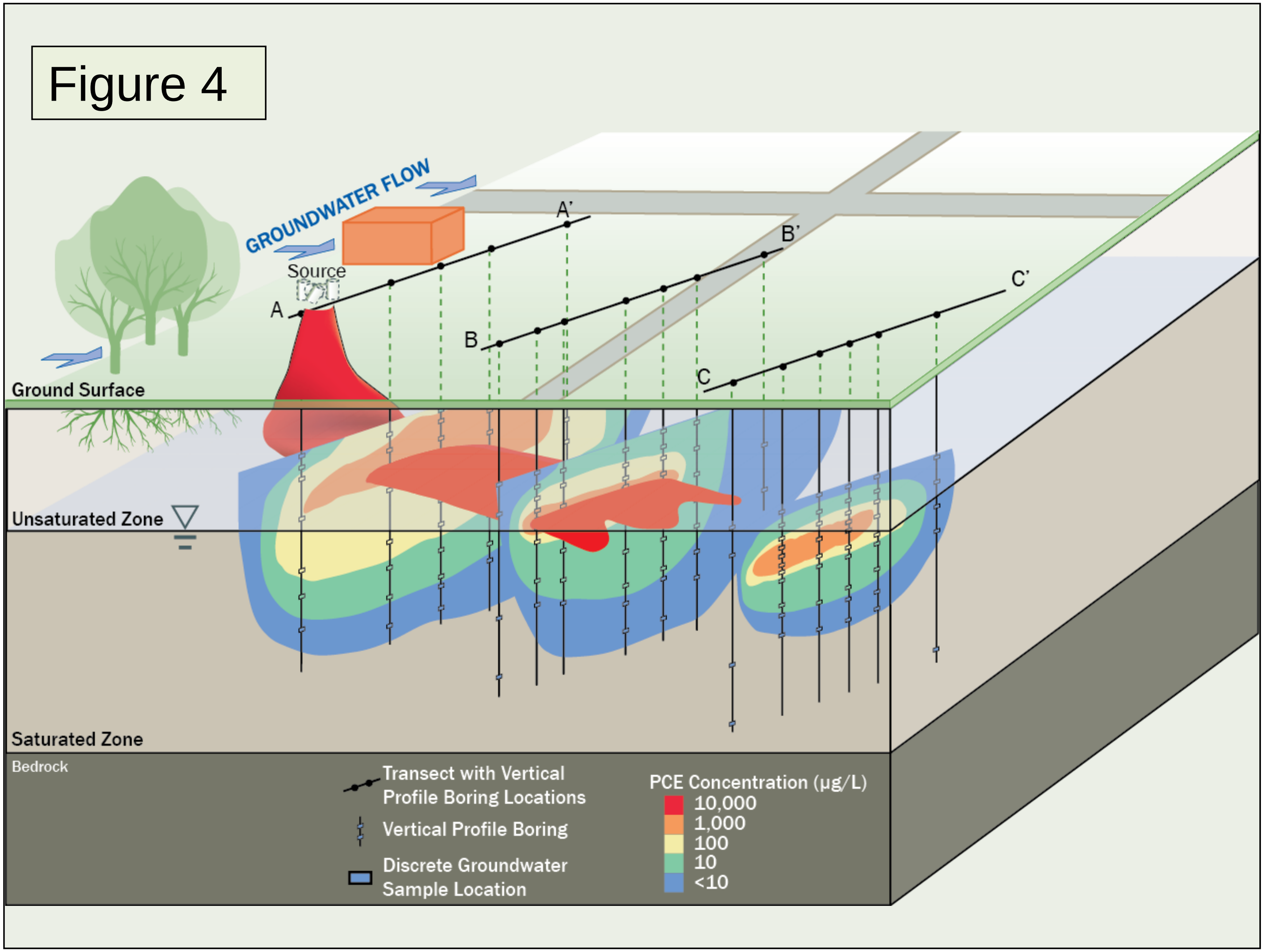
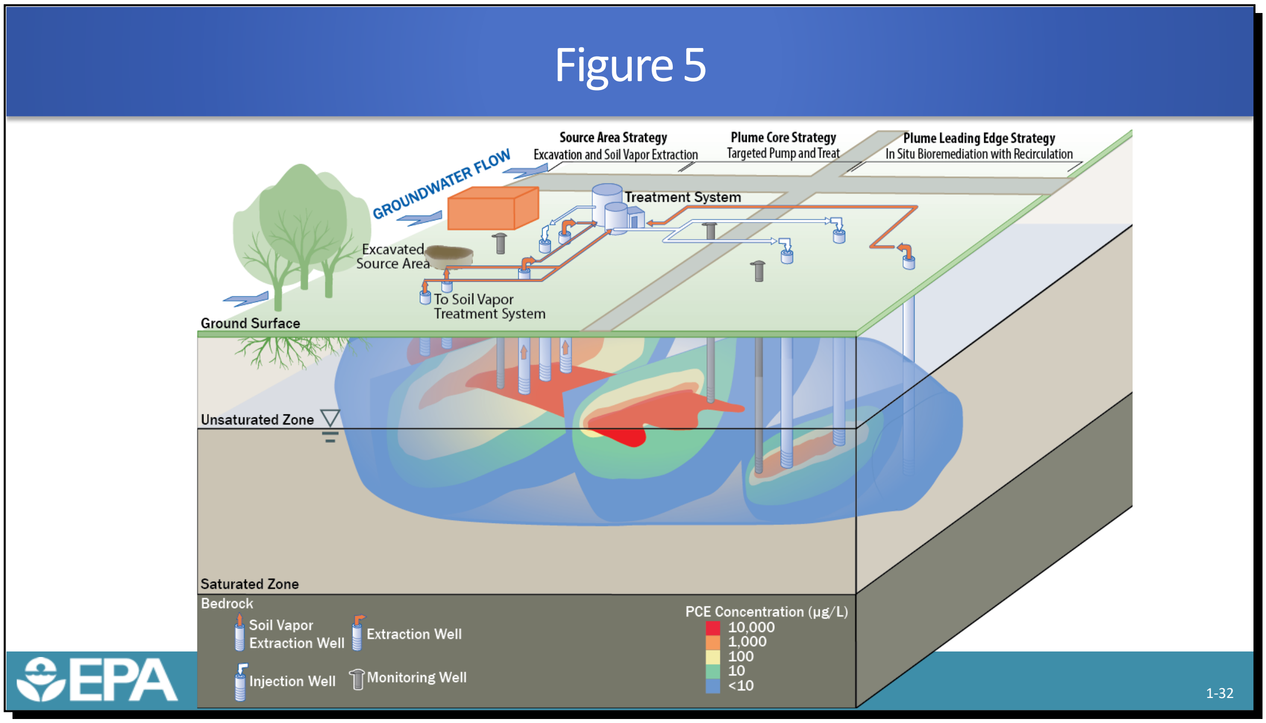


Figure 4
GROUNDWATER FLOW
Source
A
A'
B
B'
C
C'
Ground Surface
Unsaturated Zone
Saturated Zone
Bedrock
Transect with Vertical Profile Boring Locations
Vertical Profile Boring
Discrete Groundwater Sample Location
PCE Concentration (µg/L)
10,000
1,000
100
10
<10



Main Idea

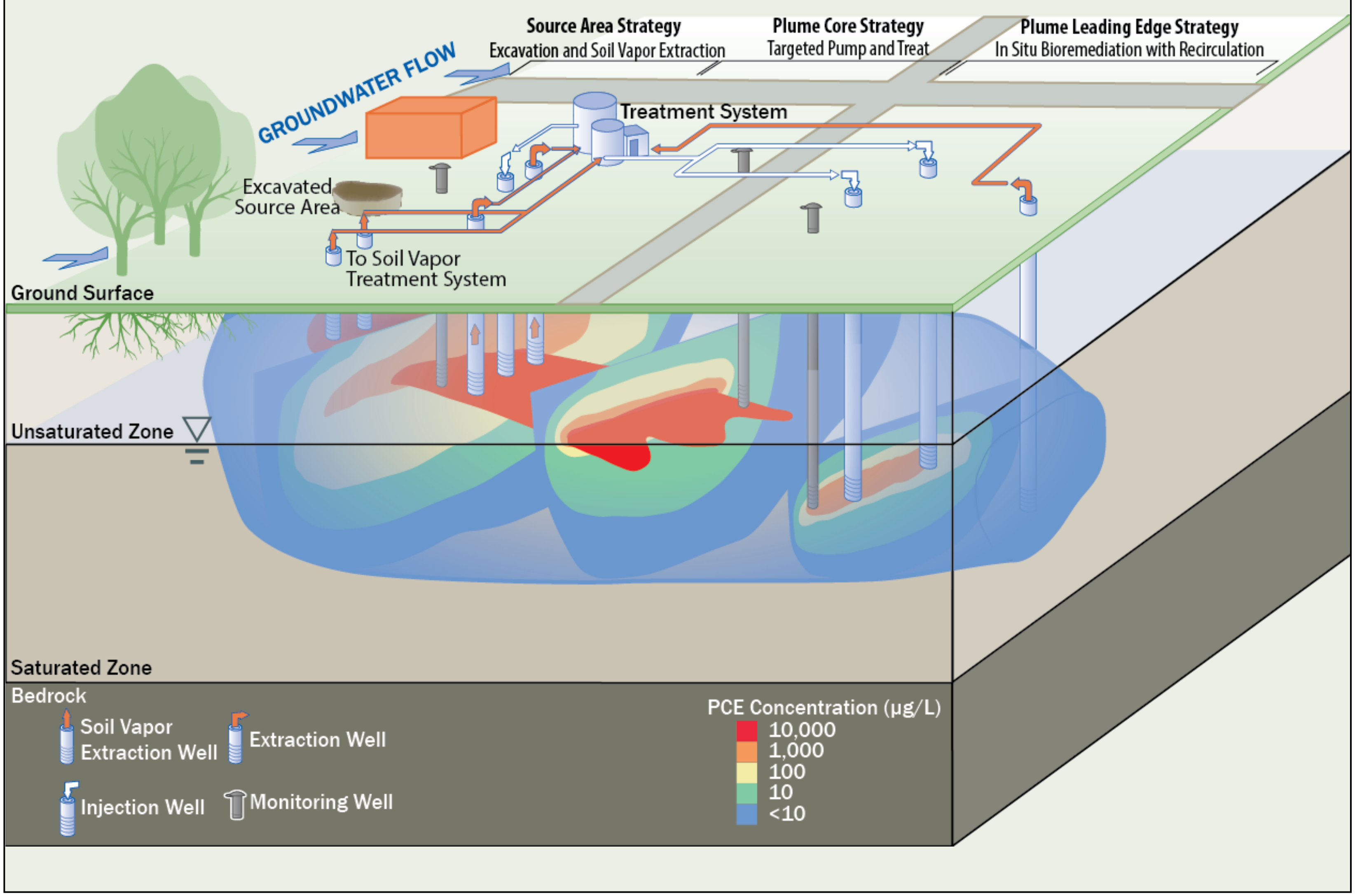
- *Figure 5 shows how HRSC data can be leveraged to design a comprehensive site remedial strategy and appropriately target remedial technologies.*

