

# Developing a Site Characterization Plan

NEWMOA

Back to Basics Part 1: Developing the CSM and Site Characterization Plan

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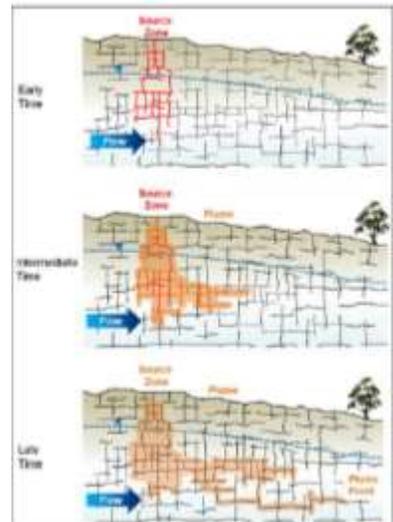
March 27-29, 2018



**CDM  
Smith**

## Introduction

- Initial CSM is already developed
- Data gaps likely exist that need to be filled
- An iterative approach is recommended for filling these data gaps
- **Recommended process is the ITRC Integrated Site Characterization (ISC) Process**



Parker et al. 2012

# Integrated Site Characterization

ISC relies on the concept of an *objectives-based site characterization*.

This emphasizes the importance of establishing clear, effective objectives to drive characterization data collection.

It is a systematic, stepwise process that encourages use of a characterization approach which emphasizes:



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# Integrated Site Characterization

## ▶ Integrated Site Characterization flow chart

- Planning
- Tool Selection
- Implementation

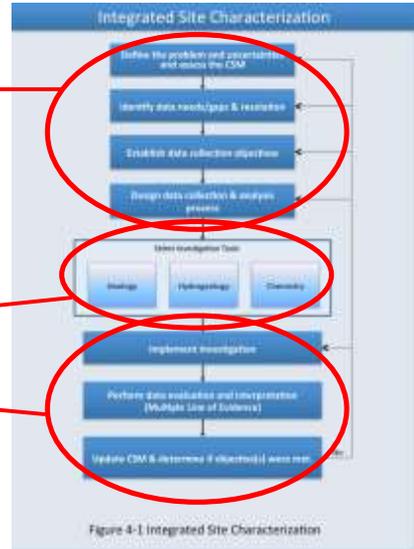
## ▶ Planning module

- Step 1: Define problem and uncertainties
- Step 2: Identify data gaps & resolution
- Step 3: Develop data collection objectives
- Step 4: Design data collection & analysis plan
- Similar to DQO process

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# 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)



# Data Quality Objectives are “Built in”

USEPA Data Quality Objectives



# Step 1: Define Problem and Assess CSM Uncertainties

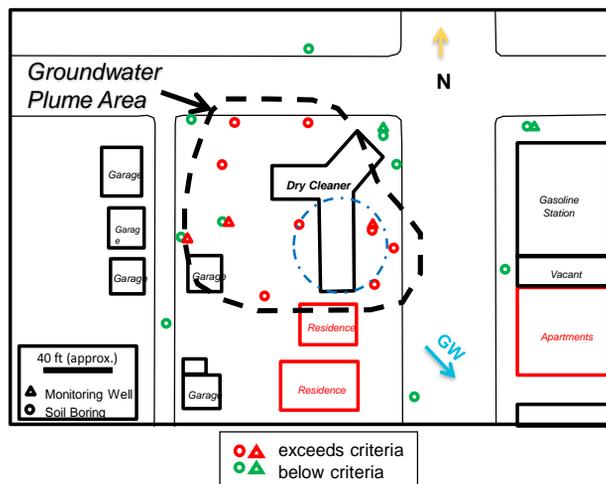
- Assess existing CSM
- Define problem
- Define uncertainties



## Case Example – Dry Cleaner Site

Case Example

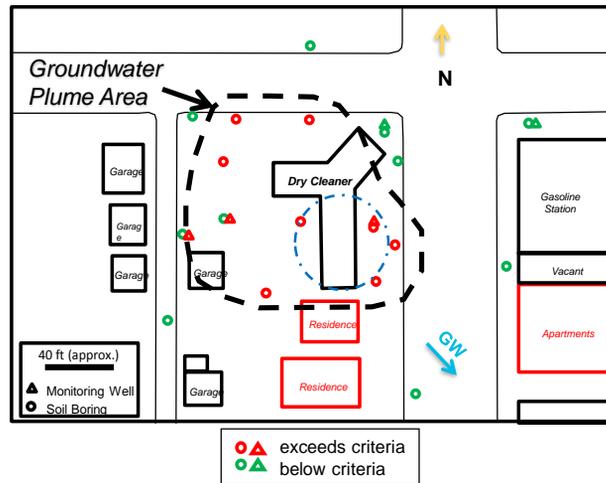
1. Commercial & residential location
2. Shallow groundwater (<20' bgs)
3. Five MWs; 10-ft screens
4. 18 soil borings; 5-ft samples
5. No soil-gas evaluation
6. In situ chemical oxidation (ISCO) & enhanced in situ bioremediation (EISB) injections in source area & plume



## Step 1: Define Problem and Assess Uncertainties

Case Example

1. Uncertain plume delineation; no down-gradient control
2. Source area inferred, not confirmed
3. No remedy evaluation
4. No soil gas or VI assessment



