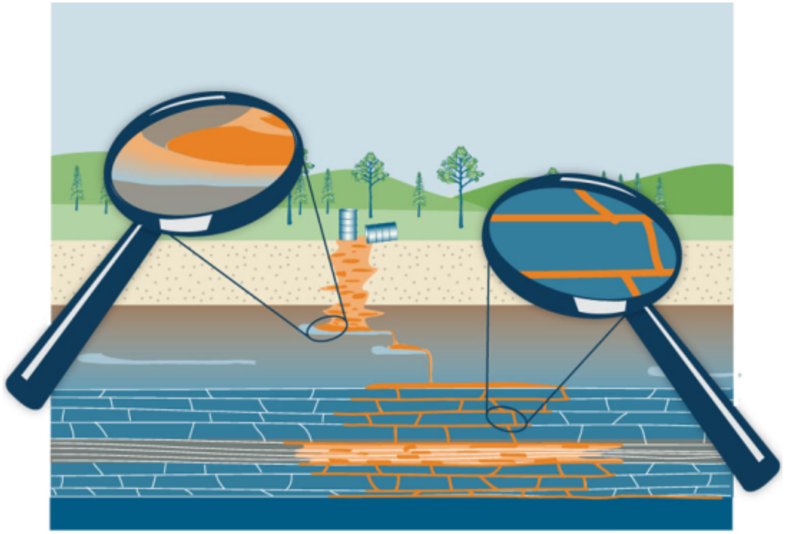
Integrated Site Characterization and Tools Selection

Tuesday, May 15, 2018
Kauffman Foundation Conference Center



Instructors:

Ryan Wymore, P.E. CDM Smith, Denver, CO

Michael B. Smith, VT Dept. Env Conservation, Montpelier, VT

Heather Rectanus PhD, P.E. Battelle, Ellicott City, Maryland, USA

Naji Akladiss, ME Dept. Environmental Protection P.E., Portland, ME

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Problem Statement: Non-Aqueous Phase Liquid (DNAPL & LNAPL) Sites

Sites contaminated with NAPLs present significant environmental challenges and have proved recalcitrant to remediation

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

Coal Tar

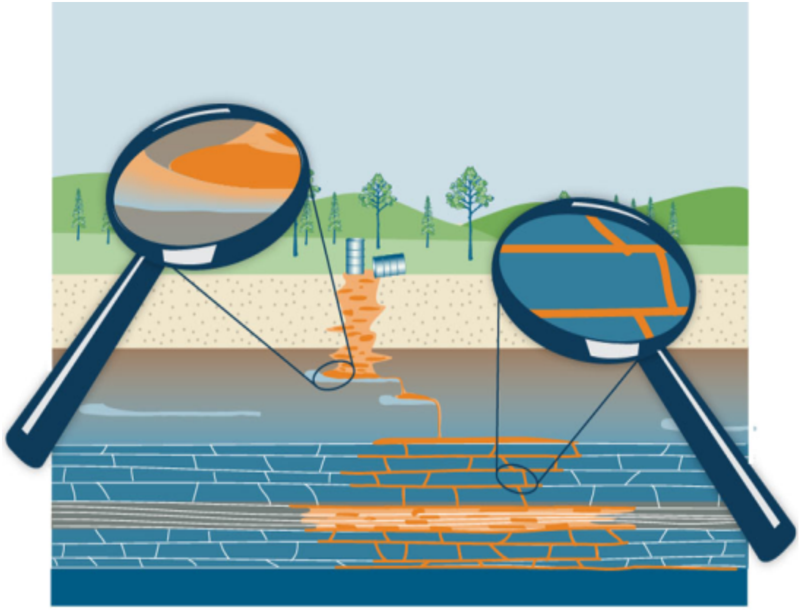
Courtesy Michael Smith

Objectives of Training

1. Understand Conceptual Site Model (CSM) for a typical NAPL-Dissolved phase plume site
2. Understand the fate and transport of NAPLs in the subsurface
3. Understand the concepts of an Integrated Site Characterization strategy
4. Present existing and new tools and techniques that can be used to improve/conduct site characterizations using the Integrated Site Characterization strategy

Training Overview

- NAPL Characteristics
- Life Cycle of a NAPL Site
- Integrated Site Characterization
- Summary



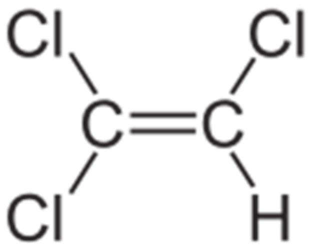
ISC-1, Chapter 2

Review of NAPL Types

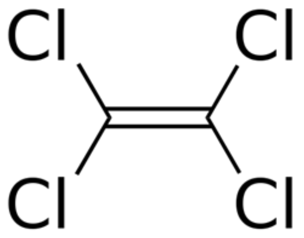
- Non-Aqueous Phase Liquid (NAPL)
  - Also known as: Neat or “Pure” Liquid, Organic Liquid, Free Product
- Light Non-Aqueous Phase Liquid (LNAPL)
  - Less dense than water (liquid density < 1.0 g/mL), floats on top of water.
- Dense Non-Aqueous Phase Liquid (DNAPL)
  - More dense than water (liquid density > 1.0 g/mL), sinks when placed in water.

Review of NAPL Types

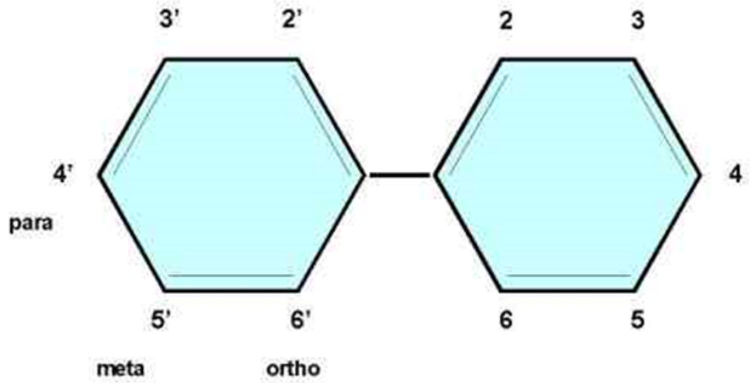
- Common types of DNAPLs
  - Chlorinated solvents
  - Coal tar
  - Creosote
  - Heavy petroleum such as some #6/Bunker fuel oil products
  - Oils containing Polychlorinated biphenyls (PCBs)



TCE (C_2HCl_3)
trichloroethene
trichloroethylene



PCE (C_2Cl_4)
Tetrachloroethene
Tetrachloroethylene
perchloroethylene (perc)



PCB
Polychlorinated biphenyl

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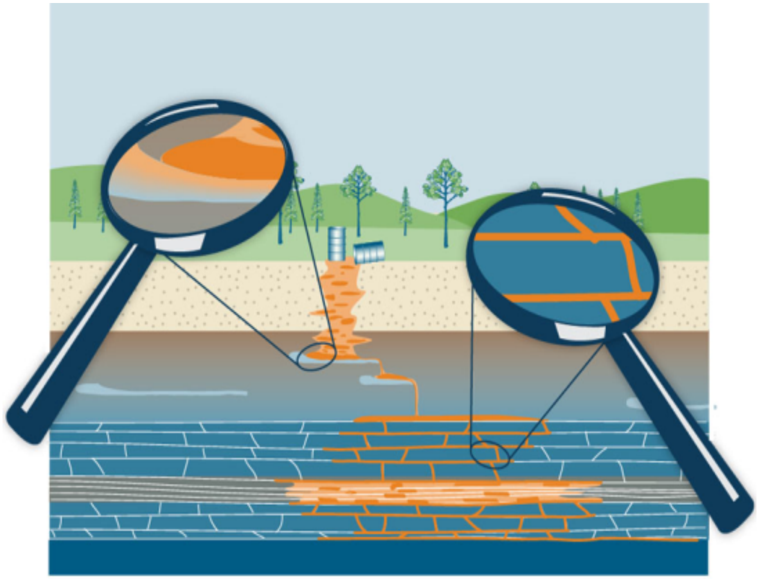


ISC-1, Chapter 3

Important NAPL Properties Affecting Mobility

NAPL Chemical & Physical Properties

- Density
- Viscosity
- Composition
- Solubility
- Volatility
- Sorption
- Phase Distribution

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**

NAPL Composition

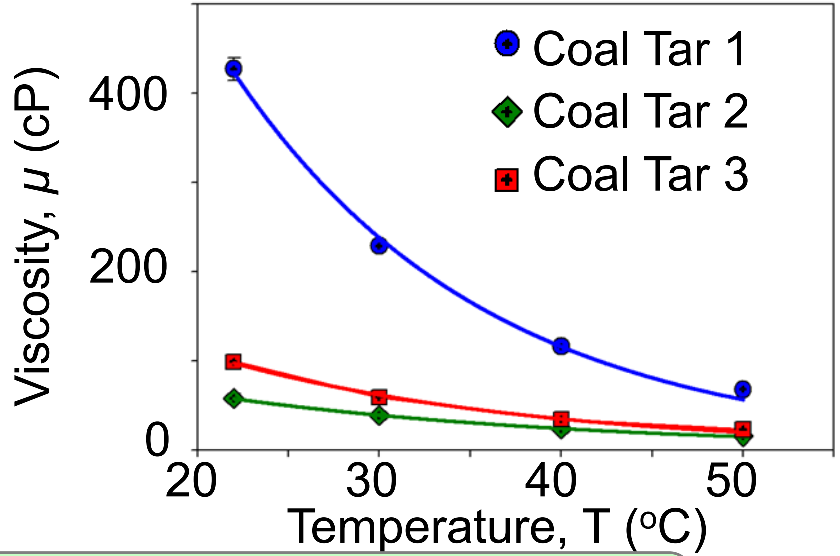
- Properties of mixed NAPL are different from pure component properties
  - Chlorinated solvents often include other compounds such as grease, oils or stabilizers
  - For mixed sources, chlorinated compounds from DNAPL could partition into LNAPL
  - NAPL weathering occurs in subsurface
    - Coal Tar – 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 Viscosity (Dynamic)

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

- Temperature dependent
  - μ_w = 0.894 cP 25 °C
  - μ_w = 1.002 cP 20 °C



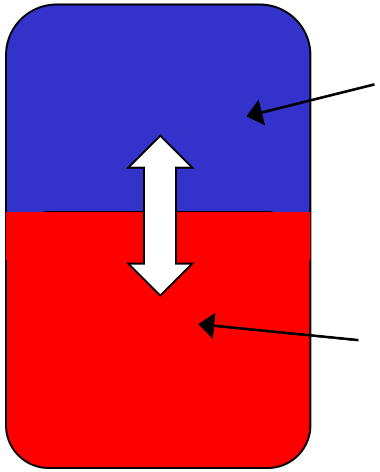
KEY POINT: **Influences mobility in the subsurface**