Notes

- For the hypothetical site, Figure 5 illustrates how separate technologies are implemented in an integrated strategy to address the source, plume core and plume leading edge areas. After excavation of source materials, soil vapor extraction (SVE) is used to reduce contaminant mass in source area soils and groundwater. Targeted groundwater pump and treat (P&T) is used to reduce mass in the plume core, with extraction wells designed to be screened only in the plume core rather than penetrating the full plume. This enables more efficient mass removal at lower pumping rates compared to fully penetrating wells. In situ bioremediation with recirculation is applied at the leading edge of the plume to control migration of the lower concentration dissolved plume. Monitoring wells installed at locations targeted using the HRSC data are used to monitor remedy performance, progress and compliance.

  Source: www.clu-in.org/characterization/technologies/hrsc/

Figure 5


Source Area Strategy
Excavation and Soil Vapor Extraction
Plume Core Strategy
Targeted Pump and Treat
Plume Leading Edge Strategy
In Situ Bioremediation with Recirculation
GROUNDWATER FLOW
Treatment System
Excavated Source Area
To Soil Vapor Treatment System
Ground Surface
Unsaturated Zone
Saturated Zone
Bedrock
Soil Vapor Extraction Well
Extraction Well
Injection Well
Monitoring Well
PCE Concentration (µg/L)
10,000
1,000
100
10
<10

Type in the Q&A Window

- **Short Answer: Type a reason why would you want to use HRSC at your sites**

  Like:

  "I have a complex site", or

  "My remediation system is not functioning as expected"

Answer in the Q&A window

EPA

1-33

Why HRSC?

1-34

What Are the Benefits of HRSC?

- **Overall cost and time savings:**
  - Reduces remedial footprint
  - Increases remedial efficiency
  - Reduces project time frames
- **Flexible and scalable**
  - Many different tools and technologies available
  - Can be used for large or small sites

EPA

1-35

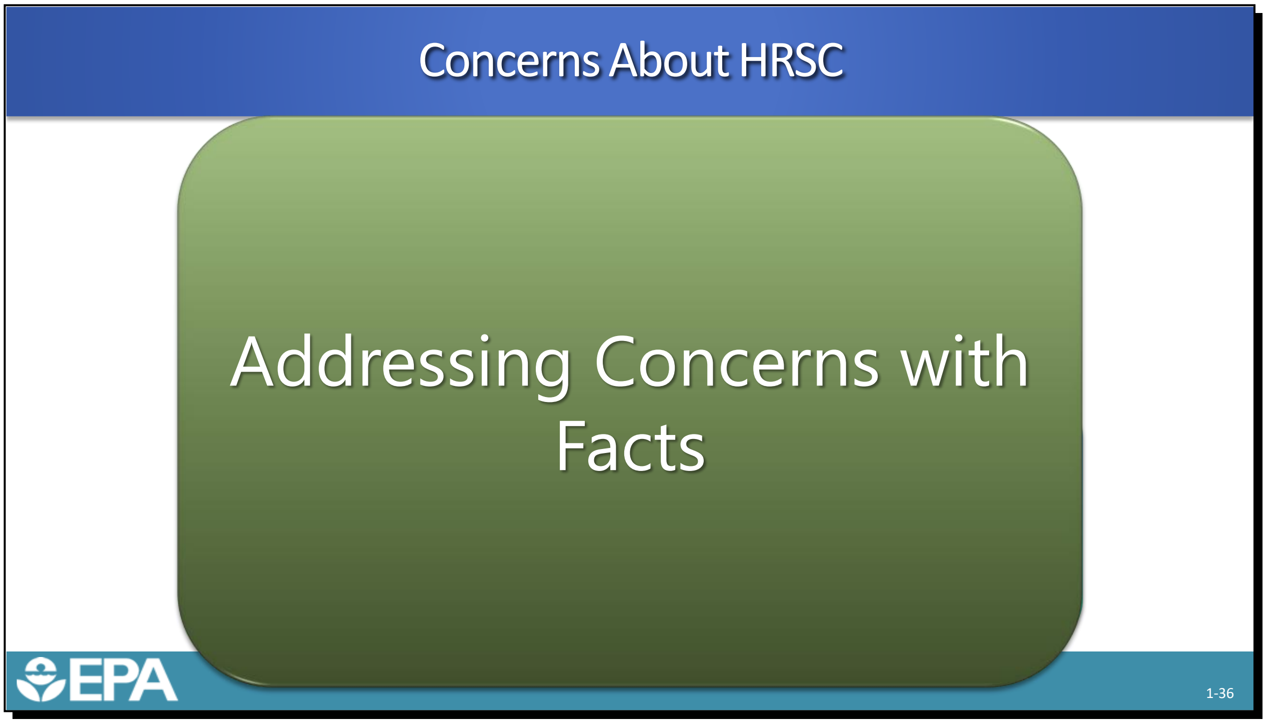
Main Idea

- *When viewed in a project lifecycle approach HRSC is likely to have cost and time savings for most sites.*

Notes

- HRSC provides overall cost and time savings by (1) reducing the remedial footprint by targeting appropriate remedial technologies, (2) increasing the efficiency of the remedial action by employing the most economic use of reagents, substrates and probes for various *in situ* applications and targeting *ex situ* pump and treat scenarios to reduce the amount of clean water extracted, and (3) reducing project time frames by lowering the number of mobilizations required to characterize the problem and by designing remedies that target the problem in a more aggressive manner. In addition, HRSC has a smaller carbon footprint, is more "green" and can improve safety performance overall by reducing mobilizations and length of time that work is performed at site. HRSC is consistent with EPA’s green remediation initiative. A case study covered later will demonstrate the smaller carbon footprint.

- HRSC is also both flexible and scalable. HRSC works on a wide range of site types and site sizes. The HRSC approach can be scaled to work for small sites and address only the most significant data gaps using the most cost-effective tools and techniques.



Main

- *There are several reasons to conduct HRSC though there are myths about what it entails.*

Notes

- There is concern that HRSC is too expensive. The cost of doing an adequate (high resolution) investigation may appear higher than a typical investigation initially, but the overall (life cycle) cost of the project will be lower due to: (1) less need for multiple phases of investigation to fill data gaps that exist due to an incomplete understanding; and (2) a more focused, appropriate and cost-effective remedy resulting from a complete understanding of the site conditions.

- There is concern that HRSC is a science project where the problem is being studied for the sake of studying. HRSC is a science project only to the extent that it uses the scientific method and employs sound scientific principles.