## Step 2: Identify Data Needs & Spatial Resolution

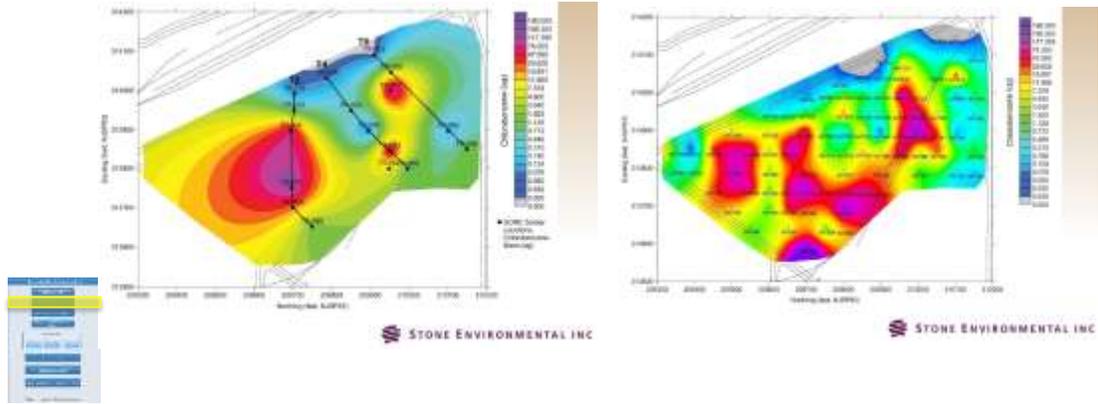
- Translate uncertainties into data needs
- Determine resolution needed to assess controlling heterogeneities



Figure 4-1 Integrated Site Characterization

## 2. Identify Data Needs / Gaps and Resolution

- Once the uncertainties in the existing CSM are recognized, specific data needs (e.g., type, location, amount, and quality) as well as data resolution (i.e., spacing or density) can be described. Spatial resolution should be assessed laterally and vertically.



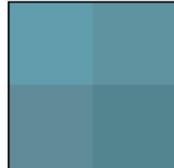
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## 2. Identify Data Needs / Gaps and Resolution

1 x 1



2 x 2



10 x 10



20 x 20



50 x 50



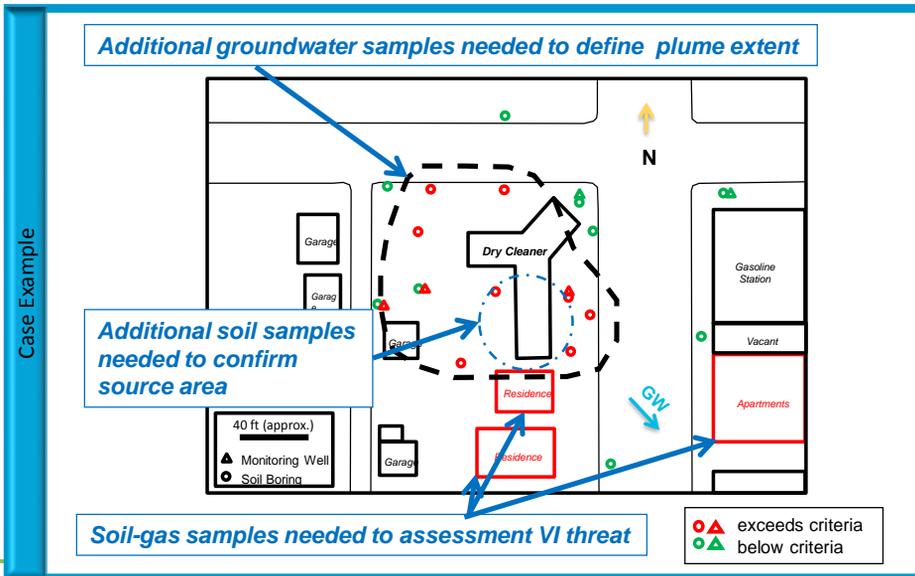
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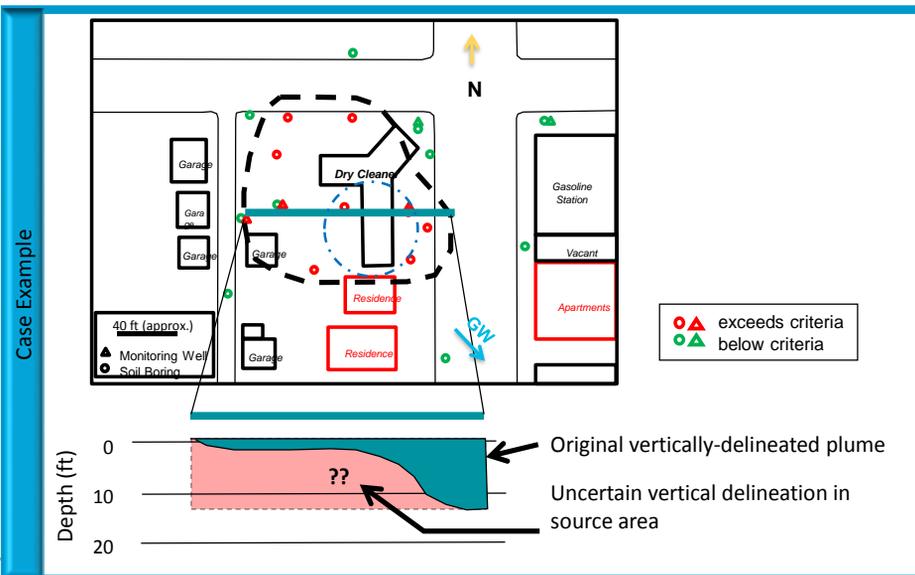
Figure courtesy of Seth Pitkin