Solubility Review - Pure NAPLs

- Aqueous Solubility ($C_{w,sol}$)
  - Maximum amount of a pure compound that can be dissolved in water at equilibrium

Mass Conc: mg_{cont}/L_{water}

C_{water}



Water (Aqueous Phase)

C_{NAPL}

NAPL (Organic Liquid) (e.g., Pure TCE)

Mass Conc: mg_{cont}/L_{NAPL}

Note: for a Pure NAPL, mass conc = liquid density

Solubility of Representative NAPLs

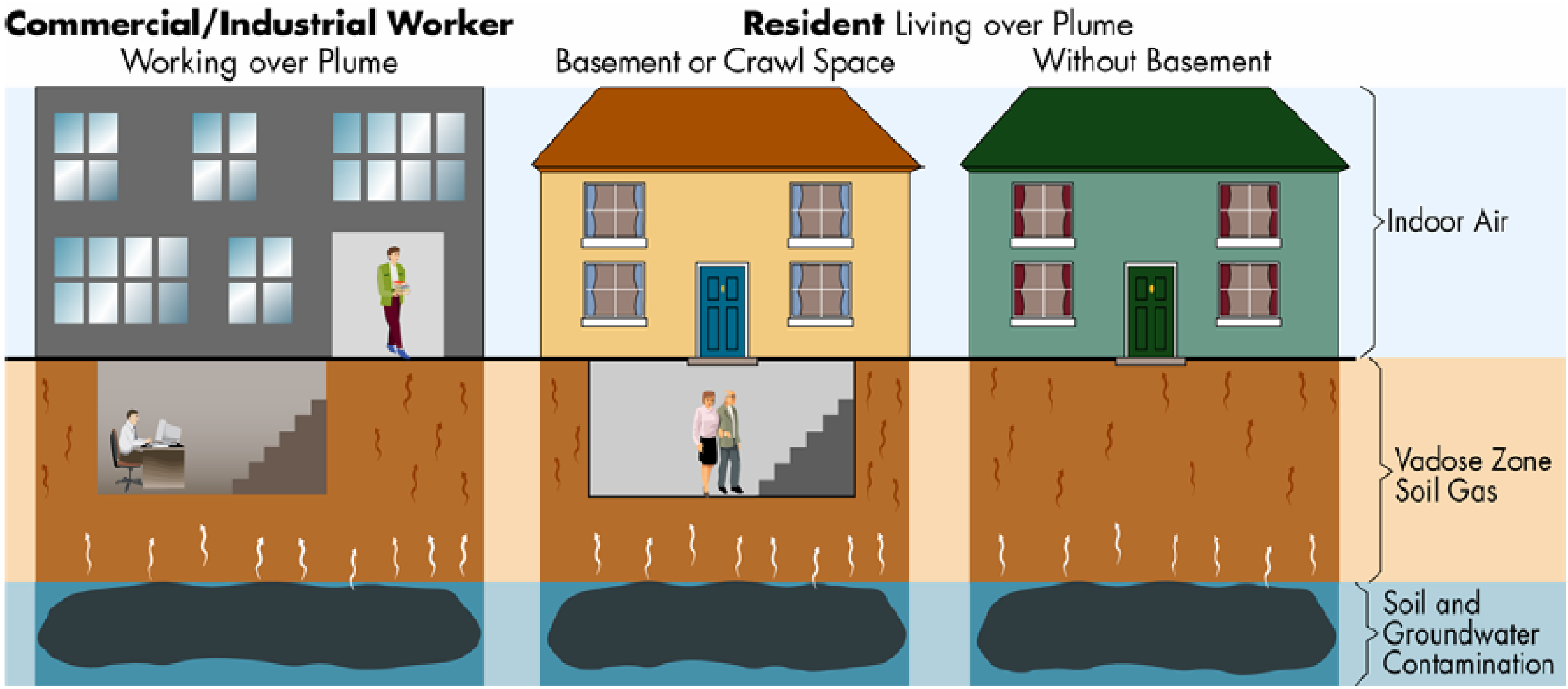
NAPL Contaminant	MW (g/mole)	Density (g/mL)	Solubility (mg/L)
Benzene	78.12	0.88	1,780
Gasoline (mixed NAPL)	100-105	0.72-0.78	100-48,000
Trichloroethylene (TCE)	131.38	1.46	1,100
Tetrachloroethylene (PCE, Perc)	165.82	1.62	150-200

- Often different in site groundwater than in the laboratory

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

NAPL Volatility: Why is it important?

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

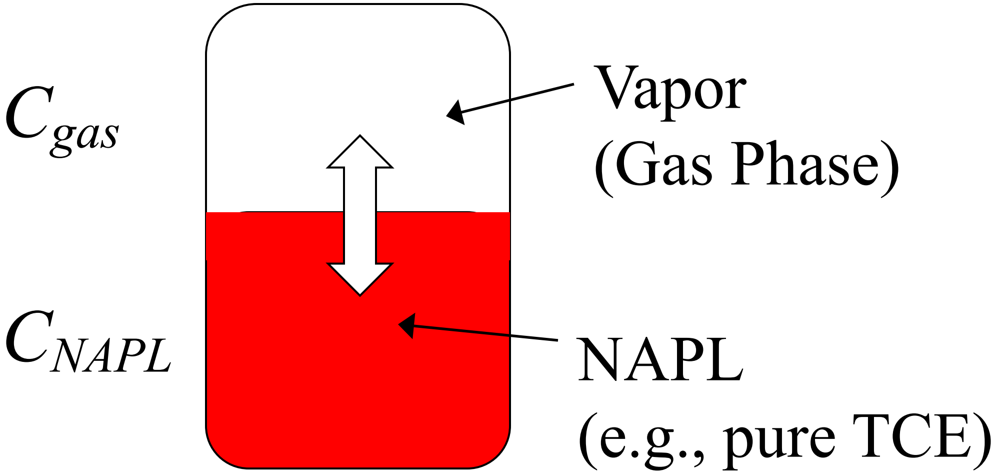


KEY POINT: **Influences contaminant fate and transport in the unsaturated zone and risk of vapor intrusion (VI)**

Volatility – Vapor Pressure (NAPL-Air)

Vapor Pressure (VP_{sat} or P_0)

– Maximum amount of a pure compound that can exist in the gas phase



Use ideal gas law to convert VP to concentration

$$PV = nRT$$

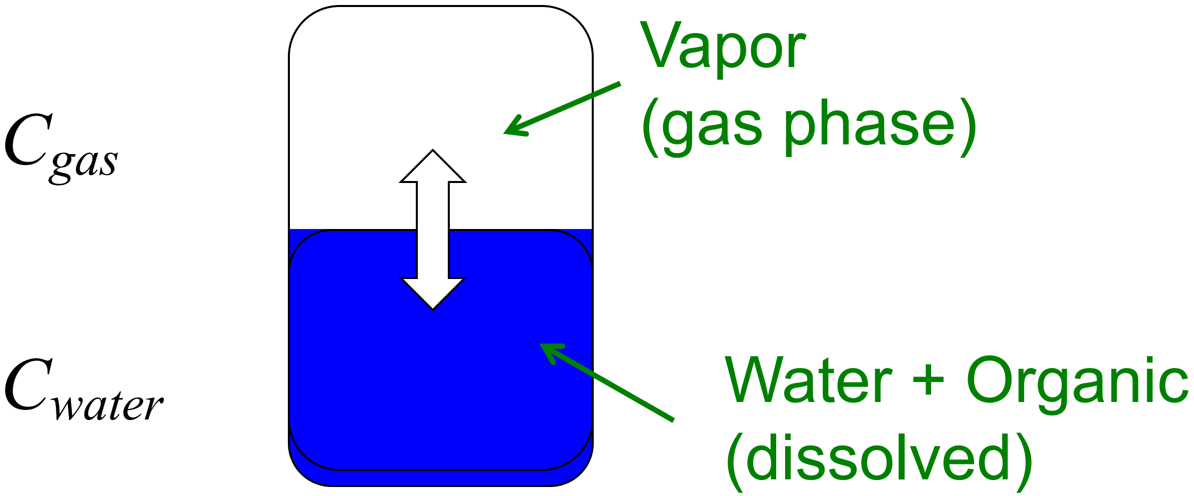
$$\frac{n}{V}(MW) = \frac{P}{RT}(MW)$$

$$C_g = \frac{P}{RT}(MW)$$

Volatility: Air-Water (dissolved)

- Henry's Law Constant (K_H or H)
  - Find the amount of organic contaminant that will exist in a gas phase in contact with water

$$P(atm) = K_H \frac{atm\ L}{mole} [C_w] \frac{mole}{L}$$



Dimensionless form of Henry's Law constant (H)

$$C_g = \frac{C_g}{C_w}(C_w) = H(C_w)$$

to convert: $H = \frac{K_H}{RT}$

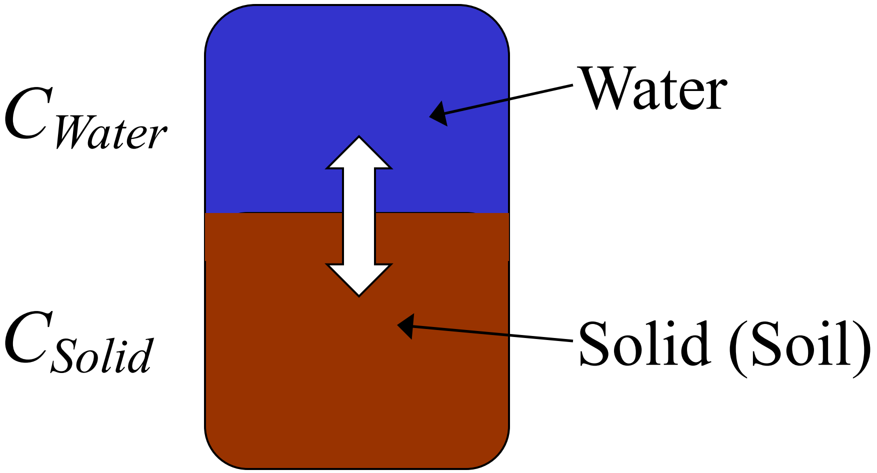
R = ideal gas constant,
T = temp (^oK)

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

Sorption: Solid – Water (dissolved)

- Sorption (Adsorption and/or Absorption)
  - Typically dominated by soil organic matter (absorption or partitioning) and high surface area minerals (adsorption)
  - A linear isotherm is often used to describe sorption

Linear Sorption – NOT always a good assumption



$$C_s = C_w * K_D$$

Soil Distribution coefficient

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

Organic Carbon Distribution coefficient

Predicting NAPL Presence

- Historically a 1% of solubility rule of thumb to estimate NAPL presence- *now viewed as unreliable, false positive and negative.*
- Instead, calculate the contaminant phase distribution (soil, water, NAPL) based on soil boring concentrations (mg/kg).

