

# Evaluating and Refining the CSM

NEWMOA

Back to Basics Part 2: Data Collection & Interpretation: State of the Practice & Lessons Learned

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## Outline

- Summary of characterization tools and technologies
- Data collection and interpretation
- Updating the CSM
- Case studies
- Available ITRC resources

# Integrated Site Characterization

- Plan characterization (1-4)
  - Define the problem
  - Identify data needs and resolution
  - Develop data collection objectives
  - Design data collection and analysis plan
- Select tools (5)
- Implement investigation and update CSM (6-8)



Figure 4-1 Integrated Site Characterization

## Tools Matrix Format and Location

- The tools matrix is a [downloadable excel spreadsheet](#) located in [Section 4.6](#)
- Tools segregated into categories and subcategories, selected by subject matter experts
- A living resource intended to be updated periodically

Excel worksheet available at  
[http://www.itrcweb.org/documents/team\\_DNAPL/DNAPL.xlsm](http://www.itrcweb.org/documents/team_DNAPL/DNAPL.xlsm)

| Tool                                       |
|--|
| Geophysics                                 |
| Surface Geophysics                         |
| Downhole Testing                           |
| Hydraulic Testing                          |
| Single well tests                          |
| Cross Borehole Testing                     |
| Vapor and Soil Gas Sampling                |
| Solid Media Sampling and Analysis Methods  |
| Solid Media Sampling Methods               |
| Solid Media Evaluation and Testing Methods |
| Direct Push Logging (In-Situ)              |
| Discrete Groundwater Sampling & Profiling  |
| Multilevel sampling                        |
| DNAPL Presence                             |
| Chemical Screening                         |
| Environmental Molecular Diagnostics        |
| Microbial Diagnostics                      |
| Stable Isotope and Environmental Tracers   |
| On-site Analytical                         |

- Contains over **100** tools
- Sorted by:
  - Characterization objective
    - Geology
    - Hydrogeology
    - Chemistry
  - Effectiveness in media
    - Unconsolidated/Bedrock
    - Unsaturated/Saturated
- Ranked by data quality
  - Quantitative
  - Semi-quantitative
  - Qualitative

[illegible]

Click any box for a description or definition

Click

[illegible]

### 2.3 Geology

Through data provided a means to describe the physical status and structure of the subsurface and to classify the sedimentary, igneous, or metamorphic environment. Data related to lithology and distribution of clasts and facies changes are generated through a variety of qualitative and quantitative collection tools and methods.

Small methods and tools used to characterize site geology include site walkovers to help gain a preliminary understanding of the site prior to a major field investigation, which can involve the use of both remote- and near-surface tools. Outcroppings offer insight into structural features of the bedrock, and much information can be obtained through basic geologic mapping techniques (for example, measuring strike and dip of plane features and plotting on a stereonet).

Following a surface investigation, the next step is to use geoscientific concepts to develop a conceptual model collecting a consistent core of sediment and bedrock data. Data provided by this core sampling may include lithology, grain size and sorting, variability, geologic contacts, bedding planes, fractures and faults, depositional environment, porosity and permeability. Generally, surface geologic data are utilized to determine the vertical and the horizontal variability of the subsurface geology. The depositional environment and facies character should also be supported in rock as possible, and these data may be combined with surface and subsurface geophysical data to determine the subsurface geology. The geophysical data and bedrock data can be used, for example, to constrain subsurface porosity (BSP, bedrock geology core log) and fracture porosity (core log) and can provide detailed data on the geology and sedimentary distribution at a site.

Effective field geology characterisation requires that personnel are trained and experienced in field geology and are able to accurately assess the collected data. It is also important that the team use consistent investigative methods - for example, characterising soil or rock types using the same agreed upon classification system. The team must determine the level of data resolution necessary to adequately characterise a specific site and whether surface and/or remote geophysical data and/or sufficient resolution.

Unfortunately, evidence exists that contaminated sites often pose insufficient geologic data leading to a high degree of uncertainty in hazard level estimations. Unfortunately, this has caused a hesitancy to commission geologic investigations at contaminated sites. The purpose of this paper is to review geologic conditions of the site that can be determined without the use of geologic investigation systems. However, currently, preliminary success rates have been poor due to either such circumstances, whereas, involving an adequately detailed site characterization has provided a positive return on investment in terms of improved estimates, success rates and reduced life cycle costs.

Overinterpretation of CO<sub>2</sub> is particularly relevant to gas-rich regions with complex depositional environments. In the northeast and Midwest, early gasified oils contain both n-alkane and glacial equifiers that have DNAPL issues. Under such conditions, hydrogeological and geological expertise specific to glacial environments and their depositional characteristics is required for developing an accurate and complete CO<sub>2</sub> and a key to the success of a DNAPL remedy.

## Detailed Tool Descriptions (Appendix D)

Click on any tool

- Additional reference material
- Description
- Applicability
- Limitations

Click

| Tool  | Data Quality  | Sub surface  |   | Zone        |
|---|---|--|---|-------------|
|   |   | Bedrock  | consolidated  | unsaturated |
|   |   |  |   |             |
| Tool/Reference  | Description   | Data Quality and Applicability/Advantages  | Limitations/Reliability   |             |
| <ul style="list-style-type: none"><li>Ground Penetrating Radar<ul style="list-style-type: none"><li>Arnesen 2003</li><li>Geyer et al. 2011</li><li>Geyer et al. 1999</li><li>Bradford 2006</li><li>Bradford and Davis 2009</li><li>Bradford, Dicks, and Borden 2010</li><li>Bradford and Borden 2013</li><li>Curren, Borden, and Reid 2005</li><li>Curren 2005</li><li>USEPA 2004</li></ul></li></ul> | <p>Ground penetrating radar (GPR) creates a cross-sectional imaging of the ground based on the reflection of an electromagnetic (EM) pulse from boundaries between layers of different dielectric properties. The quality depends on soil and water conditions as penetration is reduced by clay, water, and salinity. GPR is useful in resolving stratigraphic layers. However, independent confirmation of lithology is required.</p> <p>GPR generates a 2D profile, but it can be run with multiple lines in a grid pattern to generate a pseudo 3D image. Penetration and resolution of features depend on antenna frequency and material conductivity and moisture content, and are generally limited to 20 meters (m) deep. GPR can identify internal structures between material-bonding interfaces (e.g., cross-bedding) in some cases.</p> <p>GPR can be used to locate geologic material or property contacts associated with distinct property contrasts (e.g., clayey fill deposits vs. coarse water-saturated coarse sediments) as well as subsurface infrastructure (e.g., pipes, tanks, cavities).</p> | <p><b>Data Quality</b></p> <ul style="list-style-type: none"><li>varies with antenna and subsurface EC</li><li>relatively sharp boundaries</li><li>relative to quantitative (depending on field conditions, prior knowledge, subsurface conditions, experimental quality, demonstrable modeling)</li></ul> <p><b>Applicability/Advantages</b></p> <ul style="list-style-type: none"><li>relatively fast to acquire, and processing methodology well established</li><li>generally used in materials with low EC (sand, gravel, or rock except shales)</li><li>can be run repeatedly at time-lapse mode to track changes in moisture (delayed water table) or EC or dielectric properties (pipes or aquifers), including several experiments (timing, pressure and changes in dense materials) (see note 2)</li></ul> | <ul style="list-style-type: none"><li>moisture penetration in electrically conductive soils and clay-rich or conductive pore water (unit)</li><li>Interpretation of features in specific characterization without independent reference (well or cone penetrometer (CPT))</li></ul> |             |

