Starting Soon: Integrated DNAPL Site Characterization

- Integrated DNAPL Site Characterization and Tools Selection (ISC-1, 2015)
  - http://www.itrcweb.org/DNAPL-ISC_tools-selection/
- Download PowerPoint file
  - http://www.clu-in.org/conf/itrc/IDSC/
- Download files for reference during the training class
  - Flowcharts: http://www.cluin.org/conf/itrc/IDSC/ITRC-ISC-Figures.pdf
  - Excel file: http://www.itrcweb.org/documents/team_DNAPL/DNAPL.xlsm
- Follow ITRC

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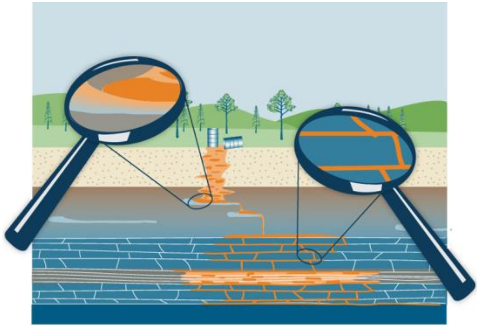
Welcome – Thanks for joining this ITRC Training Class

Integrated DNAPL Site Characterization and Tools Selection



Integrated DNAPL Site Characterization and Tools Selection (ISC-1, 2015)

Sponsored by: Interstate Technology and Regulatory Council (www.itrcweb.org)
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Meet the ITRC Trainers

Alex MacDonald
California Water Boards
Rancho Cordova, CA
916-464-4625
amacdonald@
waterboards.ca.gov

Jeremy MUsson
Pinyon Environmental, Inc
Littleton, CO
303-980-5200
musson@pinyon-env.com

Heather Rectanus
Geosyntec
Columbia, MD
410.910.765
hrectanus@geosyntec.com

Read trainer bios at https://clu-in.org/conf/itrc/IDSC/

The Problem: Dense Non-Aqueous Phase Liquid (DNAPL) Sites

- Not achieving cleanup goals
- Spending time and money, but substantial risk remains
- Common site challenges
  - Incomplete understanding of DNAPL sites
  - Complex matrix – manmade and natural
  - Unrealistic remedial objectives
  - Selected remedy is not satisfactory

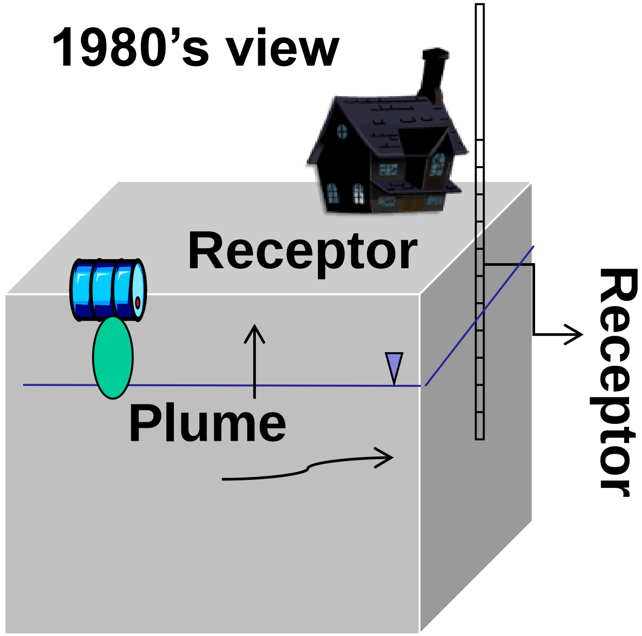
Coal Tar

Poll Question

- For sites that you work on, when did cleanup activities begin?
  - 2010 – current year
  - 2000-2009
  - 1990s
  - 1980s
  - 1970s
  - 1960s
  - before 1960

The Problem: Outdated DNAPL Site Characterization Concepts

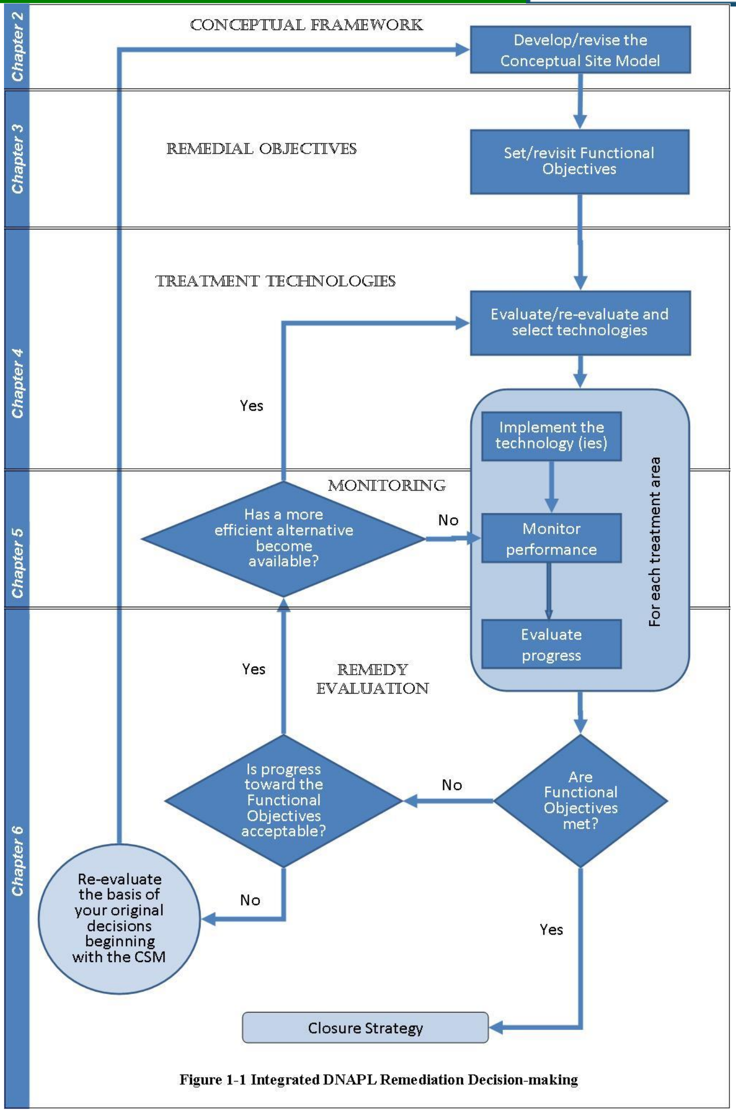
- Considered contaminant flow was similar to groundwater flow
- Simplifying assumptions in equations based on Darcy flow led to inadequate characterization of
  - Site geologic heterogeneity
  - Contaminant
    - Distribution
    - Characteristics
    - Behavior
- This approach limited success of site remediation activities



The Solution: An Integrated DNAPL Site Strategy

[ITRC Technical and Regulatory Guidance Document: **Integrated DNAPL Site Strategy (IDSS-1, 2011)**]

- Comprehensive site management
- Use at any point in site lifecycle
- Key topics
  - Conceptual site model (CSM)
  - Remedial objectives
  - Remedial approach
  - Monitoring approach
  - Evaluating your remedy
- [Associated Internet-based training]



ITRC IDSS-1, Figure 1-2

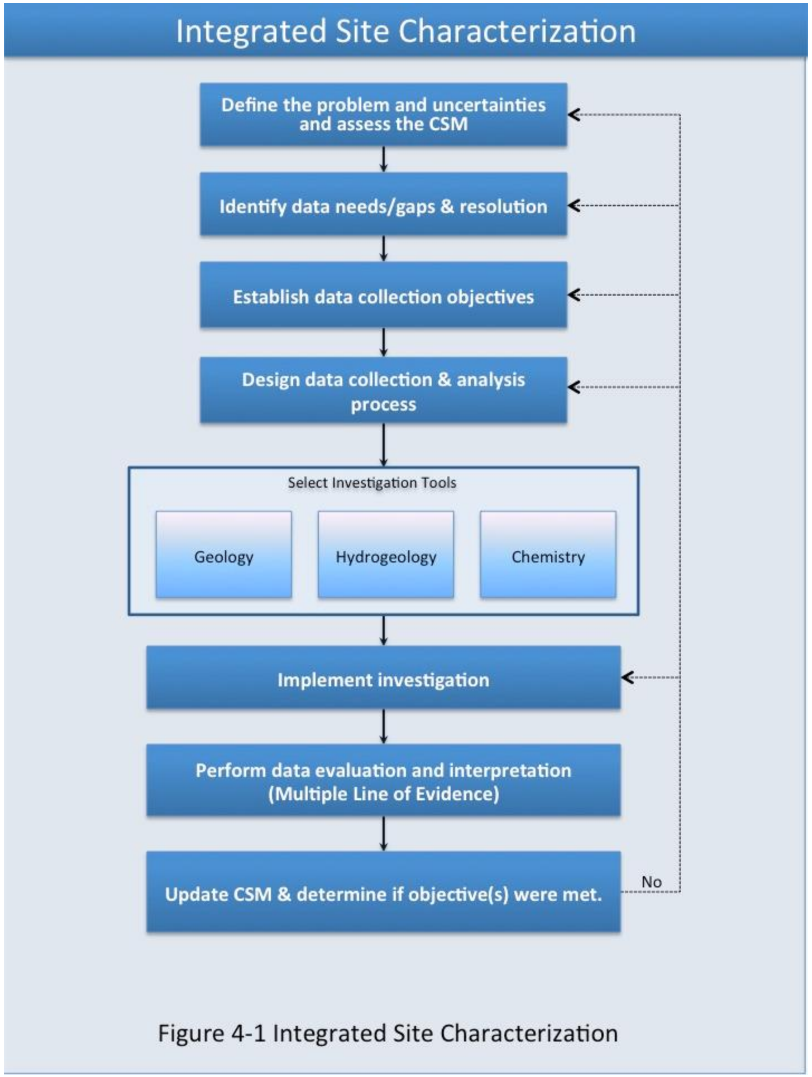
Adding to the Solution: Integrated DNAPL Site *Characterization*

Handout provided

ITRC Technical and Regulatory Guidance Document: **Integrated DNAPL Site Characterization (ISC-1, 2015)**

Benefits

- More accurate conceptual site models (CSMs)
- Improved predictability of plume behavior and risks
- More defensible knowledge of contaminant distribution
- Facilitates communication
- Reduced uncertainty
- Better performing remedies



ITRC ISC-1, Figure 4-1

Incorporated into the Solution: New DNAPL Site Characterization Approaches

- Heterogeneity replaces homogeneity
- Anisotropy replaces isotropy
- Diffusion replaces dispersion
- Back-diffusion is a significant source of contamination and plume growth
- Non-Gaussian distribution
- Transient replaces steady-state conditions
- Nonlinear replaces linear sorption
- Non-ideal sorption replaces ideal sorption

After this training you should be able to:

- Apply the ITRC document to develop and support an ***Integrated*** DNAPL Site Characterization approach
- Understand what characteristics of site conditions must be considered when developing an informative DNAPL conceptual site model (CSM)
- Defining an integrated DNAPL characterization strategy
- Understand what tools and resources are available to improve the identification, collection, and evaluation of appropriate site characterization data
- Navigate the DNAPL characterization tools table and select appropriate technologies to fill site-specific data gaps

If you gain nothing else: Geology Controls DNAPL Mobility!

- Soil heterogeneity leads to differences in subsurface pore structure and capillary properties
- Significant variations can occur over very small distances/ intervals
- NAPL migration is strongly influenced by the topography of geologic layers

Photo Courtesy of Fred Payne, Arcadis, Inc

ISC-1, Chapter 2

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- Life Cycle of a DNAPL Site
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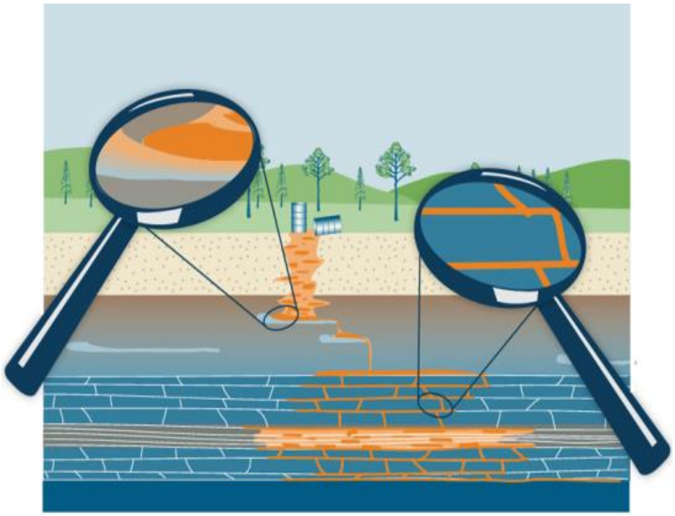
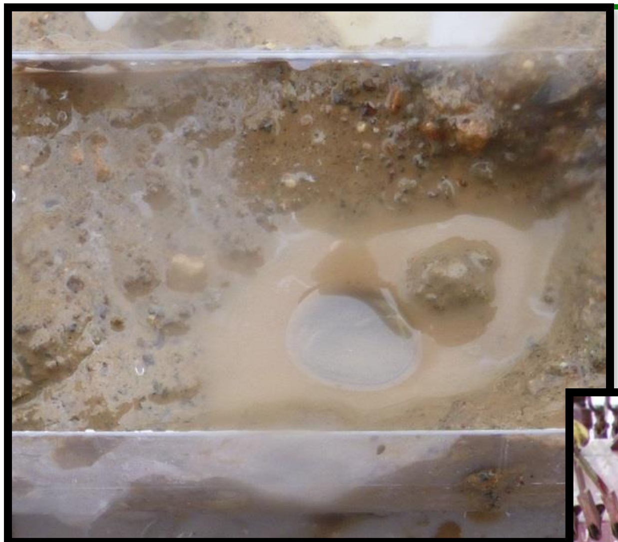


DNAPLs – Not Just Chlorinated Solvents!



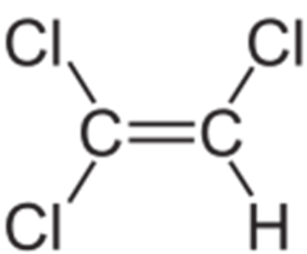
PCE in Soil Core

Coal Tar

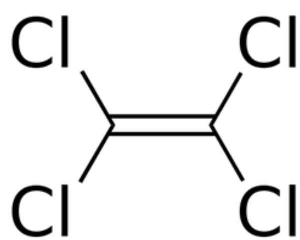
Mixed Aged Motor Oil/Bunker, Aryl Phosphate and PCB in Soil Core

DNAPL Types

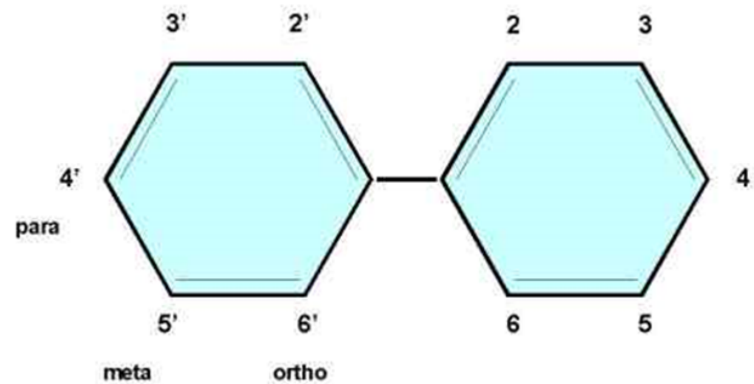
- Common types of DNAPLs
  - Chlorinated solvents
  - Coal tar
  - Creosote
  - Heavy petroleum such as some #6/Bunker fuel oil products
  - Oils containing Polychlorinated biphenyls (PCBs)



TCE (C_2HCl_3)
trichloroethene
trichloroethylene



PCE (C_2Cl_4)
Tetrachloroethene
Tetrachloroethylene
perchloroethylene (perc)



PCB
Polychlorinated biphenyl

Poll Question

- What DNAPLs do you have at your sites? (select all the apply)
  - Chlorinated solvents
  - Coal tar
  - Creosote
  - Heavy petroleum hydrocarbons
  - PCBs
  - Pesticides
  - Mercury
  - Other
  - None

See Table 2.1 Physical properties of example NAPLs & reference fluids

Important DNAPL Properties Affecting Mobility

DNAPL Chemical & Physical Properties

- Density
- Solubility
- Viscosity
- Volatility
- Composition

Modified from
ISC-1, Chapter 2

DNAPL Density

- Describes the mass per unit volume of the DNAPL and is sometimes expressed as specific gravity (SG), which is the density relative to water
- By definition, all DNAPLs have a SG greater than 1.0
  - Some DNAPLs have a SG >1.5 (e.g., PCE)
  - While others have a SG barely greater than water

KEY POINT: **Gravitational forces overwhelm hydraulic gradients**

DNAPL Aqueous Solubility (Cw,sol)

- Amount of a compound that dissolves in water at equilibrium

DNAPL Component	Density (g/mL)	Solubility (mg/L)	Types of Sites
Trichloroethylene (TCE)	1.46	1,100	Solvent
Pentachlorophenol (PCP)	1.98	20	Wood Treatment
Acid Tar (H_2SO_4 & Hydrocarbons)	1.84	Miscible	Refineries

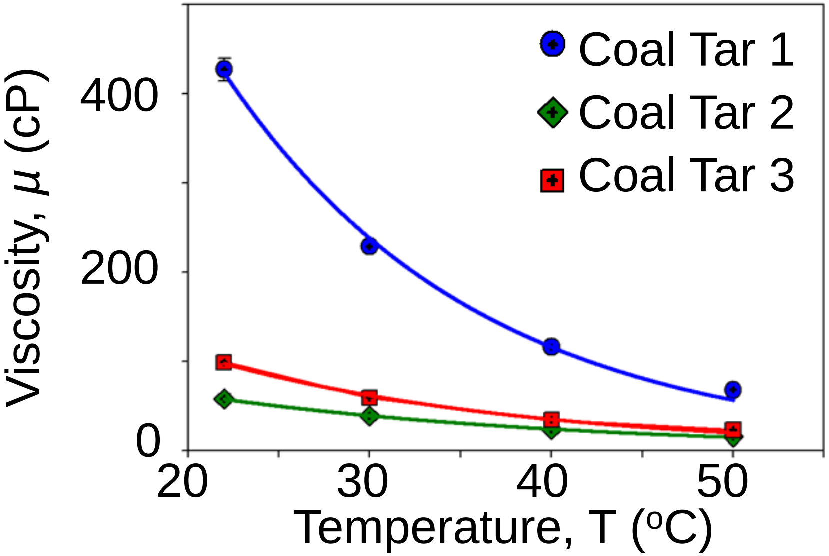
  - Often different in site groundwater than in the laboratory

KEY POINT: **Influences loss of mass to plume and trapped soil water**

DNAPL Viscosity (Dynamic)

- Represents the resistance to shear (flow) of the fluid

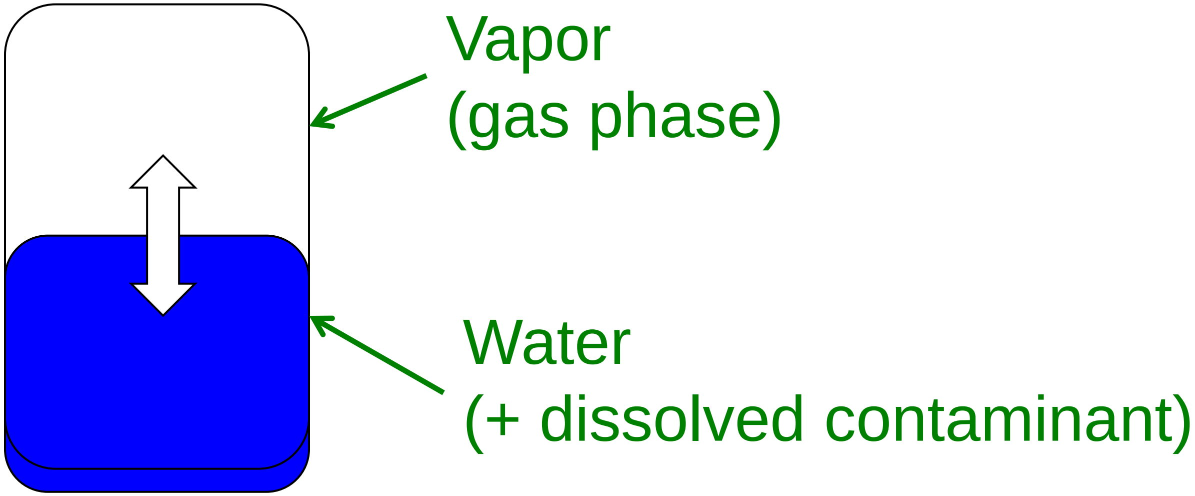
- Temperature dependent
  - μ_w = 0.894 cP 25 ^oC
  - μ_w = 1.002 cP 20 ^oC



KEY POINT: **Influences mobility in the subsurface**

DNAPL Volatility

- Volatility - Henry's Constant (KH)
- Vapor Pressure (VP_{sat} or P_0)



- See also ITRC's Vapor Intrusion Pathway: A Practical Guideline (VI-1, 2007)

KEY POINT: **Influences mass loss in the unsaturated zone and risk of vapor intrusion (VI)**

DNAPL Composition

- Properties of mixed DNAPL are different from pure component properties
  - Chlorinated solvents often include other compounds such as grease, oils or stabilizers
  - For mixed sources, chlorinated compounds from DNAPL could partition into LNAPL
  - NAPL weathering occurs in subsurface
    - Coal Tar – Water Interfacial Films
    - Loss of the soluble fraction of the NAPL

KEY POINT: **Analysis of both the chemical and physical properties of your NAPL is recommended, if a NAPL sample can be collected**

DNAPL Interactions with the Sub-Surface Media Affecting Mobility

- The following properties significantly affect the interactions between DNAPLs and sub-surface media:

Interfacial Tension

Wettability

Capillary Pressure

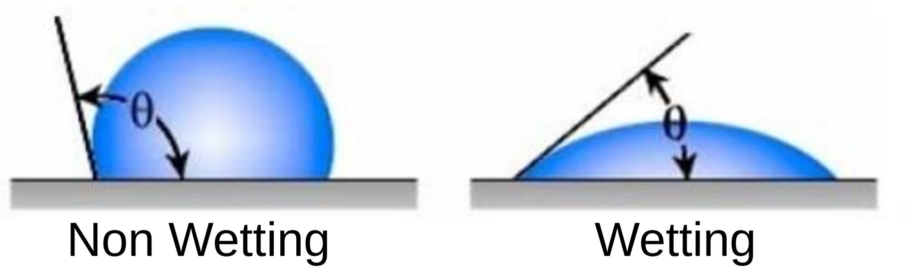
Saturation

Residual Saturation

Modified from ISC-1, Chapter 2

Interfacial Tension and Wettability

- Interact to control the capillary forces that govern NAPL migration



Graphic from Stone Environmental

Wettability of soils may change after exposure to NAPL

KEY POINT: **Influences capillary pressure and vertical migration**

Capillary Pressure (P_c)

- Represents the pressure difference between two fluids sharing pore space

$$P_c = P_n + P_w$$

(Bear, 1972)