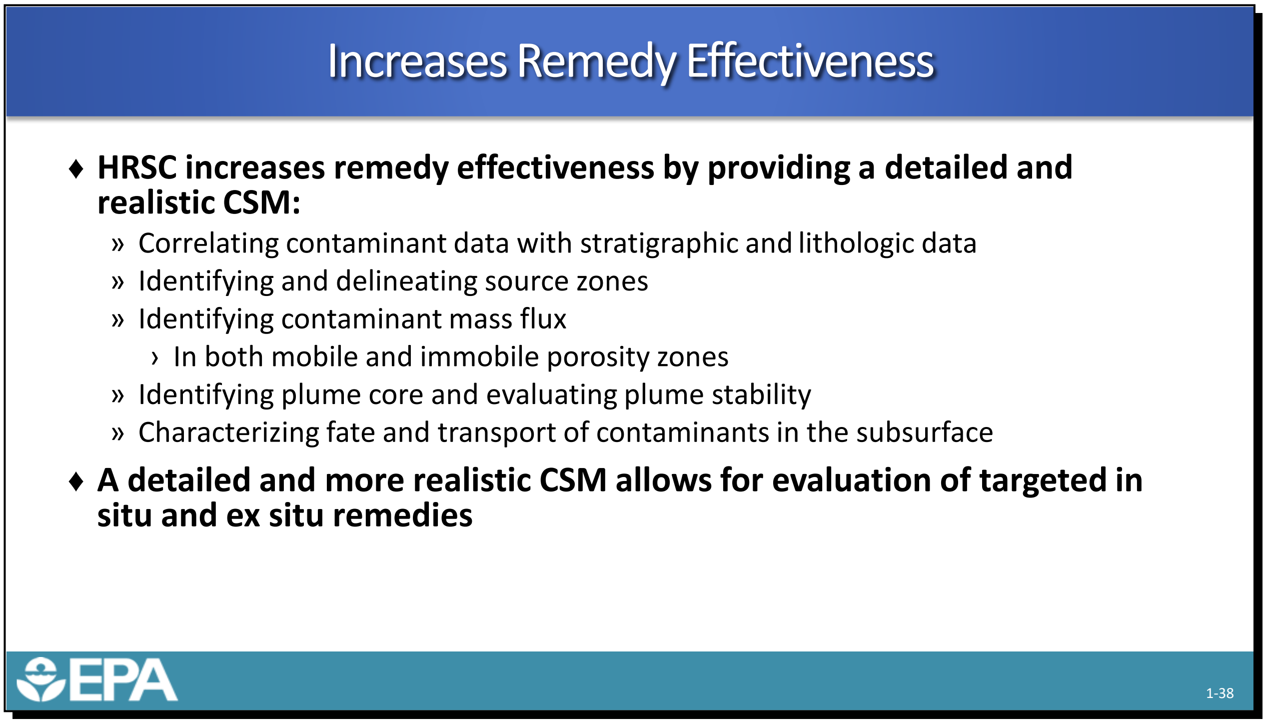
- There is concern that HRSC is only for the most complex sites. All sites can benefit from HRSC; the complexity of most sites is not known until many mobilizations and perhaps years have been spent in traditional investigation phases.

Type in the Q&A Window

- What are your concerns or questions about using HRSC?

Answer in the Q&A window

EPA 1-37



Main Idea

- *For both source and groundwater media, HRSC increases remedy effectiveness by providing a detailed and realistic CSM.*

Notes

- **HRSC increases remedy effectiveness by providing a detailed and realistic CSM:** For source areas, HRSC can pinpoint the location of the contamination so that the remedy addresses a more refined volume of material for treatment and disposal. For groundwater problems, HRSC provides the following critical information:

  » Correlation of contaminant data with stratigraphic and lithologic data.

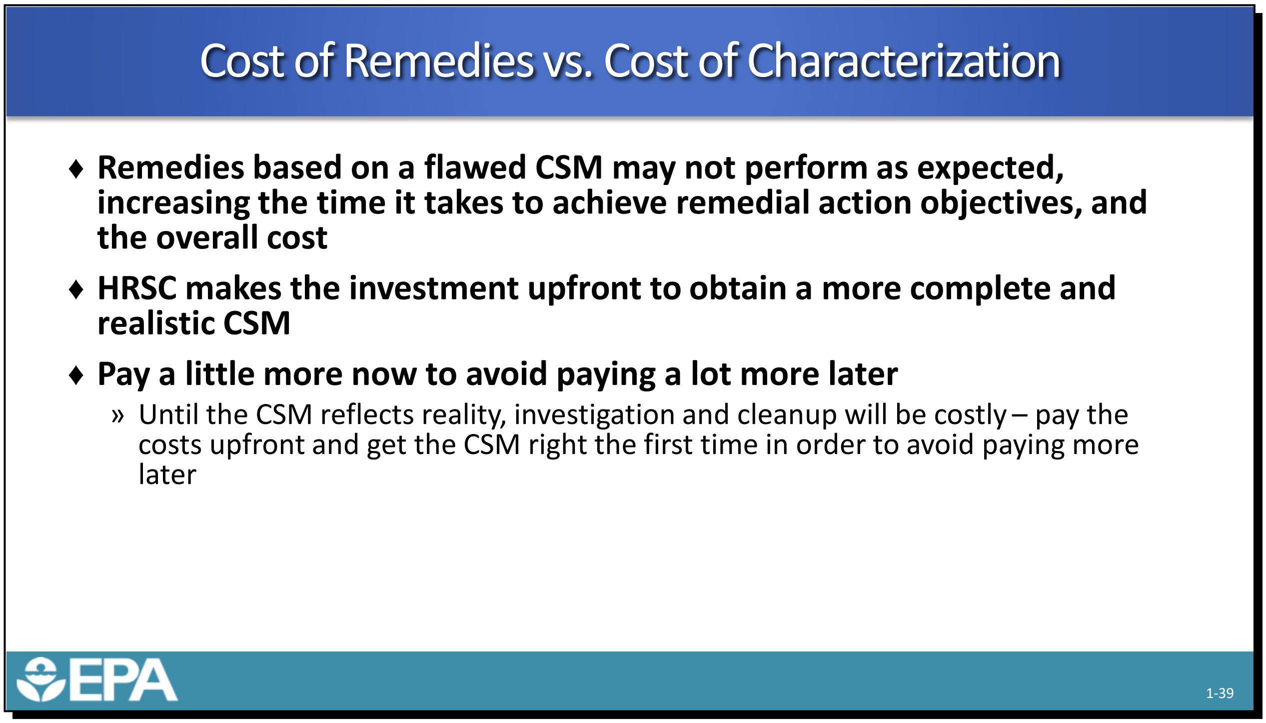
  » Identification and delineation of source zones.

  » Identification of contaminant mass flux in both the mobile and immobile porosity.

  » Identification of plume core and evaluation of plume stability.

  » Characterization of fate and transport of contaminants in the subsurface.

- **A detailed and more realistic CSM allows for evaluation of targeted in situ and ex situ remedies:** Most sites require a combination of technologies to address the site contamination. By using HRSC to develop a detailed CSM, various remedial technologies can be combined to target the zones of contamination for which they are best suited.



Main Idea

- *More characterization upfront is cheaper than a failed remedy*

Notes

- Site managers must balance the need for information with the need to take action. However, remedies based on a flawed CSM are likely to be costly because they do not perform as expected, which usually increases the time it takes to achieve cleanup levels and the overall cost. HRSC strategies and techniques provide a dense data set for the same or less cost than the traditional approach and can be completed in a much faster time frame. HRSC offers the best opportunity for developing a realistic CSM, and in the end, reality will win the day.

- According to the 2020 Optimization Progress report 77% of the Optimizations identified CSM improvements as a finding. This does not necessarily say that 77% of the time the CSM was responsible for increased time or cost, but flawed CSMs are is a significant factor in an effective remedy.

- Source: https://semspub.epa.gov/work/HQ/100002585.pdf

Notes

- The SJCC Site formerly housed a facility that engaged in the manufacture of military clothing. According to information obtained from the NJDEP files, VOCs, particularly TCE, were used in the dry cleaning processes of the company's manufacturing operations. It is reported that wastewaters containing VOCs were routinely discharged directly onto the facility grounds between the original manufacturing building and the adjacent railroad tracks. Other process wastes were also stored outside in drums that reportedly leaked over time. In addition, according to NJDEP files, in 1979, a fire at the facility may have resulted in the release of an estimated 275 gallons of TCE from an on-site storage tank.

- A ROD was prepared in 1991. TCE and tetrachloroethene (PCE) were identified as contaminants of concern in subsurface soil and groundwater. The ROD specified SVE for contaminated soil; and extraction, treatment, and reinjection of contaminated groundwater.

- In August 1995, the EPA completed the SVE and groundwater treatment system designs, and the subsequent construction was completed in January 1999. The groundwater treatment system originally consisted of 15 extraction wells (EWs) in the shallow and intermediate aquifer zones, 12 injection wells, and a 510-gpm treatment facility. The system became operational in September 2000 and continues to operate today.

- The SVE system was deemed operational in February 1999 and operated until 2001. Removal of TCE mass through June 2000 totaled over 250 pounds with approximately 80% of that coming from one extraction well. Mass removal rates had decreased significantly and most wells had reached asymptotic concentrations. Reportedly, there was little evidence for soil gas concentration rebound following the cessation of SVE.

- The SVE system operated from February 1999 to February 2001, at which time it was determined to have met the cleanup goal of 1 milligram per kilogram (mg/kg) of TCE in soil. The SVE system was subsequently dismantled and removed from the SJCC Site, although some piping may still remain.

- In March 2004, the EPA completed an initial five-year review for the SJCC Site to assure the remedies selected continued to be protective of human health and the environment. It was concluded that the remedies remained protective; however, the review recommended further investigation of the vapor intrusion pathway, installation of new extraction wells to capture contamination in the deep aquifer zone, and continued monitoring of residential wells outside the extent of the contaminated plume.

- In 2005, USACE conducted a Remediation System Evaluation (RSE) to assess the groundwater treatment system.

- In 2006, the Environmental Response Team (ERT) completed a vapor intrusion study at and around SJCC. Subslab soil gas samples and indoor air samples were collected from 19 properties. The results indicated elevated subslab TCE vapors within the SJCC treatment building and five adjacent residential homes.

- In 2007, ERT was requested to conduct an investigation of subsurface contamination. The purpose of the investigation was to characterize subsurface soils in the vadose and saturated zones and delineate the nature and extent of chlorinated volatile organic compound (CVOC) contamination source areas. The investigation was conducted using a Geoprobe® direct push technology (DPT) rig and the Membrane Interface Probe (MIP) system to close data gaps within a conceptual site model (CSM). By using a real-time measurement tool (MIP) for high-density, in-situ CVOC measurement, thousands of data points were collected during two field investigations conducted in June 2007 and June 2008. The result of this high-density sampling program, along with the collaborative soil sampling and groundwater sampling, was a more mature and robust conceptual site model for the Sites. The investigation clearly identified a previously unknown source area of high TCE spoil contamination (parts per thousand).