## Shaded Boxes Denote Tool Meets Objective

Tools collect these types of information

| Tool   | Data Quality | Sub surface |                | Zone        | Geology   |           |                    |          |              |                   |        |           |                  |               |                 |            |
|--|--------------|-------------|----------------|-------------|-----------|-----------|--------------------|----------|--------------|-------------------|--------|-----------|------------------|---------------|-----------------|------------|
|  |              | Bedrock     | Unconsolidated | Unsaturated | Saturated | Lithology | Lithology Contacts | Porosity | Permeability | Dual Permeability | Faults | Fractures | Fracture Density | Fracture sets | Rock Competence | Mineralogy |
|  |              |             |                |             |           |           |                    |          |              |                   |        |           |                  |               |                 |            |
|  |              |             |                |             |           |           |                    |          |              |                   |        |           |                  |               |                 |            |
| Geophysics                                     |              |             |                |             |           |           |                    |          |              |                   |        |           |                  |               |                 |            |
| Surface Geophysics                             |              |             |                |             |           |           |                    |          |              |                   |        |           |                  |               |                 |            |
| Ground Penetrating Radar (GPR)                 | QL - G       | ✓           | ✓              | ✓           | ✓         | ✓         | ✓                  | ✓        | ✓            | ✓                 | ✓      | ✓         | ✓                | ✓             | ✓               | ✓          |
| High Resolution Seismic Reflection (HRSR)      | QL - G       | ✓           | ✓              | ✓           | ✓         | ✓         | ✓                  | ✓        | ✓            | ✓                 | ✓      | ✓         | ✓                | ✓             | ✓               | ✓          |
| Seismic Reflection                             | QL - G       | ✓           | ✓              | ✓           | ✓         | ✓         | ✓                  | ✓        | ✓            | ✓                 | ✓      | ✓         | ✓                | ✓             | ✓               | ✓          |
| Multi-Channel Analysis of Surface Waves (MASW) | QL - G       | ✓           | ✓              | ✓           | ✓         | ✓         | ✓                  | ✓        | ✓            | ✓                 | ✓      | ✓         | ✓                | ✓             | ✓               | ✓          |
| Electrical Resistivity Tomography (ERT)        | QL - BQ      | ✓           | ✓              | ✓           | ✓         | ✓         | ✓                  | ✓        | ✓            | ✓                 | ✓      | ✓         | ✓                | ✓             | ✓               | ✓          |
| Very Low Frequency (VLF)                       | QL           | ✓           | ✓              | ✓           | ✓         | ✓         | ✓                  | ✓        | ✓            | ✓                 | ✓      | ✓         | ✓                | ✓             | ✓               | ✓          |
| ElectroMagnetic (EM) Conductivity              | QL           | ✓           | ✓              | ✓           | ✓         | ✓         | ✓                  | ✓        | ✓            | ✓                 | ✓      | ✓         | ✓                | ✓             | ✓               | ✓          |
| Overhead Logging                               |              |             |                |             |           |           |                    |          |              |                   |        |           |                  |               |                 |            |

Green shading indicates that tool is applicable to characterization objective

# Using the Tools Matrix

- Down-selecting appropriate tools to meet your characterization objectives
- A systematic process
  - Select your categories: geology, hydrogeology, chemistry
  - Select parameters of interest
  - Identify geologic media (e.g., unconsolidated, bedrock)
  - Select saturated or unsaturated zone
  - Choose data quality (quantitative, semi-quantitative, qualitative)
  - Apply filters, evaluate tools for effectiveness, availability, and cost
- Ultimately, final tools selection is site-specific, dependent upon team experience, availability, and cost

## 1. Select Category

All  
Geology  
Hydrogeology  
Chemistry  
– All  
– Soil Gas  
– Groundwater  
– Solid Media

The screenshot shows the 'Tools Matrix' application interface. At the top, there are three dropdown menus: 'Type' (set to 'All'), 'Subsurface' (set to 'All'), and 'Data Quality' (set to 'All'). Below these is a 'Subsurface Zone' dropdown (set to 'All') and a 'Search' button. A red box highlights the 'Type' dropdown menu, which is open, showing a list of categories: 'All', 'Geology', 'Hydrogeology', 'Chemistry - All', 'Chemistry - Soil Gas', 'Chemistry - Groundwater', and 'Chemistry - Solid Media'. The 'Geology' option is selected. Below the filters is a table with columns: 'Tool', 'Data Quality', 'Sub surface', 'Zones', 'Lithology', 'Lithology Contacts', and 'Porosity'. The 'Sub surface' column has sub-columns: 'Bedrock', 'Unconsolidated', 'Unsaturated', and 'Saturated'. The 'Zones' column has sub-columns: 'Lithology' and 'Lithology Contacts'. The 'Porosity' column has a sub-column: 'Porosity'.

## 2. Select Parameters of Interest

All  
Lithology Contacts  
Porosity  
Permeability  
Dual Permeability  
Faults  
Fractures  
Fracture Density  
Fracture Sets  
Rock Competence  
Mineralogy

The screenshot shows a software interface with a 'Parameter' dropdown menu. The dropdown is open, displaying a list of parameters: All, Lithology Contacts, Porosity, Permeability, Dual Permeability, Faults, Fractures, Fracture Density, Fracture Sets, Rock Competence, and Mineralogy. The dropdown is highlighted with a red box. The interface also includes fields for 'Tool', 'Subsurface', 'Data Quality', 'Sub surface', 'Zones', 'Bedrock', 'Unconsolidated', 'Unsat', 'Saturated', 'Lithology', 'Lithology Contacts', and 'Porosity'.

## 3. Identify Geologic Media

All  
Bedrock  
Unconsolidated

The screenshot shows the same software interface as in slide 2, but with the 'Parameter' dropdown menu set to 'Bedrock'. A red box highlights the 'Bedrock' option in the dropdown, and a red line connects it to the text 'Bedrock' in the list on the left. The interface also includes fields for 'Tool', 'Subsurface', 'Data Quality', 'Sub surface', 'Zones', 'Bedrock', 'Unconsolidated', 'Unsat', 'Saturated', 'Lithology', 'Lithology Contacts', and 'Porosity'.

## 4. Identify Zone

All  
Unsaturated  
Saturated

The screenshot shows a software interface with a top navigation bar and a main content area. The top bar includes dropdown menus for 'Tool', 'Subsurface', 'Data Quality', and 'Parameter'. The 'Subsurface' dropdown is open, showing a list of options: 'All', 'Unsaturated', and 'Saturated'. A red box highlights this dropdown, and a red line connects it to a text box on the left. The main content area is a table with columns: 'Tool', 'Data Quality', 'Bedrock', 'Unconsolidated', 'Unsaturated', 'Saturated', 'Lithology', 'Lithology Contacts', and 'Porosity'. The 'Subsurface' column is highlighted in blue.

## 5. Choose Data Quality

(Q) quantitative  
(SQ) semi-quantitative  
(QL) qualitative

The screenshot shows the same software interface as the previous one. The 'Data Quality' dropdown menu is open, showing a list of options: 'All', '(Q) Quantitative', '(SQ) Semi-quantitative', and '(QL) Qualitative'. A red box highlights this dropdown, and a red line connects it to a text box on the left. The main content area is a table with columns: 'Tool', 'Data Quality', 'Bedrock', 'Unconsolidated', 'Unsaturated', 'Saturated', 'Lithology', 'Lithology Contacts', and 'Porosity'. The 'Data Quality' column is highlighted in blue.

## 6. Apply Filters, Evaluate Tools

The screenshot shows the Geology Tools database interface. The search filters are set to: Type: Geology, Parameter: Lithologic, and Quality: (Q) Quantitative. The results are displayed in a table with columns for Tool, Data Quality, Bulk Surface, Zone, and various material properties. The table is filtered to show only tools that are quantitative and related to lithology.