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## Step 2: Identify Data Needs & Spatial Resolution



## Step 2: Identify Data Needs & Spatial Resolution



## Identify Significant Data Gaps

- Missing information limits the formulation of a scientifically defensible interpretation of environmental conditions and/or potential risks in a bedrock hydrogeologic system. A data gaps exists when:
  - it is not possible to conclude with confidence whether or not a release has occurred
  - evaluation of all data, in proper context, does not/cannot support the CSM
  - if more than one interpretation of existing data set
- Fractured rock CSMs will unavoidably have data gaps throughout the process**
  - the lateral and vertical extent of contamination
  - the direction the contamination is moving
  - identification of imperiled receptors
  - the rate at which the contamination is moving
  - what areas should be targeted for sampling.

Each data gap can be transformed into one or more specific characterization objectives

## Step 3: Establish Data Collection Objectives

- Specific, Clear, Actionable
- Consider data types, quality, density, and resolution



## Formulate-Revise Characterization and Data Collection Objectives

- Data collection objectives (DQOs)- determine specific data needs and to select tools to be used in the investigation
- DQOs should be clear, focused, specific, & consider:
  - fracture orientation,
  - spacing and aperture,
  - hydraulic head,
  - and flow velocity
- **Characterization Objective:** Determine the lateral and vertical extent of dissolved phase VOCs.
- **Data Gap:** The vertical and lateral extent is unknown.
- **Data Collection Objective:** Gather data on: fracture location, orientation, connectivity and VOC concentration in the source, plume and towards receptors.

## Step 3: Example Data Collection Objectives

### **Delineate extent of dissolved-phase plume; determine stability and attenuation rate**

- Grab groundwater samples at X and Y depths
- Soil borings every X feet to capture subsurface variability
- Delineate to drinking water standards
- Install three to five wells; monitor along axis of flow
  - Quarterly for two years
  - Evaluate C vs T and C vs. distance trends
  - Specify COCs and geochemical parameters

## Step 3: Drycleaner Site Data Collection Objectives

Case Example

- Objectives
  - Define plume extent exceeding standards
  - Assess remedy progress – soil and GW samples
  - Assess shallow soil vapor & VI threat
  - Streamline assessment – days not weeks
- Data types & resolution
  - Continuous cores; samples at lithologic boundaries
  - Groundwater samples every 4'
  - Soil gas at 5 and 10 feet

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## Step 4: Data Collection & Analysis Plan

- Write work plan
  - Recognize data limitations
  - Select data management tool
  - Develop data analysis process
- Consider real-time analysis

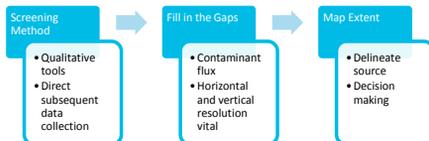
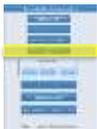


Figure 4-1: Integrated Site Characterization

## 4. Design Data Collection and Analysis Process

- There are generally three types of data collected:
  - Quantitative:**
    - A tool that provides compound-specific values in units of concentration based on traceable standards (e.g.,  $\mu\text{g/L}$ , ppm, and  $\mu\text{g/m}^3$ )
  - Semi-quantitative:**
    - A tool that provides compound-specific quantitative measurements based on traceable standards but in units other than concentrations (e.g., ng or ug) or provides measurements within a range.
  - Qualitative**
    - A tool that provides an indirect measurement (e.g. LIF and PID measurements provide a relative measure of absence or presence, but are not suitable as stand-alone tools for making remedy decisions.



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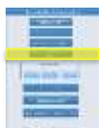
## 4. Design Data Collection and Analysis Process

### Accuracy:

- How “close” a result comes to the true value?
- Requires careful calibration of analytical methods with standards

### Precision:

- The reproducibility of multiple measurements
- Described by a standard deviation, standard error, or confidence interval.



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## 4. Design Data Collection and Analysis Process

### Develop Site Investigation Work Plan

- The plan should be Dynamic-Flexible-Adaptable
  - This concept works for large and small sites
- Consider use of field laboratory
- Incorporate real time data collection and analysis to continuously up date CSM
- Continuously adjust work plan to incorporate evolving CSM and to address data gaps as they are understood



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## Step 4: Drycleaner Site Data Collection & Analysis Plan

Case Example



Soil vapor sampling



Triad ES mobile lab and Geoprobe

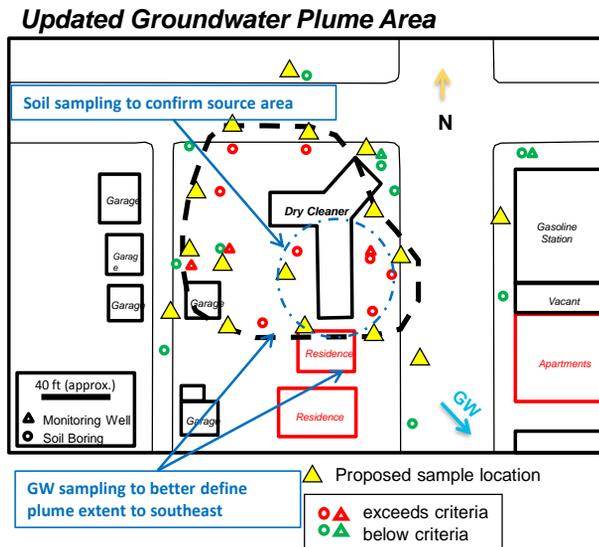


Direct sampling ion trap mass spectrometry (SW846 Method 8265) with mobile lab provides up to 80 soil/groundwater and 60 soil vapor VOC analyses per day