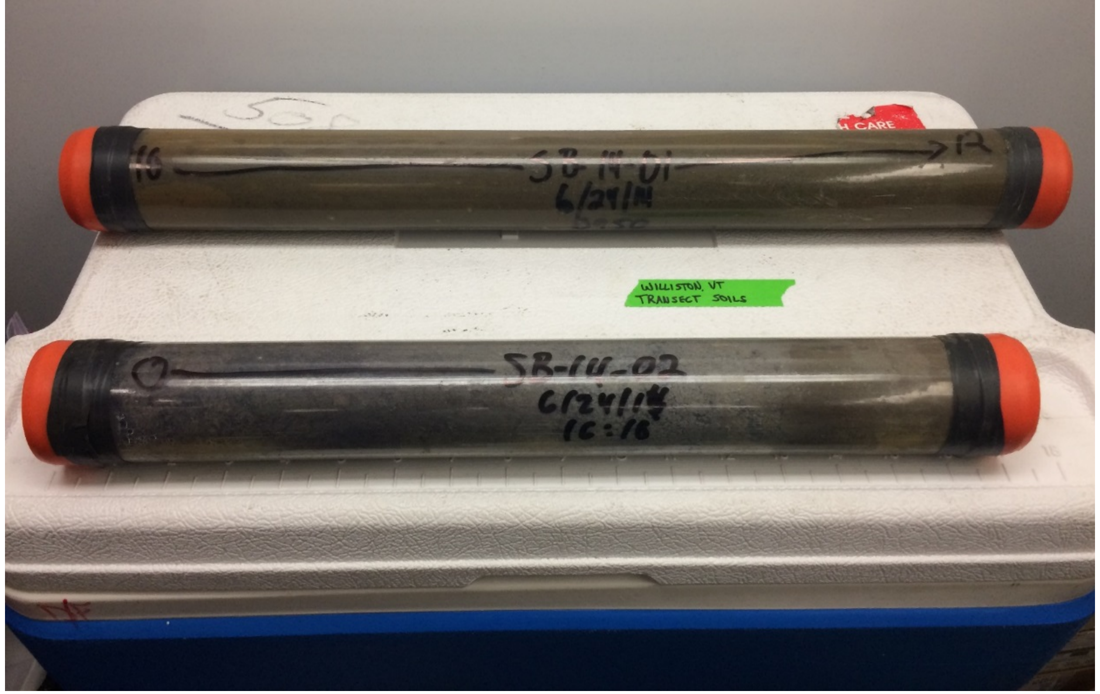
$$C_T = \underbrace{C_w\theta_w}_{\text{water}} + \underbrace{C_g\theta_g}_{\text{gas}} + \underbrace{\rho_b C_s}_{\text{solid}} + \underbrace{C_N\theta_N}_{\text{NAPL}}$$

Below Water Table: $NAPL = C_T - (C_w\theta_w + \rho_b C_s)$

NAPL present if: $C_T > C_w\theta_w + \rho_b C_s$

Soil Core Analysis: Phase Distribution Example

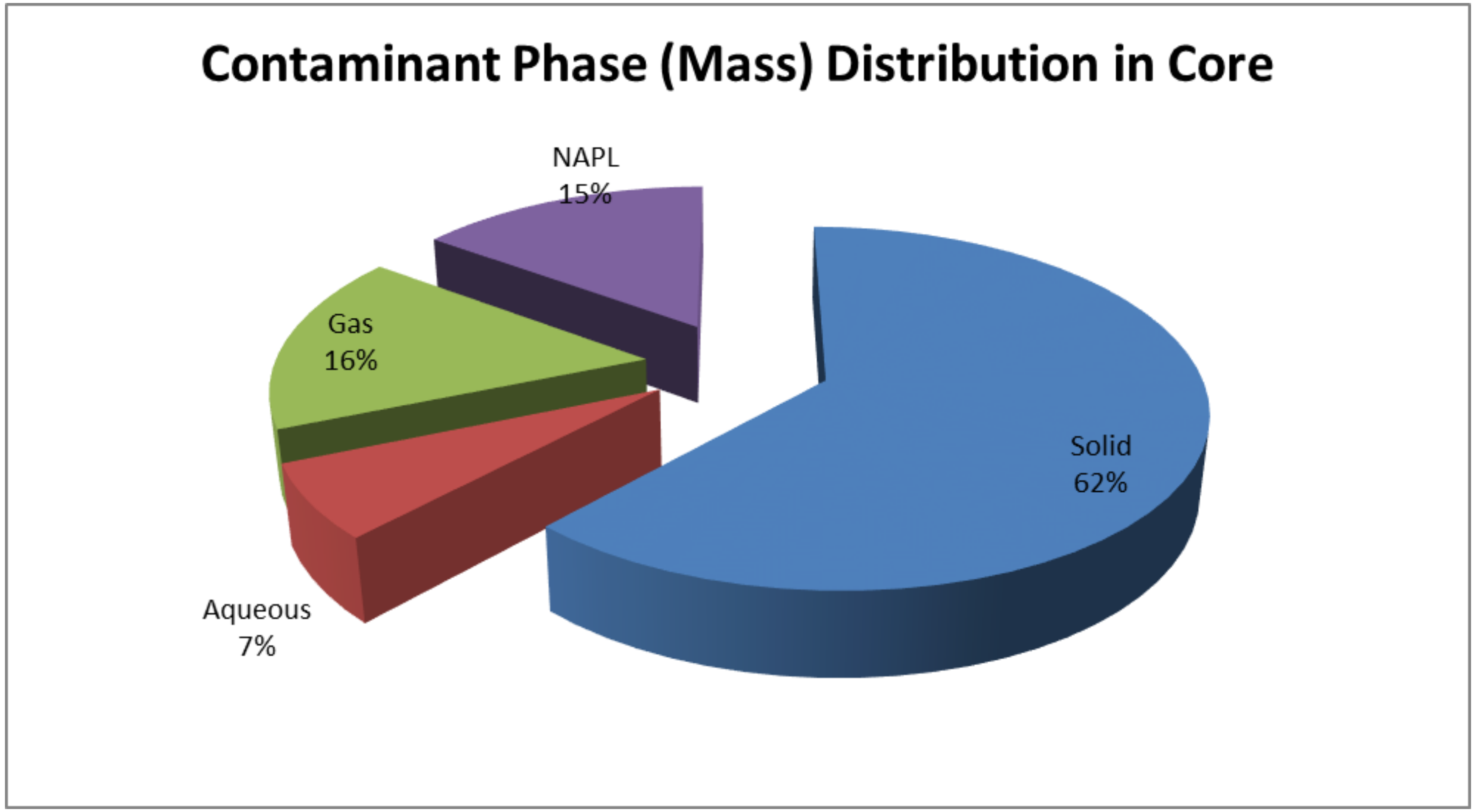
C_{PCE} = 150 mg/kg



$$C_T = C_w\theta_w + C_g\theta_g + \rho_b C_s + C_N\theta_N$$

Total (mg/L_t) = water gas solid NAPL

Phase Distribution Spreadsheet



from ISC-1,

NAPL Interactions with the Sub-Surface Media Affecting Mobility

- The following properties significantly affect NAPL mobility and the interactions between NAPLs and sub-surface media:

Interfacial Tension

Wettability

Capillary Pressure

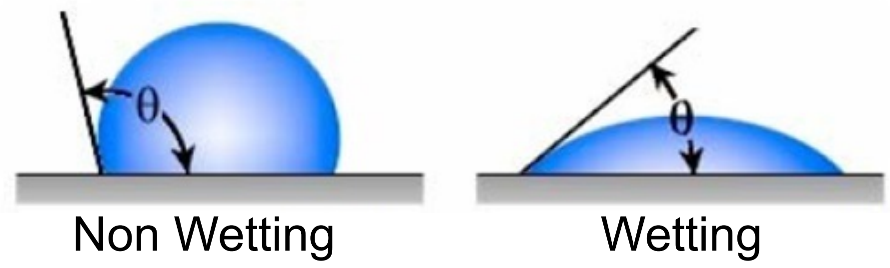
Saturation

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

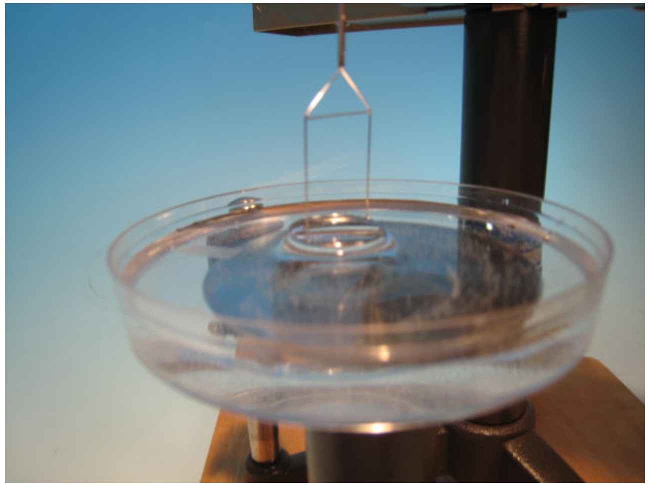
Wettability of soils may change after exposure to NAPL

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

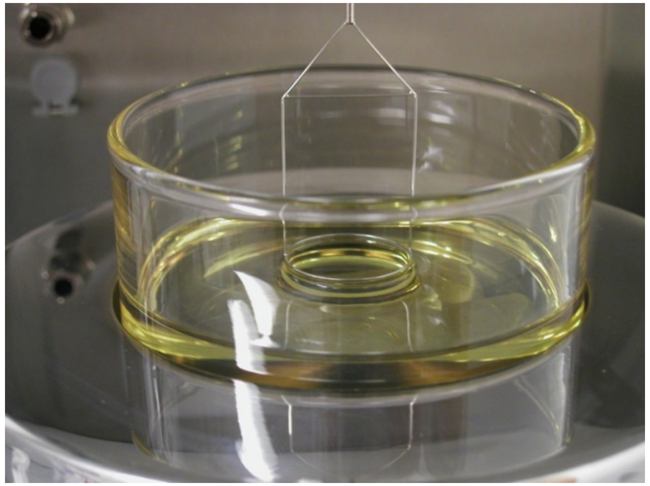
NAPL Interfacial Tension

- Interfacial Tension
  - Represents the force parallel to the interface of one fluid with another fluid (usually air or water), which leads to the formation of a meniscus and the development of capillary forces and a pressure difference between different fluids