**Search Filters:**  
 Type: Geology  
 Parameter: Lithologic  
 Quality: (Q) Quantitative

**Tools and Methods:**  
 - **Geophysics**  
 - **Surface Geophysics**  
 - Ground Penetrating Radar (GPR)  
 - High Resolution Seismic Reflection (2D or 3D)  
 - Seismic Refraction  
 - Multi-Channel Analyses of Surface Waves (MASW)  
 - **Downhole Testing**  
 - Induction Resistivity (Conductivity Logging)  
 - GPR Cross-Well Tomography  
 - Optical Telemetry  
 - Natural Gamma Log  
 - Neutron (porosity) Logging  
 - Nuclear Magnetic Resonance Logging  
 - **Solid Media Sampling and Analysis Methods**  
 - **Solid Media Sampling Methods**  
 - Split Spoon Sampler  
 - Single Tube Solid Barrel Sampler  
 - Dual Tube Sampler  
 - **Solid Media Evaluation and Testing Methods**  
 - Core Logging  
 - **Direct Push Logging (in-Situ)**  
 - Cone Penetrometer Testing (CPT & CPTu)  
 - Hydrosense (CPD)  
 - CPT In-Situ Video Camera  
 - **Discrete Groundwater Sampling & Profiling**  
 - Hydraulic Profiling Tool - Groundwater Sampler (HPT-GWSP)

## Perform Additional Searches to Find More Tools for Different Objectives

Additional parameters can be added or removed from any given search

The screenshot shows the Geology Tools database interface. The search filters are set to: Type: Geology, Parameter: Lithologic, and Quality: (Q) Quantitative. The results are displayed in a table with columns for Tool, Data Quality, Bulk Surface, Zone, and various material properties. The table is filtered to show only tools that are quantitative and related to lithology.

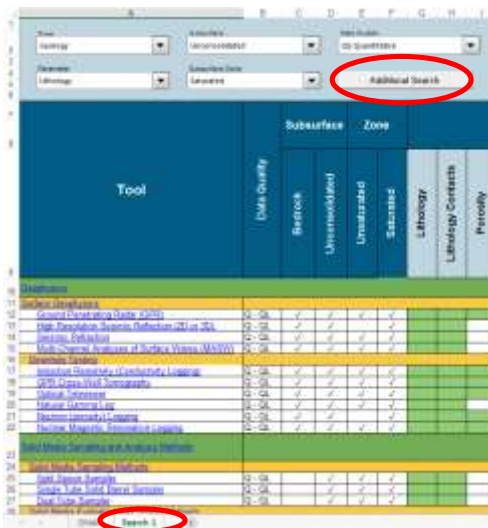
**Search Filters:**  
 Type: Geology  
 Parameter: Lithologic  
 Quality: (Q) Quantitative

**Tools and Methods:**  
 - **Geophysics**  
 - **Surface Geophysics**  
 - Ground Penetrating Radar (GPR)  
 - High Resolution Seismic Reflection (2D or 3D)  
 - Seismic Refraction  
 - Multi-Channel Analyses of Surface Waves (MASW)  
 - **Downhole Testing**  
 - Induction Resistivity (Conductivity Logging)  
 - GPR Cross-Well Tomography  
 - Optical Telemetry  
 - Natural Gamma Log  
 - Neutron (porosity) Logging  
 - Nuclear Magnetic Resonance Logging  
 - **Solid Media Sampling and Analysis Methods**  
 - **Solid Media Sampling Methods**  
 - Split Spoon Sampler  
 - Single Tube Solid Barrel Sampler  
 - Dual Tube Sampler  
 - **Solid Media Evaluation and Testing Methods**  
 - Core Logging  
 - **Direct Push Logging (in-Situ)**  
 - Cone Penetrometer Testing (CPT & CPTu)  
 - Hydrosense (CPD)  
 - CPT In-Situ Video Camera  
 - **Discrete Groundwater Sampling & Profiling**  
 - Hydraulic Profiling Tool - Groundwater Sampler (HPT-GWSP)



## Add Parameters to a previous search

Multiple searches  
can be saved on  
one matrix



## Apply Selected Tool(s)

- Incorporate selected tool(s) into characterization plan
- Implement plan, evaluate data, update CSM, reassess characterization objectives
- Repeat tool selection process as necessary

## Case Example – Characterization Objectives

Case Example

Returning to Case Example from prior section

### – Characterization Objective:

- Delineate lateral and vertical extent of dissolved-phase plume; determine stability and rate of attenuation.

### Goal:

- Define boundary exceeding groundwater standards
- Assess remedy progress – soil and groundwater samples
- Assess shallow soil vapor impacts

## Case Example – Select Tools Matrix Filters

Case Example

### Filters

- Type
  - Chemistry
- Parameter
  - Contaminant Concentration
- Subsurface Media
  - Unconsolidated
- Subsurface Zone
  - Saturated
- Data Quality
  - (Q) Quantitative

## Case Example – Apply Filters

Case Example

Type: Chemistry - All Parameter: Contaminant Concentration - Subsurface: Unconsolidated - Zone: Saturated - Quality: (Q) Quantitative

| Tool                                  | Subsurface | Zone | Parameter | Quality |
|---------------------------------------|------------|------|-----------|---------|
| Groundwater Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Sampling                         | ✓          | ✓    | ✓         | ✓       |
| Soil Gas Sampling                     | ✓          | ✓    | ✓         | ✓       |
| Soil Core Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Moisture Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Temperature Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil pH Sampling                      | ✓          | ✓    | ✓         | ✓       |
| Soil Electrical Conductivity Sampling | ✓          | ✓    | ✓         | ✓       |
| Soil Nutrient Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Heavy Metal Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Organic Carbon Sampling          | ✓          | ✓    | ✓         | ✓       |
| Soil Chlorophyll Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Microbial Activity Sampling      | ✓          | ✓    | ✓         | ✓       |
| Soil Enzyme Activity Sampling         | ✓          | ✓    | ✓         | ✓       |
| Soil Respiration Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Nitrogen Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Phosphorus Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Potassium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Calcium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Magnesium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Sulfur Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Iron Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Zinc Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Copper Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Manganese Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Nickel Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Cobalt Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Silver Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Barium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Bismuth Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Cadmium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Chromium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Lead Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Molybdenum Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Selenium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Tellurium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Vanadium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Tungsten Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Uranium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Thorium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Protactinium Sampling            | ✓          | ✓    | ✓         | ✓       |
| Soil Actinium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Francium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Radium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Polonium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Astatine Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Beryllium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Boron Sampling                   | ✓          | ✓    | ✓         | ✓       |
| Soil Carbon Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Fluorine Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Neon Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Sodium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Magnesium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Aluminum Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Silicon Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Phosphorus Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Sulfur Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Chlorine Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Nitrogen Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Oxygen Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Hydrogen Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Helium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Neon Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Argon Sampling                   | ✓          | ✓    | ✓         | ✓       |
| Soil Krypton Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Xenon Sampling                   | ✓          | ✓    | ✓         | ✓       |
| Soil Radon Sampling                   | ✓          | ✓    | ✓         | ✓       |
| Soil Francium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Radium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Actinium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Thorium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Protactinium Sampling            | ✓          | ✓    | ✓         | ✓       |
| Soil Uranium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Neptunium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Plutonium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Americium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Curium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Berkelium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Californium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Einsteinium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Fermium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Mendelevium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Nobelium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Lawrencium Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Rutherfordium Sampling           | ✓          | ✓    | ✓         | ✓       |
| Soil Dubnium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Seaborgium Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Bohrium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Hassium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Meitnerium Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Darmstadtium Sampling            | ✓          | ✓    | ✓         | ✓       |
| Soil Roentgenium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Copernicium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Nihonium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Flerovium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Tennessine Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Oganesson Sampling               | ✓          | ✓    | ✓         | ✓       |