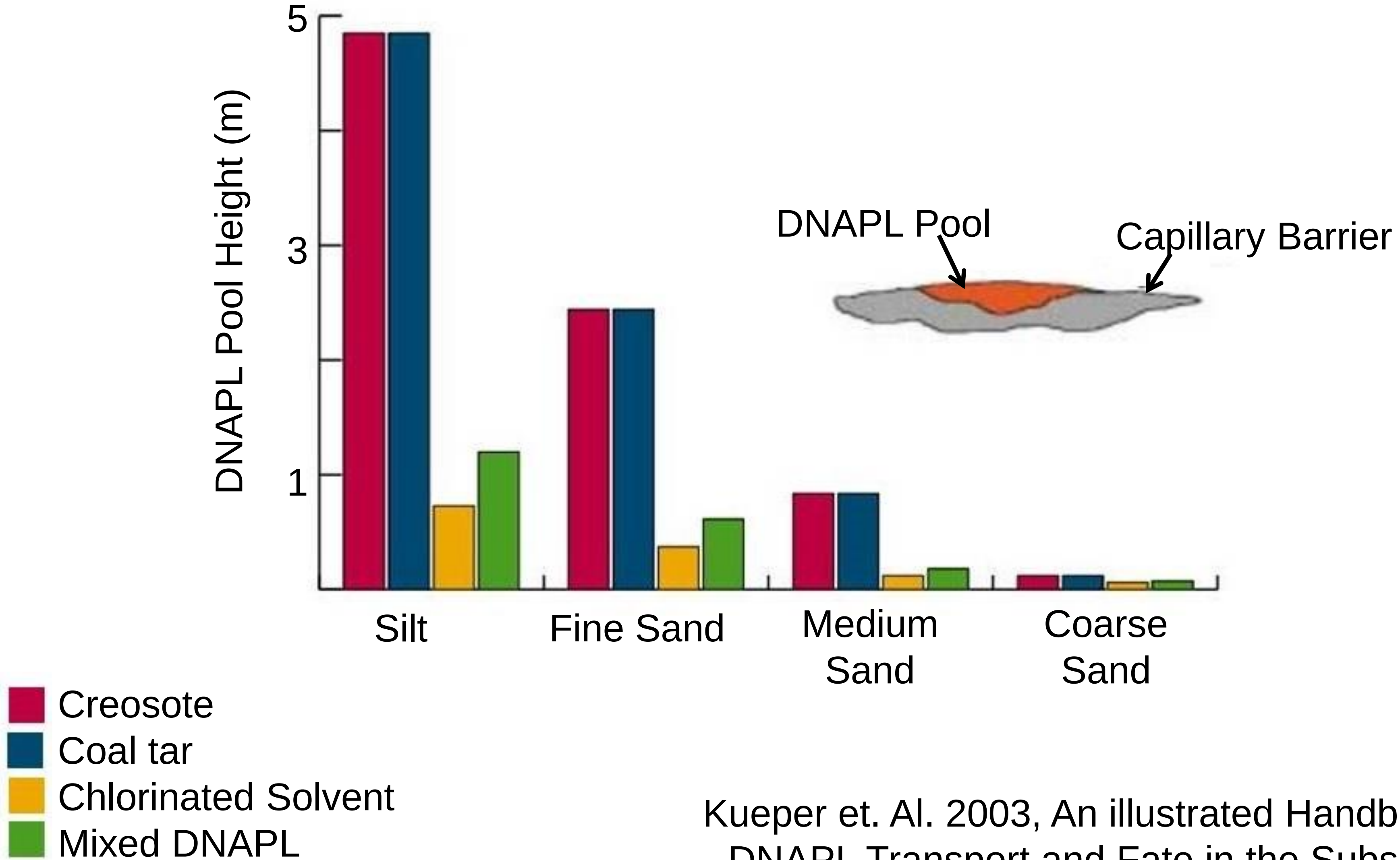
Where P_n is the NAPL pressure and
P_w is the water pressure

- P_c is a non-linear function of S, with P_c increasing at greater saturation of the non-wetting fluid

(Lenhard and Parker, 1987)

KEY POINT: **Variance of pore spaces within geologic media can dictate vertical DNAPL migration**

Capillary Pressure of Coarser Layers and DNAPL Entry



Kueper et. Al. 2003, An illustrated Handbook of DNAPL Transport and Fate in the Subsurface

DNAPL Saturation

Saturation, Relative Permeability, and Capillary Pressure

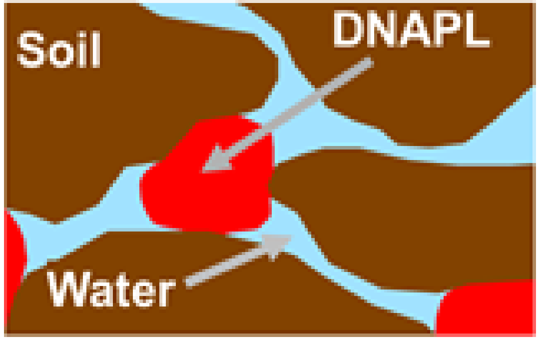
- Saturation (*S*)
  - S is the proportion (percentage) of the pore space occupied by a fluid (NAPL, air, or water)
  - Ranges from 0 to 1.0 (0 to 100%)
- Residual Saturation (S_r)
  - S_r is the saturation of NAPL remaining when **NAPL is no longer mobile**

KEY POINT: **Strongly affected by geologic heterogeneity**

NAPL Saturation and Mobility

- When $S < S_r$
  - NAPL will be immobile unless NAPL or solid phase properties change
- When $S > S_r$
  - NAPL may be mobile or potentially mobile
  - NAPL may be potentially mobile but not moving

(Pennell et al., 1996, ES&T)



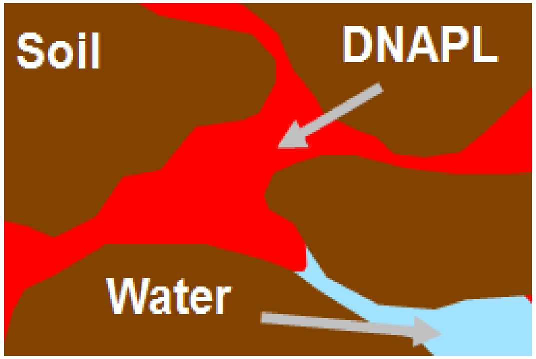


Figure modified from ISC-1, Chapter 2

KEY POINT: **A continuous NAPL phase must be connected to transmit pressure head that overcomes the entry pressure and allows DNAPL to migrate**

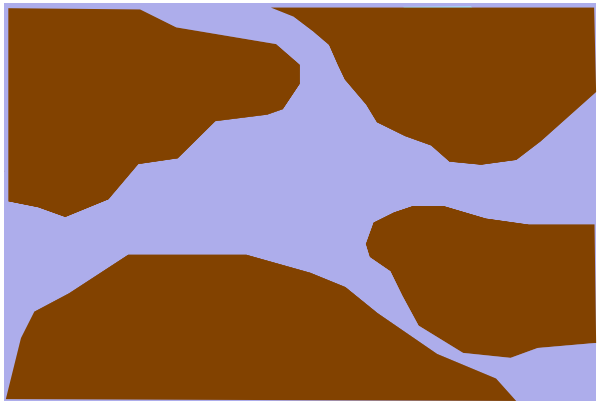
Groundwater Movement Through a DNAPL Zone

- Relative permeability (k_r)

  The value of k_r, ranges from 0 to 1.0 as a non-linear function of saturation (S)

  - k_r for groundwater = 1.0 at DNAPL S = 0
  - k_r for DNAPL approaches 1 at as DNAPL S approaches 1

  (Parker and Lenhard 1987)



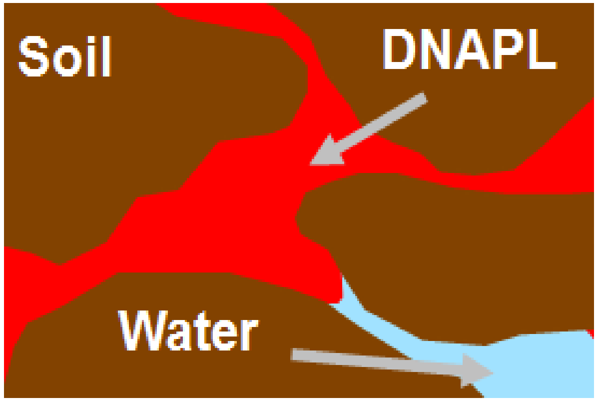


figure modified from ISC-1, Chapter 2

KEY POINT: **The presence of NAPL reduces the effective hydraulic conductivity of the media**

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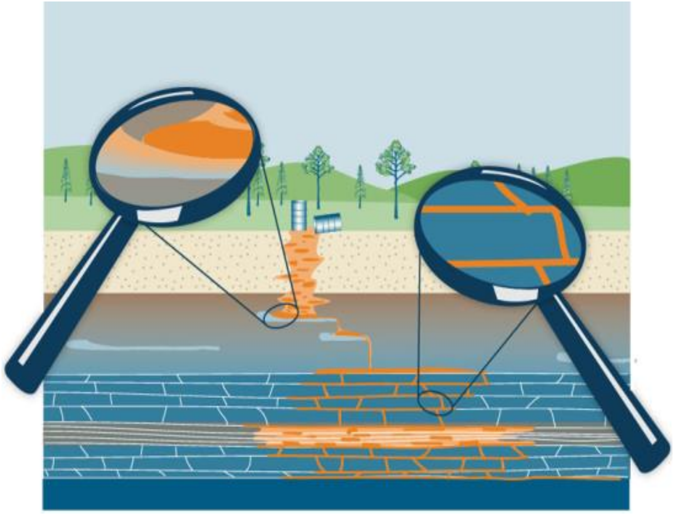
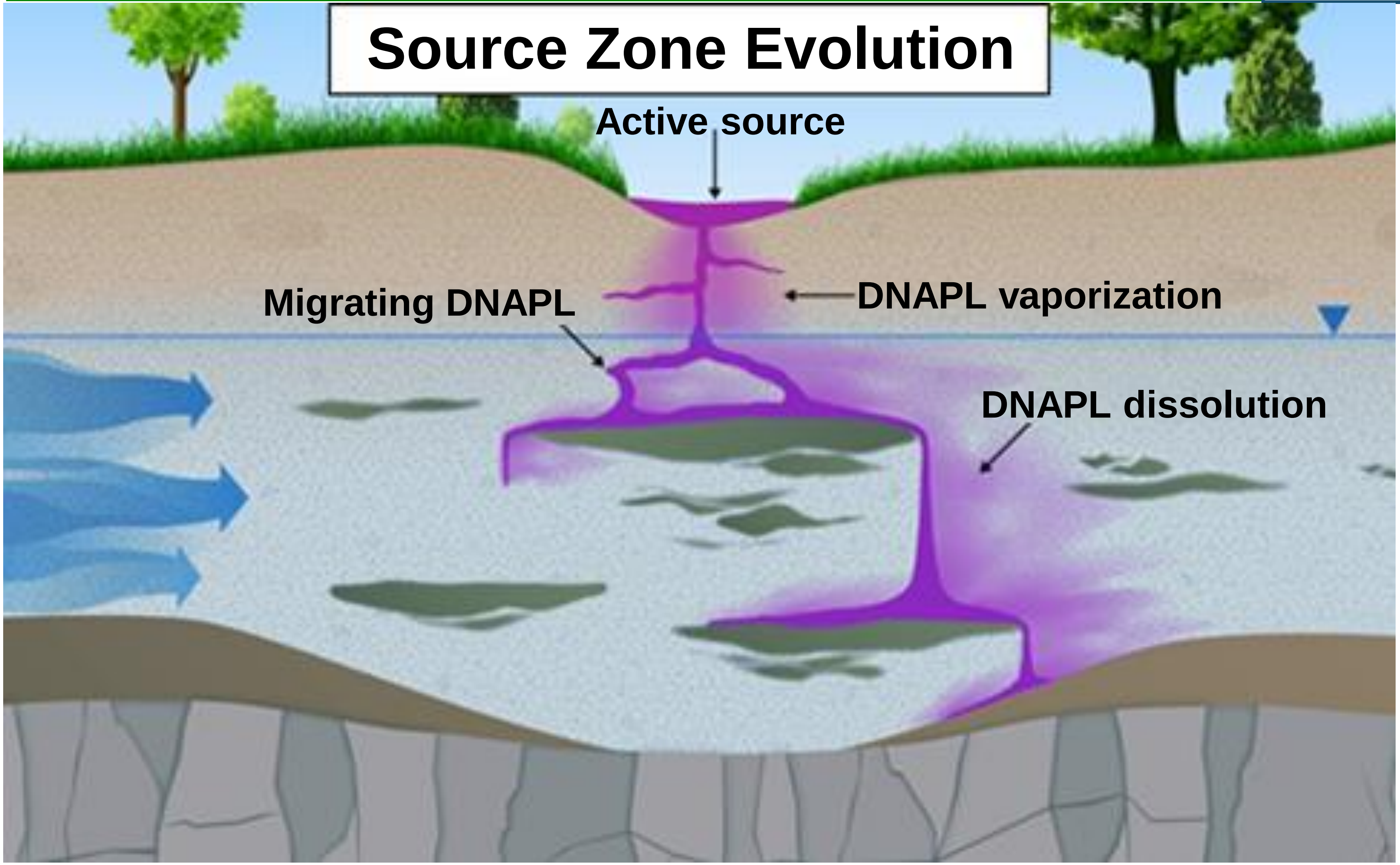


ISC-1, Chapter 3

DNAPL Life Cycle – Classical Model



Kueper et al., 2013

Secondary Sources within Groundwater Plumes

We are now revising our definition of "DNAPL Source Zone"

- The hunt for DNAPL is often distracting
- DNAPL is no longer considered the only source of groundwater contamination
  - Sorption/desorption from aquifer matrix
  - Matrix diffusion into/out of low K zones

KEY POINT: **These mechanisms may control the longevity of dissolved phase plumes at DNAPL or former DNAPL sites**

Redefining the DNAPL Source Term: Apparent Secondary Sources

Areas impacted by DNAPL

- DNAPL Source Areas
- Unsaturated (Vadose) Zone

Secondary Sources

- DNAPL may have dissolved or the DNAPL may be remediated

Sorption/ desorption to aquifer matrix

- Slow Desorption from aquifer solids

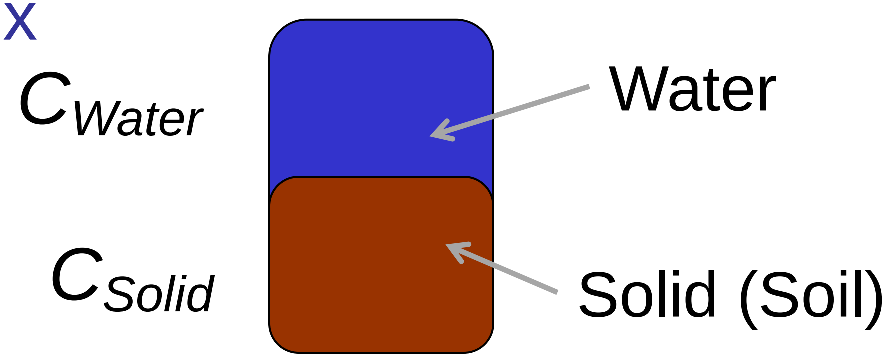
Molecular diffusion into low k zones

- Matrix Diffusion from sources within plume

Modified from ISC-1, Chapter 2

"Sorption" - Adsorption & Absorption

- A portion of the contaminant mass will adsorb/sorb to the aquifer matrix at equilibrium based on contaminant concentration and the contaminant's affinity to the matrix



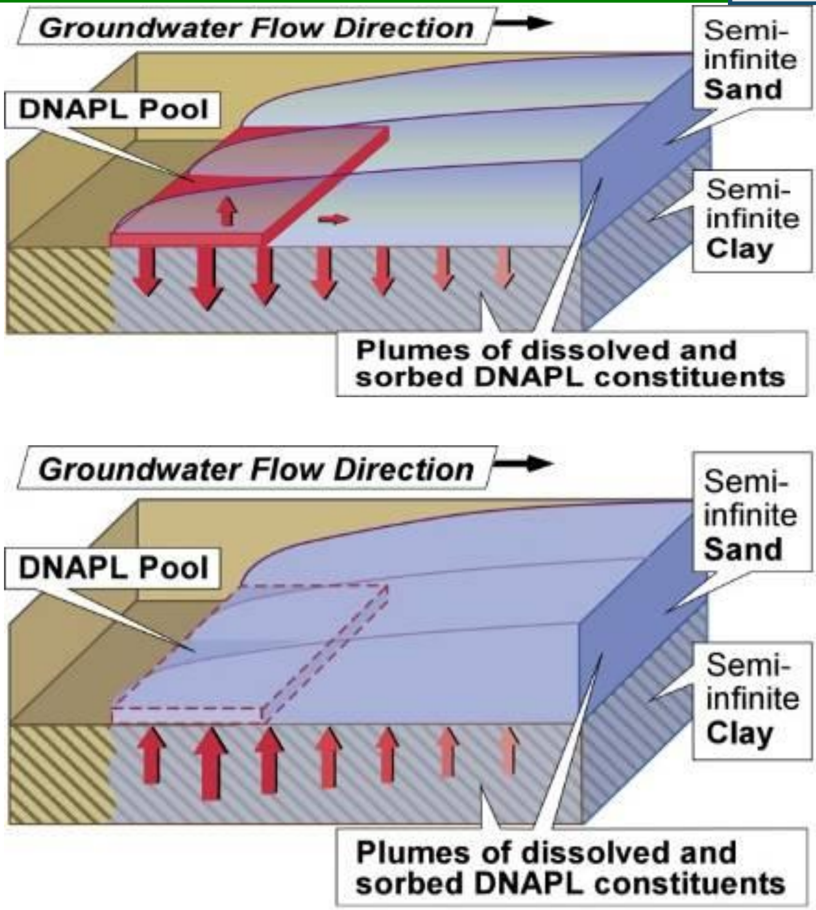
$$C_s = C_w * f_{oc} * K_{oc}$$

- Contaminant mass will desorb from matrix into groundwater as "cleaner" groundwater migrates through system

KEY POINT: **Desorption contributes to retardation and longevity of dissolved phase contaminant plumes**

Matrix Diffusion: "Back Diffusion"

- Early time
  - Molecular Diffusion into low permeability zones in the aquifer matrix:
    "Matrix Diffusion"
- Late time
  - "Back Diffusion" out of low permeability zones into higher permeability zones



ITRC IDSS-1, Figure 2-5 & 2-6

KEY POINT: **Back Diffusion contributes to retardation and longevity of dissolved phase contaminant plumes**

Controlling Role of Geology in Matrix Diffusion

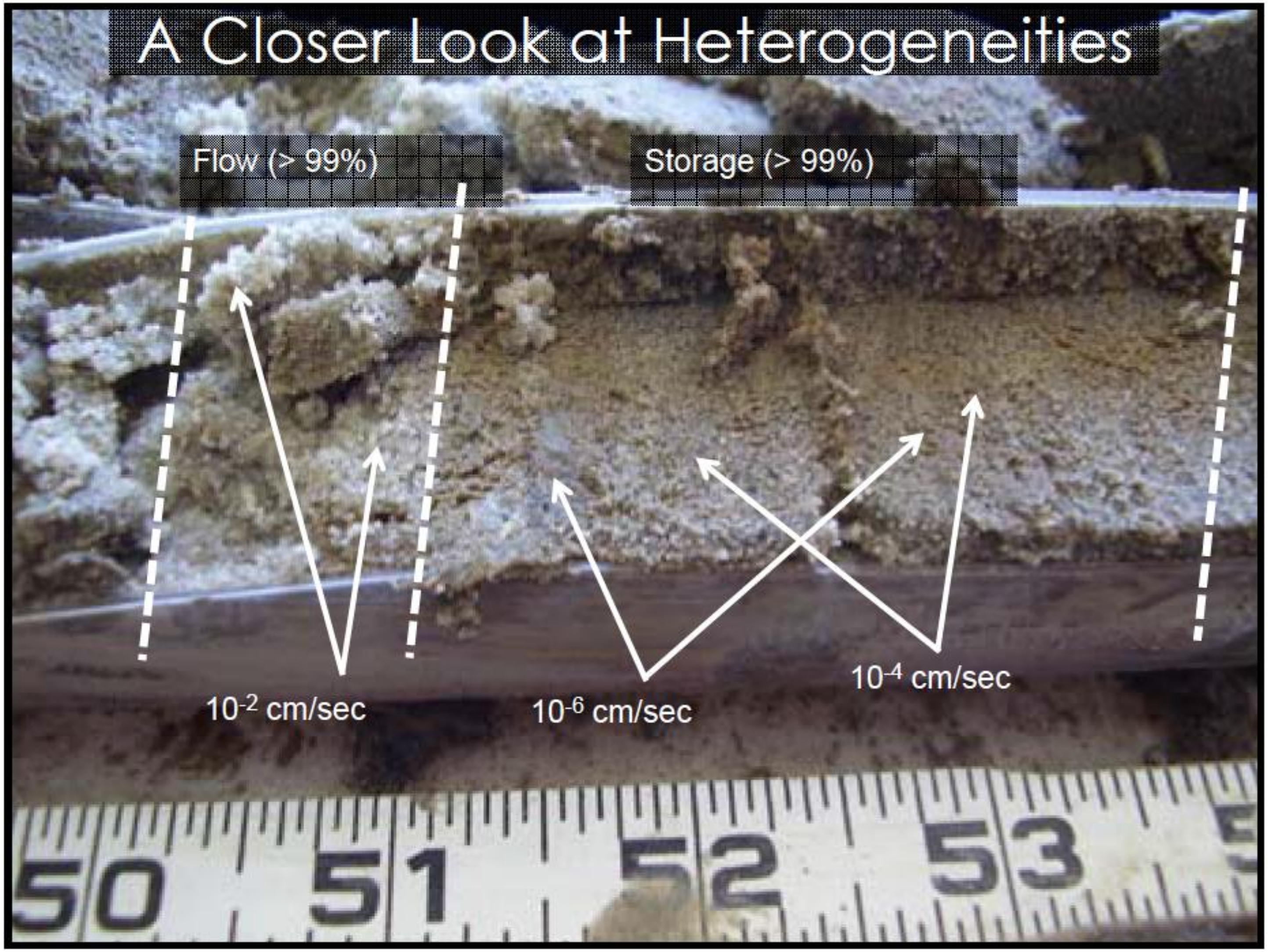
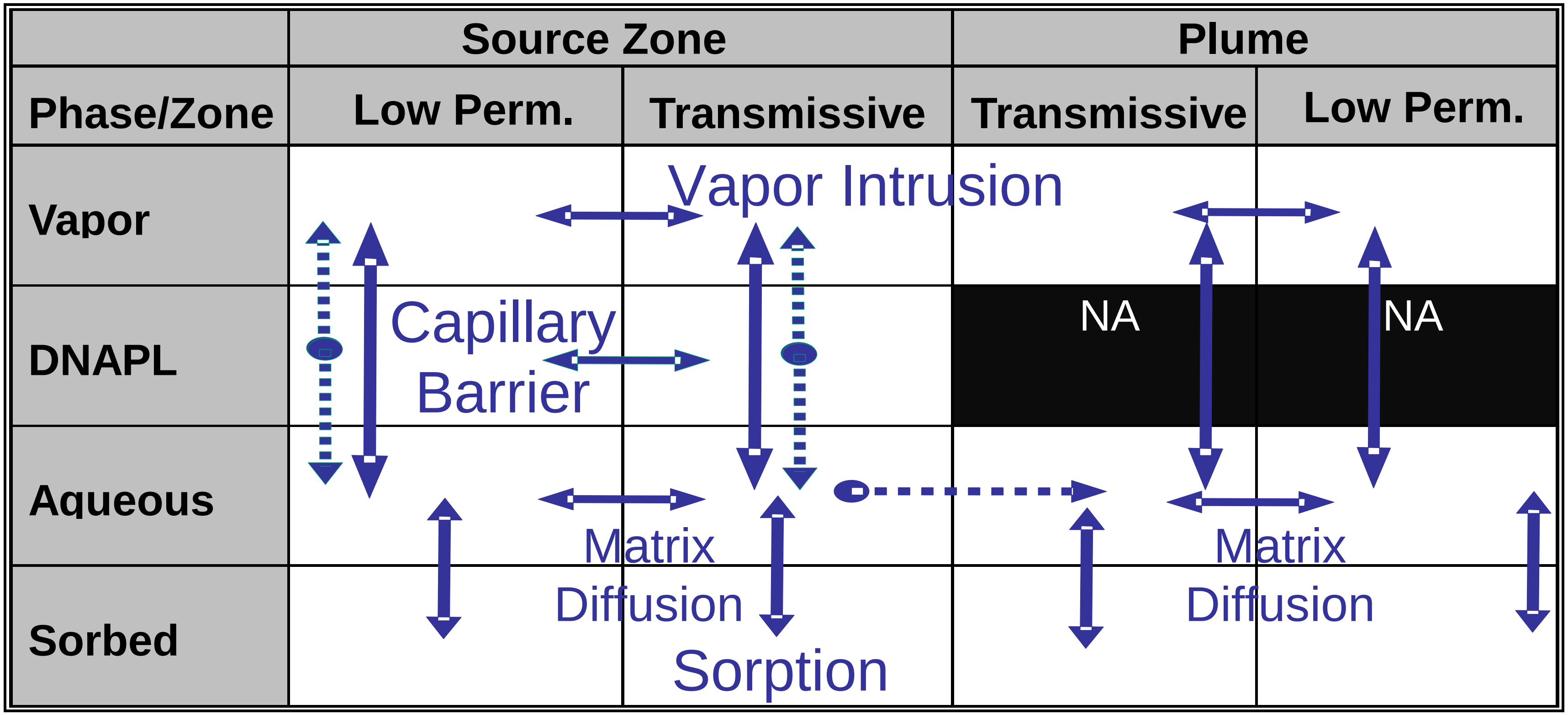