## Step 4: Data Collection & Analysis Plan

Case Example

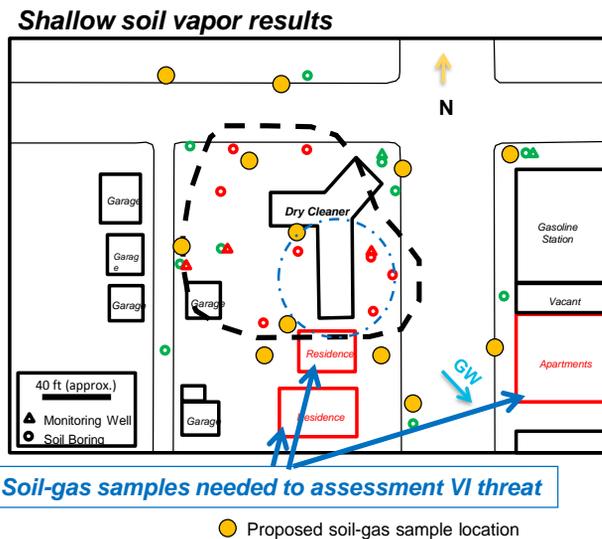
- 16 borings
- 80 soil samples (~5 per boring)
- 48 grab groundwater samples (~3 per boring)



## Step 4: Data Collection & Analysis Plan

Case Example

- Soil gas
  - 12 points
  - 24 samples





# Tools Matrix Functionality

Click any box for a description or definition



Tool	Sub surface		Zone	Geology				
	Bedrock	consolidated		unconsolidated	Saturated	Other	Other	Other

**3.1 Geology**

Geologic data provide a means to describe the physical nature and structure of the subsurface and to classify the environment, geology, or lithostratigraphic measurement. Data related to lithology and distribution of strata and facies changes are generated through a variety of qualitative and quantitative collection tools and methods.

Initial 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 mobilization, which can involve the use of both invasive and non-invasive 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 planar features and grading on a stereonet).

Following a surface investigation, the next step in site characterization commonly involves collecting a continental core of sediments and bedrock. Data provided by this core sampling may include lithology, grain size and sorting, crystallinity, geologic contacts, bedding planes, fractures and faults, depositional environment, porosity, and permeability. Generally, numerous boreholes are drilled to determine the vertical and horizontal variability of the site-specific geology. The depositional environment and facies changes should also be mapped as much as possible, and these data may be combined with surface and subsurface geophysical data to determine relationships between the layers. Considerable geophysical tools and direct push tools – for example, crosshole resistivity probe (CHRP), hydraulic probing tool (HPT), and Clusters probe – are commonly deployed wherever an geology and contains are distributed at a site.

Effective site-geology characterization 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 investigation methods – for example, characterizing soil or rock type using the same, agreed upon classification system. The team must determine the level of data resolution necessary to adequately characterize a specific site and whether surface and subsurface geophysical data are of sufficient resolution.

Unusually, collection efforts at contaminated sites often yield sufficient geologic data, leading to a high degree of uncertainty in surface characterization. Historically, there has been a tendency to overmap conceptual site models (CSMs), which has led to the misperception that physical (geologic) conditions of the site can be engineered around – that is, limitations in site characterization data can be compensated by overengineering remediation systems. However, remedy performance success rates have been poor under such circumstances, whereas investing in adequately detailed site characterization has provided a positive return on investment in terms of improved remedy success rates and reduced life cycle costs.

Overengineering of CSMs is particularly evident in glacial regions with complex depositional environments, or the northern and southern, rarely glaciated sites contain both bedrock and glacial aquifers that have DNAPL plumes. Under such conditions, hydrogeological and geological expertise specific to glacial environments and their depositional characteristics is required for developing an accurate and complete CSM, 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



Tool	Sub surface		Zone	Data Quality
	Bedrock	consolidated		
<ul style="list-style-type: none"> <li>• Ground Penetrating Radar (GPR) (Arora 2006)</li> <li>• Dixon et al. 2011</li> <li>• Dixon et al. 1999</li> <li>• Bradford 2005</li> <li>• Bradford and Davis 2009</li> <li>• Bradford, DeJong, and Beaton 2010</li> <li>• Bradford and DeJong 2013</li> <li>• Carver, Barrett, and Hunt 2009</li> <li>• Davis 2002</li> <li>• USEPA 2004</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-2D image. Penetration and resolution of features depend on antenna frequency and lateral conductivity and stratification, and are generally limited to 2D images only. GPR can identify internal structures between material-bearing refractors (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., clay fill beneath in situ water-saturated clastic sediments) or vertical subsurface infrastructure (e.g., pipes, tanks, cables).</p>	<p>Data Quality and Applicability Advantages</p> <ul style="list-style-type: none"> <li>• Data Quality                             <ul style="list-style-type: none"> <li>• varies with penetration and subsurface EC</li> <li>• relatively sharp boundaries</li> <li>• sensitive to quantitative (depending on field conditions, prior knowledge/subsurface calibration, environmental quality, appropriate imaging)</li> </ul> </li> <li>• Applicability Advantages                             <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 DNAPL)</li> <li>• can be run repeatedly in time-lapse mode to track changes in moisture balance water table or EC to detect property (pore or spill location, including several equipment failures, presence and changes in dense non-aqueous phase liquid (DNAPL) or sandy aquifers)</li> </ul> </li> </ul>	<p>Limitations/Disadvantages</p> <ul style="list-style-type: none"> <li>• minimal penetration in high EC (clay-rich soils and clay-rich or conductive brine-filled units)</li> <li>• interpretation of features and depths can require additional independent reference level or cone penetrometer (CPT)</li> </ul>	