## Case Example – Applicable Tools

Case Example

| Tool                                  | Subsurface | Zone | Parameter | Quality |
|---------------------------------------|------------|------|-----------|---------|
| Groundwater Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Sampling                         | ✓          | ✓    | ✓         | ✓       |
| Soil Gas Sampling                     | ✓          | ✓    | ✓         | ✓       |
| Soil Core Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Moisture Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Temperature Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil pH Sampling                      | ✓          | ✓    | ✓         | ✓       |
| Soil Electrical Conductivity Sampling | ✓          | ✓    | ✓         | ✓       |
| Soil Nutrient Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Heavy Metal Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Organic Carbon Sampling          | ✓          | ✓    | ✓         | ✓       |
| Soil Chlorophyll Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Microbial Activity Sampling      | ✓          | ✓    | ✓         | ✓       |
| Soil Enzyme Activity Sampling         | ✓          | ✓    | ✓         | ✓       |
| Soil Respiration Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Nitrogen Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Phosphorus Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Potassium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Calcium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Magnesium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Sulfur Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Iron Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Zinc Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Copper Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Manganese Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Nickel Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Cobalt Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Silver Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Barium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Bismuth Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Cadmium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Chromium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Lead Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Molybdenum Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Selenium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Tellurium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Vanadium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Tungsten Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Uranium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Thorium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Protactinium Sampling            | ✓          | ✓    | ✓         | ✓       |
| Soil Actinium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Francium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Radium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Polonium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Astatine Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Beryllium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Boron Sampling                   | ✓          | ✓    | ✓         | ✓       |
| Soil Carbon Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Fluorine Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Neon Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Sodium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Magnesium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Aluminum Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Silicon Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Phosphorus Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Sulfur Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Chlorine Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Nitrogen Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Oxygen Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Hydrogen Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Helium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Neon Sampling                    | ✓          | ✓    | ✓         | ✓       |
| Soil Argon Sampling                   | ✓          | ✓    | ✓         | ✓       |
| Soil Krypton Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Xenon Sampling                   | ✓          | ✓    | ✓         | ✓       |
| Soil Radon Sampling                   | ✓          | ✓    | ✓         | ✓       |
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| Soil Thorium Sampling                 | ✓          | ✓    | ✓         | ✓       |
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| Soil Americium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Curium Sampling                  | ✓          | ✓    | ✓         | ✓       |
| Soil Berkelium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Californium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Einsteinium Sampling             | ✓          | ✓    | ✓         | ✓       |
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| Soil Nobelium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Lawrencium Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Rutherfordium Sampling           | ✓          | ✓    | ✓         | ✓       |
| Soil Dubnium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Seaborgium Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Bohrium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Hassium Sampling                 | ✓          | ✓    | ✓         | ✓       |
| Soil Meitnerium Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Darmstadtium Sampling            | ✓          | ✓    | ✓         | ✓       |
| Soil Roentgenium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Copernicium Sampling             | ✓          | ✓    | ✓         | ✓       |
| Soil Nihonium Sampling                | ✓          | ✓    | ✓         | ✓       |
| Soil Flerovium Sampling               | ✓          | ✓    | ✓         | ✓       |
| Soil Tennessine Sampling              | ✓          | ✓    | ✓         | ✓       |
| Soil Oganesson Sampling               | ✓          | ✓    | ✓         | ✓       |

## Case Example – Tools Selection

Case Example

- Search returns 21 tools
- Considering desire to expedite the assessment, project team selected
  - Direct Push borings with continuous soil sampling and GW grab sampling on 4-foot intervals
  - Active Soil Gas Survey at two depth intervals
  - Direct Sampling Ion Trap Mass Spectrometer (DSITMS) mobile field lab



Active Soil Gas Survey



DSITMS Mobil Lab

## ITRC Tools Matrix Summary

- Characterization objectives guide selection of tools
- Interactive tools matrix - over 100 tools with links to detailed descriptions
- A systematic tools selection process
- Select tools, implement work plan, evaluate results
- Align data gaps with characterization objectives, update CSM
- Repeat as necessary until consensus that objectives have been met

## More on the Content of the Characterization Plan

### Develop a Work Plan

**A typical characterization work plan should:**

- Emphasize characterization and data collection objectives
- Present a data collection process
- Include the tools selected
- Be forward-looking to discuss what procedures/software/models will be used for data evaluation and interpretation
- Include data evaluation process, particularly for fractured rock sites

## More on the Content of the Characterization Plan

### Develop a Work Plan

**Use a dynamic field approach to site characterization to the extent practical, even at fractured rock sites**

- The work plan should be flexible to allow changes to the work scope based on real-time results obtained during the investigation activities.
- The work plan should outline the process for documenting field changes or adjustments during implementing the site investigation



# More on the Content of the Characterization Plan

## Develop a Work Plan

### A dynamic work plan can involve

- Real time data assessment
- Frequent (up to daily) calls or data uploads between the field team and project stakeholders to review field activities and data, to make decisions next steps for efficiently completing the characterization.
- Continuously or frequently updating the CSM



## Conducting

- Step 6: Implement investigation
- Step 7: Perform data evaluation and interpretation
- Step 8: Update CSM



## Step 6. Implement Investigation

- Time to conduct the investigation
  - Go into field
  - Use flexible plan
  - Collect data
- Often concurrent with data evaluation (Step 7)