- In 2009, ERT provided the RPM with a technical memo highlighting possible remedial options for the new source area.

- The 2009 2nd FYR noted that the SVE systems at the SJCC site did not completely remove all sources of contamination and TCE and PCE concentrations were still present in the vadose zone at concentrations above screening levels. It also noted that additional characterization of the capture of the downgradient plume by the extraction and treatment system was needed and recommended continued monitoring of indoor air at properties around the SJCC site with elevated sub-slab vapor readings.

- In 2010, ERT provided the RPM with a technical memo that focused on an ERH strategy for the source area.

- The ROD was amended in 2010.

- In 2011, R2's ERRS excavated in a 16 ft by 70 ft to a max of 9' from the northwestern corner of the Site.
- In 2012, AECOM evaluated in-situ technologies for source removal and provided additional technical services in drafting a Performance Work Statement (PWS) for ISTR.
- Between mobilizing to the site in July 2016 and site restoration in March 2017, almost 1200 lbs total VOCs were removed from the source area via ISTR.

P&T System Operation (2000-Present)

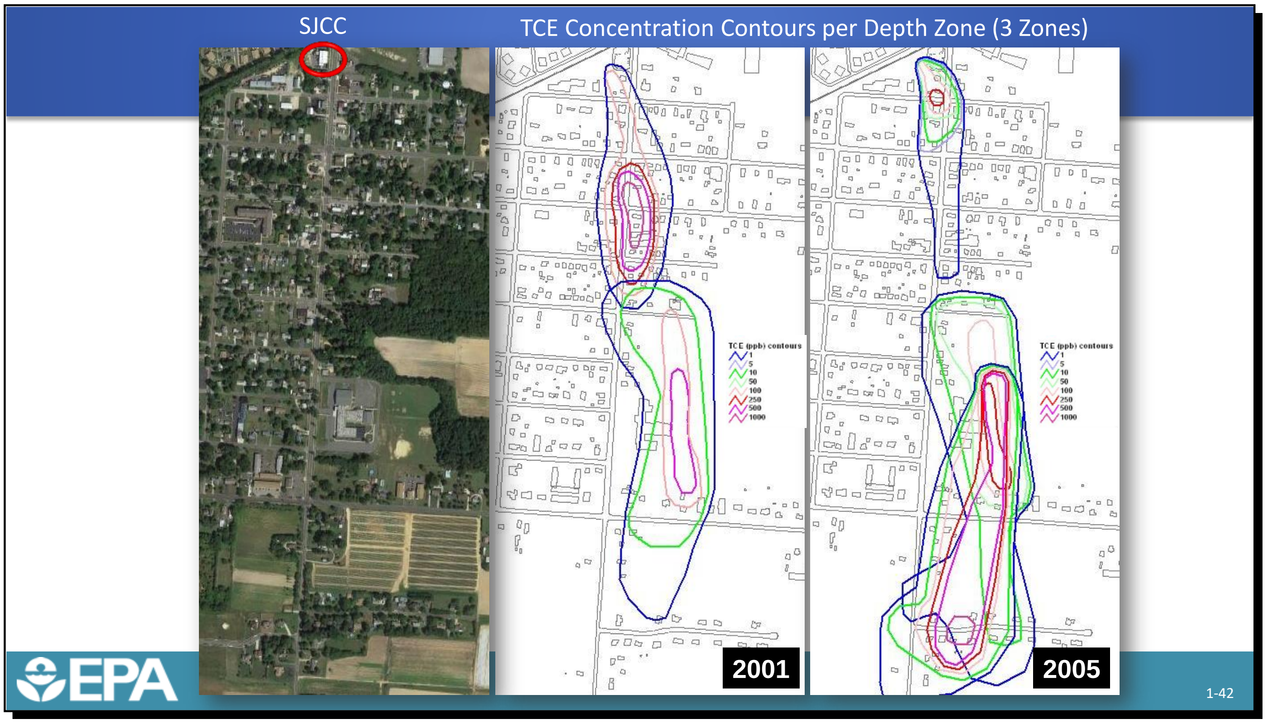
- **Annual O&M:**
  - $630,000/yr
- **Total flow through system:**
  - ~150 gpm
- **Average VOC influent:**
  - April – September 2004
  - 110 ug/L total VOC
- **Total VOC mass removed per year:**
  - ~5 lbs/yr

USACE Remediation System Evaluation
Final Report, July 2005

1-41

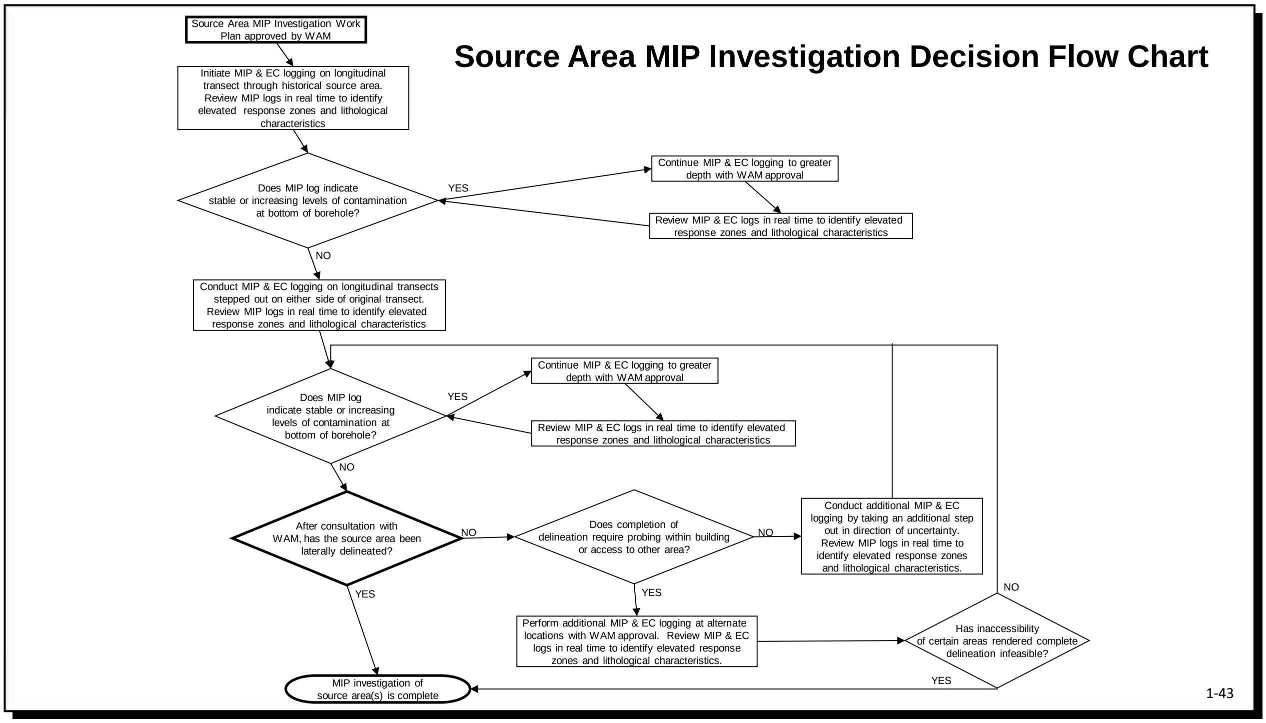
Notes

- The contractor actual cost for operating the system is approximately $630,000/year. This includes labor, utilities, materials, sampling and analysis, repair, and fees.
- The average VOC plant influent concentration identified over the 6-month period from April to September 2004 was approximately 110 µg/l.
- The groundwater treatment system was designed to operate at 510 gallons per minute (gpm) with maximum design influent concentrations for VOCs, primarily trichloroethene, and tetrachloroethene of 2,230 µg/L, and 430 µg/L respectively.
- No current data on mass removal by P&T was available.
- REMEDIATION SYSTEM EVALUATION; SOUTH JERSEY CLOTHING COMPANY/GARDEN STATE CLEANERS, ATLANTIC COUNTY, BUENA BOROUGH, NJ; Final Report; July 2005; Prepared by US Army Corps of Engineers Hazardous, Toxic, and Radioactive Waste Center of Expertise