Surface Tension (Air-Liquid)

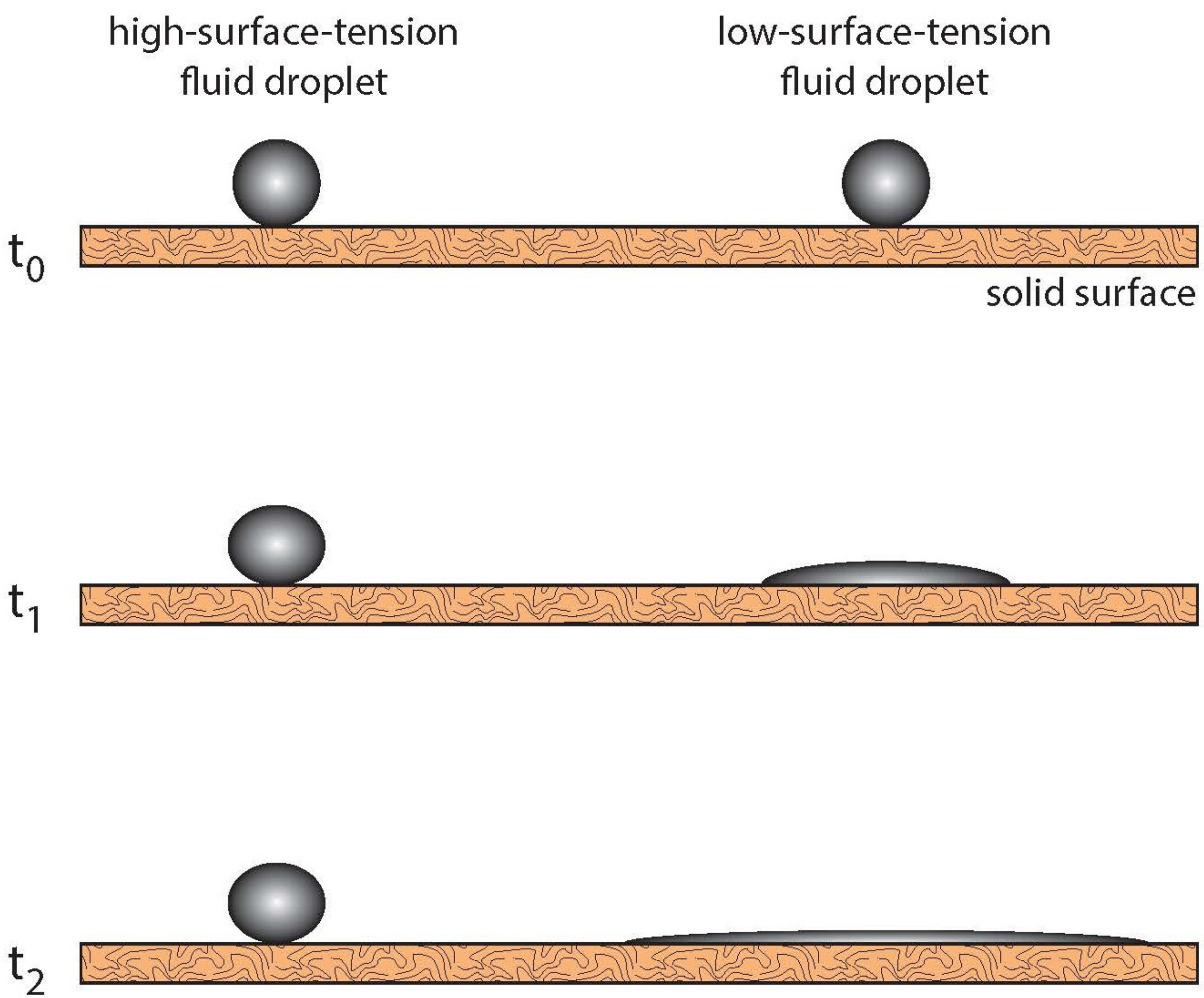


Interfacial Tension (Liquid-Liquid)



Photos Courtesy Kurt Pennell

NAPL Interfacial Tension



ISC-1 Figure 2-4.

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 in Soil

- Capillary Pressure (P_c)
  - Capillary Pressure is also a function of the, the contact angles θ , and the pore size:

$$P_c = (2\,\sigma \cos\theta\,)/r$$

(Bear, 1979)

Where σ is the interfacial tension between the two liquids

θ is the contact angle

r radius of the water filled pore space

Capillary Entry Pressure (*P_{ce}*)

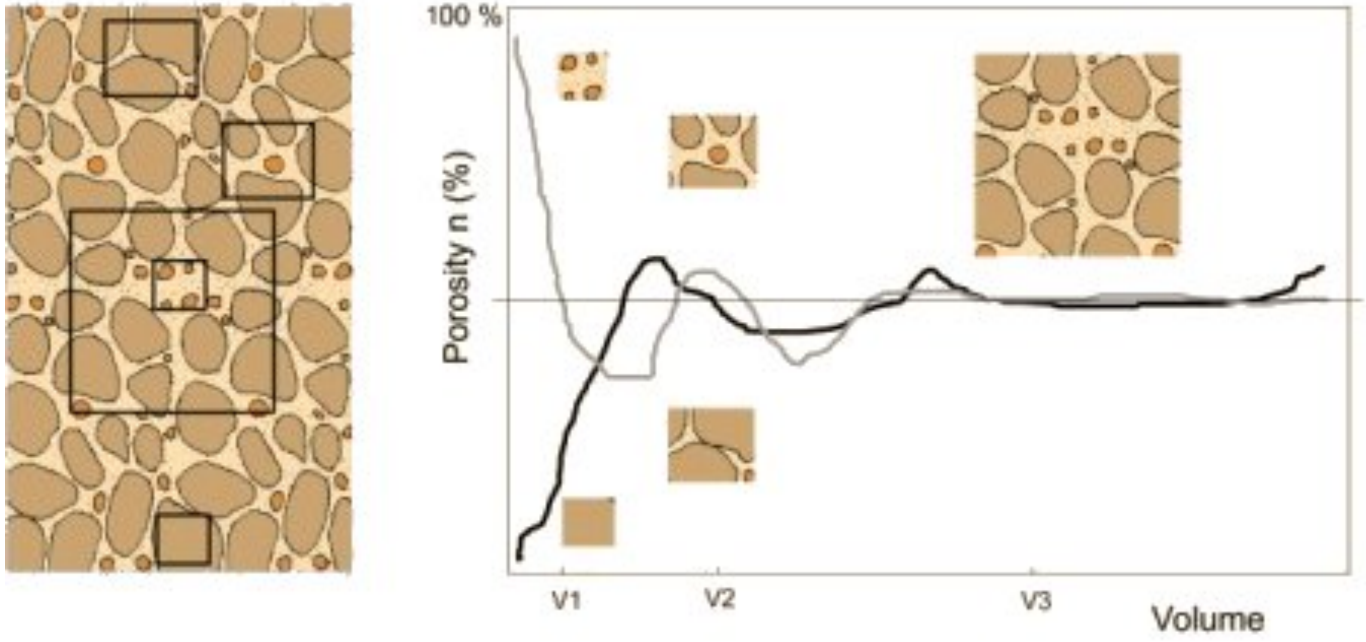
- P_{ce} represents the capillary pressure at S_r of the non-wetting fluid.

- The value of P_{ce} represents the pressure that must be overcome in order for DNAPL (as a non-wetting fluid) to initially displace water from initially water-saturated media.

- The P_{ce} represents the minimum pressure that is required for DNAPL to be mobilized into any geologic material

Representative Elementary Volume (REV)

- Volumetric dimensions of the scale on which the continuum approach can be used
- Domain of porous media



ISC-1 Figure 2-3.

DNAPL Behavior in the Subsurface

▶ DNAPL Migration:

- For non-wetting DNAPLs below the water table, capillary forces within the subsurface media are the primary resisting force to DNAPL migration.

$$z_n = (2\sigma \cos\theta) / [r\, g\, (\rho_n \;\rho_w)]$$

(Kueper and McWhorter, 1991)