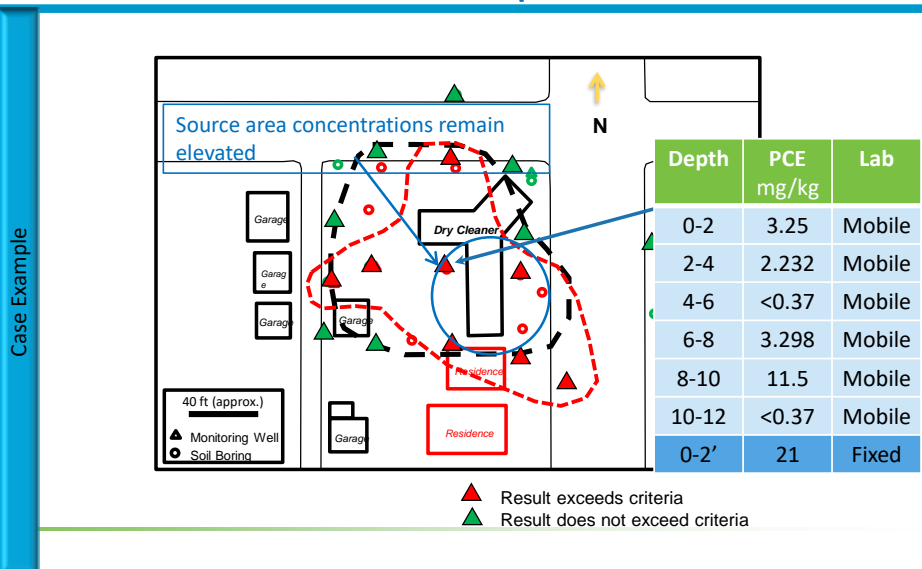


## Step 7. Data Evaluation and Interpretation

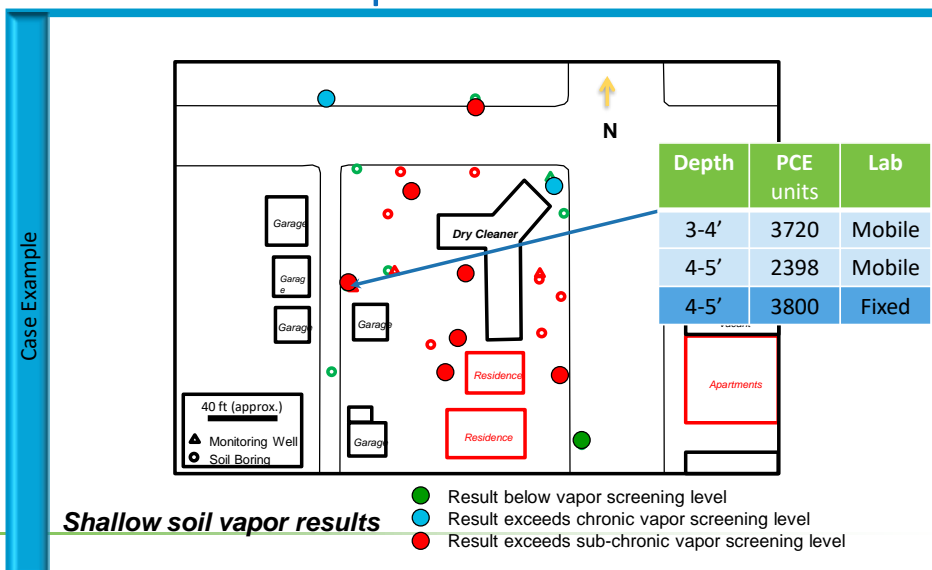
- Gain understanding of site
  - Integrate all data types
  - Generate collaborative datasets
- Multiple line of evidence
  - Contaminant transport
  - Storage
  - Attenuation



## Step 7. Soil and Groundwater Data Evaluation and Interpretation



## Step 7. Soil Vapor Data Evaluation and Interpretation





## Poll Question

Poll Question

- When do you typically update your CSM at sites where you work?
  - Whenever new data is collected
  - When a remedial technology fails
  - Whenever the CSM is determined to be inaccurate
  - Every five years
  - Never

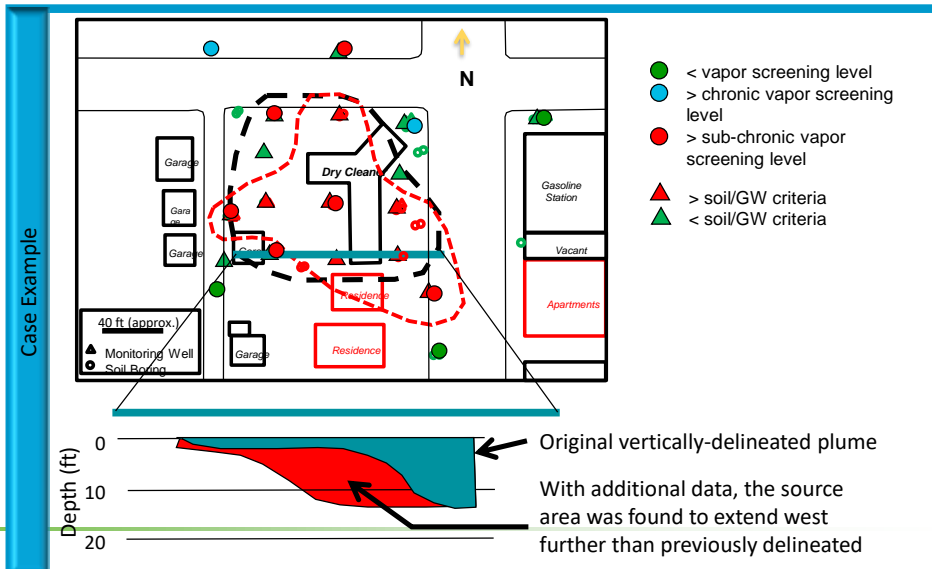


## Step 8. Update the CSM

- Data collected from all phases of a project can be used
- As a project progresses, data needs shift
- In late phases, additional data collection often driven by specific questions
- ISC continues as the CSM evolves



## Step 8: Dry Cleaners – CSM Update



## Integrated Site Characterization Benefits for Dry Cleaners Sites

- Case Example
- Confirmed need for residential indoor air evaluation and VI mitigation for commercial buildings
  - Optimized data density in specific areas; avoided unnecessary / inconclusive data collection
  - Accurately determined source zone and remediation target area
  - Completed ahead of schedule; saved \$50k of \$150k budget (33%)



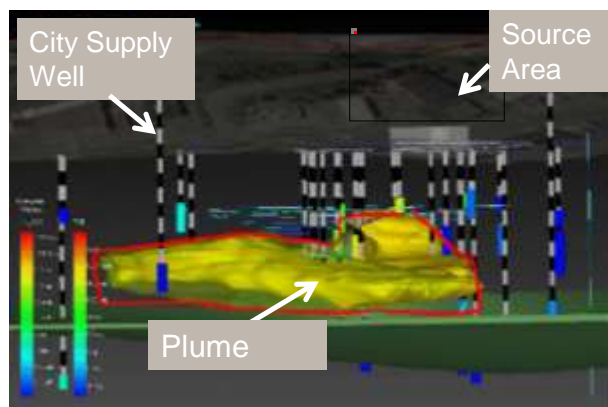
## Case Study Examples

### Well 12A Superfund Site, WA

#### Mass flux and mass discharge

Focused Feasibility Study evaluation: Reduce source strength (Md) by 90%, MNA sufficient to achieve compliance

ROD amendment: Multi-component remedy- reduce source discharge Md by 90% & transition technology (if necessary)



## Starting CSM: 2D TCE Plume

- In situ bioremediation remedy selected for large areas of the plume, along with thermal and excavation
- Entire ~75 to 95 ft contaminated thickness required active ISB treatment



## Characterization Objectives

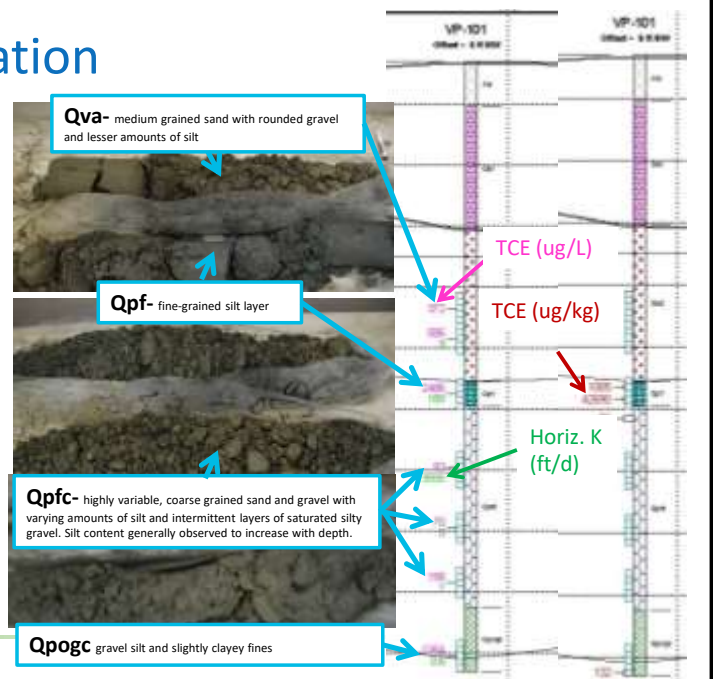


- 34 soil borings to reduce uncertainty and delineate sources
- 12 locations for vertical profiling
- Depth discrete samples:
  - Groundwater
  - Soil
  - Slug testing
  - Stratigraphy
- Gradient assessment
- Mass flux assessment



## Vertical Characterization

- Install borings in transects
- Conduct depth-discrete soil and groundwater sampling
- Perform slug testing



## Calculating Mass Discharge: Transect Method

### Steps for Well 12A:

1. Draw polygons (use Theissen)
2. Calculate Darcy velocity ( $q$ ) for each polygon:  $q = K \cdot I$
3. Characterize polygon flux ( $M_f = q \cdot C_n$ )
4. Determine area ( $W \cdot b = A$ )
5. Evaluate mass discharge:

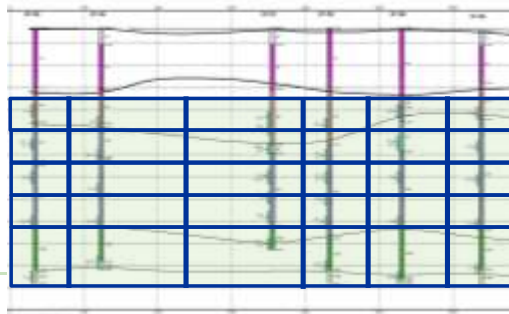
$$M_d = \sum (M_f \cdot A_n)$$

$M_f$  = Mass flux

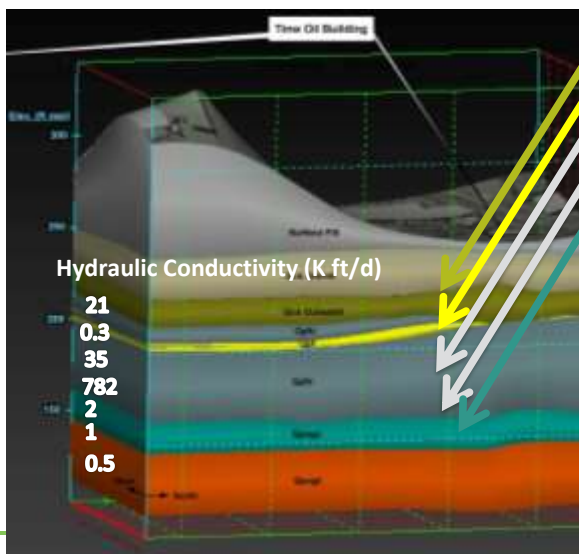
$M_d$  = Mass discharge

$C_n$  = concentration in polygon n

$A_n$  = Area of segment n



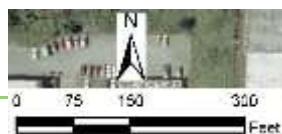
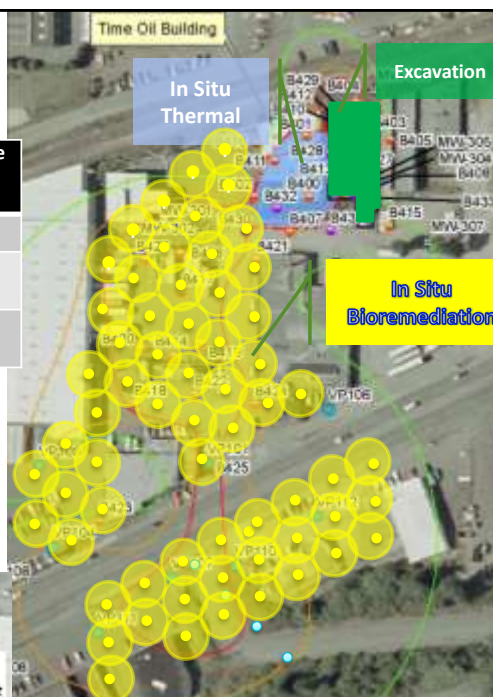
## Mass Discharge Across Transects



|                   | Total VOC MD<br>(kg/yr) | % of Total MD |
|-------------------|-------------------------|---------------|
| <b>Transect 1</b> |                         |               |
| Qva               | 0.1                     | 1%            |
| Qpfc1/Qpf         | 2.9                     | 31%           |
| Qpfc2             | 5.9                     | 96%           |
| Qpfc3             | 0.06                    | 1%            |
| Qpogc             | 0.3                     | 4%            |
| Total             | 9.3                     |               |
| % of Total        |                         |               |
| <b>Transect 2</b> |                         |               |
| Qva               | 0.01                    | 0.4%          |
| Qpfc1/Qpf         | 0.2                     | 7%            |
| Qpfc2             | 1.7                     | 57%           |
| Qpfc3             | 0.1                     | 3%            |
| Qpogc             | 1.0                     | 33%           |
| Total             | 3.0                     |               |

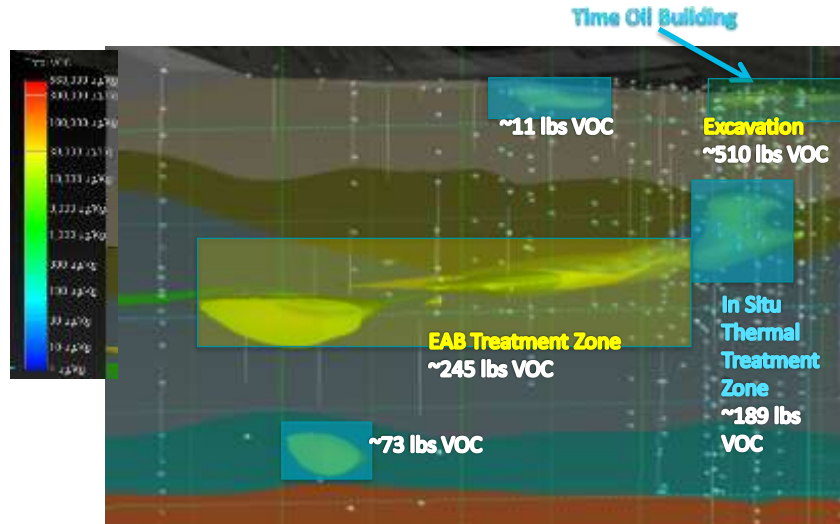
## Mapping Technologies

| Zone                   | Surface Area (ft <sup>2</sup> ) | VOC Mass (kg) | % Discharge to GETS |
|------------------------|---------------------------------|---------------|---------------------|
| Excavated Zone         | 3819                            | 510           | NA                  |
| Thermal Treatment Zone | 11,746                          | ~189          | 70 kg/yr            |
| In Situ Bioremediation | 162,005                         | ~245          | 25 kg/yr            |





## Treatment Zones: Selecting Vertical Intervals



## Well 12A HRSC Conclusions – Updated CSM

- Revising the CSM to evaluate the plume in 3D:
  - Stratification of residual contaminant mass in soils
  - Transport through the groundwater plume
- Nearly 95% of the mass discharge was occurring within 20 feet of the 75 foot vertical extent of the contaminated aquifer near major source
- This reduction in target treatment volume will save nearly \$3M on the remedy, resulting in a large return on the ~\$350K characterization investment



## Commerce Street Plume Superfund Site

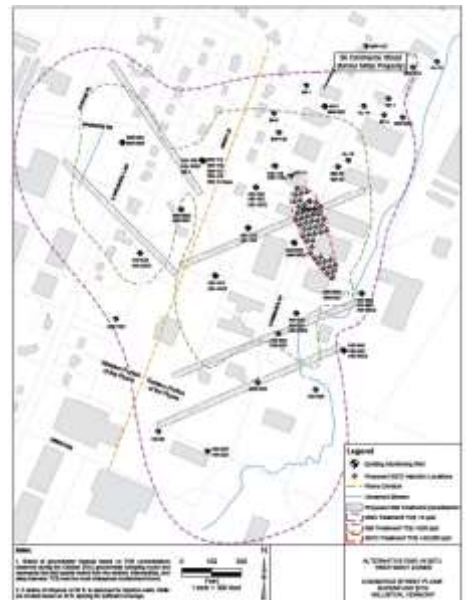
- TCE plume in mixed-use area
- ROD-selected remedy:
  - In situ chemical oxidation (ISCO) for TCE > 50,000 ppb
  - In situ bioremediation (ISB) for TCE > 500 ppb but <50,000 ppb
  - Monitored natural attenuation (MNA) for TCE < 500 ppb
- Follow ISC process to define data gaps, set objectives, and select tools
- Lesson Learned – site conditions can change over relatively short time frames