## Shaded Boxes Denote Tool Meets Objective

Tools collect these types of information

Tool	Data Quality	Sub surface				Geology										
		Bedrock	Unconsolidated	Unsaturated	Saturated	Lithology	Lithology Contacts	Porosity	Permeability	Dual Permeability	Faults	Fractures	Fracture Density	Fracture sets	Rock Competence	Mineralogy
<b>Geophysics</b>																
Surface Geophysics	QL - G															
Shoof Penetration Radar (SPR)	QL - G															
High Resolution Seismic Reflection (HRSR)	QL - G															
Seismic Tomography	QL - G															
Multi-Channel Analysis of Surface Waves (MASW)	QL - G															
Electrical Resistivity Tomography (ERT)	QL - GQ															
Very Low Frequency (VLF)	QL - G															
ElectroMagnetic Induction (EMI) Conductivity	QL															
Overhole Logging																

Green shading indicates that tool is applicable to characterization objective

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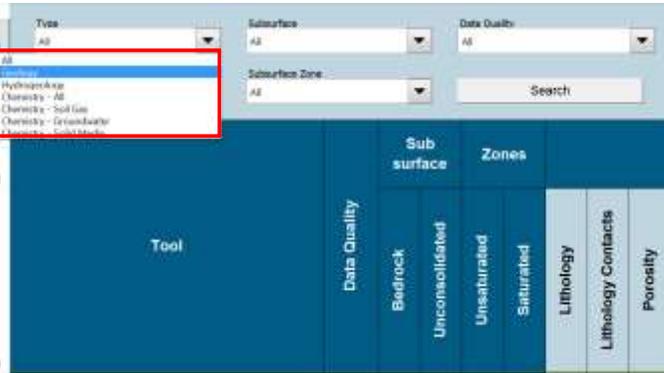
## Using the Tools Matrix

- 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

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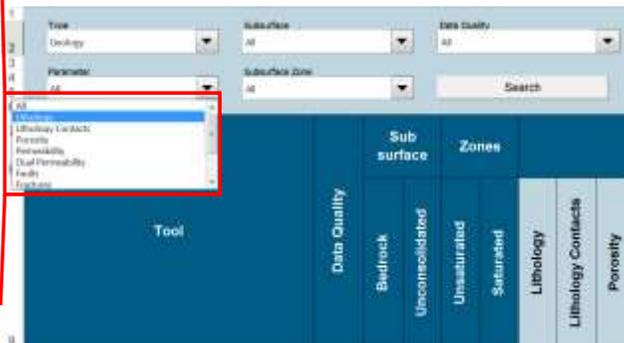
# 1. Select Category

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



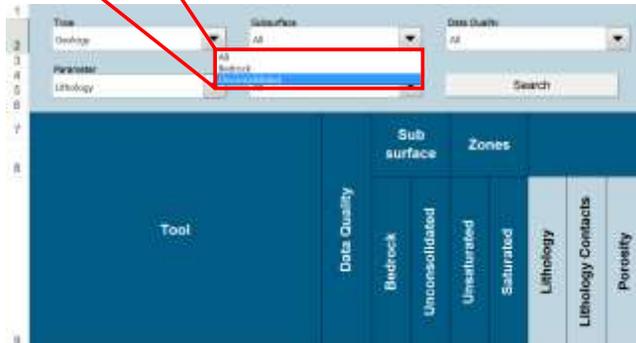
# 2. Select Parameters of Interest

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



### 3. Identify Geologic Media

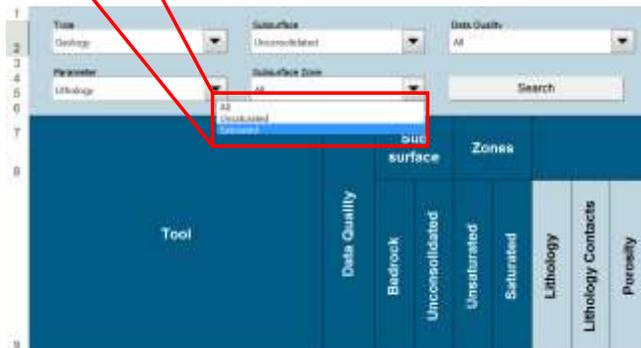
All  
Bedrock  
Unconsolidated



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### 4. Identify Zone

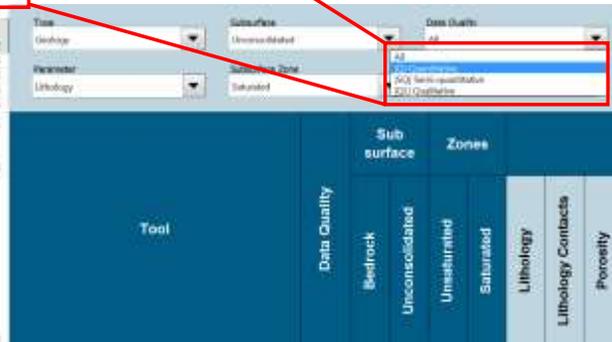
All  
Unsat  
Saturated



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## 5. Choose Data Quality

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



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## 6. Apply Filters, Evaluate Tools