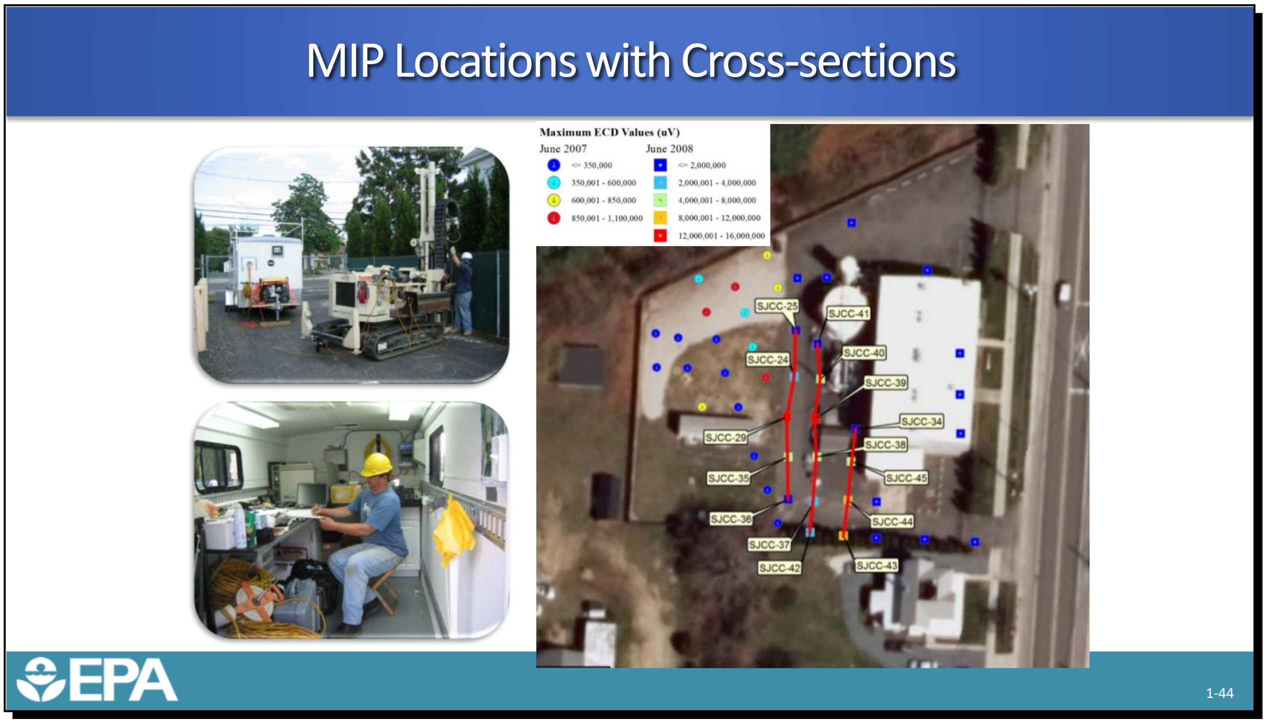


Notes

- Depiction of TCE concentrations over the depth ranges. Shows how the plumes “connect”.
- Despite the SVE system removal of the historically identified source area before 2001, the groundwater plume continued to emanate from the site as shown in the figures.
- With additional extraction wells and monitoring wells the plume was observed to continue expanding.



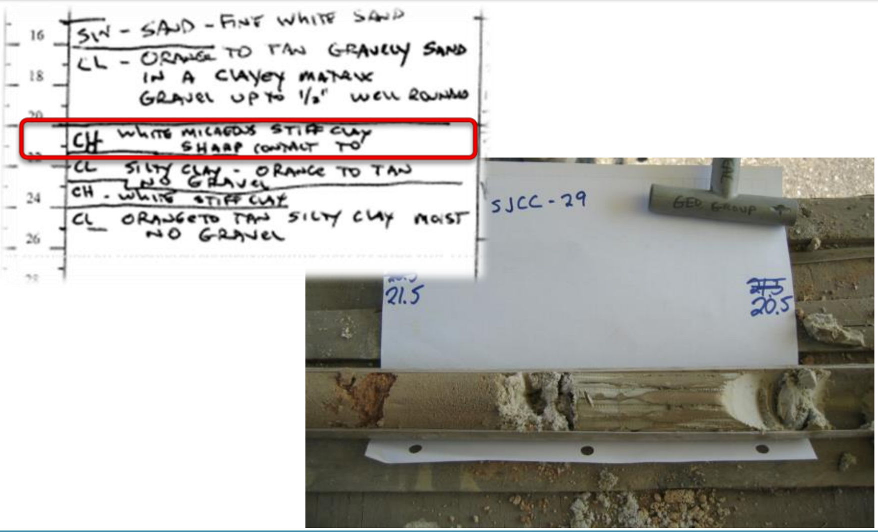
- ◆ Dynamic work strategies (DWS) are key to productive site investigations.
  - » Help accomplish adequate characterization often in single mobilizations
  - » DWS decision tree logic enable real-time decision making
  - » Consensus on DWS decision tree logic should be established during systematic project planning (SPP)
- ◆ DWS decision tree logic guides step-out location for MIP probes
  - » Based on previous MIP data & field observations



Notes

- A recent aerial photo from 2015 of the SJCC site with the MIP locations overlaid on it.

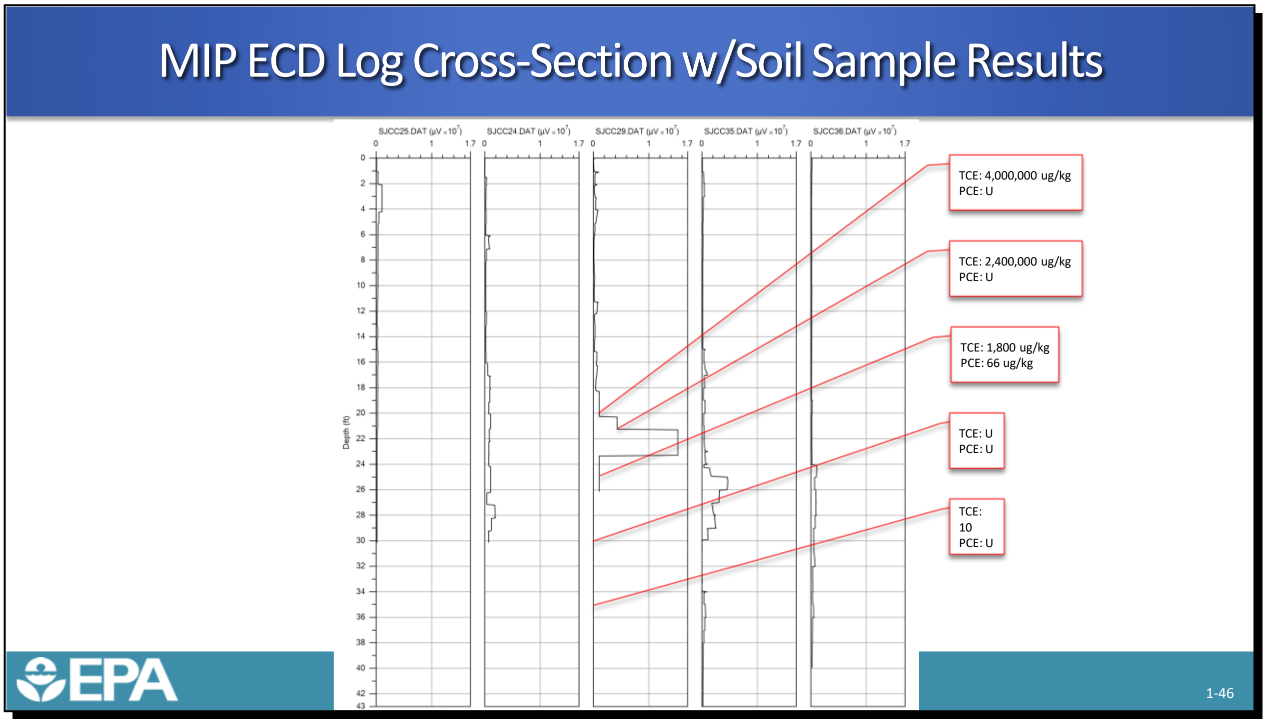
SJCC-29 Boring Log and Soil Core



EPA 1-45

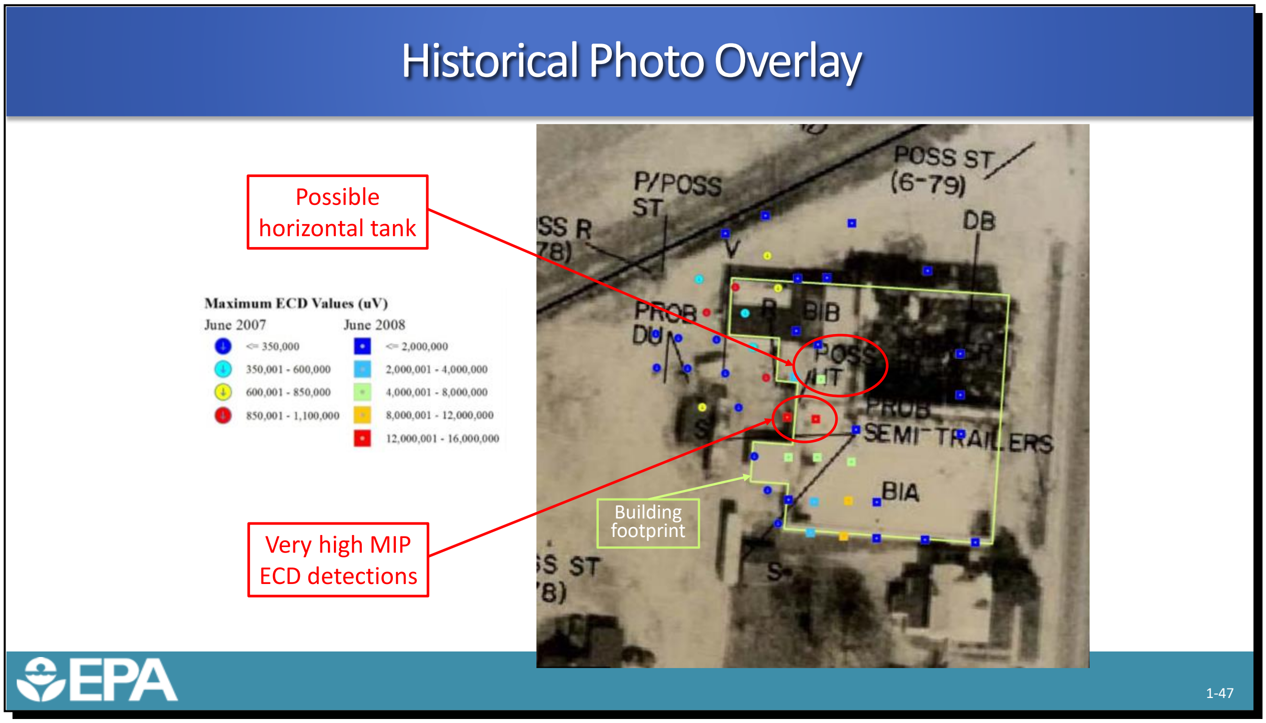
Notes

- Note the white stiff clay layer.
- There were very strong odors & high PID detections
- Soil coring to collect collaborative soil samples for lab analysis.
- Note the abrupt transition from sand to plastic clay/silt layer in this soil core.
  - Clay layer had a very strong solvent odor
  - DPT coring pushed through this clay layer to allow soil sampling below it
  - Analytical results were ND just below this layer in sandy material



Notes

- Soil sample results on the MIP ECD log cross-section.
- Note that the high ECD detections don't line up perfectly with the depth of the high soil sample results. This is likely due to recovery issues in the soil core.