## High Resolution Site Characterization

### Initial CSM

- TCE DNAPL released into sandy aquifer
- Sand unit:
  - Shallow zone 10-20 ft below ground surface (bgs)
  - Intermediate zone 20-30 ft bgs
  - Deep zone 30-40 ft bgs
- Continuous clay unit underlying sand unit (40 ft bgs)





# Characterization Activities and Preliminary Results

## Characterization program

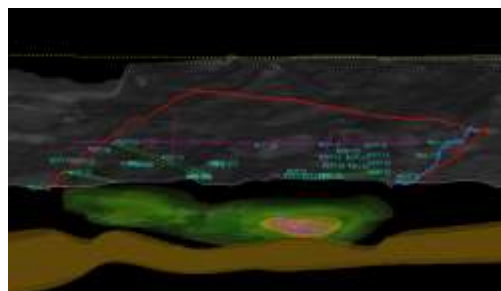
- Membrane interface probe/hydraulic profiling tool (MiHPT)
- Waterloo Advanced Profiling System (APS)
- DPT soil and groundwater sampling
- Onsite VOC analysis

## Results Summary

- 50,000 ppb hotspot no longer exists
- In east-central portion of site, TCE is almost completely converted to c-DCE
- Sand unit is hydraulically somewhat variable and not related to previous designations

## Path Forward

- ISCO may no longer be needed – potential savings of nearly \$3M
- Current nature and extent of contaminants could be treated by ISB and MNA
- Bench and pilot testing approach is being modified
- RD will incorporate new CSM and bench/pilot results







## Pre-RA Characterization (2008-2009)

- Source area & Biobarrier # 1
  - Membrane interface probe (MIP) / Electrical Conductivity (EC) characterization to determine contaminant profile and lithology
  - Direct push technology (DPT) points to confirm MIP/EC results
- Biobarrier # 2 and # 3
  - MIP/EC and DPT along plume axis to look for hotspots > 200 µg/L
  - Additional MIP/EC and DPT at the identified hot spots to define biobarrier locations
- Monitoring well installation and baseline sampling

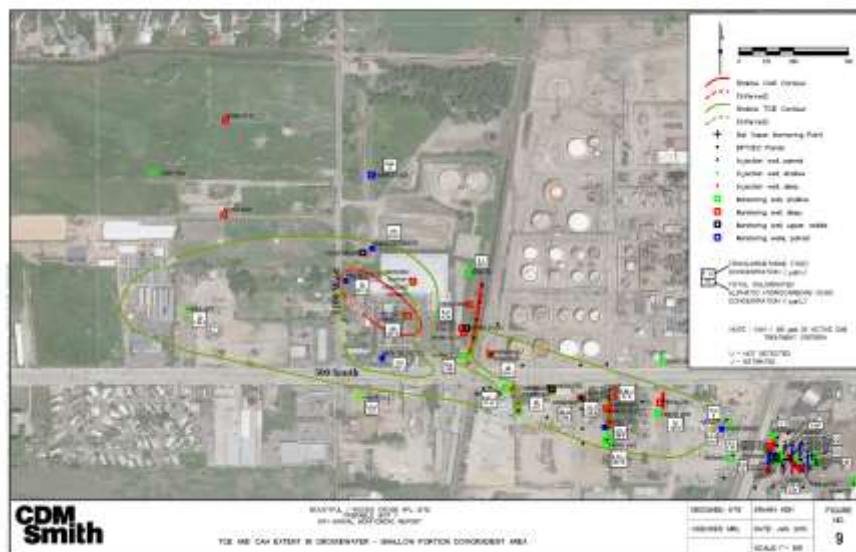
## Pre-RA Characterization Results: Contaminant Distribution

- Membrane-interface probe (MIP) used to determine areas with high concentrations of VOCs
- MIP results showed responses at depths greater than 40 ft. throughout the source area and downgradient plume
- DPT sampling confirmed MIP results as source concentrations greater than 15,000 ppb were found below 40 ft.
- Downgradient concentrations were greater than 3,000 ppb in one location

## Pre-RA Characterization Results: Hydrogeology

- Clay layer at 35 ft. bgs was found to be laterally discontinuous
- Modified DPT/EC approach was used to investigate hydrogeology below 60 ft.
- Below 35 ft., layers of sand and gravel exist to 80 feet bgs, with intermittent thin clay layers present in some areas
- A several foot thick clay layer was found at depths of approximately 80 ft. throughout the source area
- The deep clay layer was confirmed in the downgradient area during other site drilling activities
- As a result, the remedial design was changed to include injection into deeper zones

## Shallow Zone Results







## Deep Zone Results



## HPT-GWS investigation approach

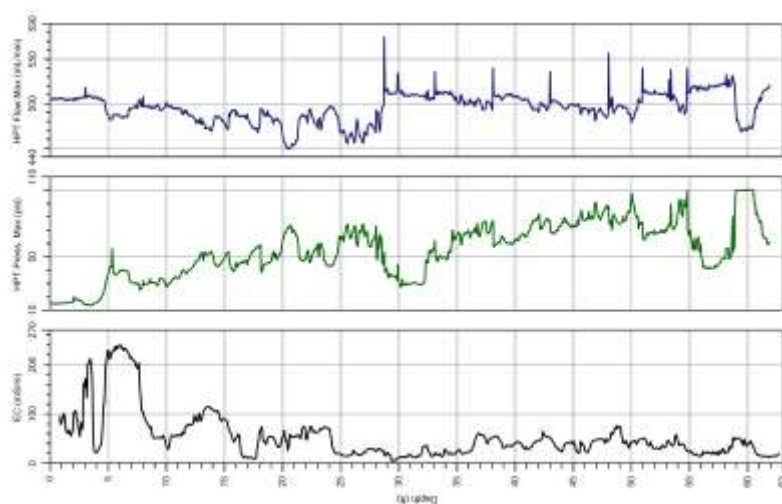
- Objective: plume delineation to MCLs
  - TRIAD approach with EPA mobile lab
  - Continuous hydraulic profiling
  - GW samples collected at high conductivity zone
  - Lithologic and analytical data used to guide well installation
- 
- 