Type: Geology Parameter: Lithology

Quality: (Q) Quantitative

The screenshot shows a software interface with a list of tools and methods. The list is filtered by 'Type: Geology Parameter: Lithology' and 'Quality: (Q) Quantitative'. The list includes various geophysical and sampling methods, such as '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 Telemeter', 'Natural Gamma Log', 'Neutron (porosity) Logging', 'Nuclear Magnetic Resonance Logging', 'Solid Media Sampling and Analysis Methods', 'Solid Media Sampling Methods', 'Soft Spoon Sampler', 'Single Tube Solid Barrel Sampler', 'Dual Tube Sampler', 'Solid Media Evaluation and Testing Methods', 'Core Logging', 'Direct Push Logging (In-Situ)', 'Cone Penetration Testing (CPT & CPTu)', 'Hydroprobe (CPT)', 'CPT In-Situ Video Camera', 'Discrete Groundwater Sampling & Profiling', and 'Hydraulic Profiling Tool - Groundwater Sampler (HPT-GWS)\*'. The list is organized into sections and has columns for 'Tool', 'Data Quality', 'Sub surface', and 'Zones'.

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# Perform Additional Searches to Find More Tools for Different Objectives

Additional parameters can be added or removed from any given search

The screenshot shows a software interface with a search bar at the top right containing the word "Search" circled in red. Below the search bar is a table with the following columns: Tool, Date Quality, Subsurface (Backrock, Unconsolidated, Unconsolidated, Substrated), Zone, Lithology, Lithology Contacts, and Porosity. The table contains several rows of data, including entries like "General Geology Data (GSD)", "High Resolution Seismic Reflection (HRS)", and "Seismic Reflection". A "Search" button is also circled in red at the bottom of the table.

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# Add Parameters to a previous search

Multiple searches can be saved on one matrix

The screenshot shows a software interface with a search bar at the top right containing the text "Additional Search" circled in red. Below the search bar is a table with the following columns: Tool, Date Quality, Subsurface (Backrock, Unconsolidated, Unconsolidated, Substrated), Zone, Lithology, Lithology Contacts, and Porosity. The table contains several rows of data, including entries like "General Geology Data (GSD)", "High Resolution Seismic Reflection (HRS)", and "Seismic Reflection". A "Search" button is also circled in red at the bottom of the table.

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## 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

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## 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

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# 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

The screenshot shows a software interface with a filter bar at the top containing the text: "Type: Chemistry - All Parameter: Contaminant Concentration Subsurface: Unconsolidated Zone: Saturated Quality: (Q) Quantitative". Below the filter bar is a grid with columns for "Resources", "Zone", "Category", "Hydrogeology", "Soil Gas", "Inconsistency", "Chemistry", and "Data Quality". The grid contains multiple rows of data, with some rows highlighted in green and others in yellow. A red box highlights the filter bar, and a red arrow points from it to the filtered data rows in the grid.



## 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

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## Conducting Investigation – Details in Subsequent Workshop!

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



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## 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



## Additional Words of Wisdom

- Understand the difference between characterization and monitoring
  - Don't use monitoring wells for site characterization (fractured rock sites excepted)
- Value quantity of data collected over quality
  - Profiling tools
  - Field laboratories/instrumentation
- Don't wait to deploy innovative tools and technologies
  - Molecular diagnostics
  - In situ microcosms
  - Mass flux/mass discharge evaluations

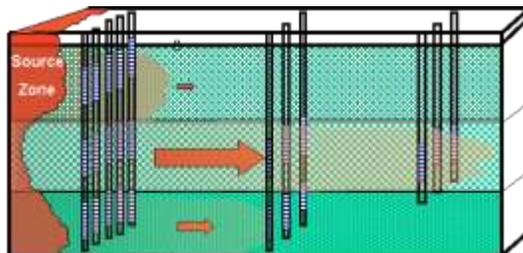
## Molecular Tools

- Don't wait until late stages of project (e.g. pre-design or later) to evaluate microbial community/degradation potential
- Valuable information can be gained from a small number of samples
- One example is QuantArray from Microbial Insights, which can provide data on several key types of microbes and enzyme systems

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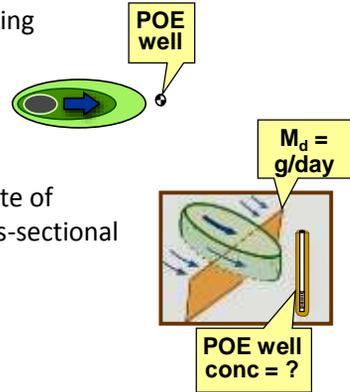
## Use and Measurement of Mass Flux and Mass Discharge

An ITRC Technology Overview Document (published 2010)



# Mass Discharge vs. Traditional Approach

- **Traditional Approach:** Measure existing plume **concentrations** to assess
  - Impact on receptor wells
  - Natural attenuation rates
  - Remedial options
- **Mass Discharge Approach:** Define rate of **mass discharge** across specified cross-sectional areas of plume to assess
  - Impact on receptor wells
  - Natural attenuation rates
  - Remedial options

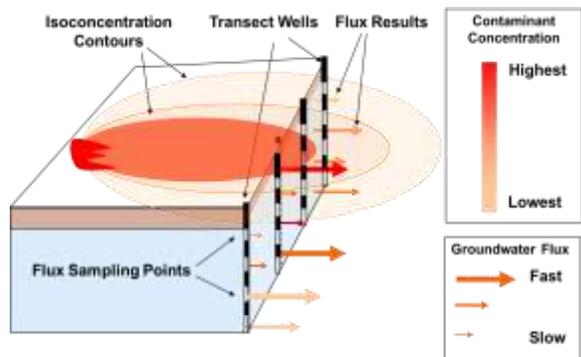


**KEY BENEFITS:** Mass discharge approach sometimes offers a better understanding of potential risks and attenuation rates, and can lead to sounder remediation strategies.