Figure courtesy of Fred Payne, Arcadis

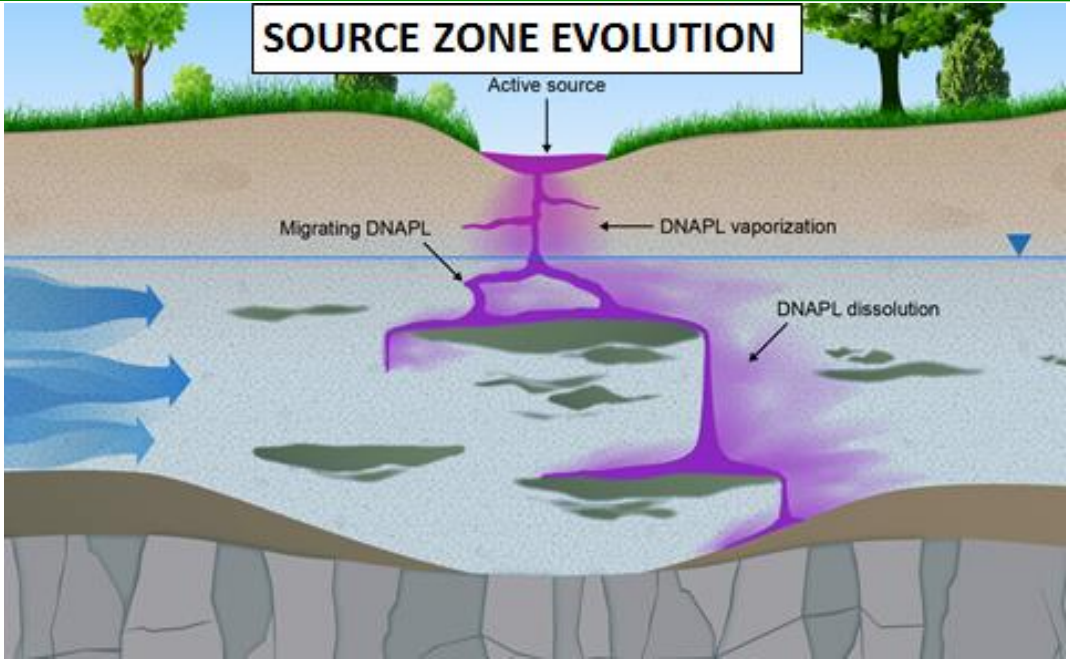
14-Compartment Model: Phase Distribution and Mass Transfer



ITRC IDSS-1, Table 2-2 from Sale and Newell 2011

KEY POINT: **The 14-Compartment Model helps Stakeholders align on the Life Cycle of the Site and Characterization Objectives**

DNAPL Life Cycle – Early Stage



ZONE	SOURCE		PLUME	
	Lower-K	Transmissive	Transmissive	Lower-K
Vapor	LOW	MODERATE	LOW	LOW
DNAPL	LOW	HIGH		
Aqueous	LOW	MODERATE	MODERATE	LOW
Sorbed	LOW	MODERATE	LOW	LOW

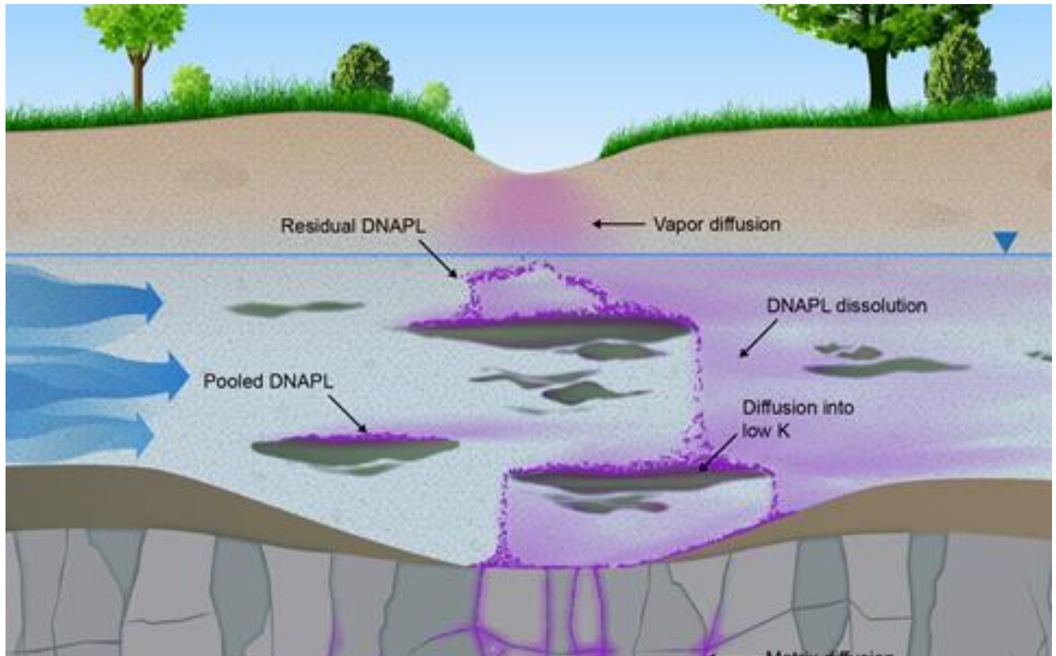
Kueper et al., 2013

Prolonged Early Stage Behavior

- Low solubility and high viscosity DNAPLs
- High DNAPL saturations and still immobile.
- Highly DNAPL saturation causes flow by-passing

KEY POINT: **Coal tar and creosote sites may remain as Early Stage for generations**

DNAPL Life Cycle – Middle Stage

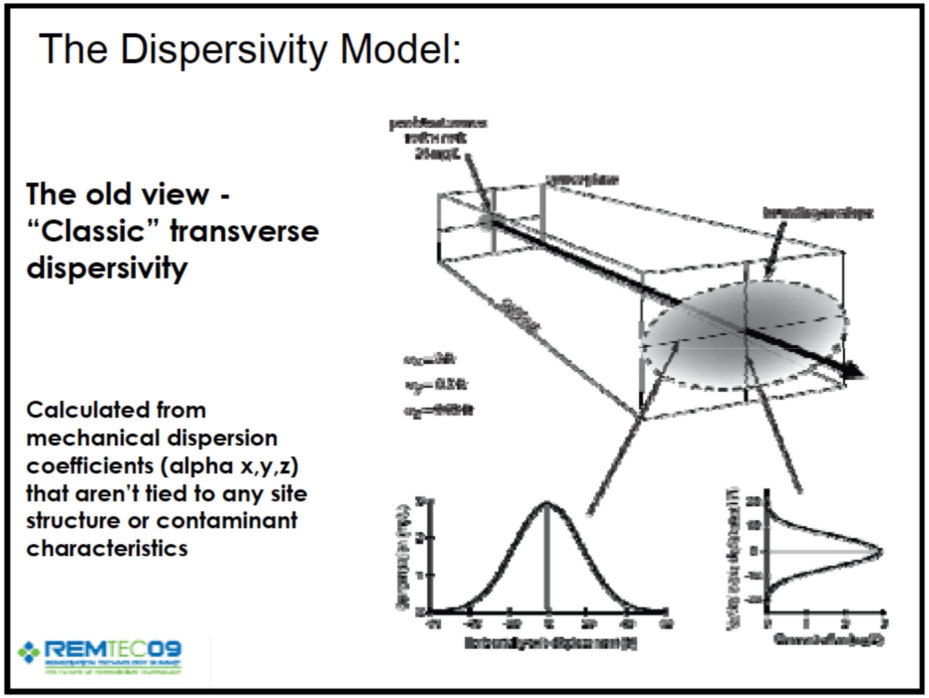


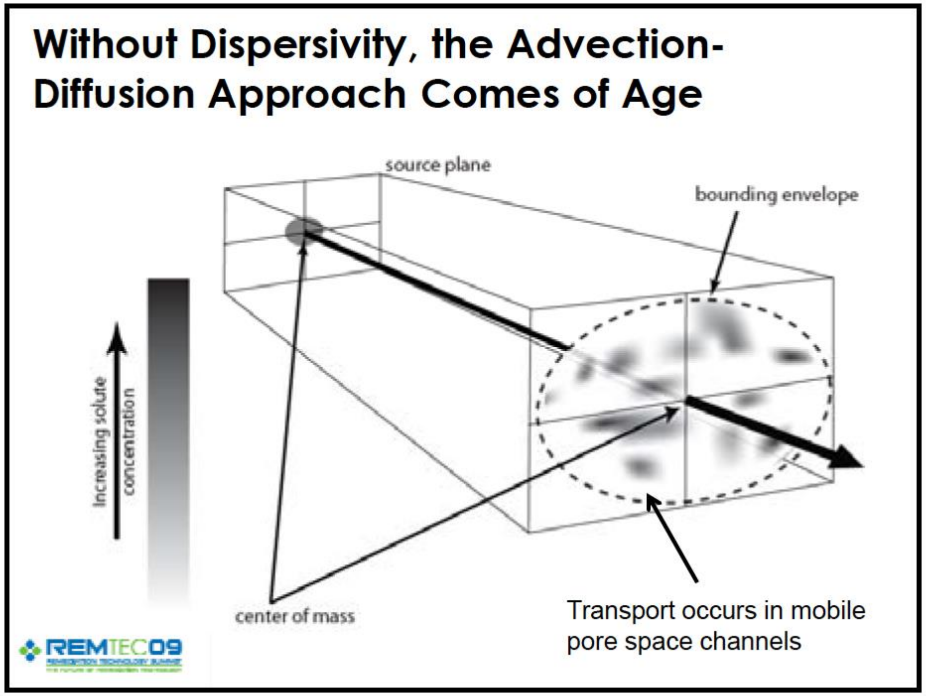
ZONE	SOURCE		PLUME	
	Lower-K	Transmissive	Transmissive	Lower-K
Vapor	MODERATE	MODERATE	MODERATE	MODERATE
DNAPL	MODERATE	MODERATE		
Aqueous	MODERATE	MODERATE	MODERATE	MODERATE
Sorbed	MODERATE	MODERATE	MODERATE	MODERATE

Kueper et al., 2013

Diffusion Replaces Dispersion in Dissolved Phase Plumes

- As the length scale of interest decreases Diffusion replaces Dispersion in plume behavior
- Geologic heterogeneity and anisotropy also lead to numerous small plumes within each groundwater plume





Figures courtesy of Fred Payne, Arcadis

Heterogeneity Replaces Homogeneity

- Simplifying the subsurface as homogeneous & isotropic has not worked well for remediation-scale plume geometry
- **Anisotropy replaces isotropy**
- Non-ideal behavior is as pronounced in the vertical

Borden Tracer Simulation – Combined Heterogeneity and Diffusivity Effects

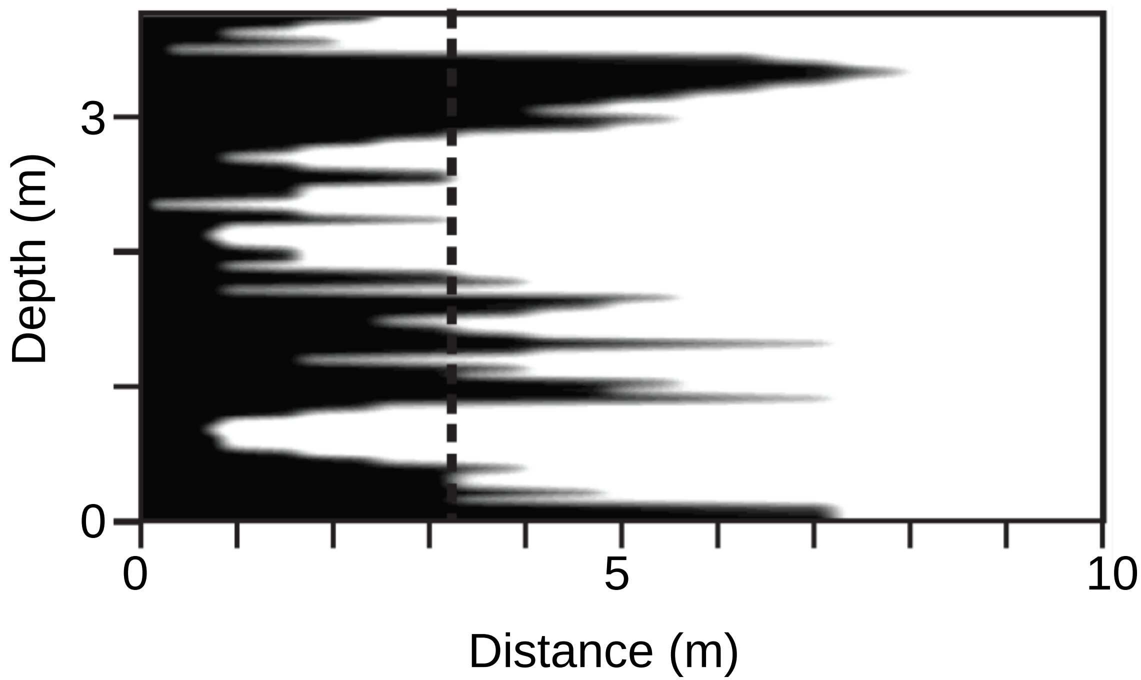
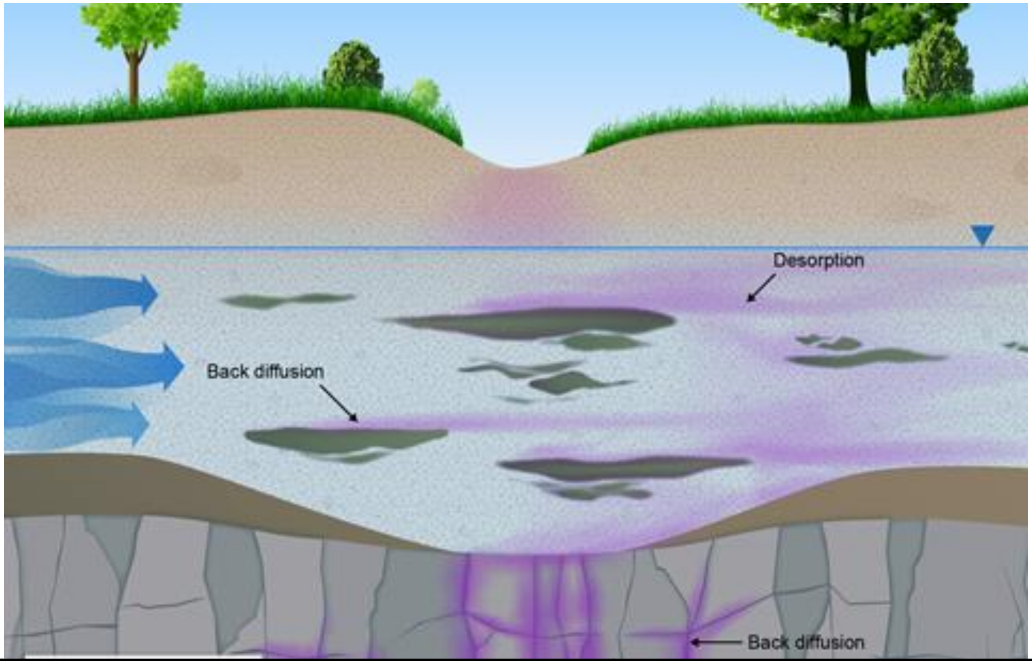


Figure courtesy of Fred Payne, Arcadis

DNAPL Life Cycle – Late Stage



ZONE	SOURCE		PLUME	
	Lower-K	Transmissive	Transmissive	Lower-K
Vapor	LOW	LOW	LOW	LOW
DNAPL	LOW	LOW		
Aqueous	MODERATE	LOW	LOW	MODERATE
Sorbed	MODERATE	LOW	LOW	MODERATE

Kueper et al., 2013

Poll Question

- Based on what we have just presented, and remembering that life-cycle phase is not only dependent on age of the site; what phase is your site?
  - Early
  - Middle
  - Late
    - Select more than one if you have multiple sites in different phases

Understanding Your DNAPL CSM

Characterizing sites contaminated with DNAPLs needs to take into account

- Geology
  - Depositional environment, media properties
  - Orientation of fractures, bedding planes
- Characteristics of the released DNAPL
- Distribution DNAPL in Subsurface Media
- Life-cycle of your DNAPL site
  - Roles of Matrix Diffusion and Non-ideal Sorption
- The objectives of the characterization and decisions that need to be made

Q&A

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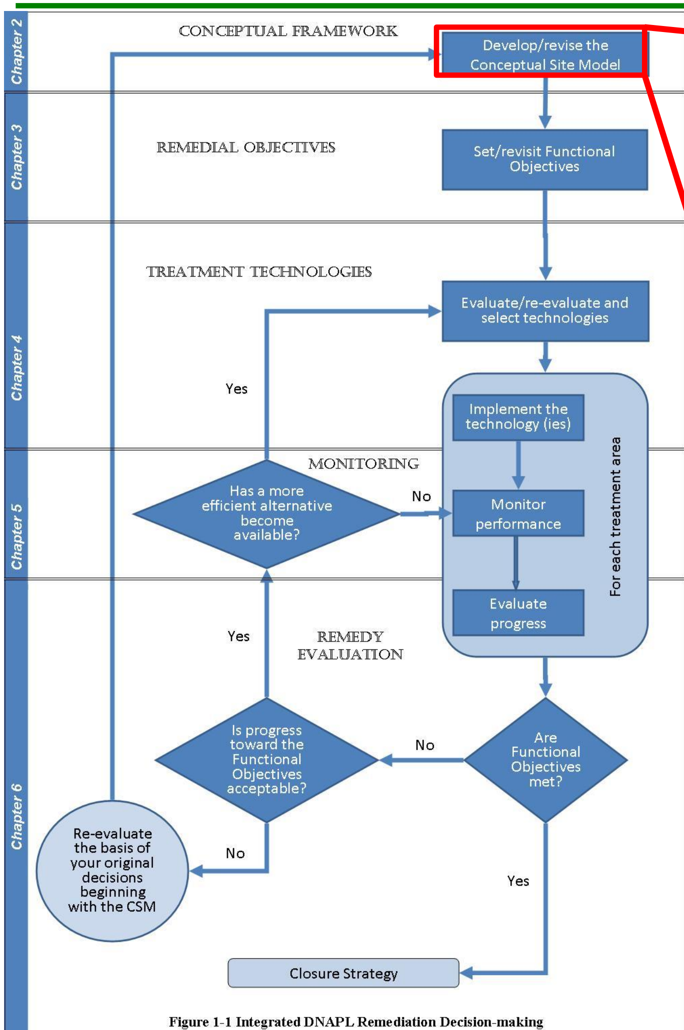
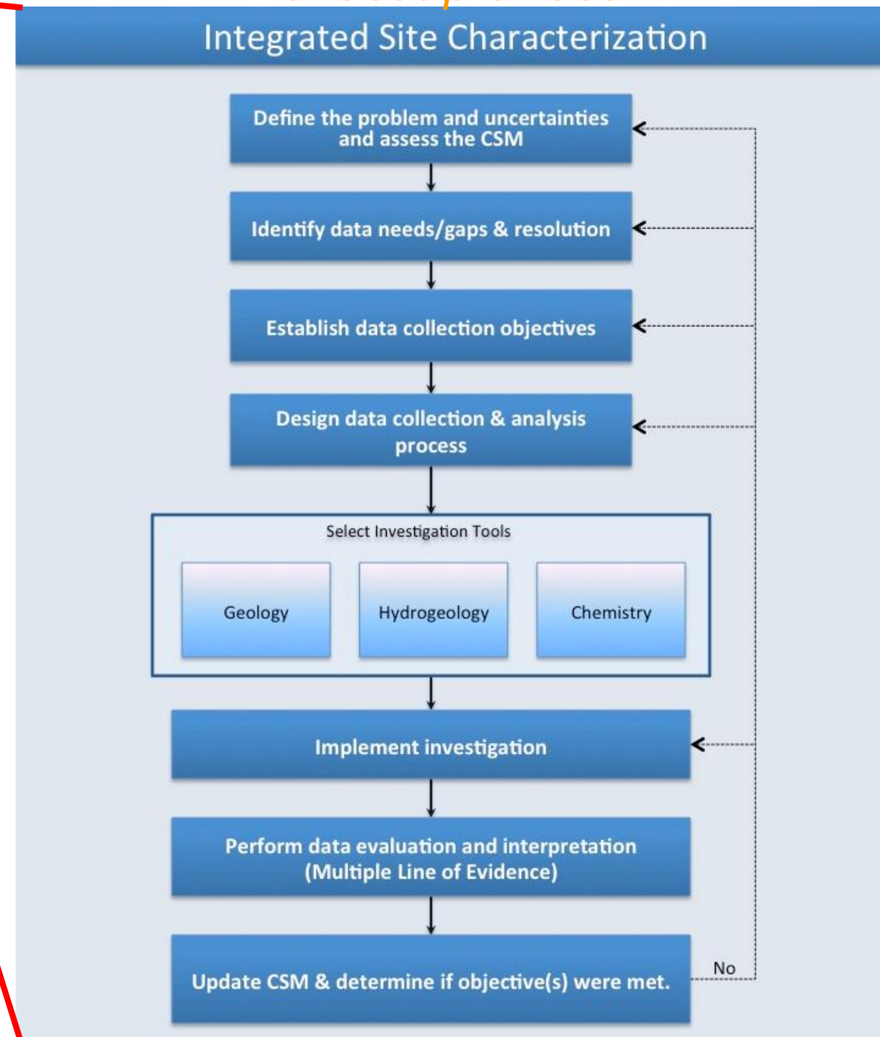


Figure 1-1 Integrated DNAPL Remediation Decision-making

ITRC IDSS-1, Figure 1-2

Handout provided



ITRC ISC-1, Figure 4-1

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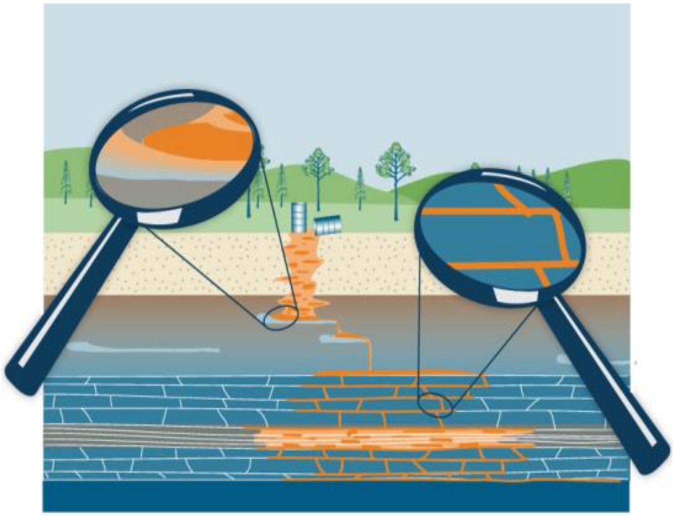


Integrated Site Characterization

- Flexible, iterative 8-step process for CSM refinement
- Focus areas
  - Data resolution matches scale of heterogeneity
  - Objectives are clear and actionable
  - Tools are optimal for site conditions and data needs

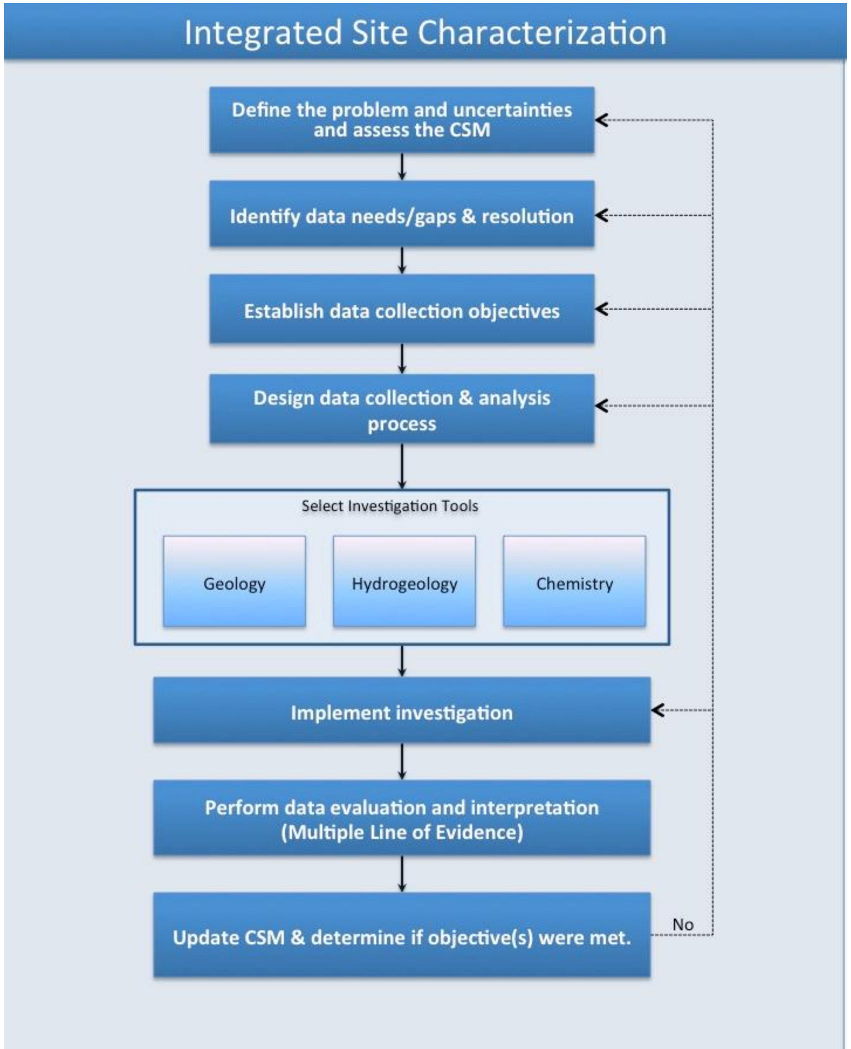


Figure 4-1 Integrated Site Characterization

Benefits of Integrated Site Characterization

- Reduces uncertainties to improve CSM
- Enables more efficient remedies
  - ITRC Integrated DNAPL Site Strategy (IDSS-1, 2011)
- Avoids costly do-overs
- Supports stakeholder needs and confidence