Notes

- A historical aerial photo of the SJCC building was geo-rectified with the MIP locations overlaid on it.
- It is obvious that "hot" MIP locations are just adjacent to the back of the historical SJCC building.
- Note the location of the possible horizontal tank (POSS HT) where two high MIP ECD detections and part per thousand soil sample results
- It is highly likely that soil samples were never collected beneath, or immediately adjacent to, the building footprint during the RI/FS and other earlier investigations.
- Thus the main source area was never identified.

Chronology of ERH Events

Activity	Start Date	Date Completed
Preconstruction Meeting	1/20/2016	1/20/2016
Project Plans and Procurement	1/4/2016	5/19/2016
Preconstruction Photographs and Video	5/19/2016	5/19/2016
Preconstruction Conditions Survey	6/21/2016	6/21/2016
Mobilization to Site	7/8/2016	7/15/2016
TMP Installation	7/19/2016	7/27/2016
Monitoring Well Installation	7/20/2016	7/22/2016
Base Line Sampling	7/19/2016	8/16/2016
Electrode Installation	7/28/2016	8/12/2016
Surface Installation	8/17/2016	8/27/2016
System Startup	8/28/2016	10/23/2016
System Operation	10/24/2016	12/23/2016
Operational Phase Sampling	12/07/2016	12/15/2016
System Shut Down	12/23/2016	1/6/2017
Surface Deconstruction	1/6/2017	1/31/2017
Post Treatment Sampling	1/9/2017	1/13/2017
Well Abandonment	1/23/2017	1/30/2017
Site Restoration	1/27/2017	3/10/2017

1,180 lbs total VOC removed during ERH operation
Post Treatment vs Baseline Sampling: **>95%** reduction

EPA

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Notes

- Note dates of mobilization to the site & site restoration - ~8 months.

Remedial Comparison; Total Mass Removal

- **P&T system**
  - ~5lbs/yr VOC removal at $630,000/yr = $126,000/lb/yr
- **ERH in HRSC-identified source area**
  - 1,180lbs/3 months VOC removal at $2,330,433 = **$1,975/lb**

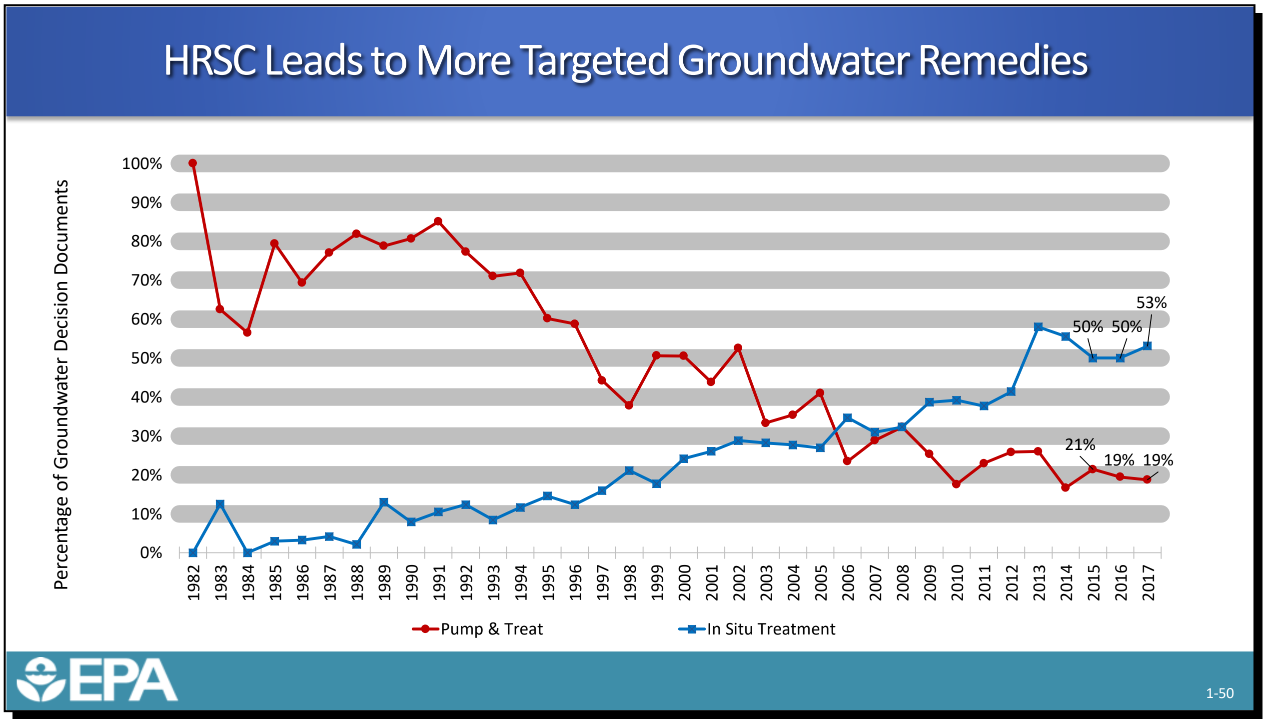
HRSC: <$100,000

EPA

1-49

Notes

- The contract for the ERH was Fixed Firm Price contract for $1,929,820 plus USACE cost of $400,613
- USACE cost of $400,613 includes Philadelphia District construction oversight, project management, QA, and safety; Kansas City District technical management and contracting.
- Acknowledge that the ERH didn't immediately eliminate the P&T. However, it does eliminate the ~240 years of P&T to remove the 1200lbs of VOCs that would have entered the aqueous phase in the HRSC-identified source area.



Main Idea

- *HRSC provides the level of detail necessary to design and implement targeted in situ treatment technologies.*

Notes

- This figure is taken from EPA's Superfund Remedy Report, 16th Edition analysis. The figure shows the trend in selection of in situ treatment as a component of groundwater decision documents from fiscal year (FY) 1982-2017. Groundwater decision documents include RODs, ROD amendments and explanations of significant differences (ESD). As the graph shows, selection of in situ treatment as a percentage of groundwater decision documents has followed an upward trend since FY 1982. HRSC provides the level of detail necessary to design and implement targeted in situ treatment technologies.

- Decision documents with groundwater remedies = 2,542. Decision documents may be included in more than one category

Groundwater Remedy Completion Strategy

- **Recommended site-specific course of actions to achieve RAOs using:**
  - » Updated CSM
  - » Performance metrics
  - » Data derived from site-specific remedy evaluations
- **Focuses tight resources toward efficient and effective completion of restoration remedies**
  - » Remediation phase monitoring
  - » Attainment phase monitoring
- **Use Groundwater Statistics Tool**

EPA 1-51

Notes

- To develop a groundwater completion strategy, a CSM is needed, as well as the confidence that you are monitoring the right parts of the plume. Following an HRSC strategy gives you that confidence. HRSC supports groundwater completion strategy in these ways:

- **Recommended site-specific course of actions to achieve RAOs:** A Groundwater Remedy Completion Strategy ("the strategy") is a recommended site-specific course of actions and decision making processes to achieve groundwater RAOs and associated cleanup levels using an updated conceptual site model, performance metrics and data derived from site-specific remedy evaluations. Selecting the right monitoring locations and performance metrics is based on a robust and realistic CSM that is developed during characterization.

- **Focuses tight resources toward efficient and effective completion of restoration remedies:** The guidance helps focus tight resources toward the efficient and effective completion of groundwater remedies to ensure protection of human health and the environment.

Reference

- The Groundwater Statistics Tool is designed to help evaluate contaminant of concern (COC) concentrations on a well-by-well basis to determine whether a groundwater restoration remedial action is complete. The tool is designed to support the U.S. Environmental Protection Agency (EPA) memorandum "Guidance for Evaluating Completion of Groundwater Restoration Remedial Actions" (OSWER 9355.0-129) and comports with principles outlined in the "Recommended Approach for Evaluating Completion of Groundwater Restoration Remedial Actions" (OSWER 9283.1-44). The tool is a Microsoft Excel workbook that is intended to evaluate data for a single COC at a single well. Each Excel worksheet ("screen") is protected to prevent accidental overwriting of formulas.

The tool was developed in Excel 2010; using an older version of Excel or a version using personal computer (PC) emulation in a non-PC environment may not allow use of all the tool’s capabilities. The tool should generally be run separately for each well and each COC being evaluated.