Mass discharge approach based on Einarson and Mackay (2001) ES&T, 35(3): 67A-73A

# Mass Flux/Mass Discharge

- ITRC guidance provides thorough discussion of this topic, including measurement methods
- If this is a goal for your site characterization plan, it will impact the data to be collected
  - Mass flux/mass discharge evaluations can be very data intensive
  - Difficult to “retrofit” data into a mass flux/mass discharge evaluation
- Can be very useful to understand your site





## Case Study Examples

### Commerce Street Plume Superfund Site

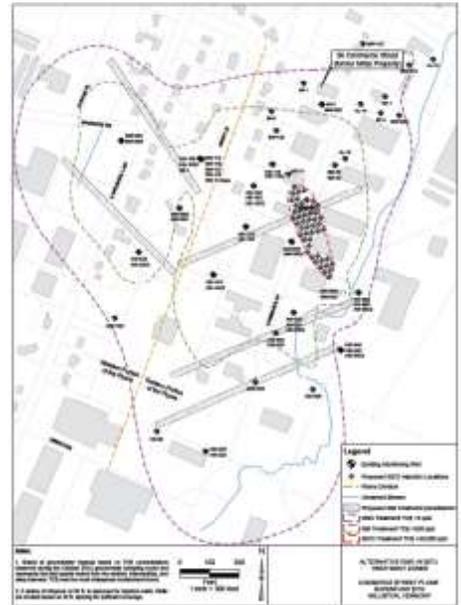
- TCE plume in mixed-use area
- ROD-selected remedy:
  - In situ chemical oxidation (ISCO) for TCE > 50,000 ppb
  - In situ bioremediation (ISB) for TCE > 500 ppb but <50,000 ppb
  - Monitored natural attenuation (MNA) for TCE < 500 ppb
- Follow ISC process to define data gaps, set objectives, and select 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

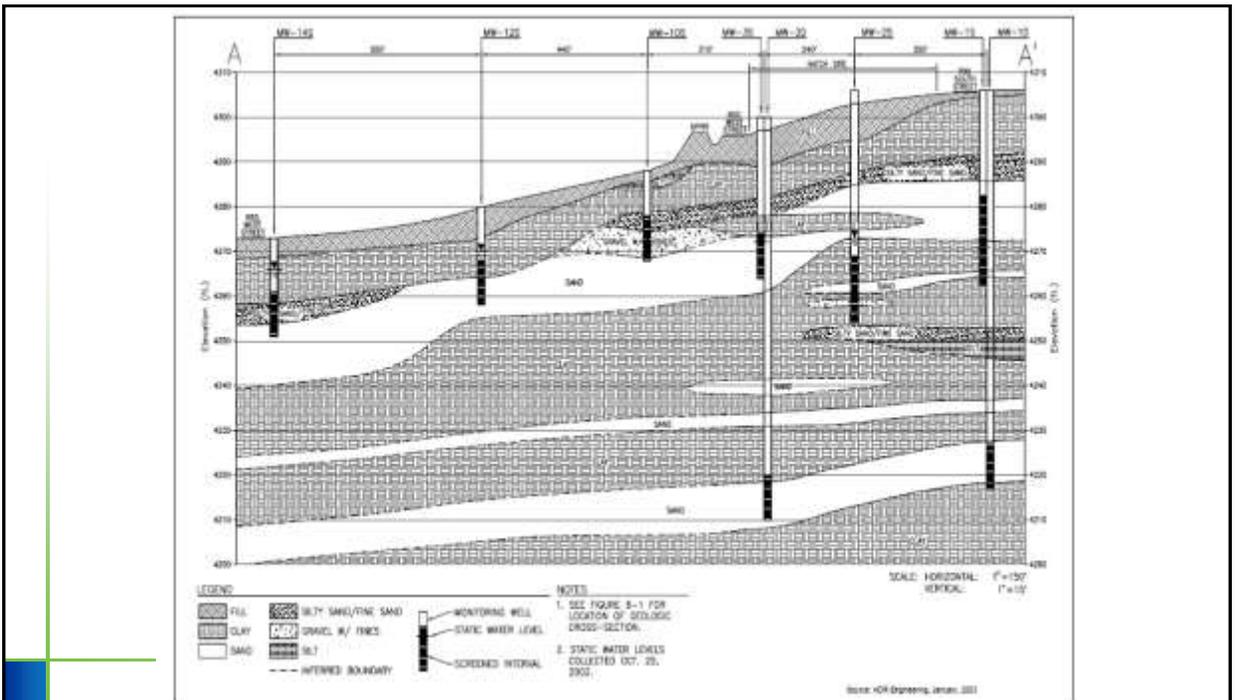
## Results Summary

- 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



## Site Hydrogeology - RI

- Water table generally at about 25-30 ft. bgs
- Sand and gravel zones present to 35-40 ft. bgs
- Clay aquitard present below sand and gravel unit
- Separate, uncontaminated sand and gravel unit below clay