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)

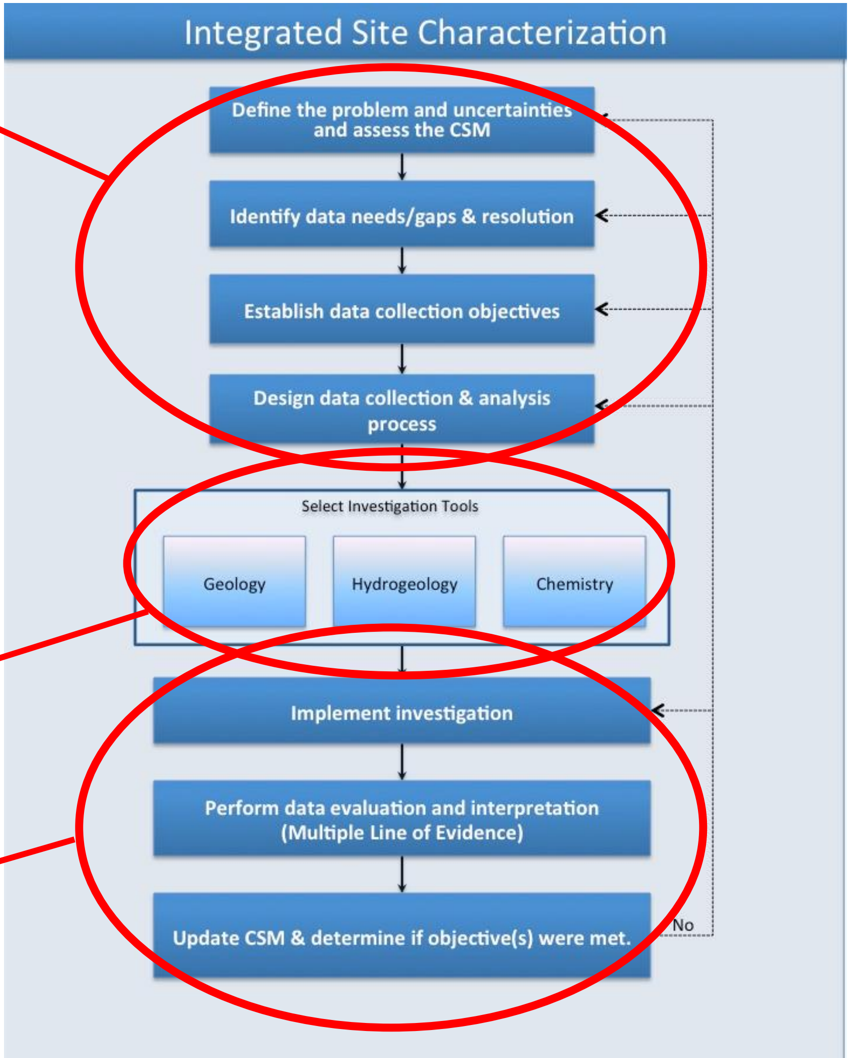


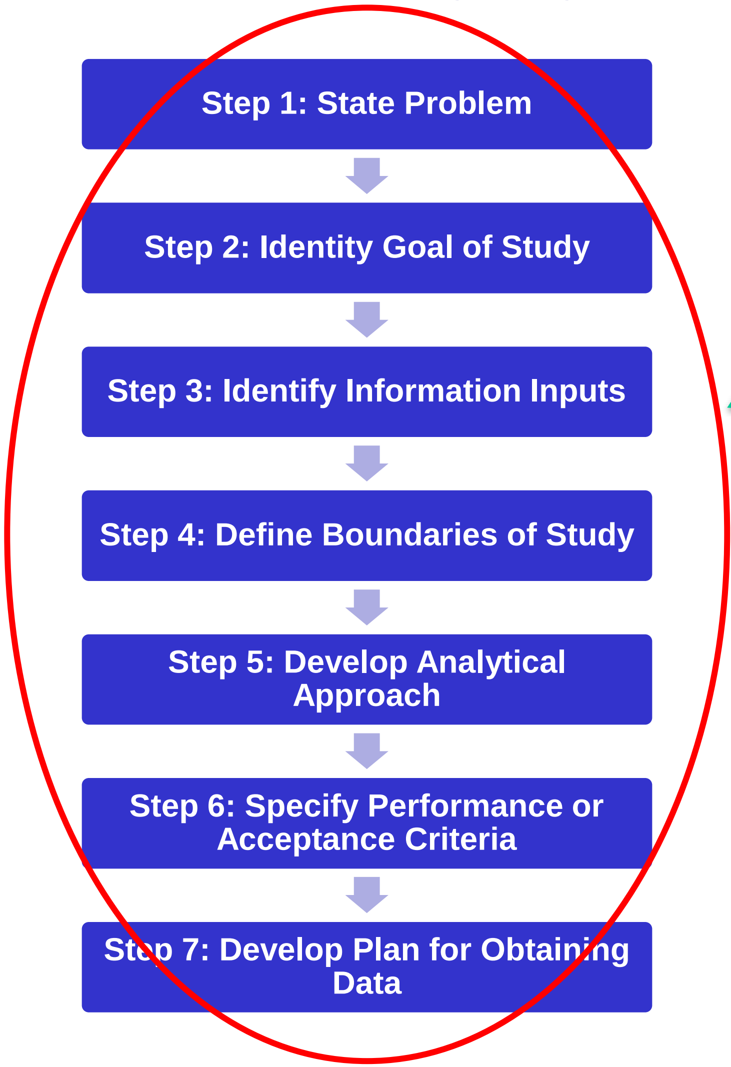
Figure 4-1 Integrated Site Characterization

Poll Question

- Do you have a DNAPL site that is being characterized for the first time or where prior characterization was insufficient?
  - Yes – first time
  - Yes – insufficient
  - No

Data Quality Objectives are "Built in"

USEPA Data Quality Objectives



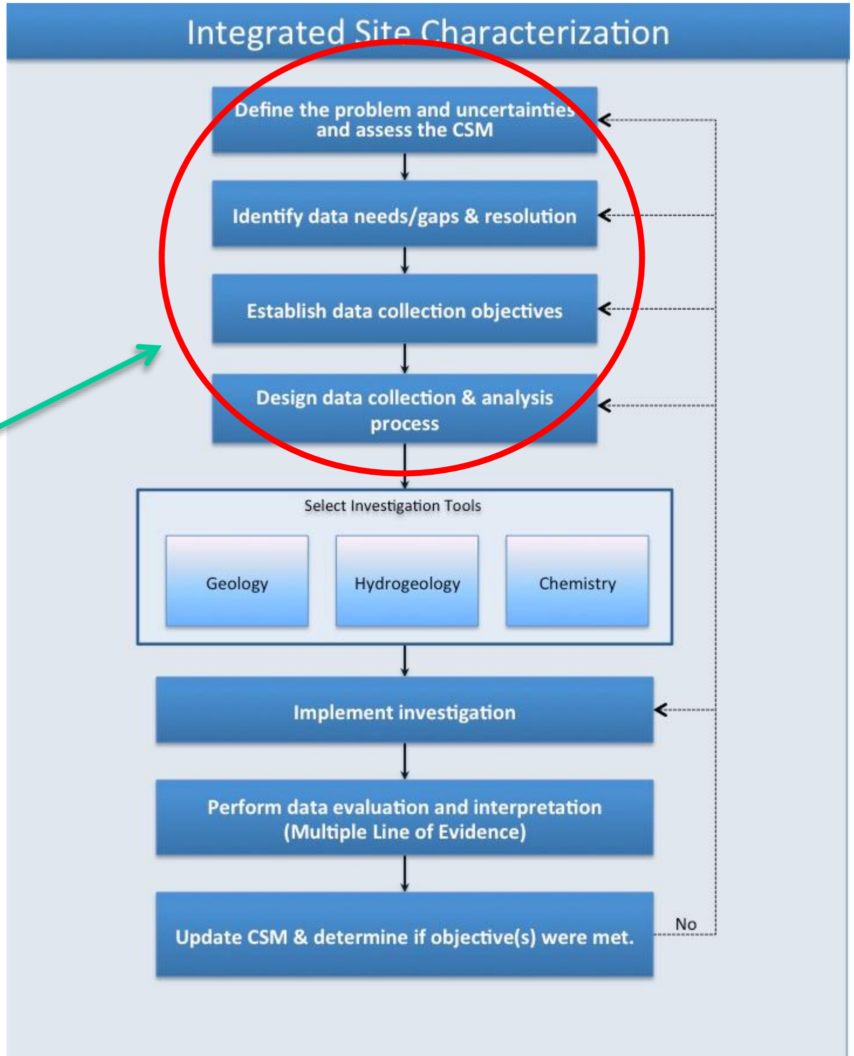


Figure 4-1 Integrated Site Characterization

Step 1: Define Problem and Assess CSM Uncertainties

- Assess existing CSM
- Define problem
- Define uncertainties

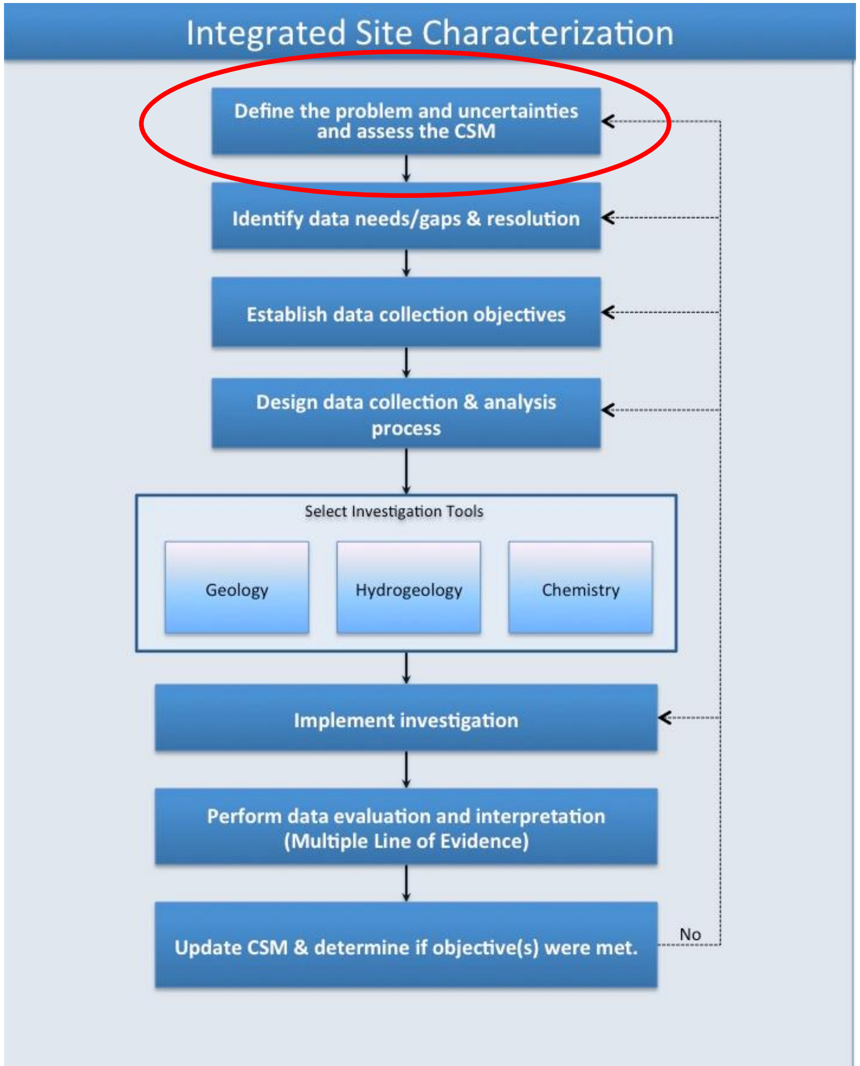
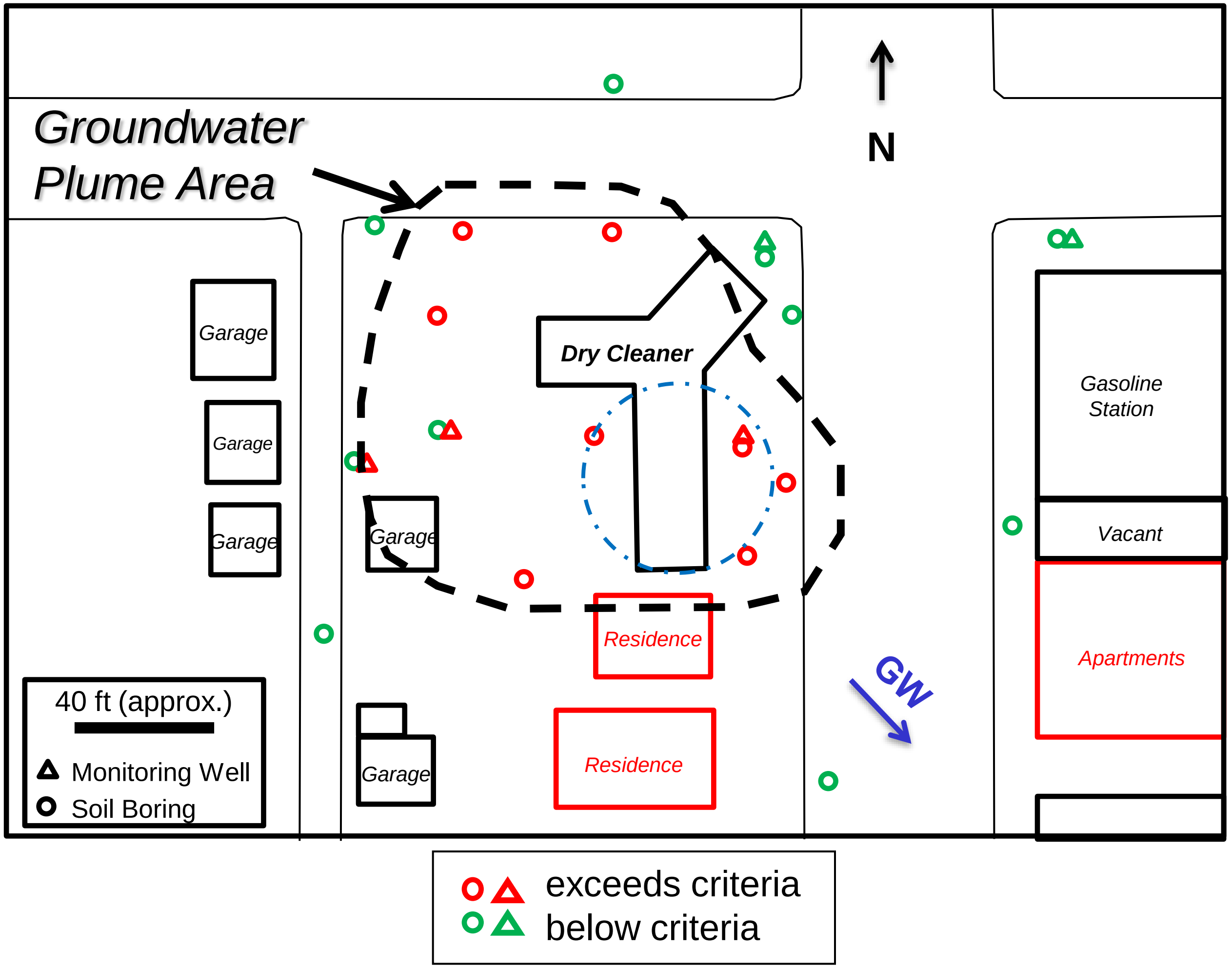


Figure 4-1 Integrated Site Characterization

Case Example – Dry Cleaner Site

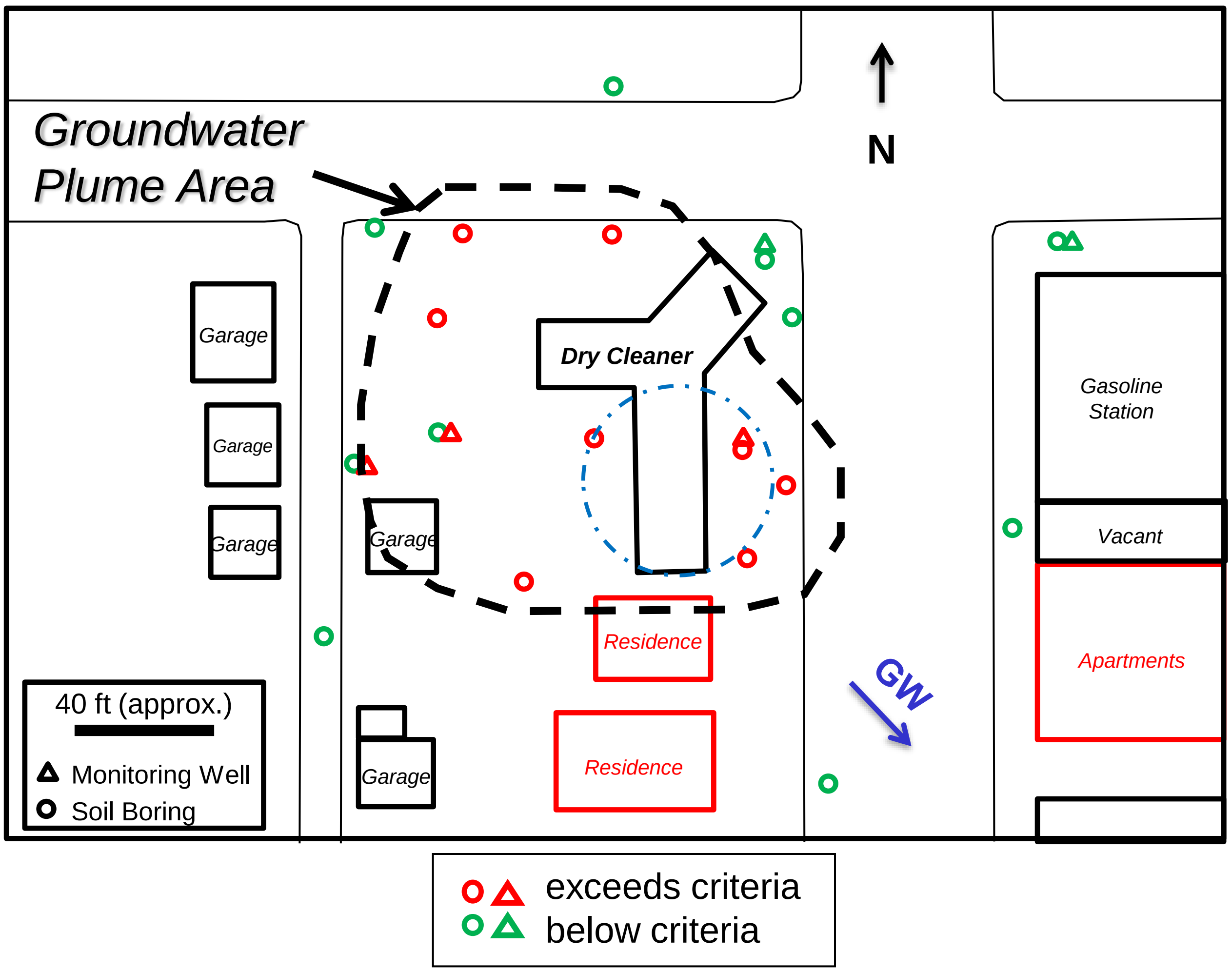
Case Example

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

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

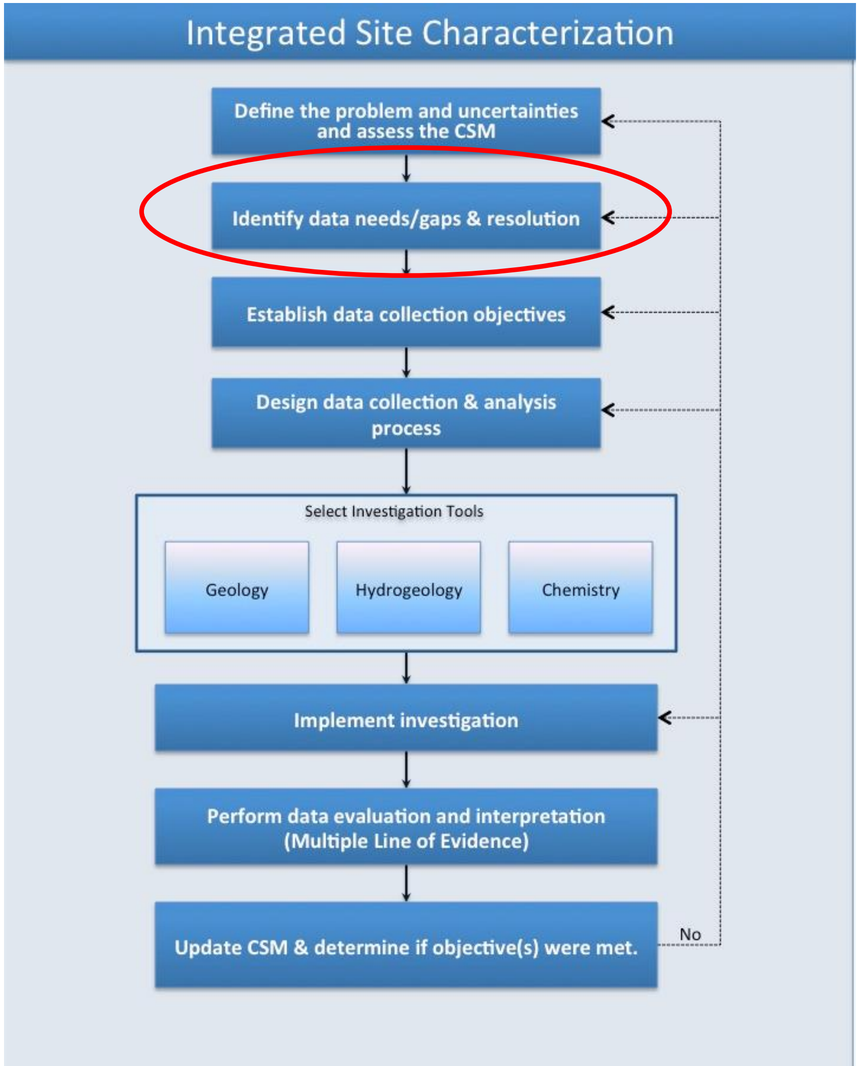
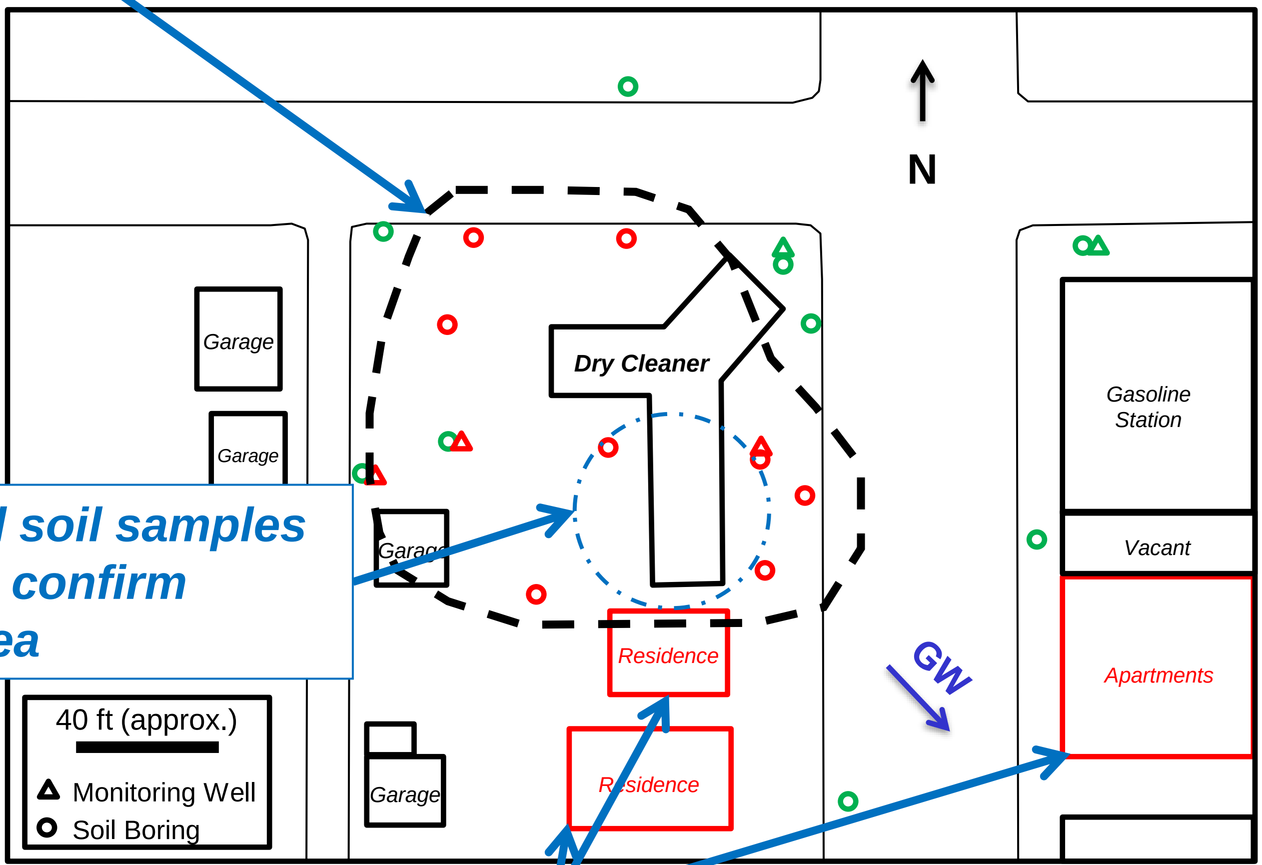