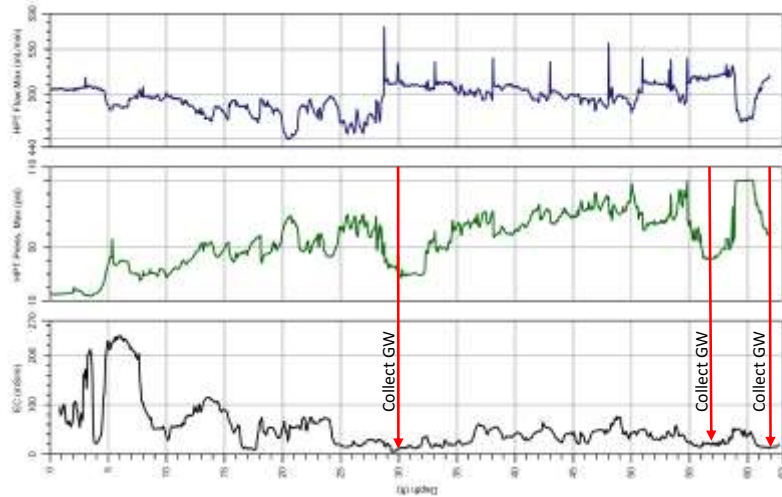
## Downgradient plume



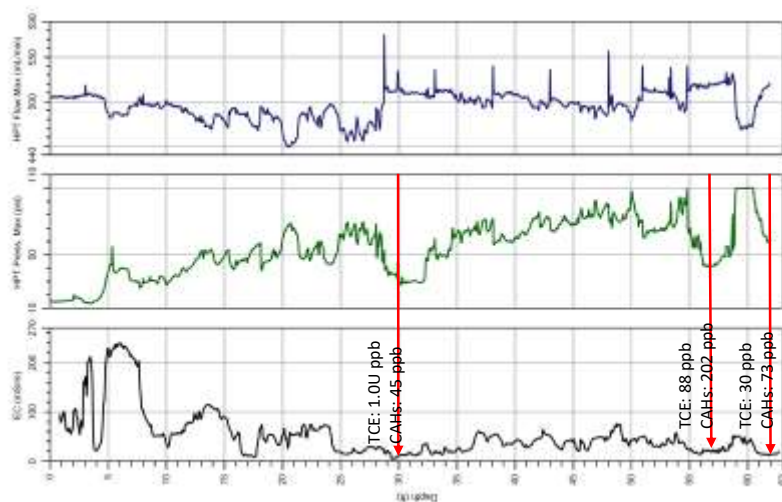
## Example HPT log – HPT-D10



## Example HPT log – HPT-D10

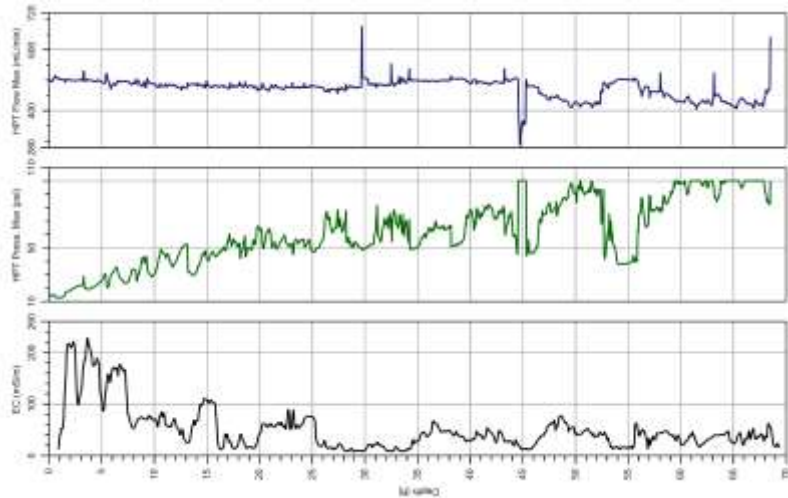


## Example HPT log – HPT-D10

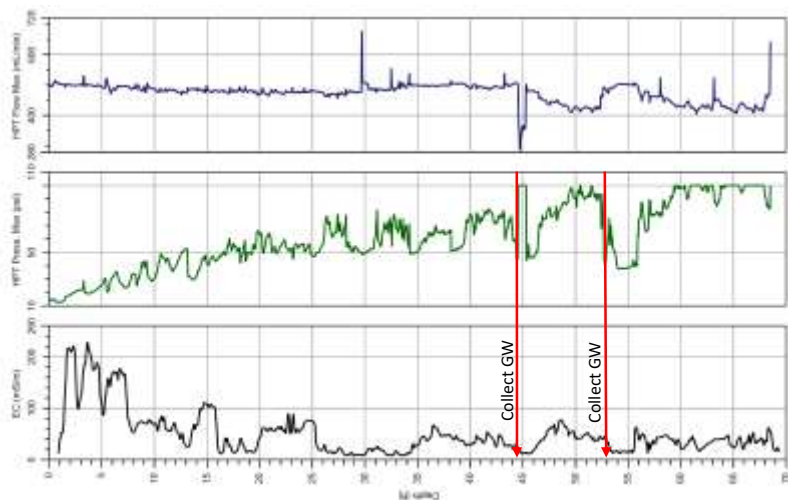




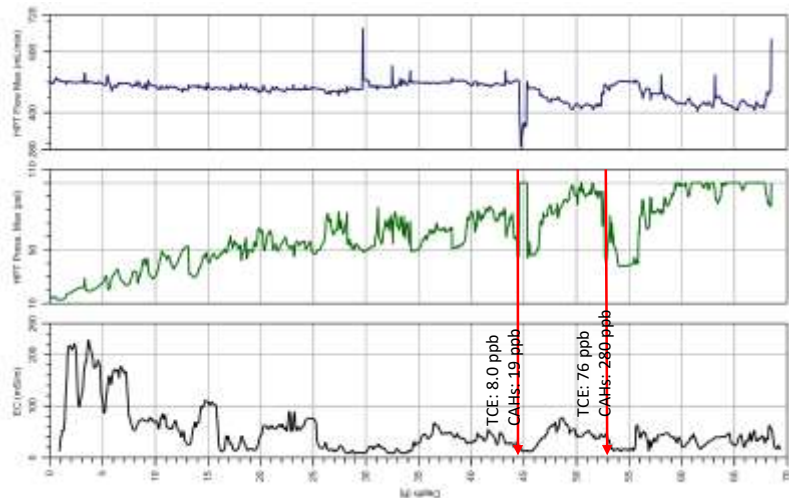
## Example HPT log – HPT-D11



## Example HPT log – HPT-D11



## Example HPT log – HPT-D11



## Delineated plume



## Summary: ITRC Resources

- Integrated DNAPL Site Strategy  
[https://www.itrcweb.org/GuidanceDocuments/IntegratedDNAPLStrategy\\_IDSSDoc/IDSS-1.pdf](https://www.itrcweb.org/GuidanceDocuments/IntegratedDNAPLStrategy_IDSSDoc/IDSS-1.pdf)
- Integrated Site Characterization and Tools Selection  
[https://www.itrcweb.org/DNAPL-ISC\\_tools-selection/](https://www.itrcweb.org/DNAPL-ISC_tools-selection/)
- Characterization and Remediation in Fractured Rock  
<https://fracturedrx-1.itrcweb.org/>
- Incremental Sampling Methodology (ISM)  
<https://www.itrcweb.org/ism-1/>

## Geology controls flow!

- Lithologic heterogeneity leads to differences in subsurface pore structure and capillary properties.
- These can be over very small distances/ intervals



Photo Courtesy of Fred Payne, Arcadis, Inc

# Controlling Role of Geology in Matrix Diffusion

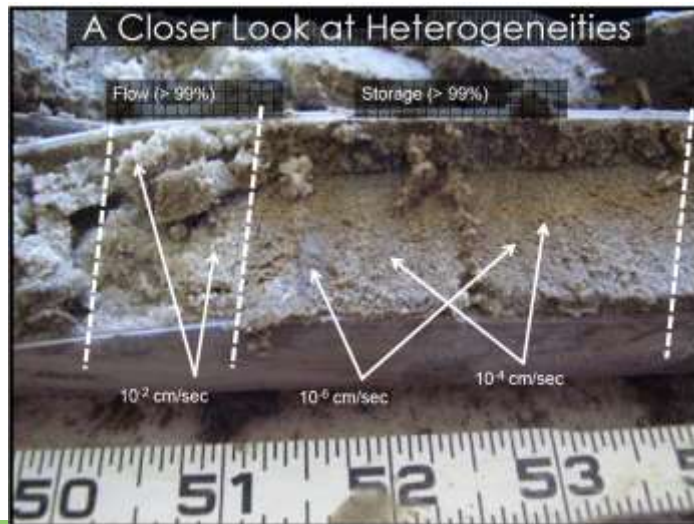


Figure courtesy of Fred Payne, Arcadis

## Summary

- Characterization activities should be driven by objectives (e.g. SMART)
- Characterization plan should facilitate dynamic decision making
- **The CSM should be continuously updated during all project phases**

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