Other HRSC-Related Courses

- **Other HRSC-related courses**
  - Best Management Practices for Site Characterization Throughout the Remediation Process – CEC
  - High Resolution Site Characterization (HRSC): Pragmatic Approaches to Remediation Success – CLU-IN Webinar
  - Incremental Sampling – NARPM, CEC and ITRC
  - 3D Visualization – NARPM
  - Characterization and Remediation of Fractured Rock - ITRC
- **For more information, visit**
  - https://clu-in.org/training/
  - www.trainex.org (CEC courses)
  - www.itrcweb.org
  - https://www.serdp-estcp.org

1-52

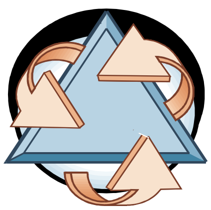
How is HRSC Implemented?

- **Systemic Project Planning (SPP)**
- **Real Time Technologies**
- **Dynamic Work Strategies (DWS)**

1-53

HRSC Implementation

- **HRSC is implemented using a "Triad Approach"**
  - » SPP
  - » Real-time measurement technologies
  - » DWS

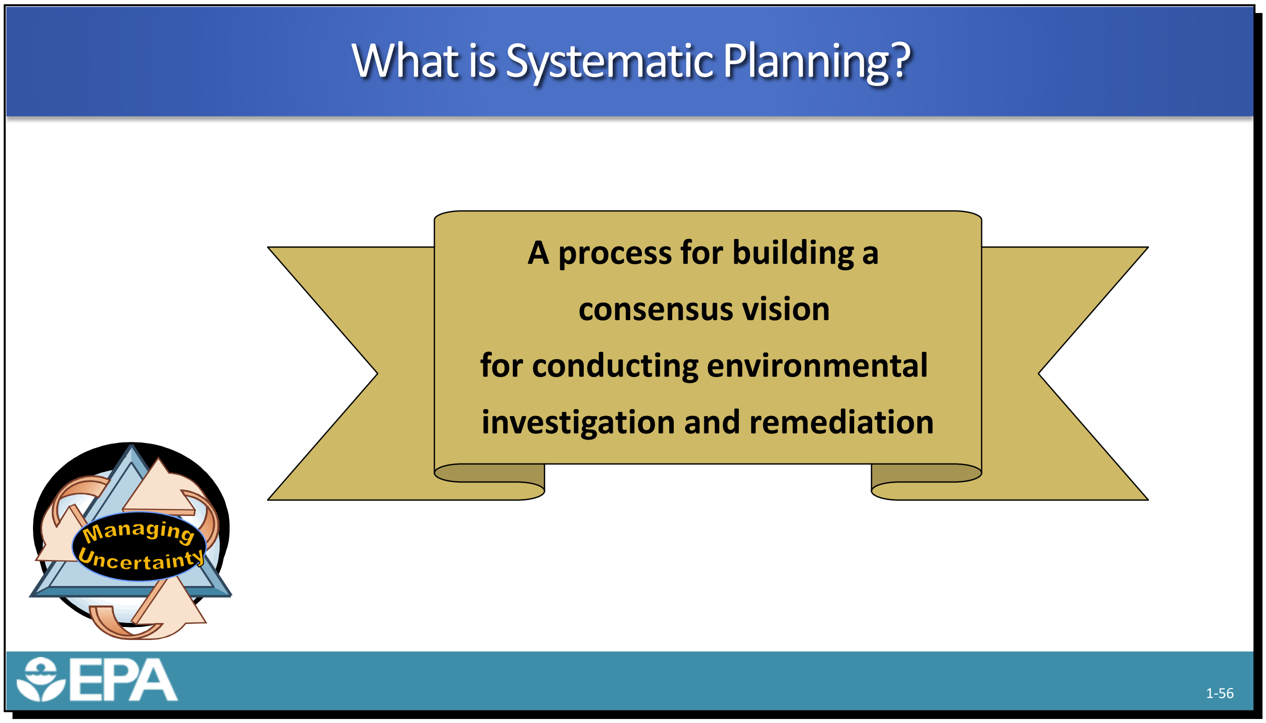


EPA 1-54

Test Your Knowledge

- **The goal of the "Triad Approach" of Systemic Project Planning (SPP), Real Time Technologies, and Dynamic Work Strategies (DWS) is to:**
  - A. Bring down cost
  - B. Increase cost
  - C. Manage uncertainty
  - D. Create more uncertainty

EPA 1-55



Main Idea

- *Systematic planning (SPP) is the process that builds a consensus vision for conducting environmental investigation and remediation.*

Notes

- Systematic planning is one of the three components of the "Triad Approach". The Triad is composed of SPP, real-time technologies, and Dynamic Work Strategies (DWS). SPP addresses all aspects of the project so that all the data collected meet a defined need and all needs are defined. The process avoids two common problems:

  (1) Having a large amount of data that do not contribute to a better understanding of the site

  (2) Not having adequate data to make critical decisions

  Remember HRSC helps you achieve the appropriate resolution for data collection, so SPP and HRSC go together.

  The planning process involves the necessary stakeholders to ensure all needs are addressed and to build a consensus on how to facilitate the project through various stages of key site decision-making. It involves planning for known decision points and building in contingencies throughout the investigation and remediation process.

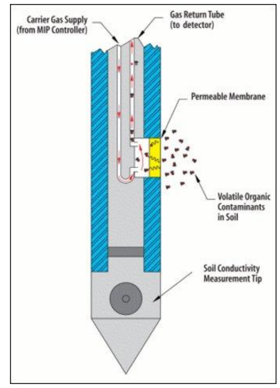
Internet

EPA's Triad Central website, www.triadcentral.org, defines systematic project planning as a planning process that lays a scientifically defensible foundation for proposed project activities.

Real Time Measurement Technologies

- **Direct sensing tools that provide instantaneous data**
- **Field-generated sample collection and analysis technologies that require various lengths of time to produce end data**

Managing Uncertainty



MIP Probe Schematic

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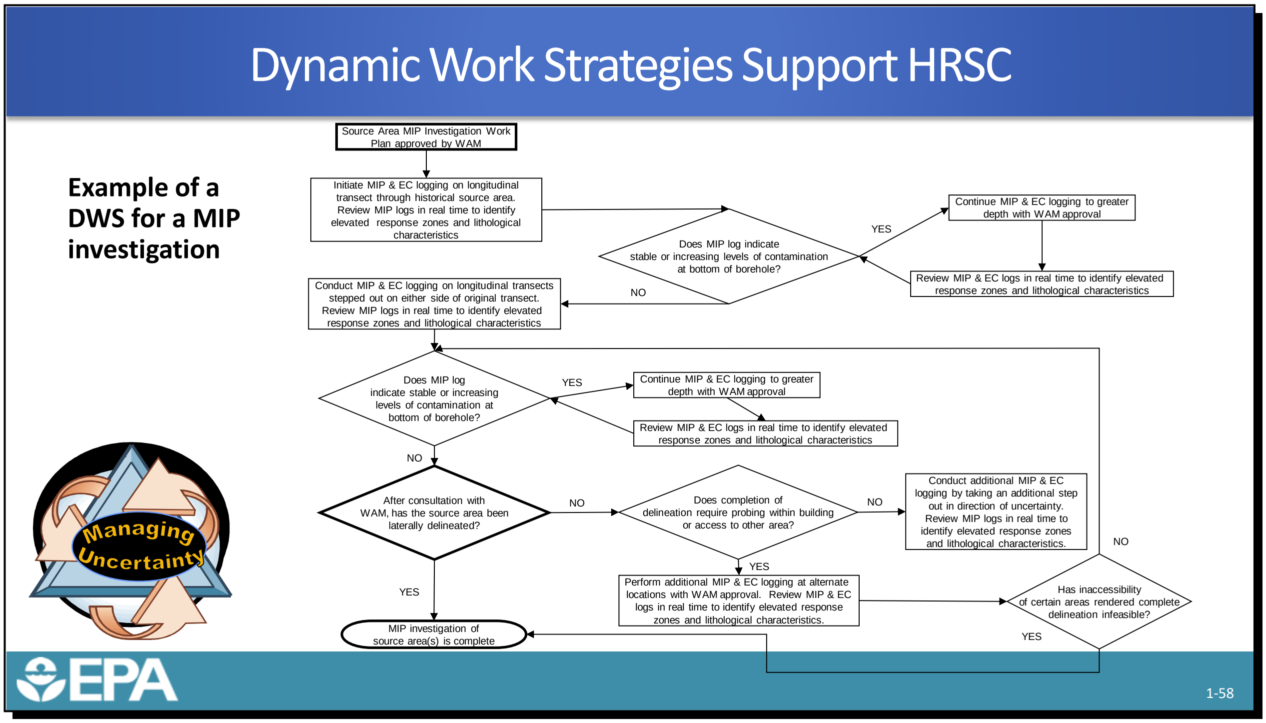
Main Idea

- *The timeframe over which real-time measurement technologies provide data can vary, from instantaneous (e.g., PID) to several hours (e.g., mobile laboratories).*

Notes

- **Direct sensing tools that provide instantaneous data:** Direct sensing tools provide instantaneous qualitative and quantitative data on contaminants and geophysical information. They include field portable instruments, downhole sensors, and various geophysical techniques.

- **Field-generated sample collection and analysis technologies that require various lengths of time to produce end data:** These technologies allow for the collection and analysis of samples that may not be instantaneous but meet a timeframe to be considered “real time.” The technologies include direct push samples, passive diffusion samplers, field test kits, X-ray fluorescence (XRF) analyzer, and mobile laboratories.