Figure 4-1 Integrated Site Characterization

Step 2: Identify Data Needs & Spatial Resolution

Case Example

Additional groundwater samples needed to define plume extent



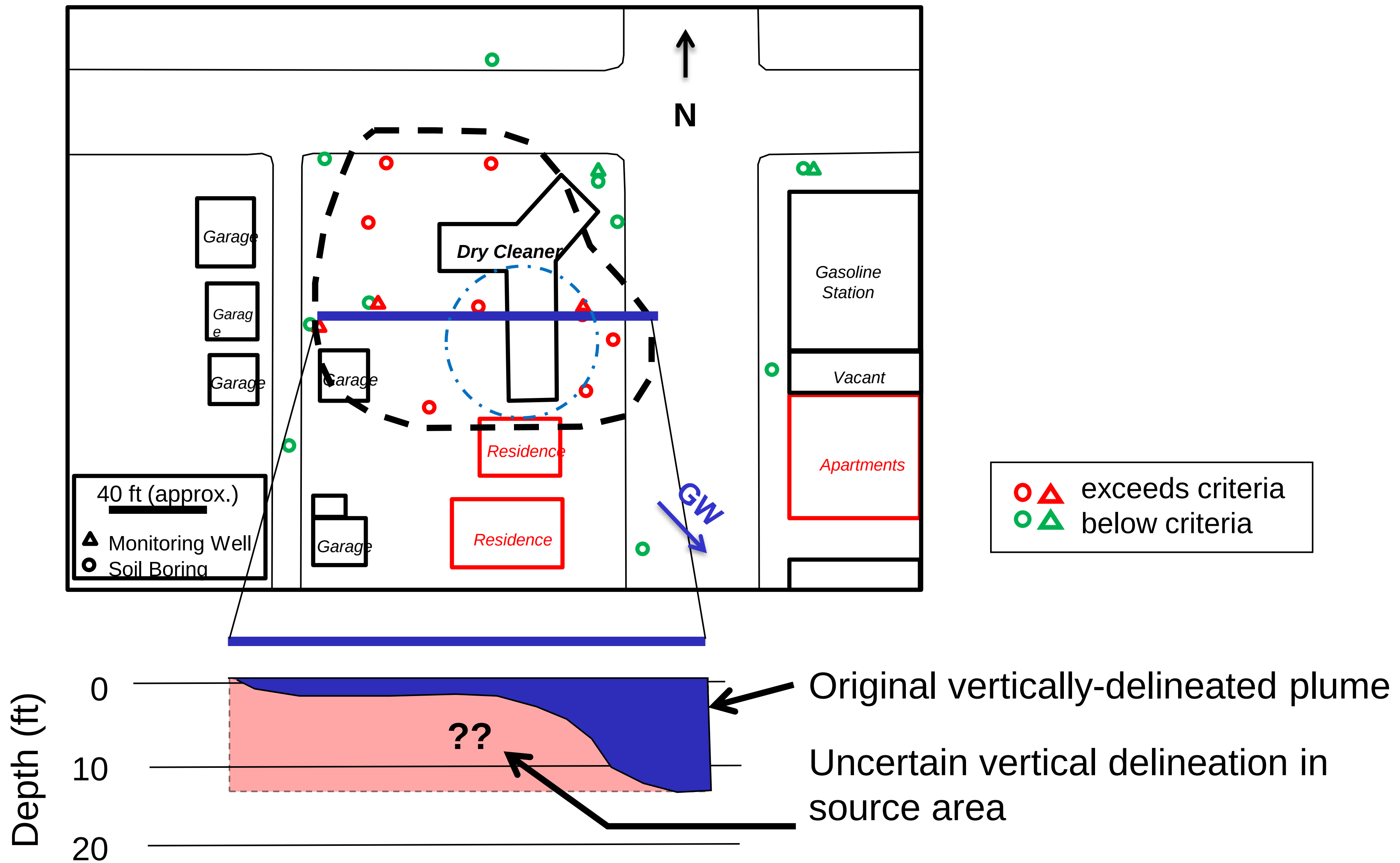
Additional soil samples needed to confirm source area

Soil-gas samples needed to assessment VI threat

exceeds criteria
below criteria

Step 2: Identify Data Needs & Spatial Resolution

Case Example



Step 3: Establish Data Collection Objectives

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

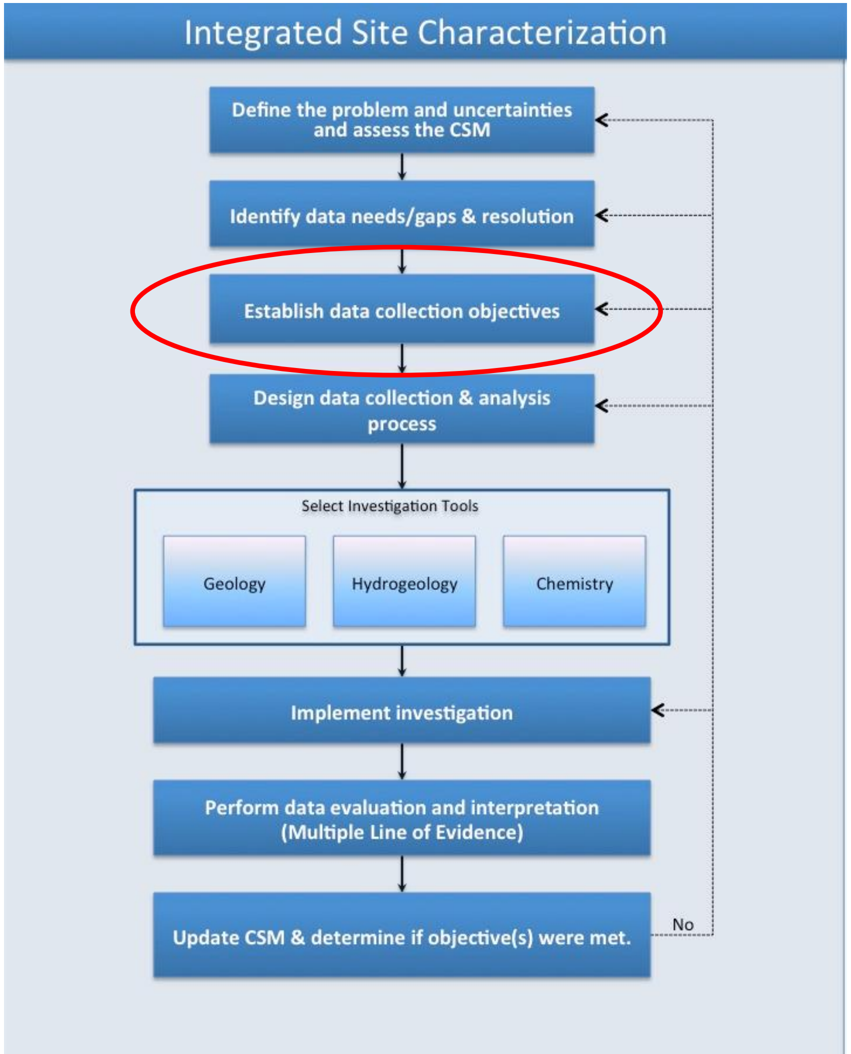


Figure 4-1 Integrated Site Characterization

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

Poll Question

- Have you ever collected data types that were not optimal for deciding what to do next?
  - Yes
  - No

Step 3: Drycleaner Site Data Collection Objectives

- 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

Step 4: Data Collection & Analysis Plan

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

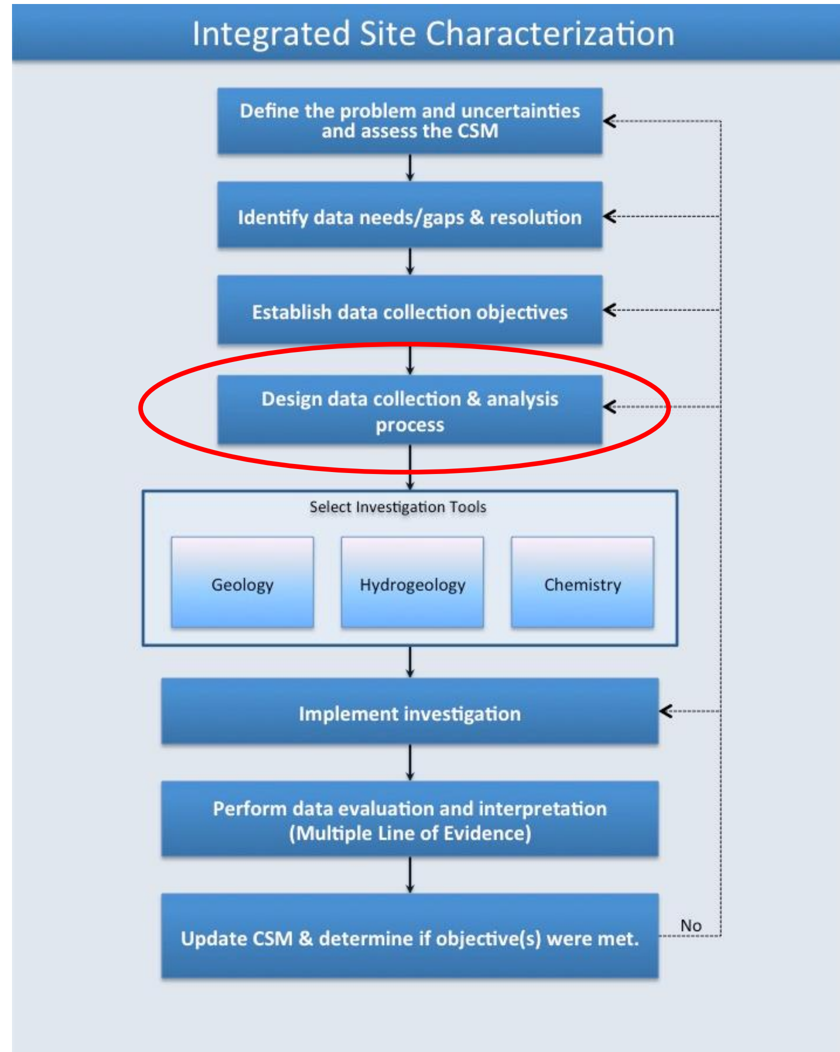


Figure 4-1 Integrated Site Characterization

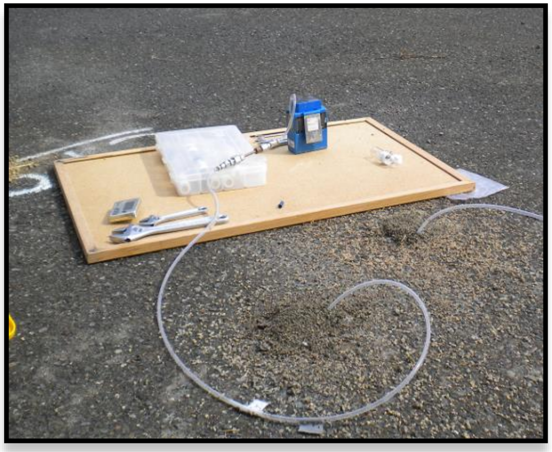
Screening Method
- Qualitative tools
- Direct subsequent data collection

Fill in the Gaps
- Contaminant flux
- Horizontal and vertical resolution vital

Map Extent
- Delineate source
- Decision making

Step 4: Drycleaner Site Data Collection & Analysis Plan

Case Example



Soil vapor sampling

Triad ES mobile lab and Geoprobe

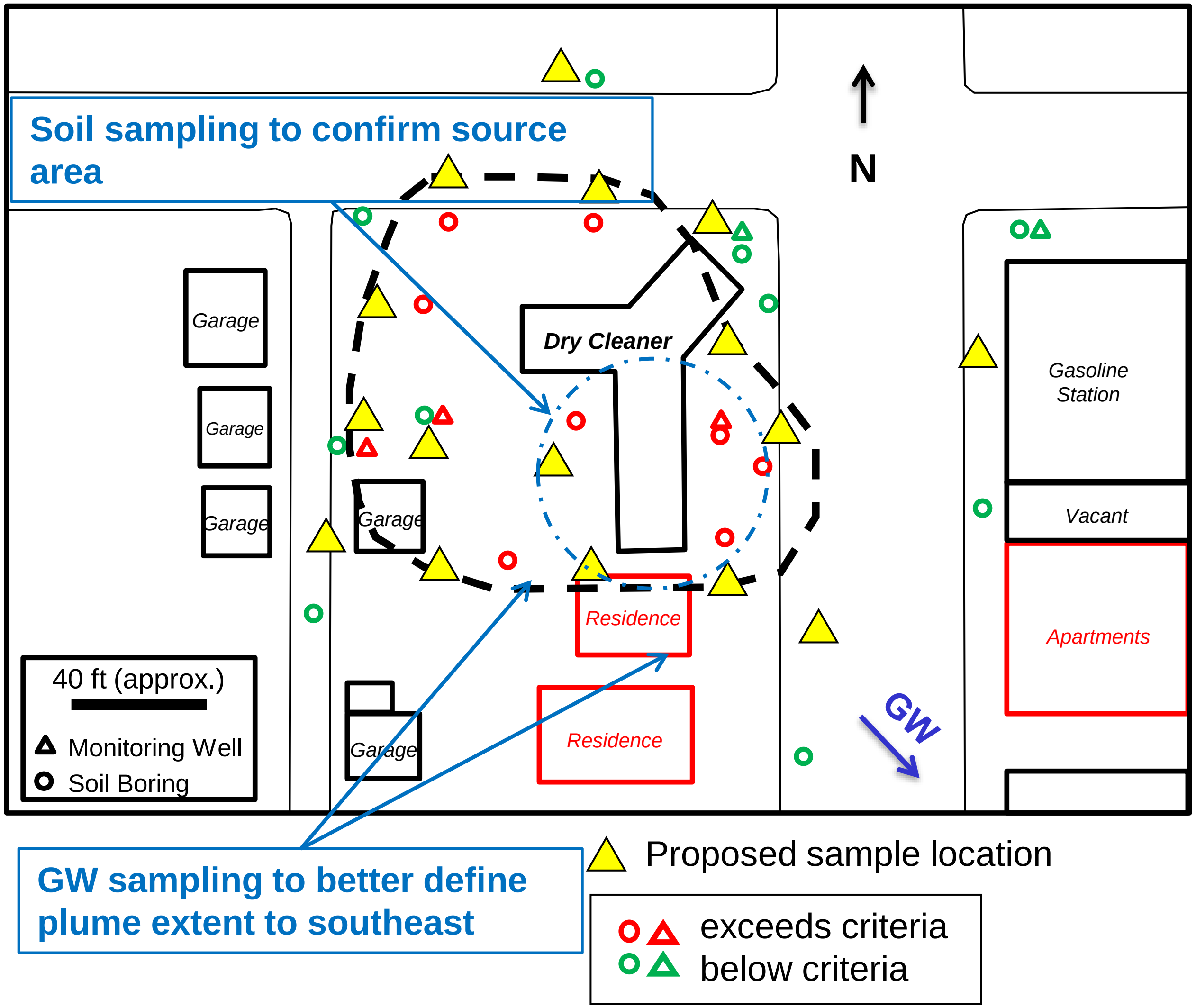
Direct sampling ion trap mass spectrometry (SW846 Method 8265) with mobile lab provides up to 80 soil/groundwater and 60 soil vapor VOC analyses per day

Step 4: Data Collection & Analysis Plan

Case Example

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

Updated Groundwater Plume Area

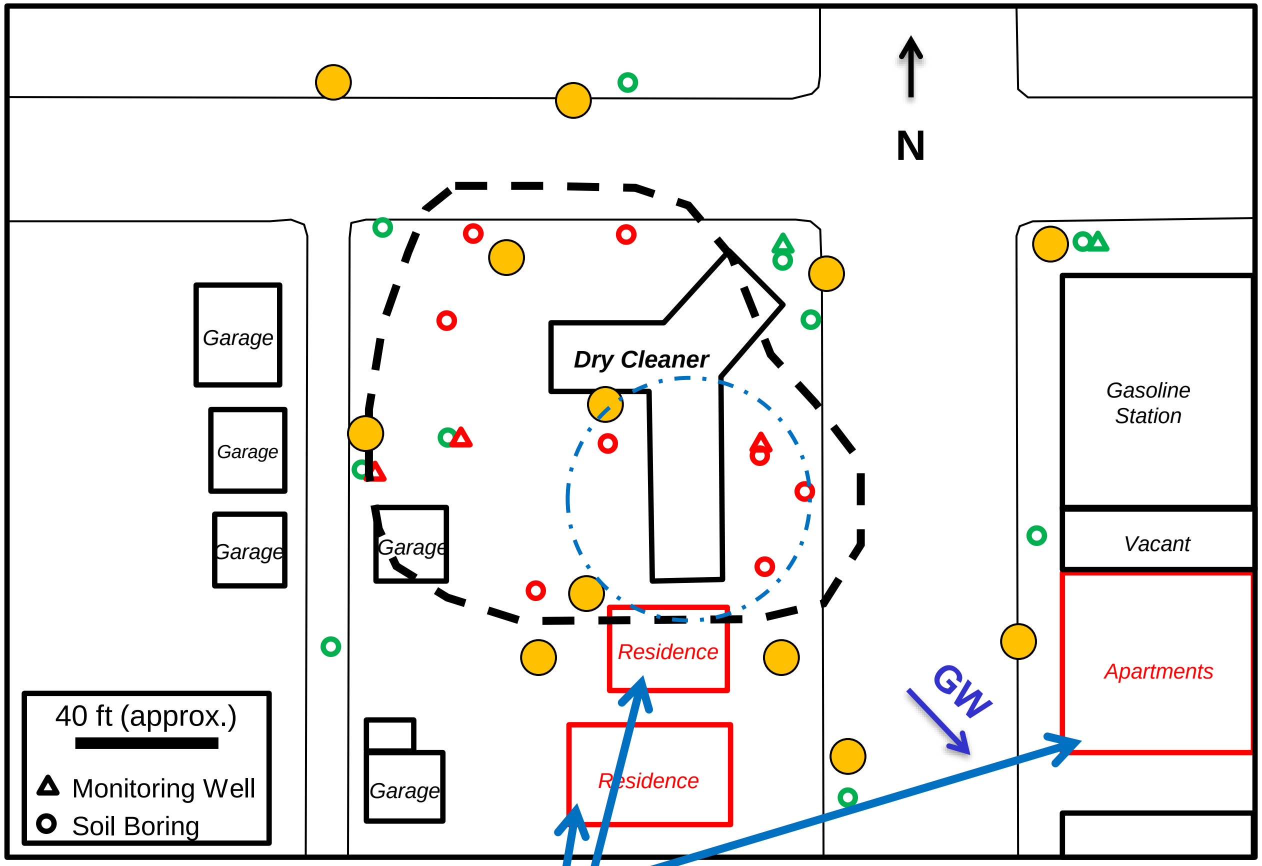


Step 4: Data Collection & Analysis Plan

Case Example

- Soil gas
  - 12 points
  - 24 samples

Shallow soil vapor results



Soil-gas samples needed to assessment VI threat

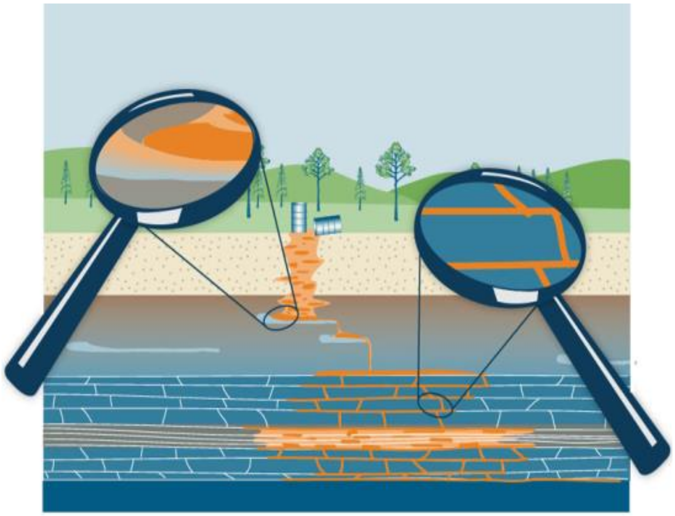
Proposed soil-gas sample location

Summary – 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; focus on DNAPL sites

Training Overview

- DNAPL Characteristics
- Life Cycle of a DNAPL Site
- Integrated Site Characterization
  - Plan
  - Tools Selection
  - Implementation
- Summary



ISC-1, Chapter 4

Tools Selection Process: Contents of this Section

- Orientation to the tools matrix
- Tools selection framework
- Tools matrix functionality
- Case studies
- Summary

Poll Question

- Which of these tools have been used on your sites? Check all that apply.
  - Split Spoon Sampler
  - Hydraulic Profiling Tool
  - Membrane Interface Probe
  - Portable GC/MS
  - Colorimetric Screening
  - Electrical Resistivity Tomography
  - Raman Spectroscopy
  - Fluorescence In-situ Hybridization (FISH)
  - Partitioning Interwell Tracer Test (PITT)

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

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

Orientation to the Tools Matrix

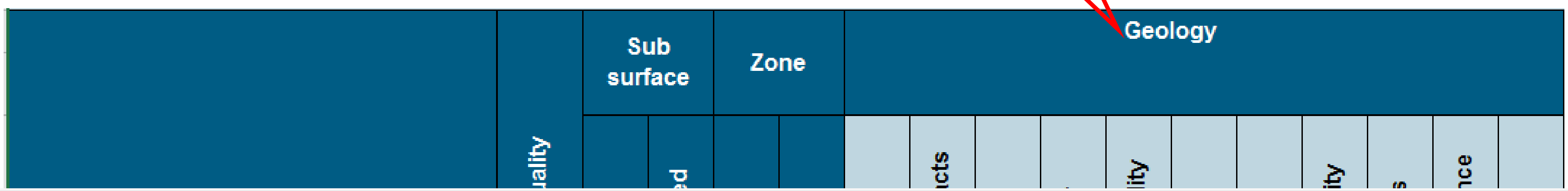
- Contains over **100** tools
- Sorted by:
  - Characterization objective
    - Geology
    - Hydrogeology
    - Chemistry
  - Effectiveness in media
    - Unconsolidated/Bedrock
    - Unsaturated/Saturated
- Ranked by data quality
  - Quantitative
  - Semi-quantitative
  - Qualitative

Tool	Data Quality	Sub surface		Zone	
		Bedrock	Unconsolidated	Unsaturated	Saturated
Geophysics					
Surface Geophysics					
Ground Penetrating Radar (GPR)	QL - Q	✓	✓	✓	✓
High Resolution Seismic Reflection (2D or 3D)	QL - Q	✓	✓		✓
Seismic Refraction	QL - Q	✓	✓	✓	✓
Multi-Channel Analyses of Surface Waves (MASW)	QL - Q	✓	✓	✓	✓
Electrical Resistivity Tomography (ERT)	QL - SQ	✓	✓	✓	✓
Very Low Frequency (VLF)	QL	✓	✓	✓	✓
ElectroMagnetic (EM) Conductivity	QL	✓	✓	✓	✓
Downhole Testing					
Magnetometric Resistivity	QL	✓	✓		✓
Induction Resistivity (Conductivity Logging)	QL - Q	✓	✓	✓	✓
Resistivity (Elog)	QL - SQ	✓			✓
GPR Cross-Well Tomography	QL - Q	✓	✓	✓	✓
Optical Televiewer	QL - Q	✓	✓	✓	✓
Acoustic Televiewer	QL - Q	✓			✓
Natural Gamma Log	QL - Q	✓	✓	✓	✓
Neutron (porosity) Logging	QL - Q	✓	✓		✓
Nuclear Magnetic Resonance Logging	QL - Q	✓	✓	✓	✓
Video Log	QL - SQ	✓	✓	✓	✓
Caliper Log	QL - Q	✓	✓	✓	✓
Temperature Profiling	QL - Q	✓	✓		✓
Full Wave Form Seismic	Q - QL	✓			✓

Tools Matrix Functionality

Click any box for a description or definition

Click



E.3 Geology

Geologic data provide a means to describe the physical matrix and structure of the subsurface and to classify the sedimentary, igneous, or metamorphic environment. 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 intrusive and nonintrusive 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 plotting on a stereonet).