z_n: Height of DNAPL required to penetrate water saturated pores

σ: interfacial tension between NAPL and water

θ: contact angle

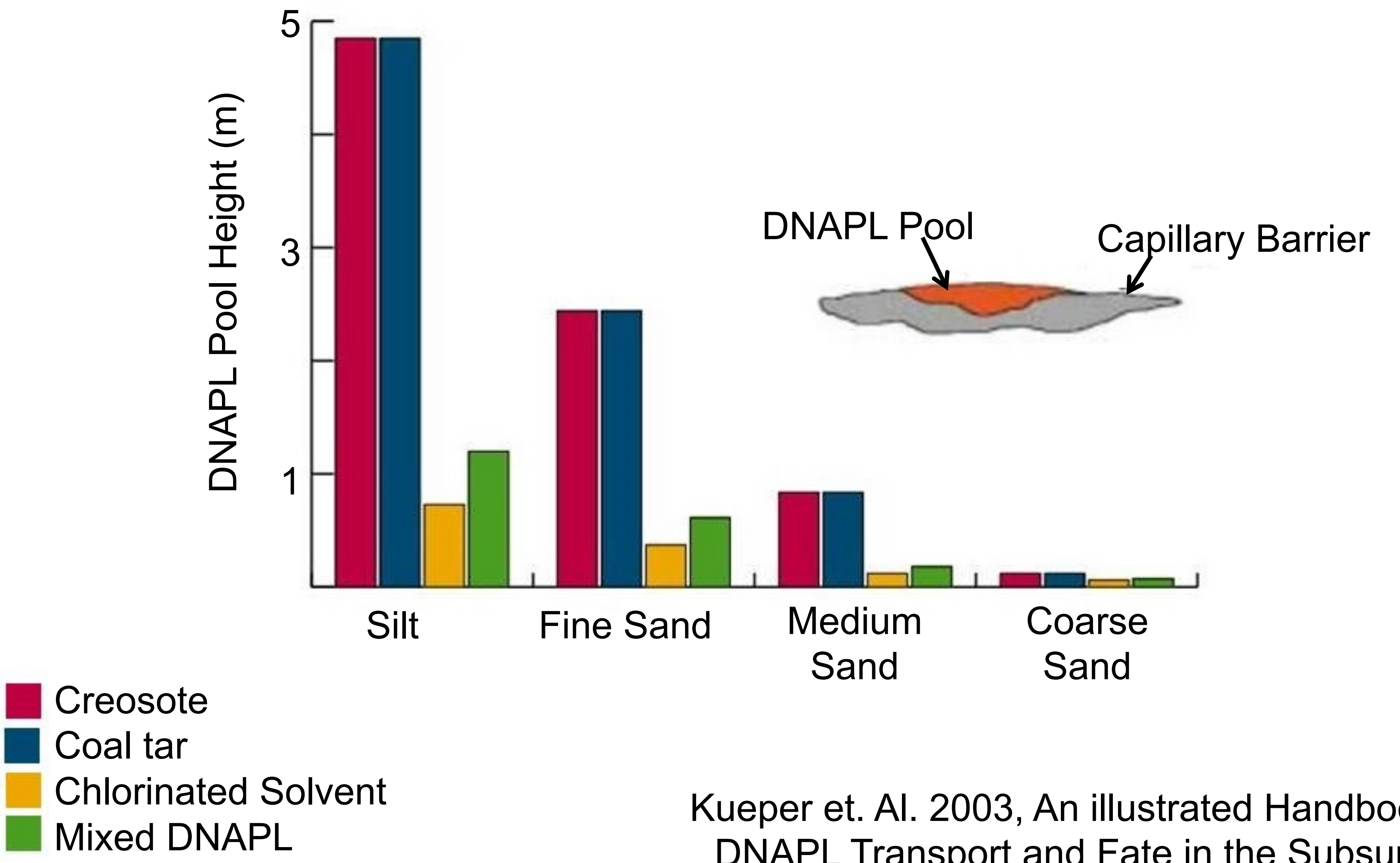
r: radius of water fill pore

g: gravity

ρ_w: water density

ρ_n: NAPL density

Capillary Pressure of Coarser Layers and DNAPL Entry

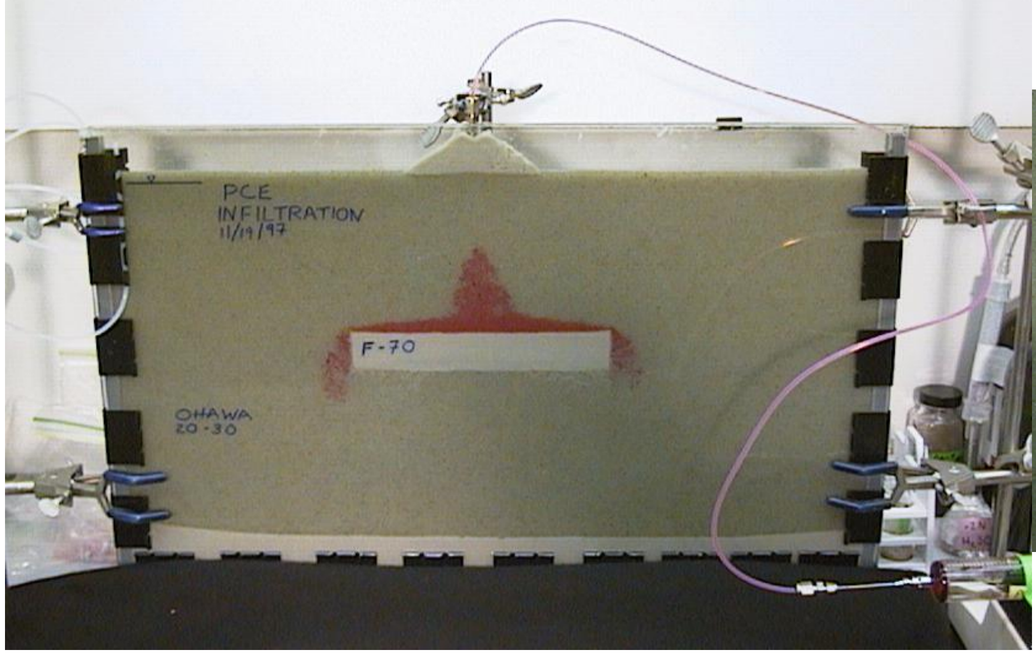


Kueper et. Al. 2003, An illustrated Handbook of DNAPL Transport and Fate in the Subsurface

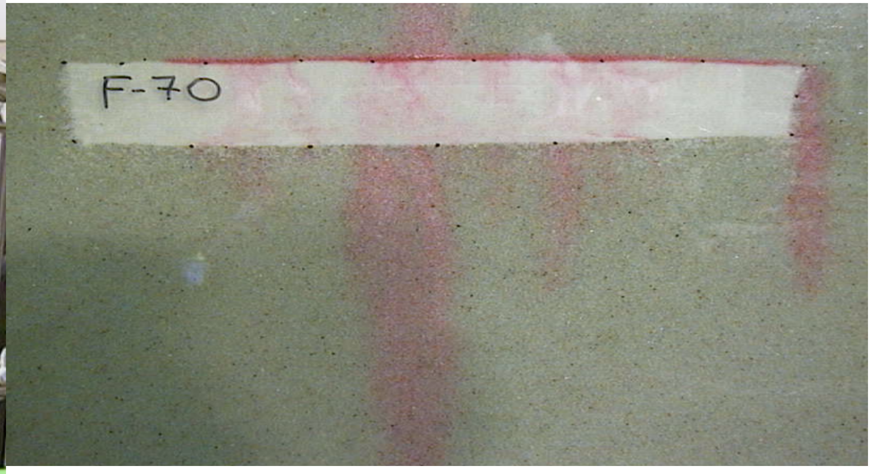
Effect of IFT on DNAPL Infiltration

DNAPL takes the path of least resistance

PCE-DNAPL, IFT = 47.8 dyn/cm (water)



PCE-DNAPL, IFT = 0.5 dyn/cm



Rathfelder et al., 2003, JCH

NAPL Saturation

- Saturation (S)
  - S represents the proportion of the subsurface pore space within a **Representative Elementary Volume** (REV) that is occupied by a fluid (NAPL, air, or water), ranging from 0 to 1.0.
- Residual Saturation (S_r)
  - S_r is the fraction of pore space within an REV that is filled by the NAPL at the point where it becomes **disconnected from NAPL** in an adjacent REV and 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)

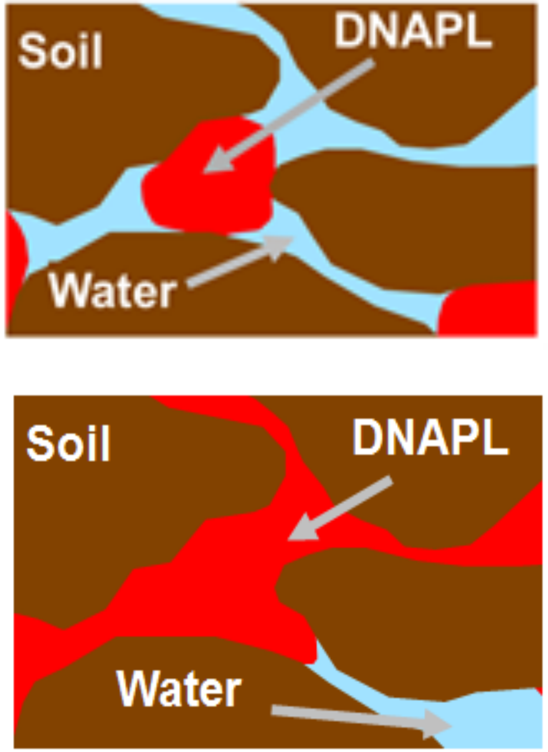


Figure modified from ISC-1, Chapter 2

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)

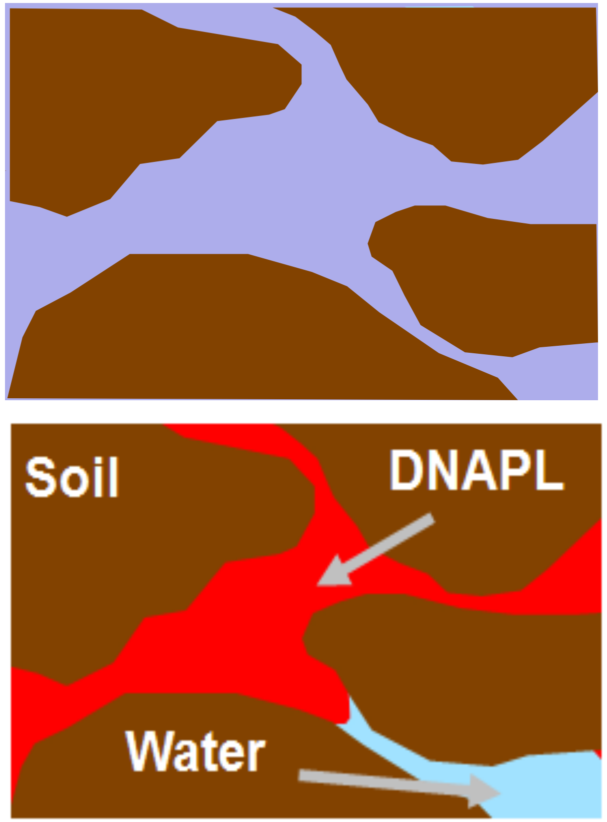
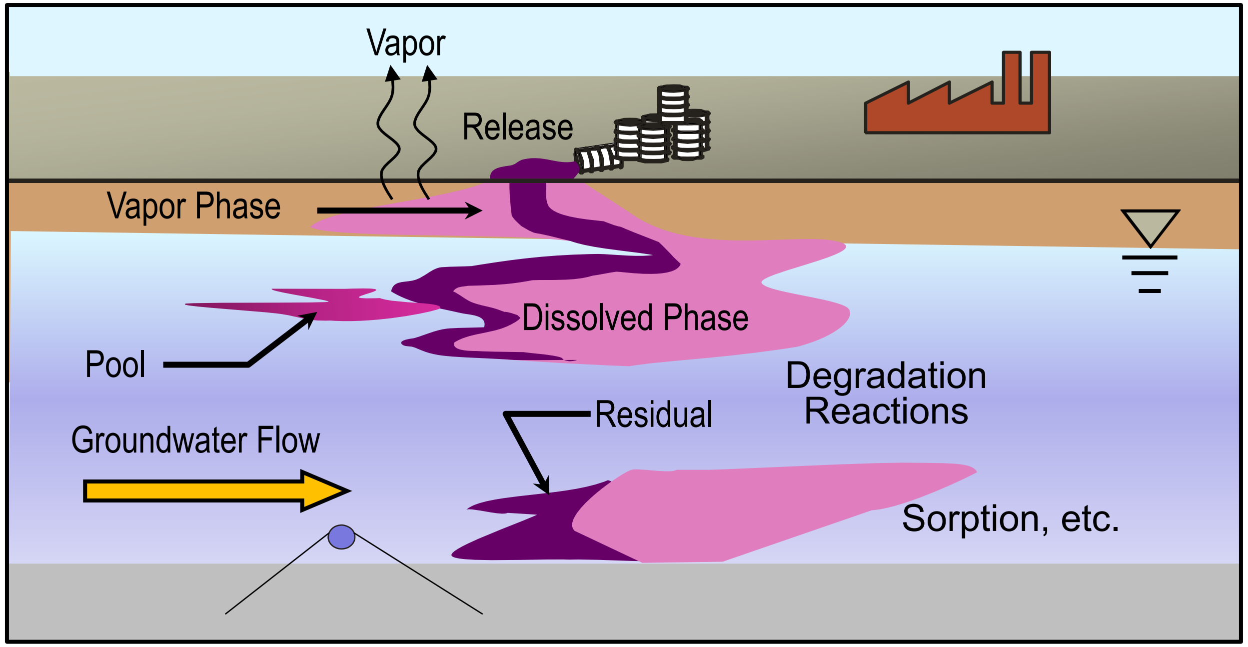
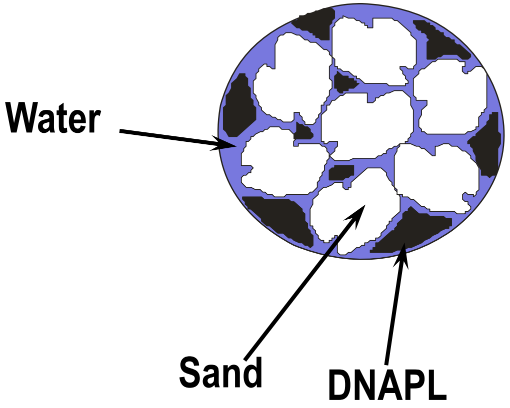