Notes

- Dynamic work strategies (DWS) are key to productive site investigations. HRSC is best performed using an DWS approach to ensure the investigation addresses the data gaps and project objectives efficiently.
  - Helps accomplish adequate characterization often in single mobilizations
  - DWS decision tree logic enables real-time decision making
  - Consensus on DWS decision tree logic should be established during systematic project planning (SPP)
- DWS decision tree logic guides step-out location for MIP probes
  - Based on previous MIP data & field observations

In Review

- **What**
  - HRSC is a methodology for understanding and properly accounting for the effects of subsurface heterogeneity
  - HRSC uses scale-appropriate measurements and sample spacings that are consistent with the scale of variability of the property being measured
  - Transect-based vertical profiling
- **Why**
  - Realistic CSM
  - Better defined contaminant mass distribution
  - Targeted and more efficient remedies
- **How**
  - Triad Approach

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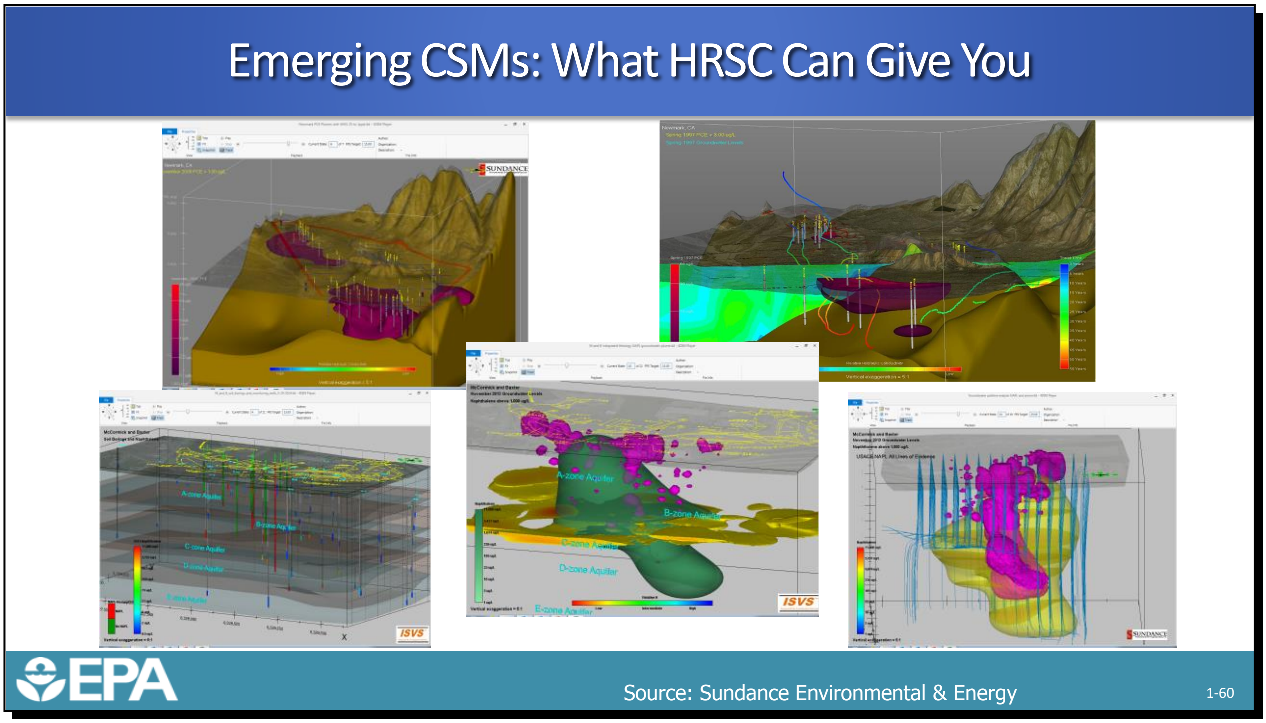


Main Idea

- *These pictures provide a sneak peek into the world of quality data that HRSC can provide about your site.*

Notes

◆ Three-dimensional (3-D) visualization and 3-D visualization shown over time (4-D), is being used with increasing frequency to improve the effectiveness of environmental investigation and cleanup efforts. Visualization and analysis methods can be used to support projects at various stages in a project lifecycle and can help resolve a number of common, but critical, issues at environmental cleanup sites.

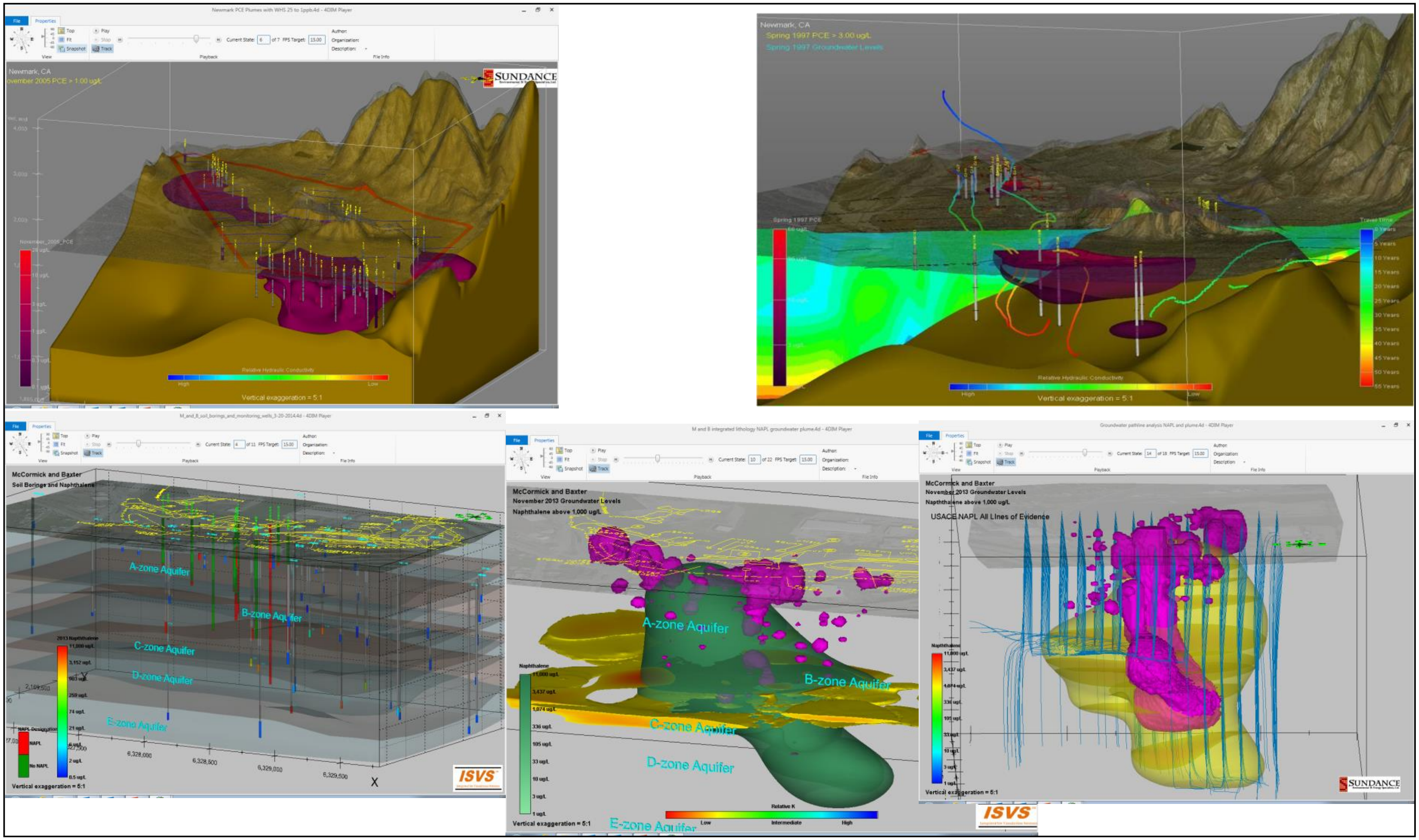
Source: Sundance Environmental & Energy

NOTE: This slide can be viewed in color in the Appendix A to this manual.

Internet

An Internet Seminar of the “EPA Office of Research and Development's Office of Science Policy Mine and Mineral Processing Virtual Workshop Session 4 - Big Data” includes topics like new 3DVA efforts at Superfund sites; fate and transport at watershed scales; and visualization of mining data. A complete archive of this seminar is available for free download and replay at: www.clu-in.org/live/archive/.

An Internet Seminar called “Use of Geostatistical 3-D Data Visualization/Analysis in Superfund Remedial Action Investigations” was delivered on September 23, 2011. The presentation: (1) described the setup and use of 3-D data visualization systems; (2) showed how visualization and analysis can help resolve a number of common, but critical, issues at environmental cleanup sites; (3) identified BMPs developed from a broad range of Superfund site 3-D visualization applications; (4) described quality control procedures when using 3-D visualization for analyzing existing data in EPA investigations; (5) and presented guidelines for contracting 3-D visualization and analysis services. A complete archive of this seminar is available for free download and replay at: www.clu-in.org/live/archive/.


Newmark, CA
SUNDANCE
Relative Hydraulic Conductivity
Vertical exaggeration = 5:1
Spring 1997 PCE > 3.00 ug/L
Spring 1997 Groundwater Levels
Spring 1997 PCE
Travel time
McCormick and Baxter
Soil Borings and Naphthalene
A-zone Aquifer
B-zone Aquifer
C-zone Aquifer
D-zone Aquifer
E-zone Aquifer
NAPL Designation
NAPL
No NAPL
ISVS
McCormick and Baxter
November 2013 Groundwater Levels
Naphthalene above 1,000 ug/L
Naphthalene
Relative K
Low
Intermediate
High
USACE NAPL All Lines of Evidence

Questions?

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