Following a surface investigation, the next step in site characterization commonly involves collecting a continuous core of sediments and bedrock. Data provided by this core sampling may include lithology, grain size and sorting, crystalinity, 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 borehole geophysical data to interpolate conditions between the holes. Downhole geophysical tools and direct-push tools – for example, membrane interface probe (MIP), hydraulic profiling tool (HPT), and Waterloo profiler – can provide detailed information on the geology and contaminant distribution 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 investigative 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 borehole geophysical data are of sufficient resolution.

Unfortunately, collection efforts at contaminated sites often yield insufficient geologic data, leading to a high degree of uncertainty in subsurface interpretation. Historically, there has been a tendency to oversimplify 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 overdesigning 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 investigation in terms of improved remedy success rates and reduced life cycle costs.

Oversimplification of CSMs is particularly relevant to glaciated regions with complex depositional environments. In the northeast and Midwest, many glaciated sites contain both bedrock and glacial aquifers 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 CSM, and is 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	onsolidated	nsaturated	Saturated

Tool/References	Description	Data Quality and Applicability/Advantages	Limitations/Difficulty
Ground Penetrating Radar • Annan 2005 • Bayer et al. 2011 • Beres et al. 1999 • Bradford 2006 • Bradford and Deeds 2006 • Bradford, Dickins. and Brandvik 2010 • Bradford and Babcock 2013 • Clement, Barrash, and Knoll 2006 • Guerin 2005 • USEPA 2004	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. 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 interferences, and are generally limited to 20 meters (m) deep. GPR can identify internal structures between material-bounding reflectors (e.g., cross-bedding) in some cases. GPR can be used to locate geologic material or property contacts associated with dielectric property contrasts (e.g., proxy for porosity in some water-saturated clastic sediments) as well as subsurface infrastructure (e.g., pipes, tanks, cavities).	Data Quality • varies with antennas and subsurface EC • relatively sharp boundaries • qualitative to quantitative depending on field conditions, prior knowledge/subsurface calibration, experimental quality, appropriate modeling Applicability/Advantages • relatively fast to acquire, and processing methodology well established • primarily used in materials with low EC (sand, gravel, or rock except shales) • can be run repeatedly in time-lapse mode to track changes in moisture (above water table) or EC or dielectric properties (plume or spill bodies, including several experiments tracking presence and changes in dense nonaqueous phase liquid [DNAPL] in sandy aquifers)	• minimal penetration in electrically conductive (silts and clay-rich or conductive pore water) units • interpretation of features and depths semiquantitative without independent reference (well or cone penetrometer [CPT])

Shaded Boxes Denote Tool Meets Objective

Tools collect these types of information

Tool	Data Quality	Sub surface: Bedrock	Sub surface: Unconsolidated	Zone: Unsaturated	Zone: Saturated	Geology: Lithology	Lithology Contacts	Porosity	Permeability	Dual Permeability	Faults	Fractures	Fracture Density	Fracture sets	Rock Competence	Mineralogy
Geophysics																
Surface Geophysics																
Ground Penetrating Radar (GPR)	QL - Q	✓	✓	✓	✓	■	■	■			■					
High Resolution Seismic Reflection (2D or 3D)	QL - Q	✓	✓		✓	■	■				■	■	■		■	
Seismic Refraction	QL - Q	✓	✓	✓	✓	■	■				■				■	
Multi-Channel Analyses of Surface Waves (MASW)	QL - Q	✓	✓	✓	✓	■	■				■					
Electrical Resistivity Tomography (ERT)	QL - SQ	✓	✓	✓	✓	■	■	■			■				■	
Very Low Frequency (VLF)	QL	✓	✓	✓	✓		■				■	■				
ElectroMagnetic (EM) Conductivity	QL	✓	✓	✓	✓	■	■				■					
Downhole Testing																

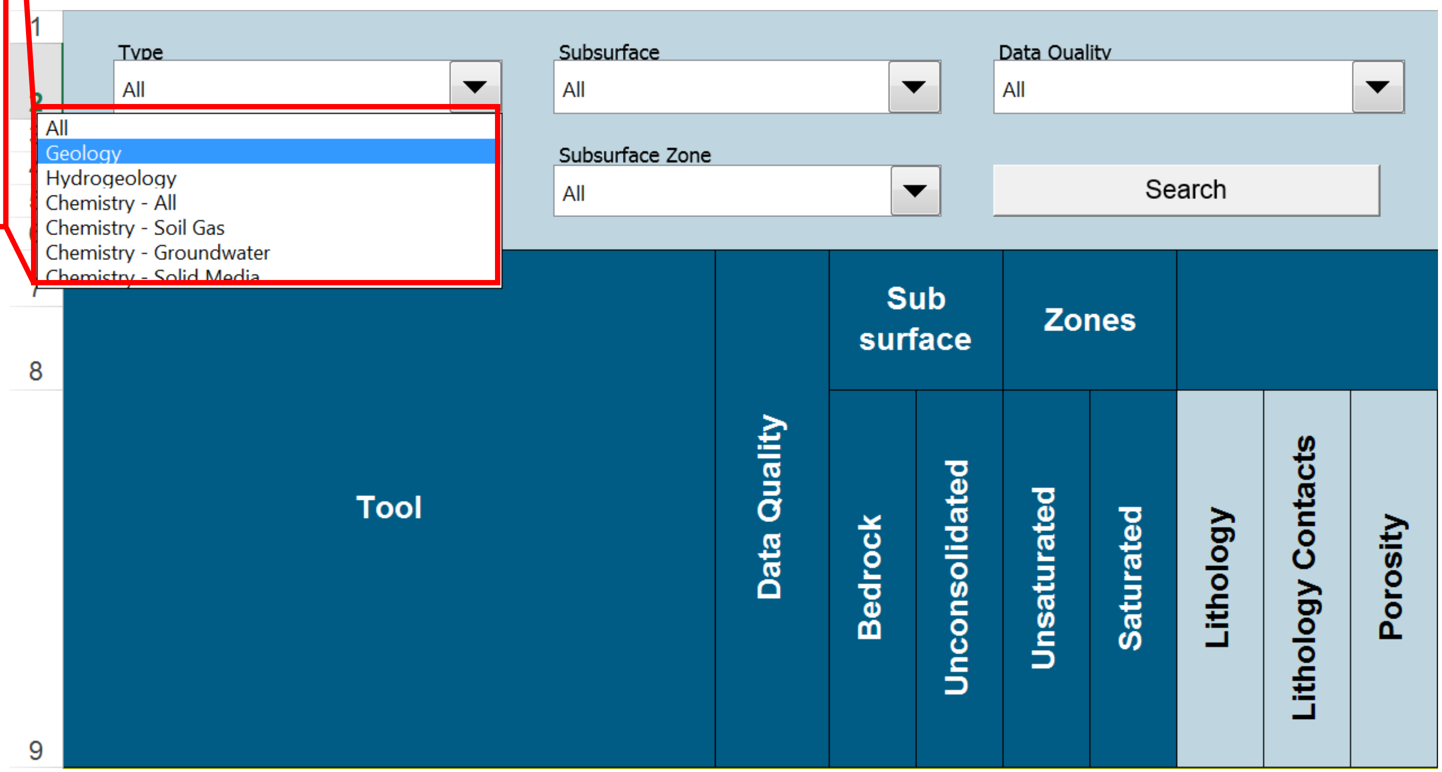
Green shading indicates that tool is applicable to characterization objective

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

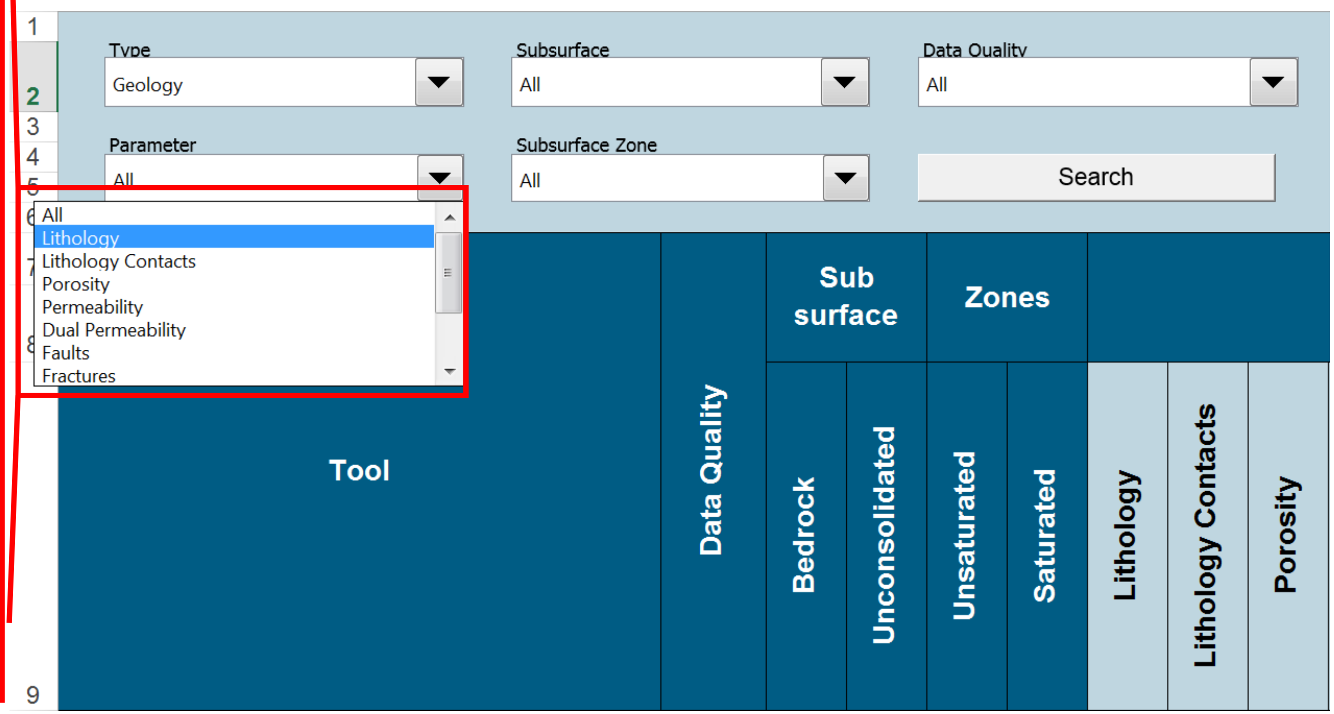
1. Select Category

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



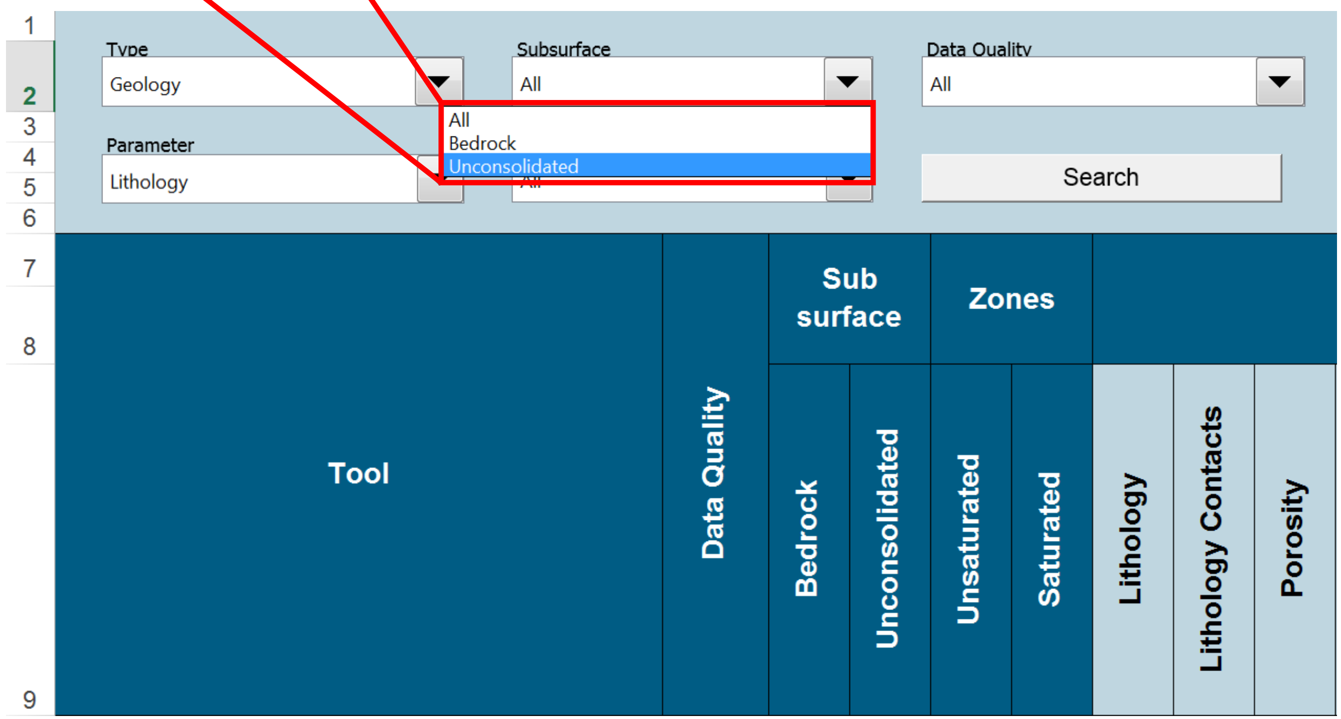
2. Select Parameters of Interest

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



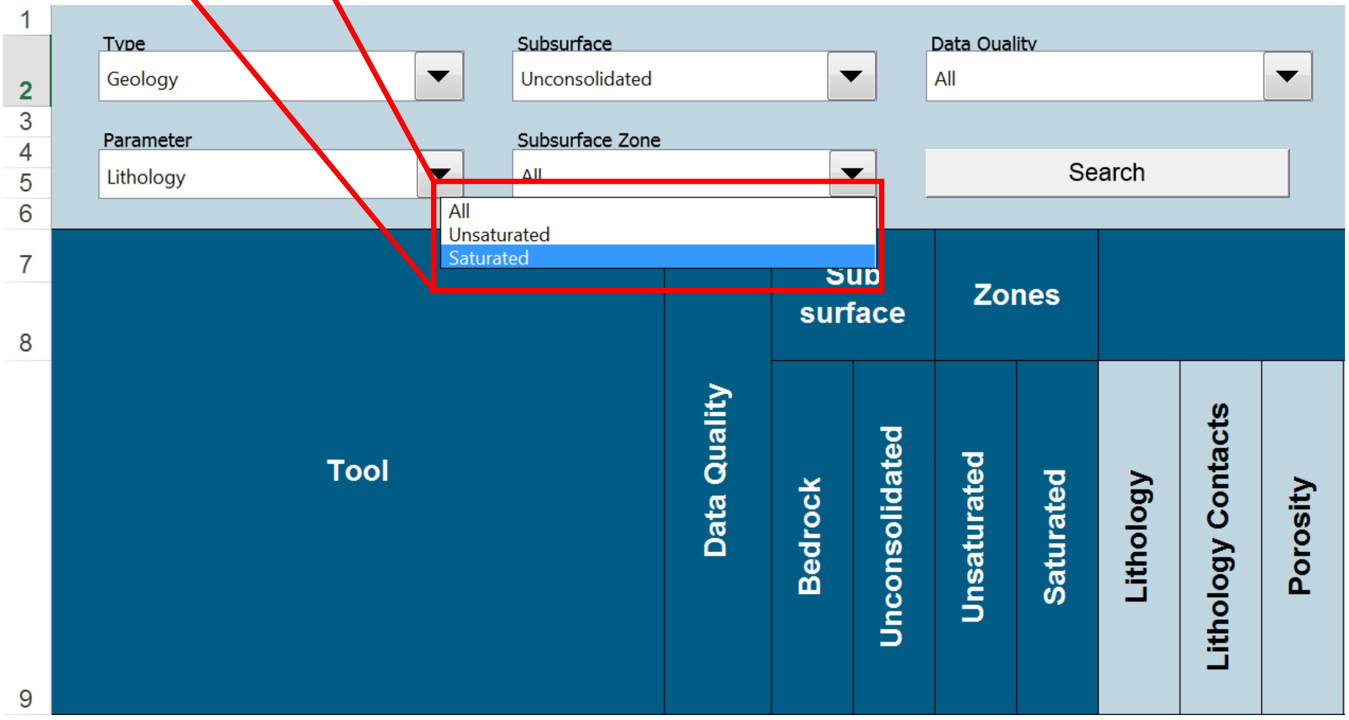
3. Identify Geologic Media

All
Bedrock
Unconsolidated



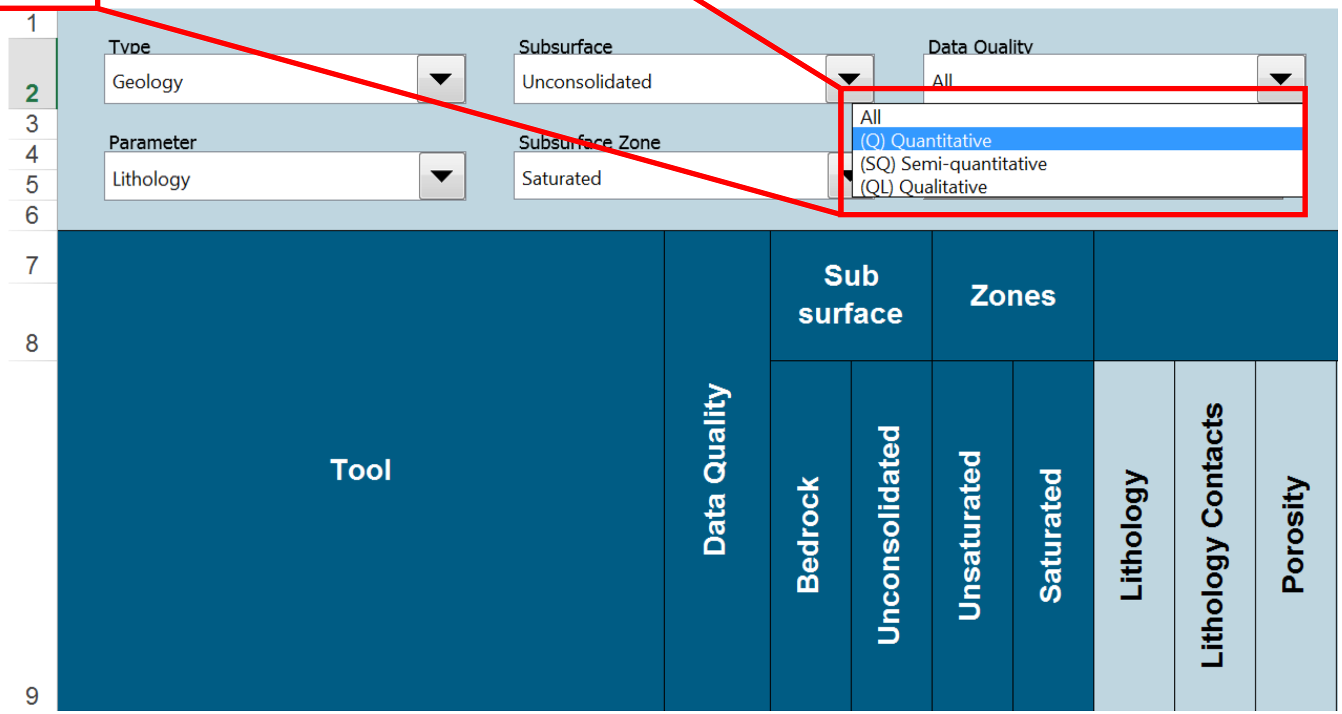
4. Identify Zone

All
Unsaturated
Saturated



5. Choose Data Quality

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



6. Apply Filters, Evaluate Tools

Type: Geology Parameter: Litholo… | Quality: (Q) Quantitative

- 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 Televiewer
    - 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)
  - Hydrosparge (CPT)
  - CPT In-Situ Video Camera
- Discrete Groundwater Sampling & Profiling
  - Hydraulic Profiling Tool Groundwater Sampler (HPT-GWS)*

Perform Additional Searches to Find More Tools for Different Objectives

Additional parameters can be added or removed from any given search

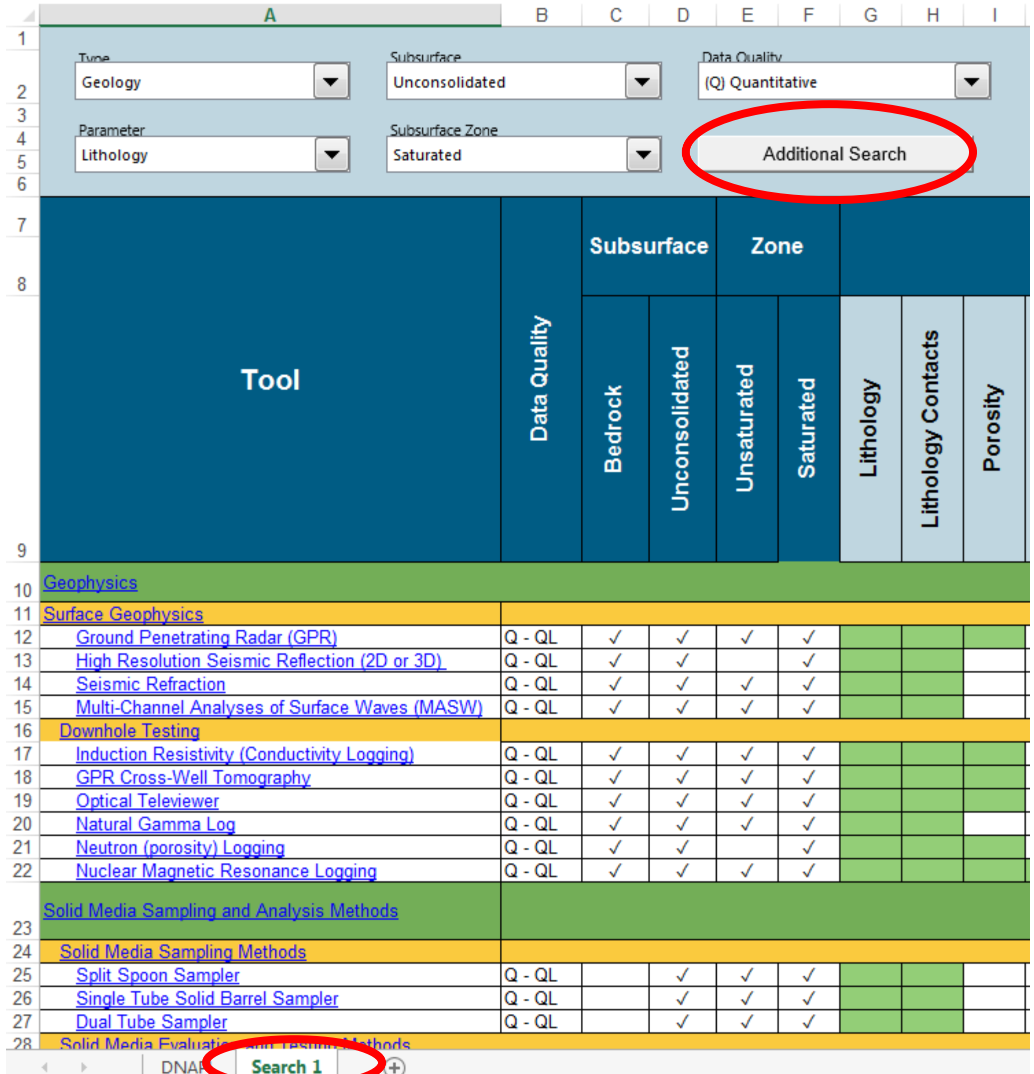
Type: All
Subsurface: All
Data Quality: All
Parameter: All
Subsurface Zone: All
Search

Tool	Data Quality	Sub surface		Zone				
		Bedrock	Unconsolidated	Unsaturated	Saturated	Lithology	Lithology Contacts	Porosity
Geophysics								
Surface Geophysics								
Ground Penetrating Radar (GPR)	QL - Q	✓	✓	✓	✓			
High Resolution Seismic Reflection (2D or 3D)	QL - Q	✓	✓		✓			
Seismic Refraction	QL - Q	✓	✓	✓	✓			
Multi-Channel Analyses of Surface Waves (MASW)	QL - Q	✓	✓	✓	✓			
Electrical Resistivity Tomography (ERT)	QL - SQ	✓	✓	✓	✓			
Very Low Frequency (VLF)	QL	✓	✓	✓	✓			
ElectroMagnetic (EM) Conductivity	QL	✓	✓	✓	✓			
Downhole Testing								
Magnetometric Resistivity	QL	✓	✓		✓			
Induction Resistivity (Conductivity Logging)	QL - Q	✓	✓	✓	✓			
Resistivity (Elog)	QL - SQ	✓			✓			
GPR Cross-Well Tomography	QL - Q	✓	✓	✓	✓			
Optical Televiewer	QL - Q	✓	✓	✓	✓			
Acoustic Televiewer	QL - Q	✓			✓			
Natural Gamma Log	QL - Q	✓	✓	✓	✓			
Neutron (porosity) Logging	QL - Q	✓	✓		✓			
Nuclear Magnetic Resonance Logging	QL - Q	✓	✓	✓	✓			
Video Log	QL - SQ	✓	✓	✓	✓			
Caliper Log	QL - Q	✓	✓	✓	✓			