## Full-Scale Design



## 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

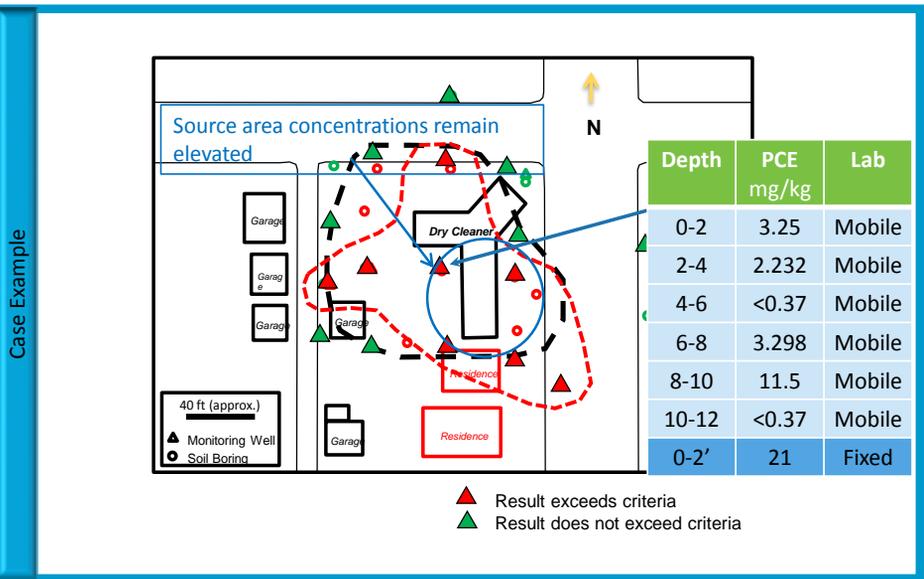
## Pre-RA Characterization Results: Hydrogeology

- 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

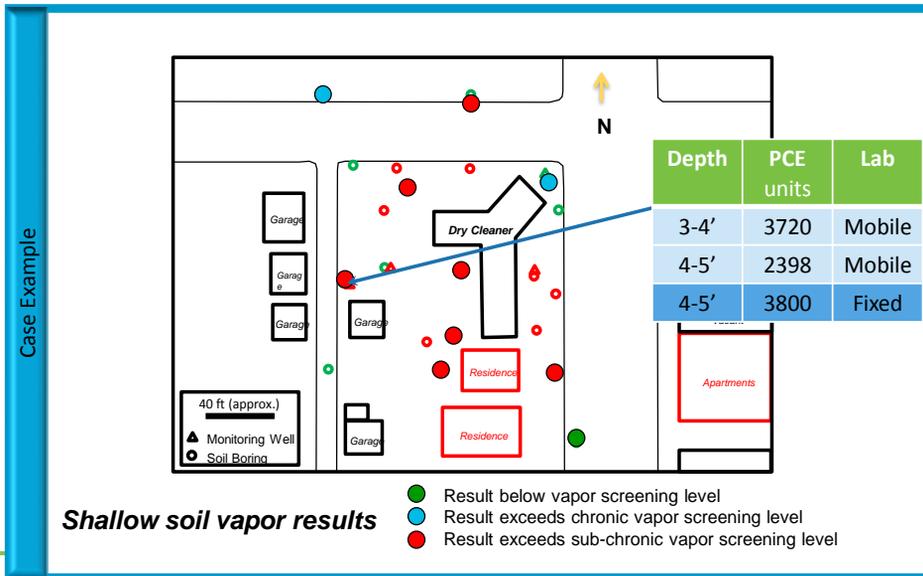


# Wrapping up the ISC case study

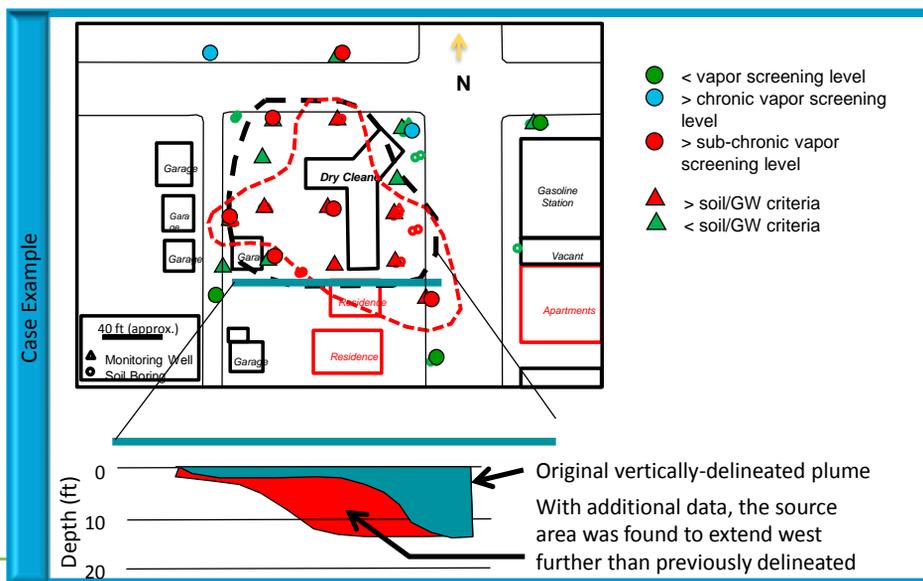
## Step 7. Soil and Groundwater Data Evaluation and Interpretation



## Step 7. Soil Vapor Data Evaluation and Interpretation



## 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%)

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## 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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