figure modified from ISC-1, Chapter 2

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

DNAPL Behavior in the Subsurface





- DNAPL migrates as a mobile and "continuous" body as long as the there is enough pressure (NAPL "head") to displace groundwater from the pores in the aquifer matrix.

Effects of NAPL properties on NAPL Fate and Transport

Saturation, Relative Permeability, and Capillary Pressure

- At S_r, NAPL is immobile.
- At very low S, approaching the value of S_r, NAPL mobility is very limited because k_r is very small.
- Increasing NAPL mobility (increasing k_r) can be influenced by
  - changes in pressure conditions affecting P_c,
  - or by changes in chemistry that affect interfacial tension.

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

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  - Plan
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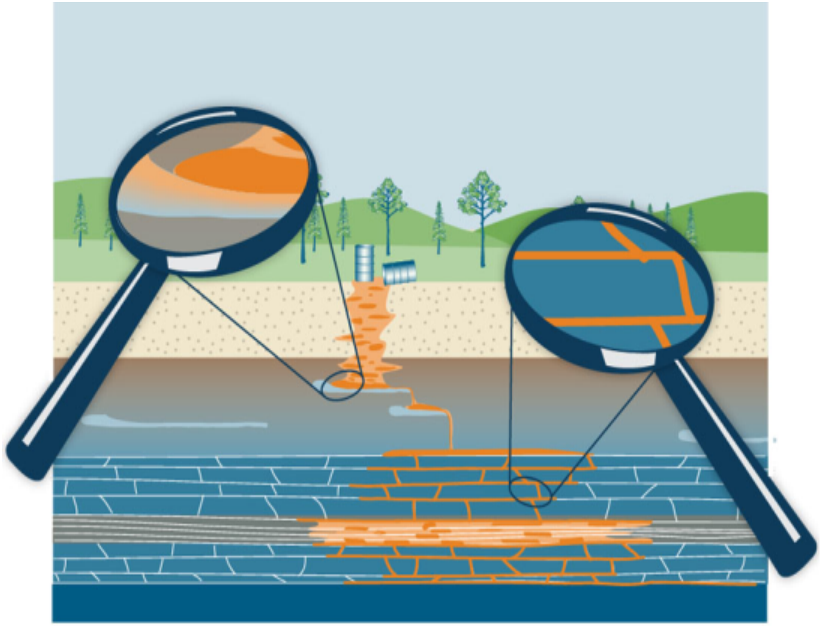
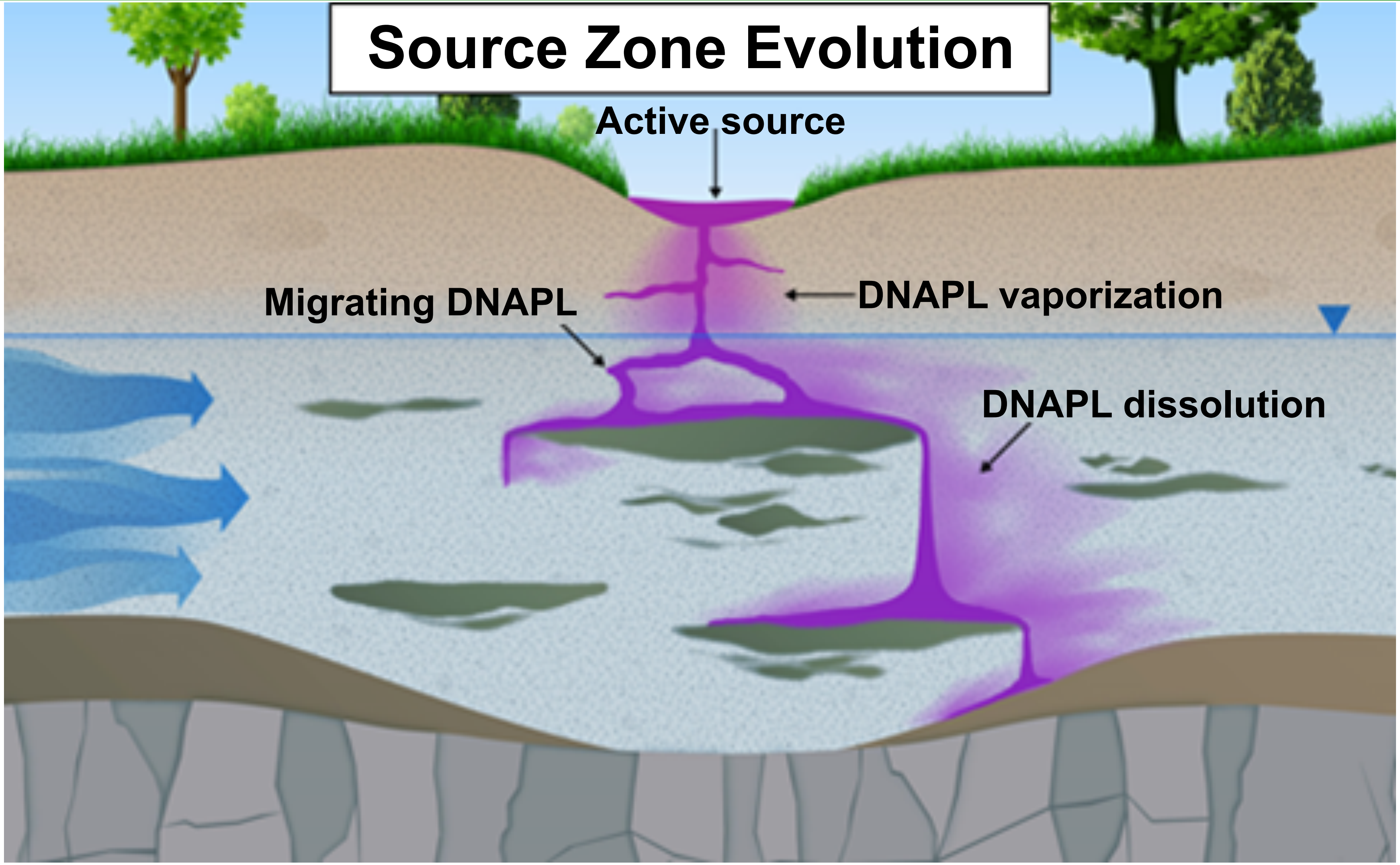
  - Implementation
- Summary



DNAPL Life Cycle – Classical Model



Kueper et al., 2013

Geology controls flow!

Lithologic heterogeneity leads to differences in subsurface pore structure and capillary properties.

These can be over very small distances/ intervals

Photo Courtesy of Fred Payne, Arcadis, Inc

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

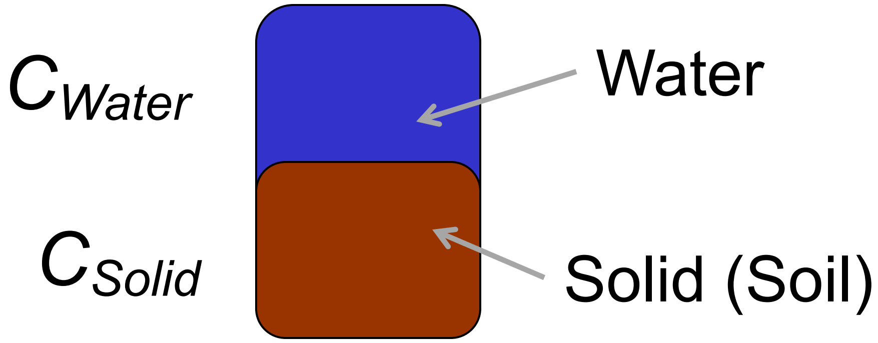
Molecular diffusion into low k zones

- 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



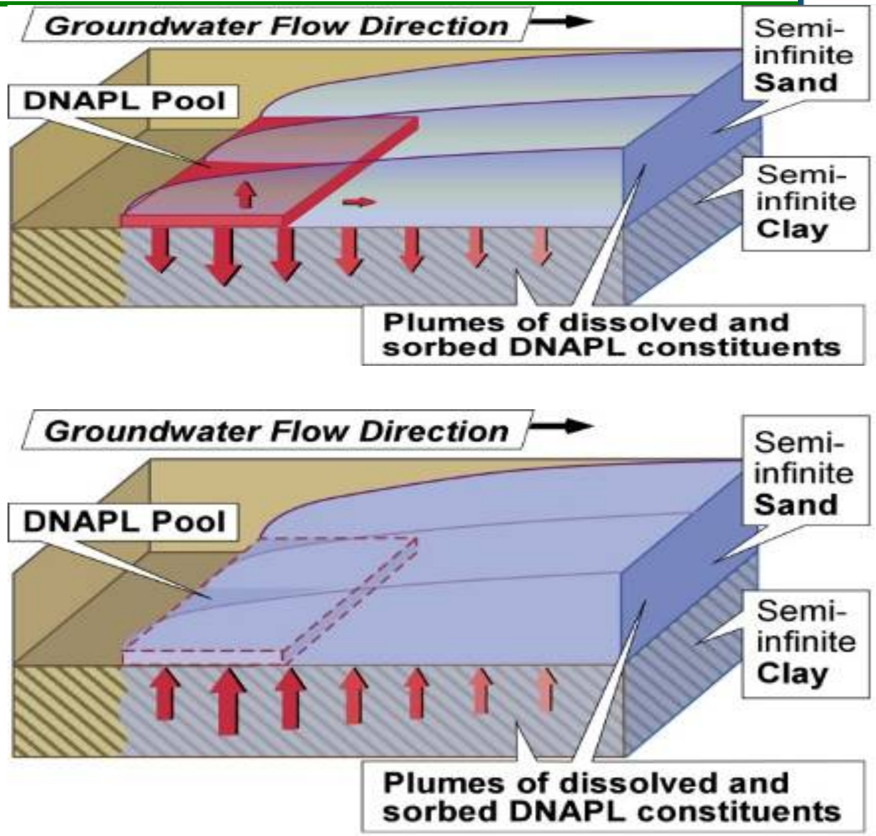
$$C_s = C_w * f_{oc} * K_{oc}$$

- 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"