DNAPL | Search 1

Add Parameters to a previous search

Multiple searches can be saved on one matrix



	Tool	Data Quality	Subsurface: Bedrock	Subsurface: Unconsolidated	Zone: Unsaturated	Zone: Saturated	Lithology	Lithology Contacts	Porosity
10	Geophysics								
11	Surface Geophysics								
12	Ground Penetrating Radar (GPR)	Q - QL	✓	✓	✓	✓			
13	High Resolution Seismic Reflection (2D or 3D)	Q - QL	✓	✓		✓			
14	Seismic Refraction	Q - QL	✓	✓	✓	✓			
15	Multi-Channel Analyses of Surface Waves (MASW)	Q - QL	✓	✓	✓	✓			
16	Downhole Testing								
17	Induction Resistivity (Conductivity Logging)	Q - QL	✓	✓	✓	✓			
18	GPR Cross-Well Tomography	Q - QL	✓	✓	✓	✓			
19	Optical Televiewer	Q - QL	✓	✓	✓	✓			
20	Natural Gamma Log	Q - QL	✓	✓	✓	✓			
21	Neutron (porosity) Logging	Q - QL	✓	✓		✓			
22	Nuclear Magnetic Resonance Logging	Q - QL	✓	✓	✓	✓			
23	Solid Media Sampling and Analysis Methods								
24	Solid Media Sampling Methods								
25	Split Spoon Sampler	Q - QL		✓	✓	✓			
26	Single Tube Solid Barrel Sampler	Q - QL		✓	✓	✓			
27	Dual Tube Sampler	Q - QL		✓	✓	✓			
28	Solid Media Evaluati... Methods								

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

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

Filters

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

Case Example – Apply Filters

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

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

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

Tool	Data Quality	Subsurface		Zone		Geology											Hydrogeology								Chemistry								
																									Soil Gas	Groundwater				Solid Media			
		Bedrock	Unconsolidated	Unsaturated	Saturated	Lithology	Lithology Contacts	Porosity	Permeability	Dual Permeability	Faults	Fractures	Fracture Density	Fracture sets	Rock Competence	Mineralogy	Open Hole Flow	Ambient Flow	Groundwater Age	Fracture Aperture	Fracture Connectivity	Hydraulic Conductivity	Hydraulic Head	Borehole Condition	Contaminant Concentration	Geochemistry	Microbial Community	NAPL Presence	Contaminant Concentration	Geochemistry	Foc	NAPL Presence	Contaminant Concentration
Geophysics																																	
Downhole Testing																																	
Induction Resistivity (Conductivity Logging)	Q - QL	✓	✓	✓	✓																												
GPR Cross-Well Tomography	Q - QL	✓	✓	✓	✓																												
Vapor and Soil Gas Sampling																																	
Active soil gas surveys	Q - SQ	✓	✓	✓																													
Solid Media Sampling and Analysis Methods																																	
Solid Media Evaluation and Testing Methods																																	
Contaminant Analysis	Q - QL	✓	✓	✓	✓																												
Direct Push Logging (In-Situ)																																	
Hydrosparge (CPT)	Q - SQ		✓		✓																												
Raman Spectroscopy	Q - SQ		✓	✓	✓																												
Discrete Groundwater Sampling & Profiling																																	
Screen Point (SP) 22 Groundwater Sampling Tool	Q - QL		✓		✓																												
Screen Point (SP) 16 Groundwater Sampling Tool	Q - QL		✓		✓																												
Hydraulic Profiling Tool _ Groundwater Sampler (HPT-GWS)*	Q - QL		✓		✓																												

Case Example

Case Example – Applicable Tools

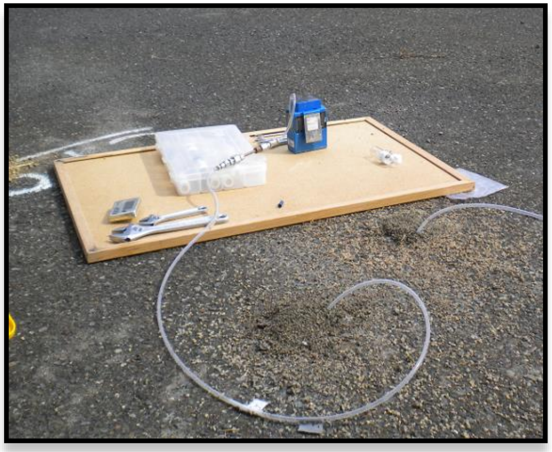
Case Example

Tool	Data Quality		Subsurface: Bedrock	Subsurface: Unconsolidated	Zone: Unsaturated	Zone: Saturated	Soil Gas: Contaminant Concentration	Groundwater: Contaminant Concentration	Groundwater: Geochemistry	Groundwater: Microbial Community	Groundwater: NAPL Presence	Contaminant
Geophysics												
Downhole Testing												
Induction Resistivity (Conductivity Logging)	Q	QL	✓	✓	✓	✓						
GPR Cross-Well Tomography	Q	QL	✓	✓	✓	✓						
Vapor and Soil Gas Sampling												
Active soil gas surveys	Q	SQ	✓	✓	✓							
Solid Media Sampling and Analysis Methods												
Solid Media Evaluation and Testing Methods												
Contaminant Analysis	Q	QL	✓	✓	✓	✓						
Direct Push Logging (In-Situ)												
Hydrosparge (CPT)	Q	SQ		✓		✓						
Raman Spectroscopy	Q	SQ		✓	✓	✓						
Discrete Groundwater Sampling & Profiling												
Screen Point (SP) 22 Groundwater Sampling	Q	QL		✓		✓						
Screen Point (SP) 16 Groundwater Sampling	Q	QL		✓		✓						
Hydraulic Profiling Tool _ Groundwater Sampler (HPT-GWS)*	Q	QL		✓		✓						
Grab well water sampler (SNAP, Hydrasleeve)	Q	SQ	✓	✓		✓						
Straddle packer sampling	Q		✓	✓		✓						
Hydropunch	Q	SQ		✓		✓						
ZONFLO-Hydraulic sampling system	Q		✓	✓		✓						
Multilevel sampling												
Westbay	Q		✓	✓		✓						
Solinist	Q		✓	✓		✓						
Fact Systems (FLUTe)	Q	SQ	✓	✓		✓						
CMT (Continuous Multichannel Tubing)	Q		✓	✓		✓						
Chemical Screening												
Direct Sampling Ion trap Mass Spectrometer	Q		✓	✓	✓	✓						
Environmental Molecular Diagnostics												
Microbial Diagnostics												
Compound Specific Isotope Analysis (CSIA)	Q	SQ	✓	✓	✓	✓						
On-site Analytical												
Mobile labs	Q	QL	✓	✓	✓	✓						
Portable Gas Chromatograph	Q	SQ	✓	✓	✓	✓						
Portable Gas Chromatograph / Mass	Q	SQ	✓	✓	✓	✓						

Geophysics
Downhole Testing
Induction Resistivity (Conductivity Logging)
GPR Cross-Well Tomography
Vapor and Soil Gas Sampling
Active soil gas surveys
Solid Media Sampling and Analysis Methods
Solid Media Evaluation and Testing Methods
Contaminant Analysis
Direct Push Logging (In-Situ)
Hydrosparge (CPT)
Raman Spectroscopy
Discrete Groundwater Sampling & Profiling
Screen Point (SP) 22 Groundwater Sampling
Screen Point (SP) 16 Groundwater Sampling
Hydraulic Profiling Tool _ Groundwater Sampler (HPT-GWS)*
Grab well water sampler (SNAP, Hydrasleeve)
Straddle packer sampling
Hydropunch
ZONFLO-Hydraulic sampling system
Multilevel sampling
Westbay
Solinist
Fact Systems (FLUTe)
CMT (Continuous Multichannel Tubing)
Chemical Screening
Direct Sampling Ion trap Mass Spectrometer
Environmental Molecular Diagnostics
Microbial Diagnostics
Compound Specific Isotope Analysis (CSIA)
On-site Analytical
Mobile labs
Portable Gas Chromatograph
Portable Gas Chromatograph / Mass

Case Example – Tools Selection

- Search returns 22 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

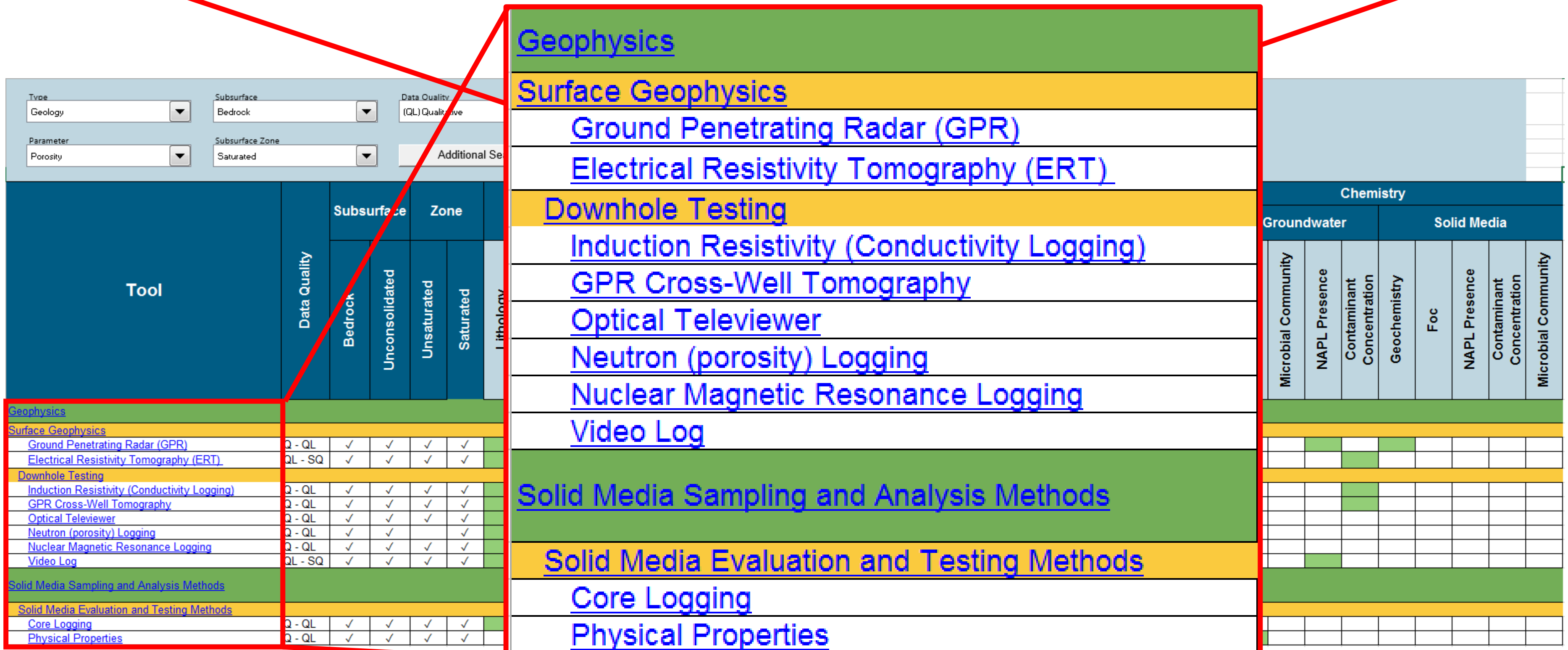
Example #2

Characterization Objective – Determine the porosity of a fractured bedrock formation in a DNAPL source zone to evaluate the potential storage capacity of the rock

- Type
  - Geology
- Parameter
  - Porosity
- Subsurface Media
  - Bedrock
- Subsurface Zone
  - Saturated
- Data Quality
  - (Q) Qualitative

Example #2 – Bedrock Porosity

Type: Geology Parameter: Porosity Subsurface: Bedrock Zone: Saturated Quality: (QL) Qualitative



Over 100 tools distilled to 10 that are applicable to the Characterization Objective

Example #3

Characterization Objective – Evaluate potential matrix diffusion issues associated with variations in hydraulic conductivity

- Type
  - Hydrogeology
- Parameter
  - Hydraulic Conductivity
- Subsurface Media
  - Unconsolidated
- Subsurface Zone
  - Saturated
- Data Quality
  - All

Example #3 – Hydraulic Conductivity

Type: Hydrogeology Parameter: H... nsolidated Zone: Saturated Quality: All

Type: Hydrogeology | Subsurface: Unconsolidated | Data Quality: All
Parameter: Hydraulic Conductivity | Subsurface Zone: Saturated | Additional Search

Tool	Data Quality	Bedrock	Unconsolidated	Unsaturated	Saturated
Geophysics					
Downhole Testing					
Nuclear Magnetic Resonance Logging	Q - QL	✓	✓	✓	✓
Hydraulic Testing					
Single well tests					
Packer Testing	Q - SQ	✓	✓		✓
FLUTe™ Profiling	Q - SQ	✓	✓		✓
Borehole Dilution	Q - SQ	✓	✓		✓
Flow Metering	Q - SQ	✓	✓		✓
Pumping and Recovery Tests	Q - SQ	✓	✓		✓
Slug Tests	Q - SQ	✓	✓		✓
Constant Head Step Test	Q - SQ	✓	✓		✓
Cross Borehole Testing					
Tracer testing	Q - SQ	✓	✓		✓
Hydraulic Tomography	Q - SQ	✓	✓		✓
Flow Metering	Q - SQ	✓	✓		✓
Pumping and Recovery Tests	Q - SQ	✓	✓		✓
Slug Tests	Q - SQ	✓	✓		✓
Solid Media Sampling and Analysis Methods					
Solid Media Evaluation and Testing Methods					
Physical Properties	Q - QL	✓	✓	✓	✓
Direct Push Logging (In-Situ)					
Hydraulic Profiling Tool (HPT)	QL - SQ		✓	✓	✓
Electrical Conductivity (EC) Logging	QL		✓	✓	✓
Cone Penetrometer Testing (CPT &CPTu)	Q - SQ		✓	✓	✓
Discrete Groundwater Sampling & Profiling					
Screen Point (SP) 22 Groundwater Sampling Tool	Q - QL		✓		✓
Screen Point (SP) 16 Groundwater Sampling Tool	Q - QL		✓		✓
Hydraulic Profiling Tool _ Groundwater Sampler (HPT-GWS)*	Q - QL		✓		✓
Waterloo Advanced Profiling System (Waterloo APS)*	Q - QL		✓		✓

21 tools returned. Can we refine?

Example #3 – Hydraulic Conductivity (refined)

Type: Hydrogeology Parameter: Hydraulic Conductivity Subsurface: Unconsolidated Zone: Saturated Quality: (QL) Qualitative

- Geophysics
  - Downhole Testing
    - Nuclear Magnetic Resonance Logging
- Solid Media Sampling and Analysis Methods
  - Solid Media Evaluation and Testing Methods
    - Physical Properties
- Direct Push Logging (In-Situ)
  - Hydraulic Profiling Tool (HPT)
  - Electrical Conductivity (EC) Logging
- Discrete Groundwater Sampling & Profiling
  - Screen Point (SP) 22 Groundwater Sampling Tool
  - Screen Point (SP) 16 Groundwater Sampling Tool
  - Hydraulic Profiling Tool _ Groundwater Sampler (HPT-GWS)*

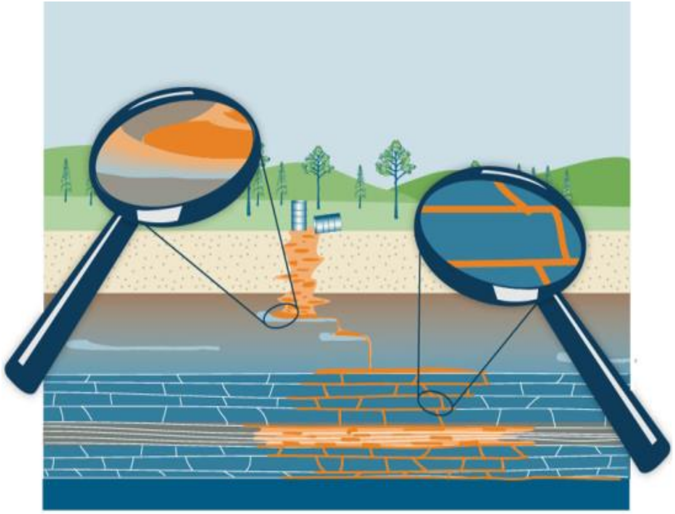
Change data quality to QL   7 tools returned

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

Training Overview

- DNAPL Characteristics
- Life Cycle of a DNAPL Site
- Integrated Site Characterization
  - Plan
  - Tools Selection
  - Implementation
- Summary



ISC-1, Chapter 4

Conducting

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

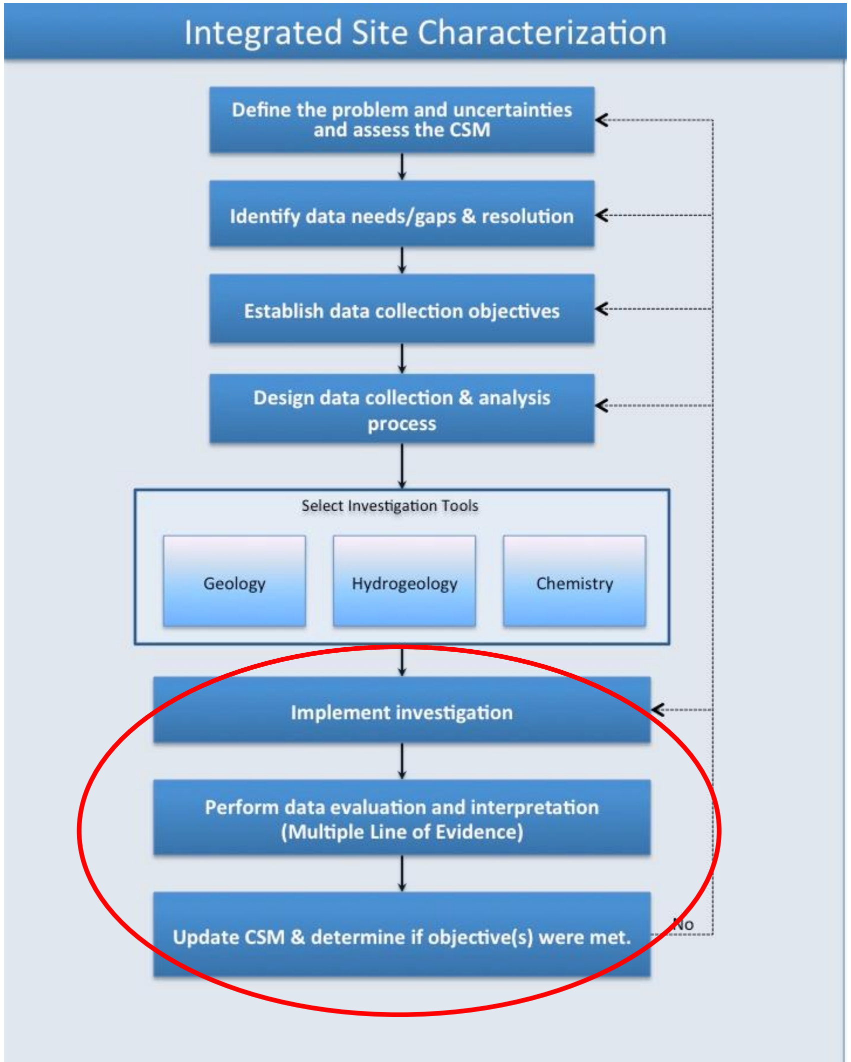


Figure 4-1 Integrated Site Characterization

Step 6. Implement Investigation

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

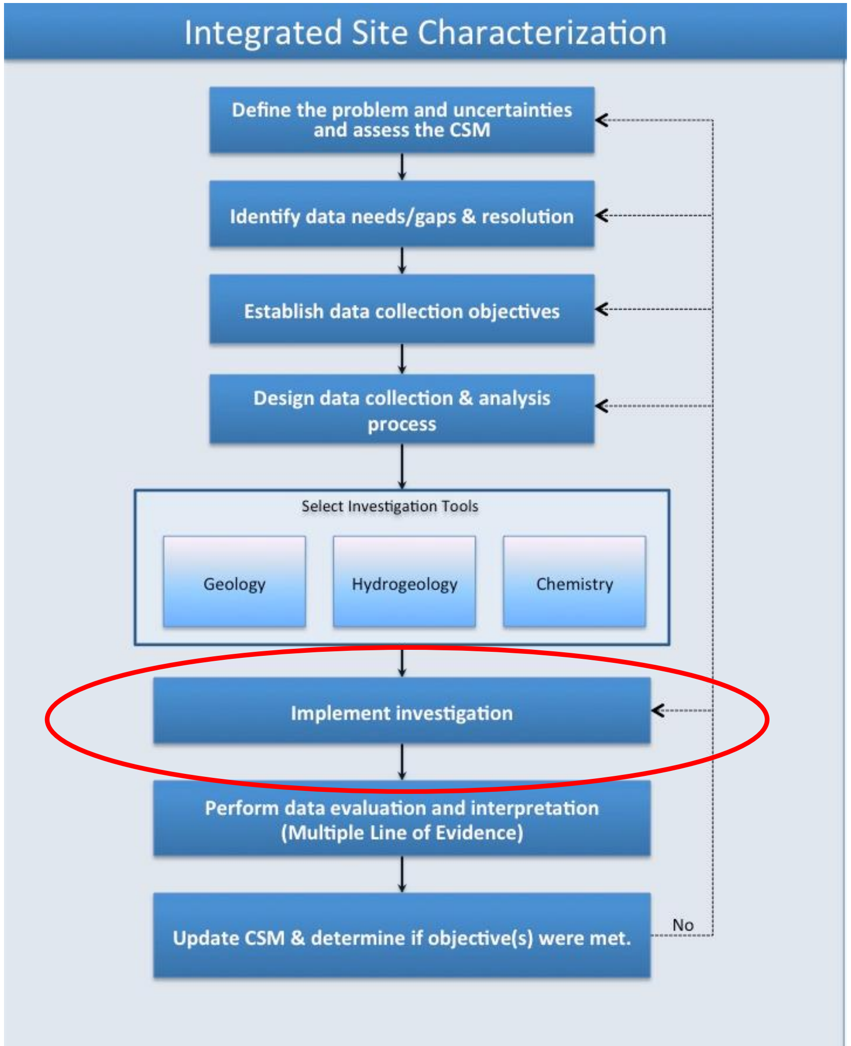


Figure 4-1 Integrated Site Characterization

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

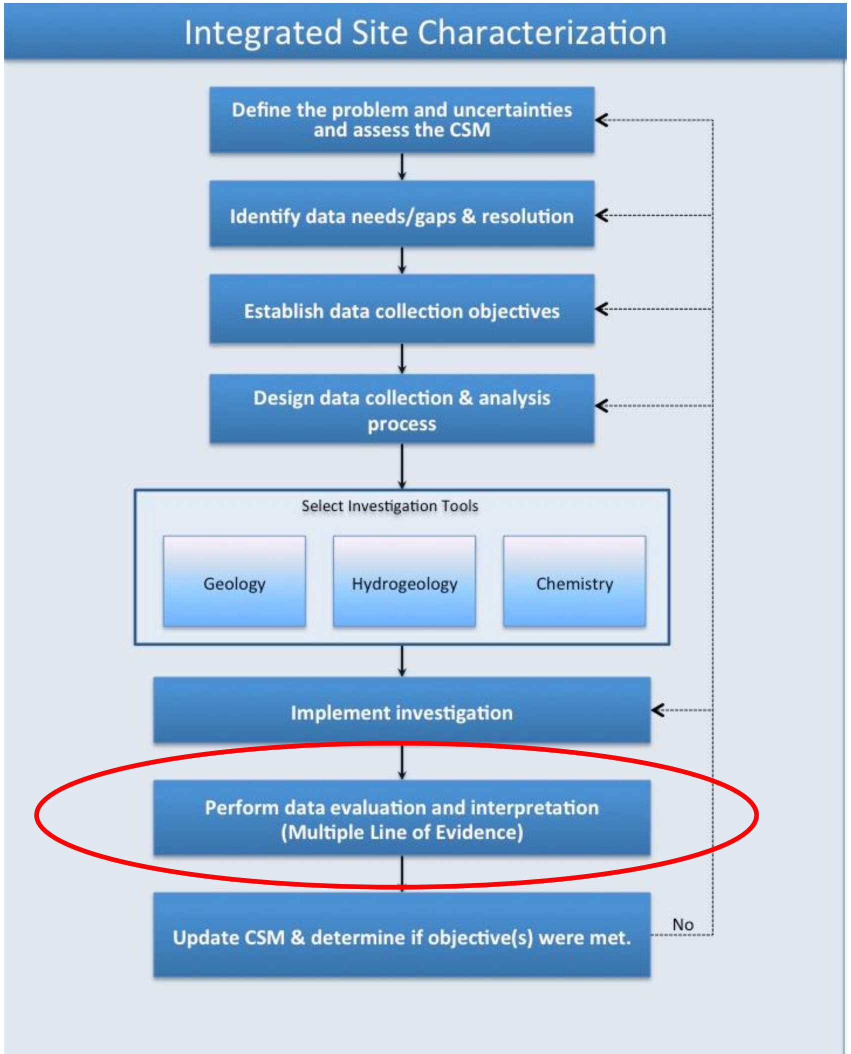
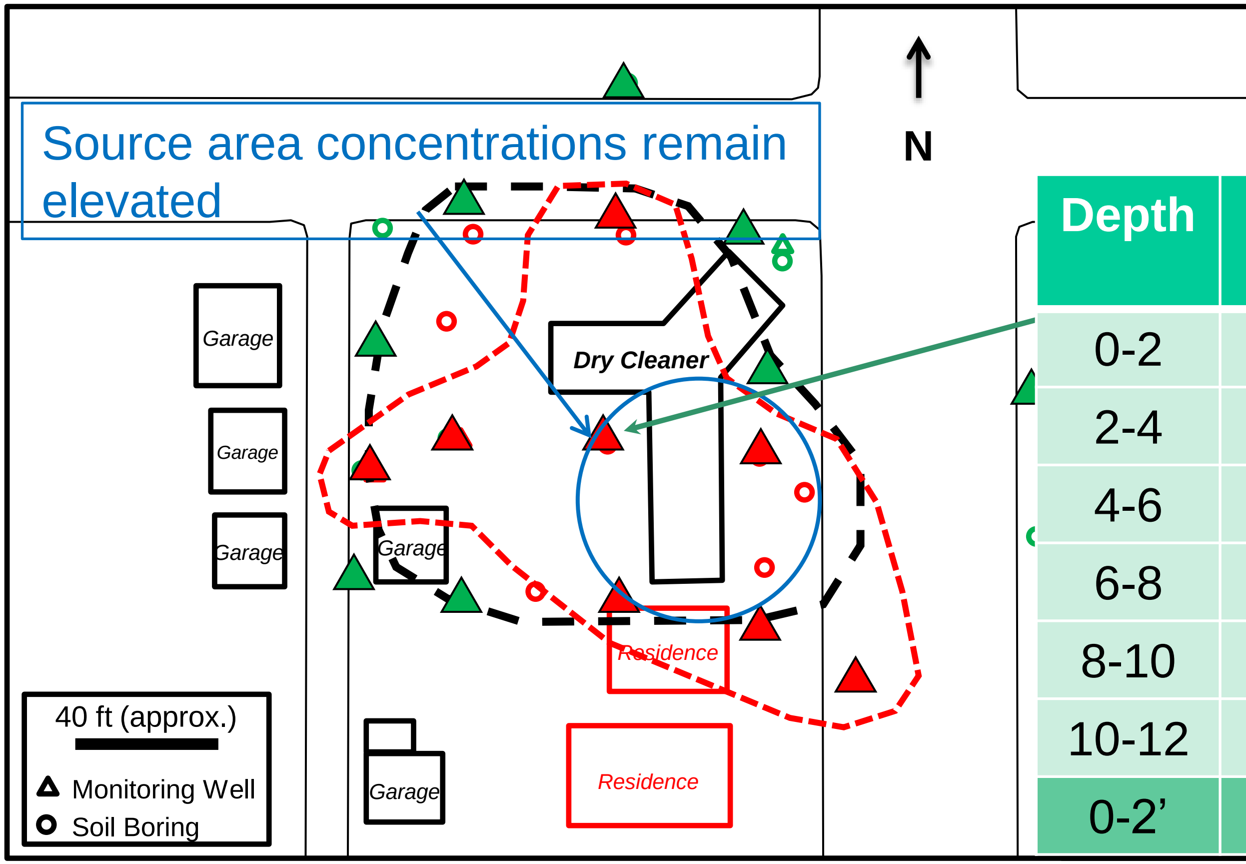


Figure 4-1 Integrated Site Characterization

Step 7. Soil and Groundwater Data Evaluation and Interpretation

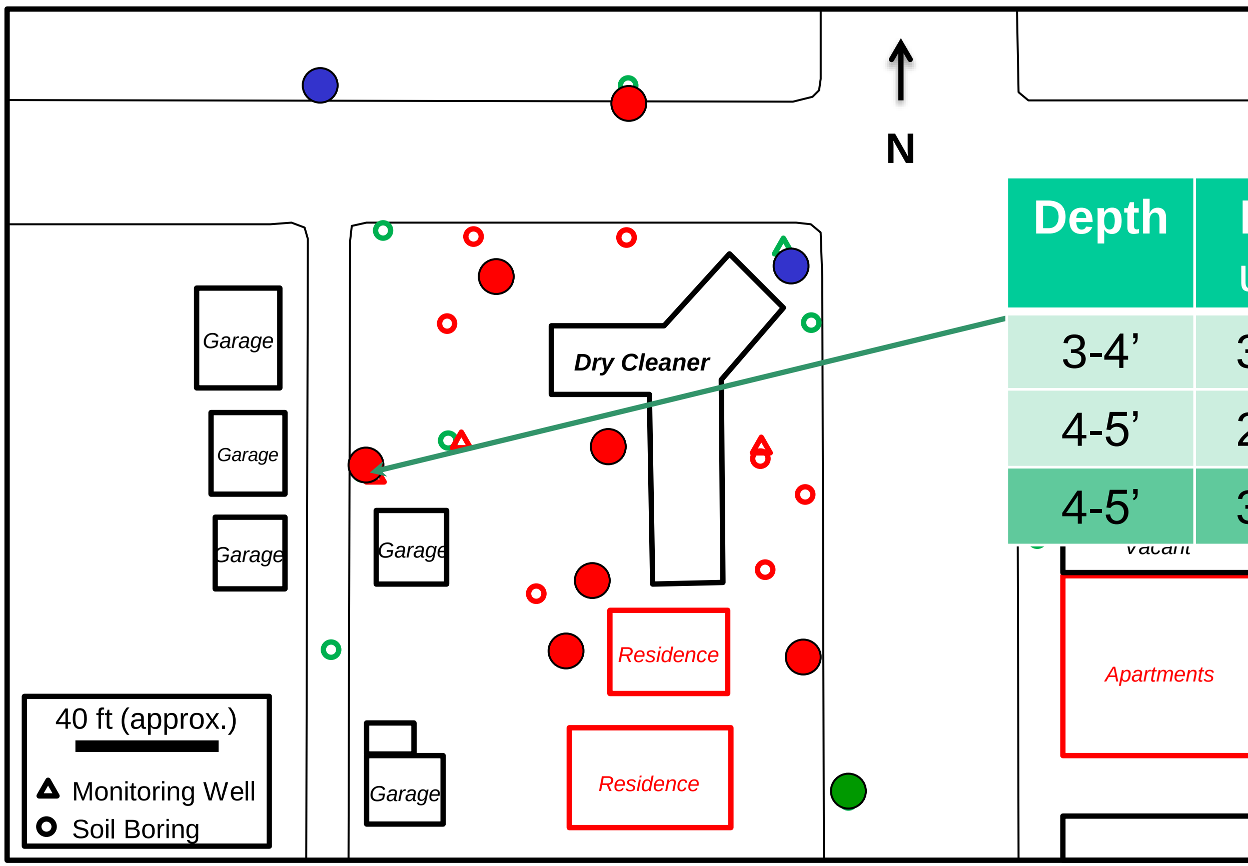


Depth	PCE mg/kg	Lab
0-2	3.25	Mobile
2-4	2.232	Mobile
4-6	<0.37	Mobile
6-8	3.298	Mobile
8-10	11.5	Mobile
10-12	<0.37	Mobile
0-2’	21	Fixed

Result exceeds criteria
Result does not exceed criteria

Step 7. Soil Vapor Data Evaluation and Interpretation

Case Example



Depth	PCE units	Lab
3-4’	3720	Mobile
4-5’	2398	Mobile
4-5’	3800	Fixed

Shallow soil vapor results

- Result below vapor screening level
- Result exceeds chronic vapor screening level
- Result exceeds sub-chronic vapor screening level

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

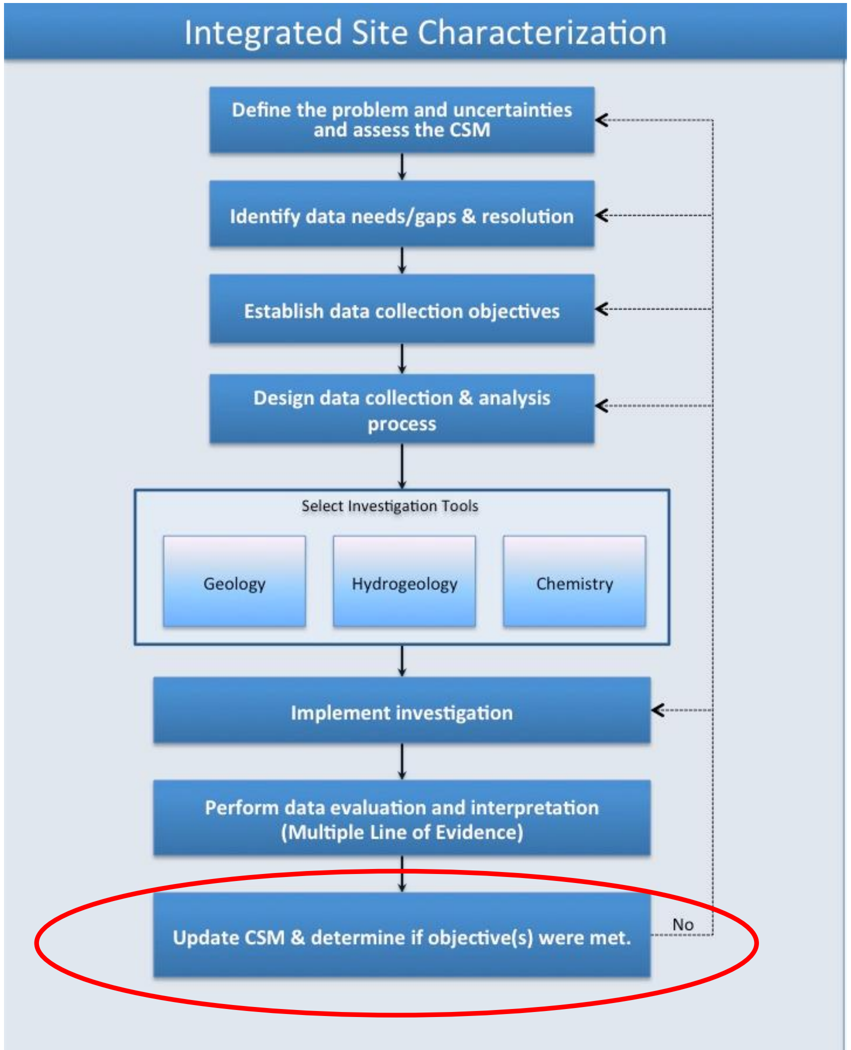


Figure 4-1 Integrated Site Characterization

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

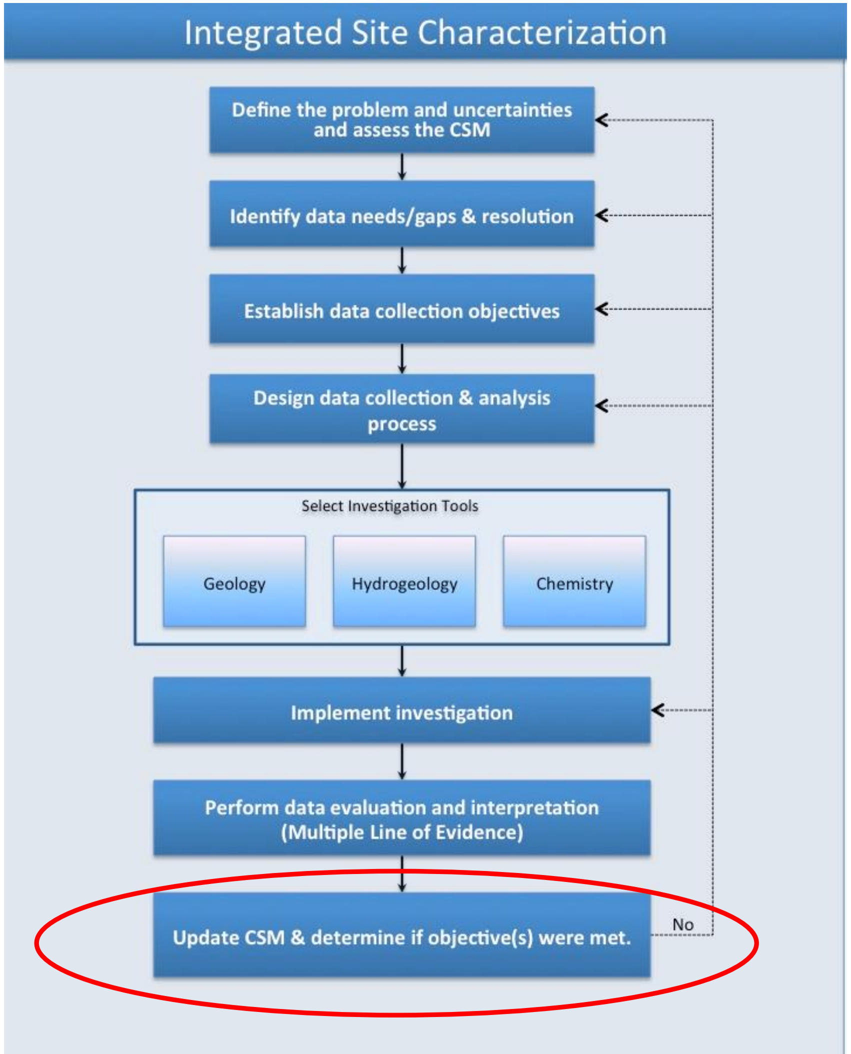
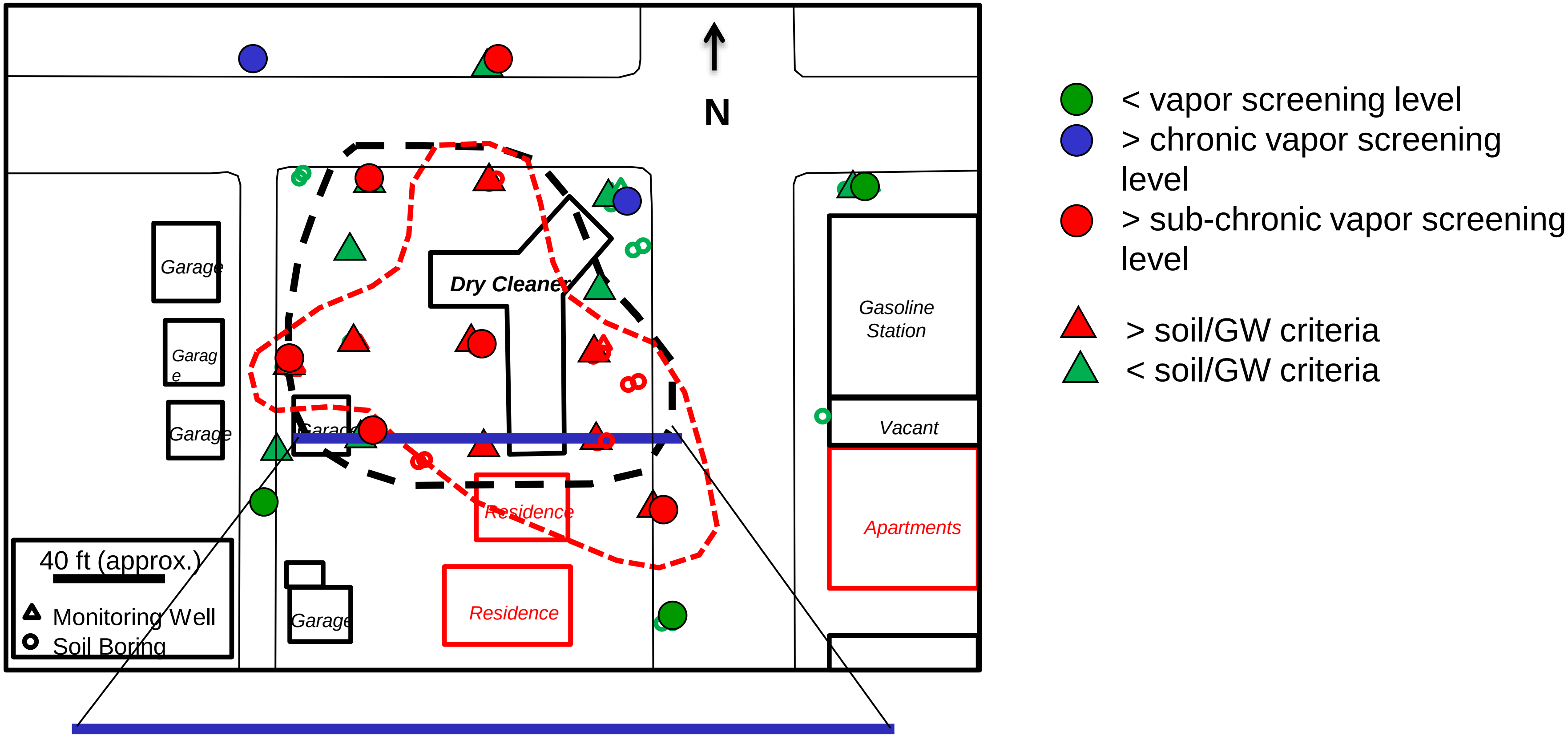
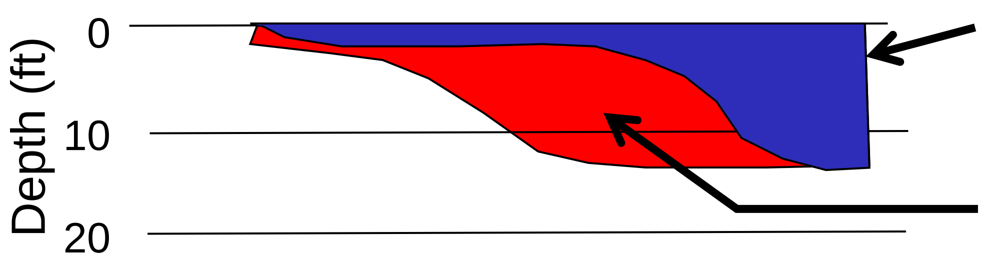


Figure 4-1 Integrated Site Characterization

Step 8: Dry Cleaners – CSM Update





Original vertically-delineated plume

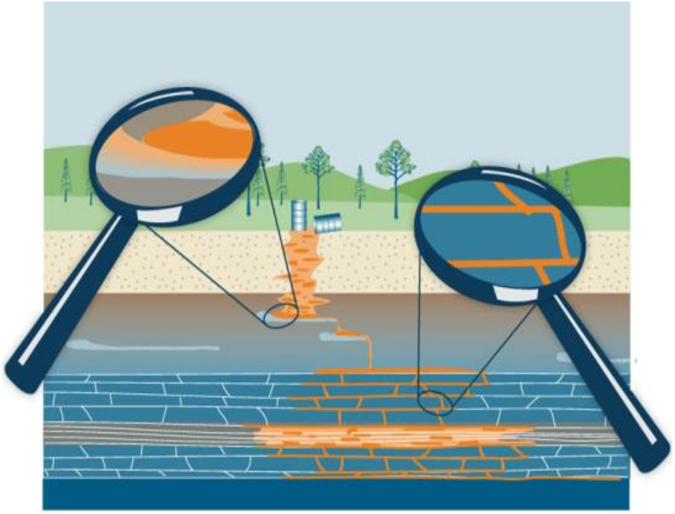
With additional data, the source area was found to extend west further than previously delineated

Integrated Site Characterization Benefits for Dry Cleaners Sites

- 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%)

Training Overview

- DNAPL Characteristics
- Life Cycle of a DNAPL Site
- Integrated Site Characterization
  - Plan
  - Tools Selection
  - Implementation
- Summary



Summary Integrated Site Characterization

- Planning
- Tools selection
- Implementation

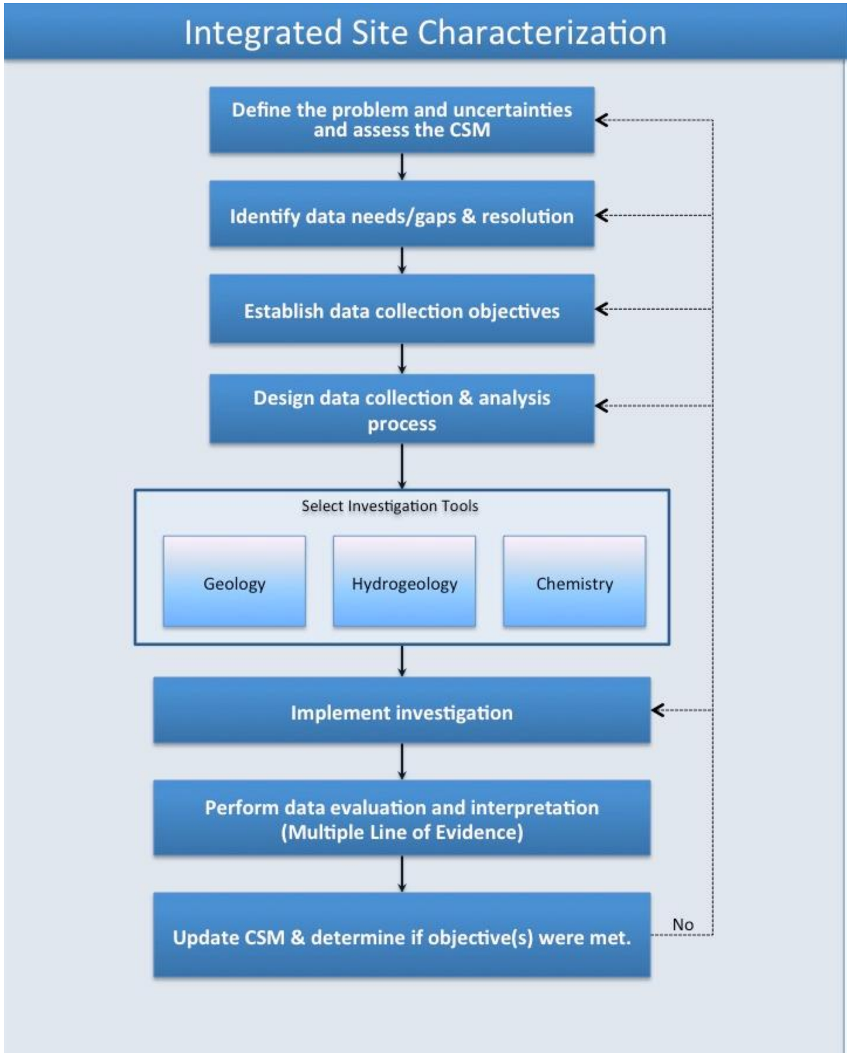


Figure 4-1 Integrated Site Characterization

Integrated Site Characterization is the Path Forward

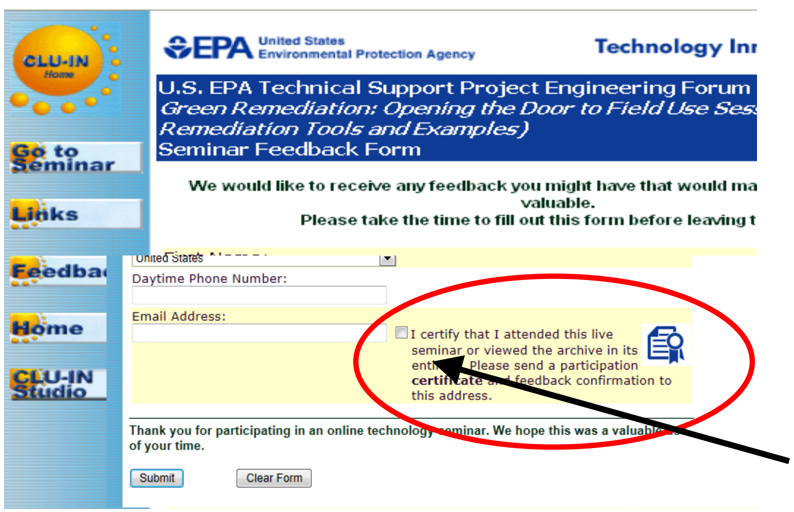
- Too many DNAPL sites are stalled or unresolved
- Examining DNAPL mobility in heterogeneous environments promoted better remedy selection
- Better characterization builds trust and confidence in site decisions

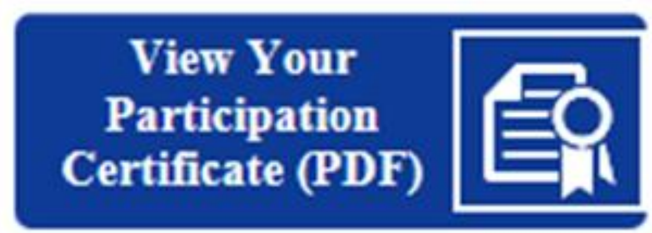
Thank You

Follow ITRC

Poll Question

- **2nd question and answer break**
- **Links to additional resources**
  - http://www.clu-in.org/conf/itrc/IDSC/resource.cfm
- **Feedback form – *please* complete**
  - http://www.clu-in.org/conf/itrc/IDSC/feedback.cfm





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