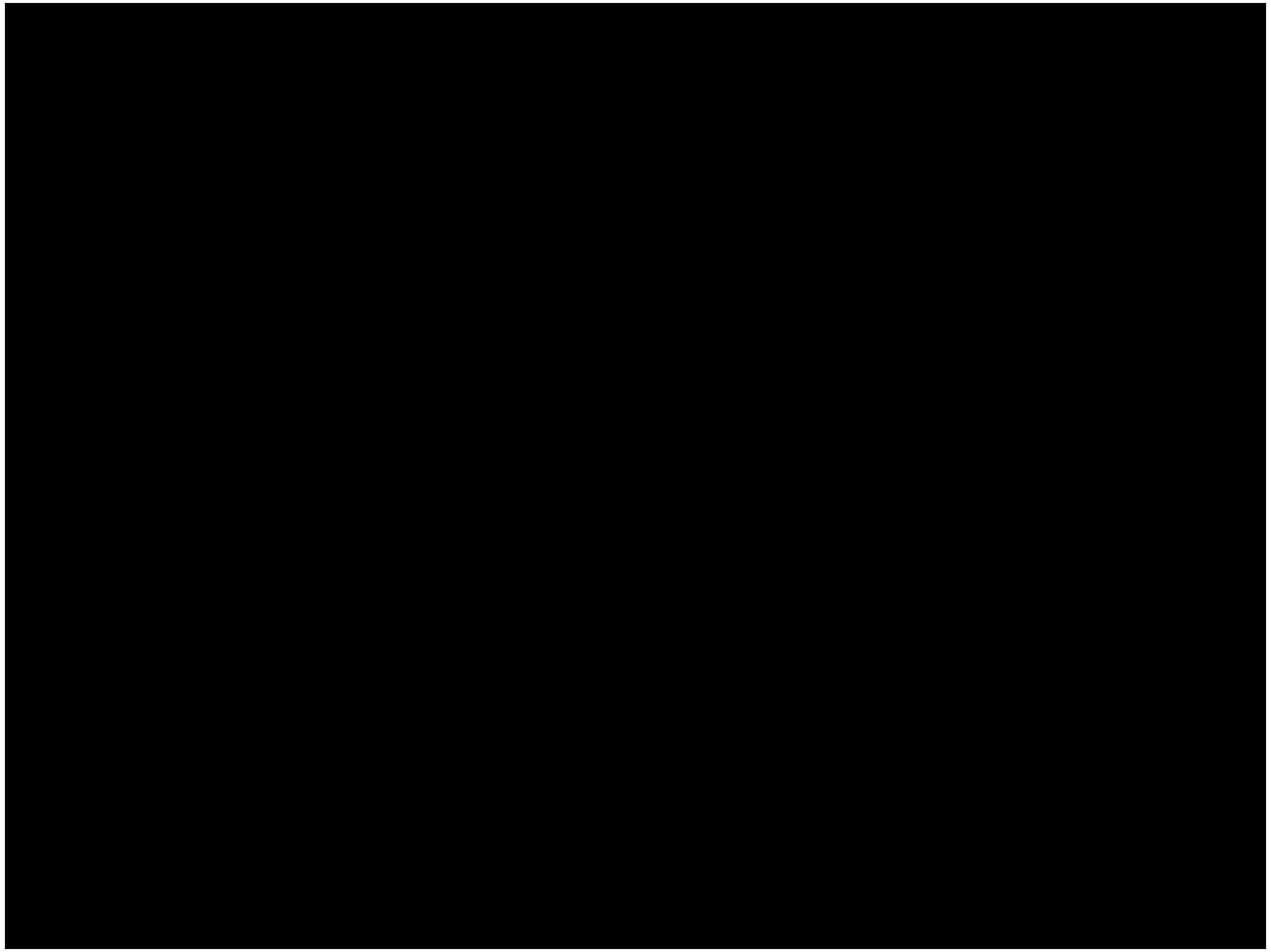
- ▶ Early time
  - Molecular Diffusion into low permeability zones in the aquifer matrix: "Matrix Diffusion"
- ▶ Late time
  - "Back Diffusion" out of low permeability zones into higher permeability zones



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

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

Colorado State Tank Study on Diffusion



Courtesy Tom Sale, Colorado State University

Controlling Role of Geology in Matrix Diffusion

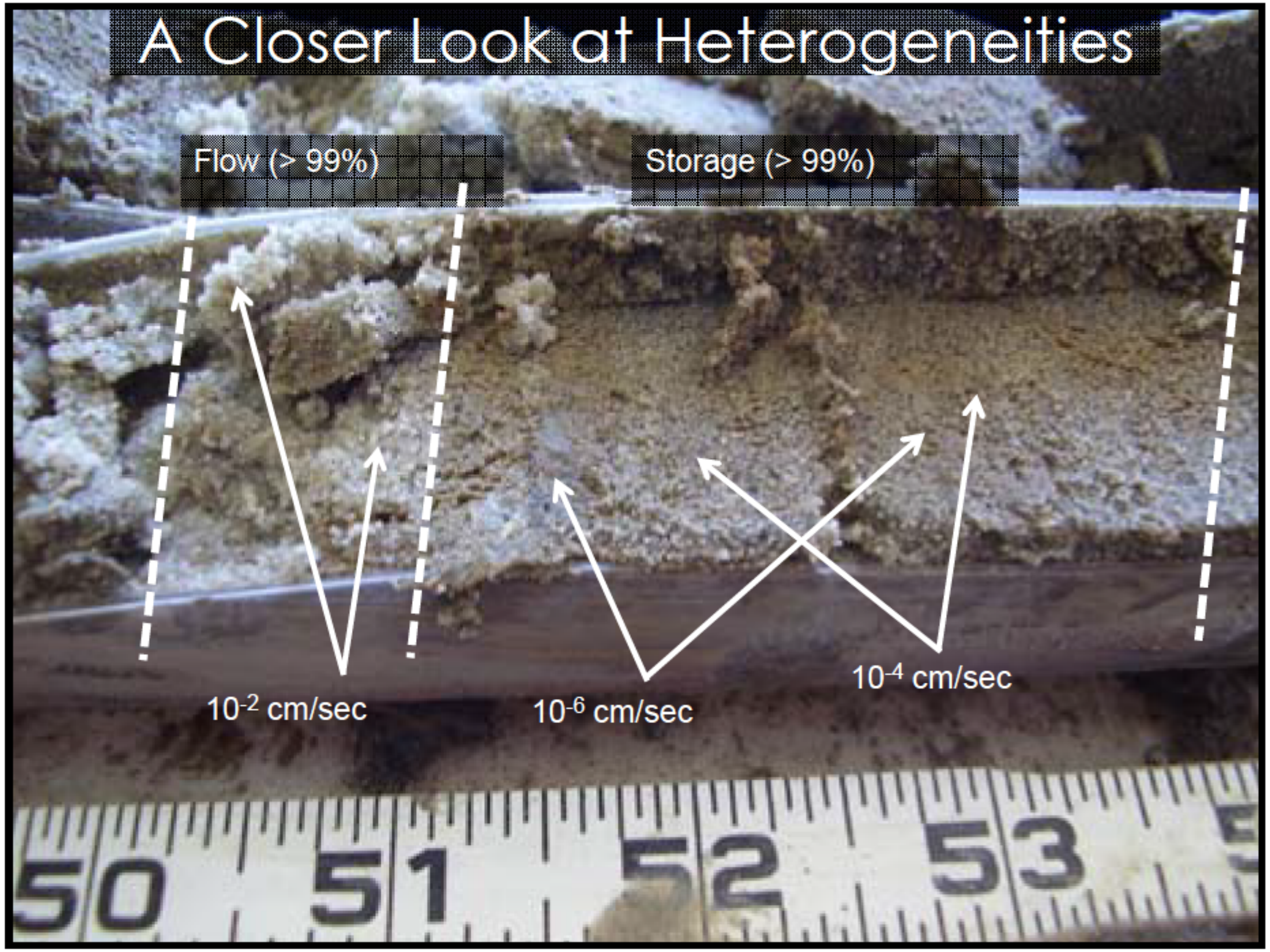
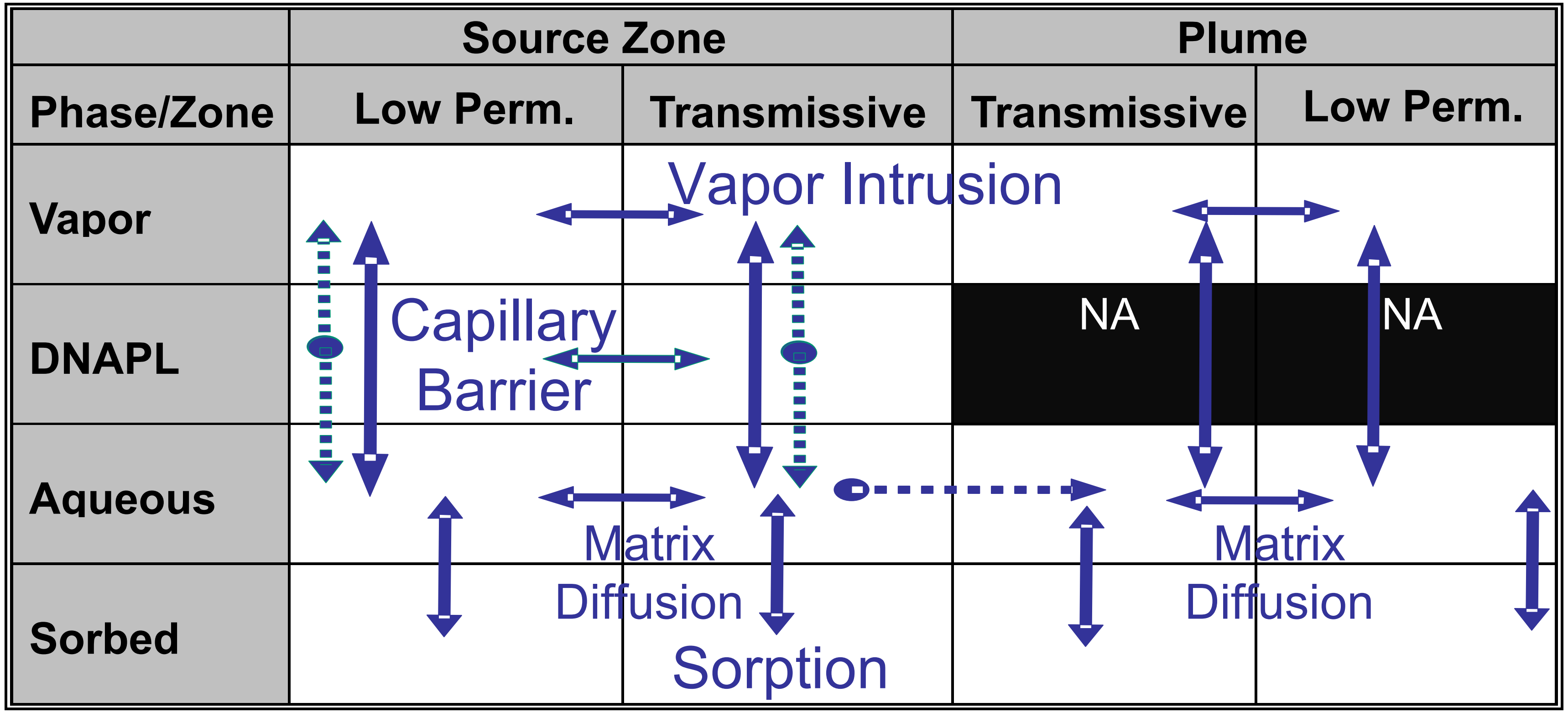


Figure courtesy of Fred Payne, Arcadis

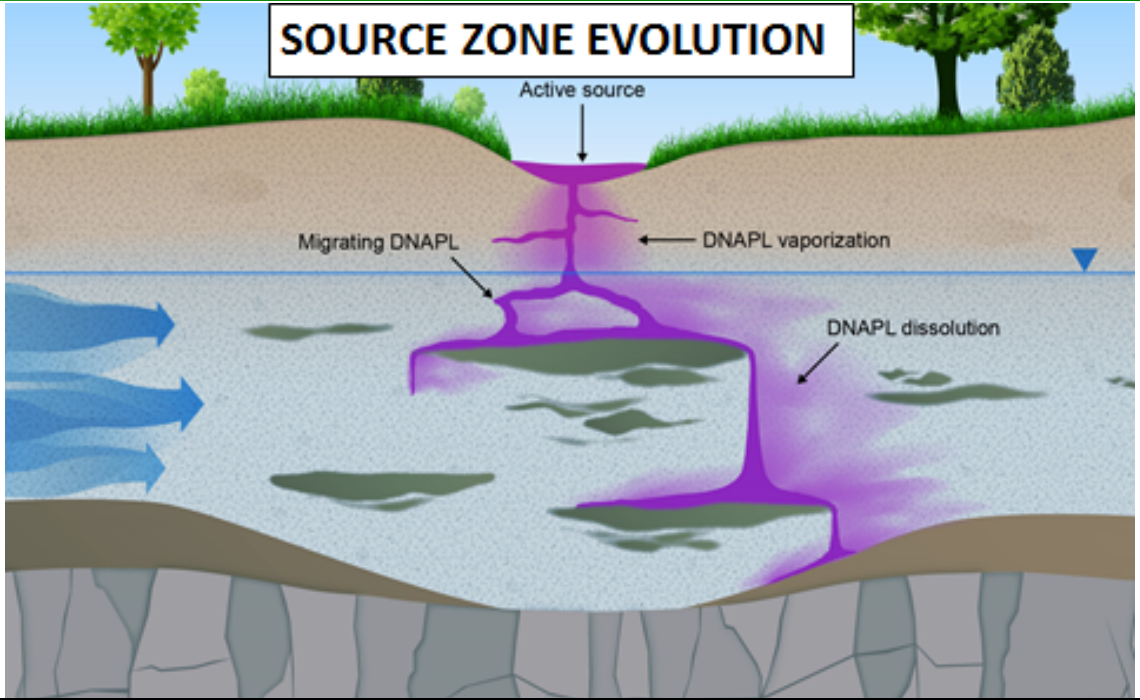
14-Compartment Model: Phase Distribution and Mass Transfer



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
NAPL	LOW	HIGH		
Aqueous	LOW	MODERATE	MODERATE	LOW
Sorbed	LOW	MODERATE	LOW	LOW

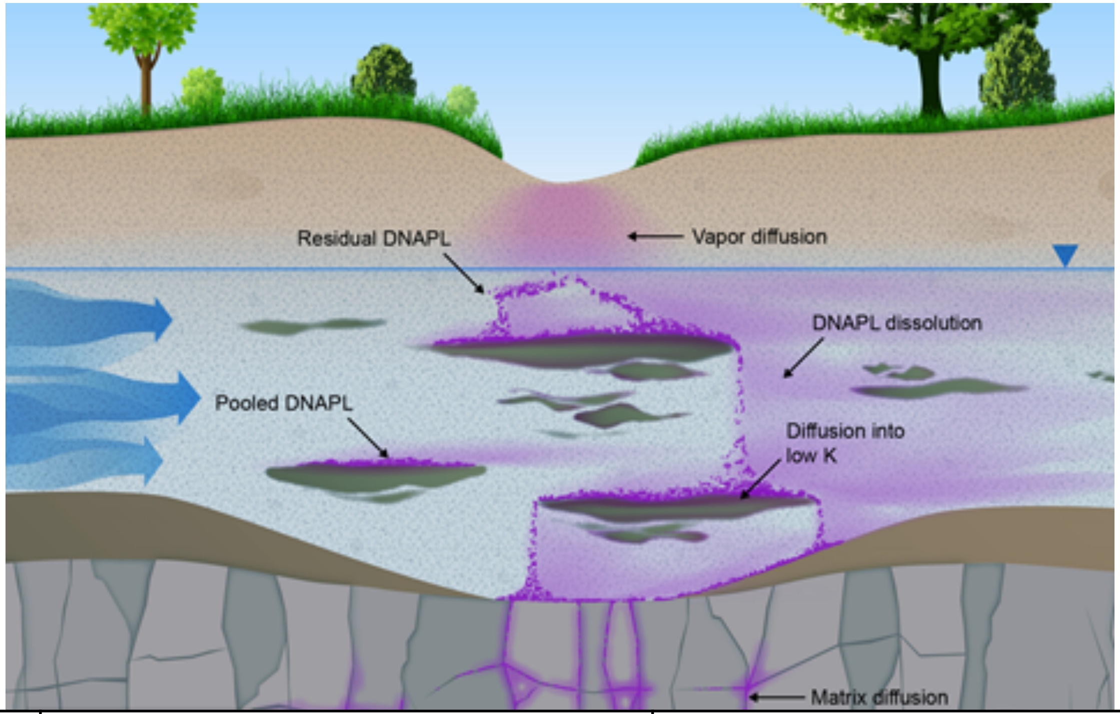
Kueper et al., 2013

Prolonged Early Stage Behavior

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

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

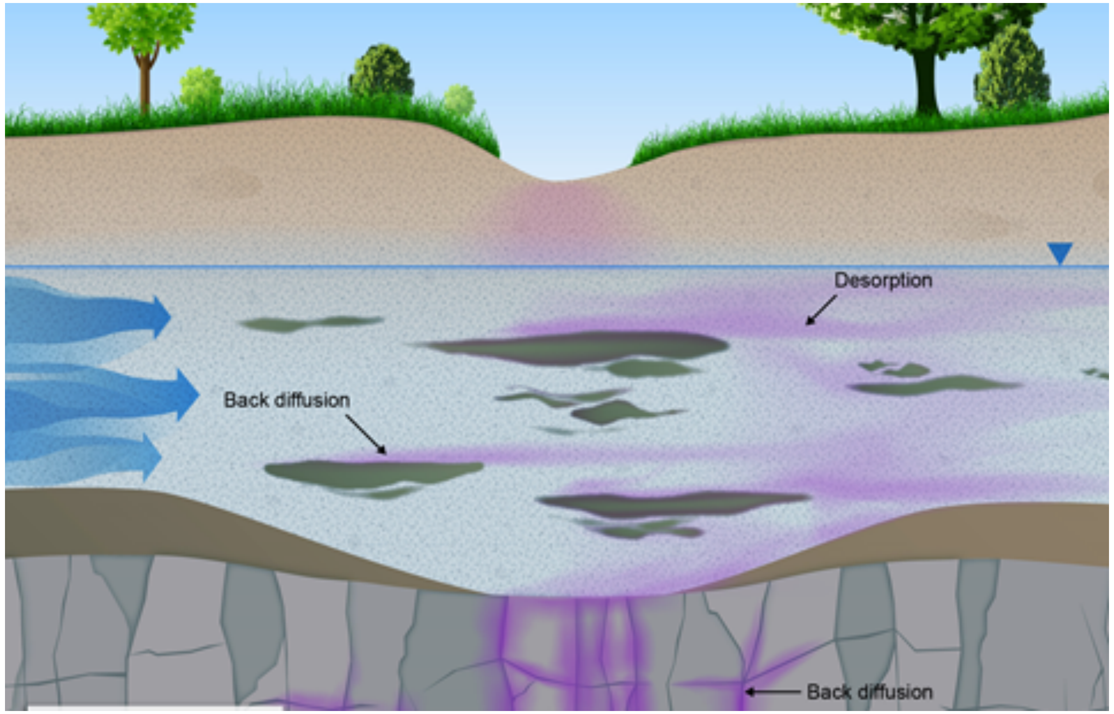
DNAPL Life Cycle – Middle Stage



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

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

Understanding Your DNAPL CSM

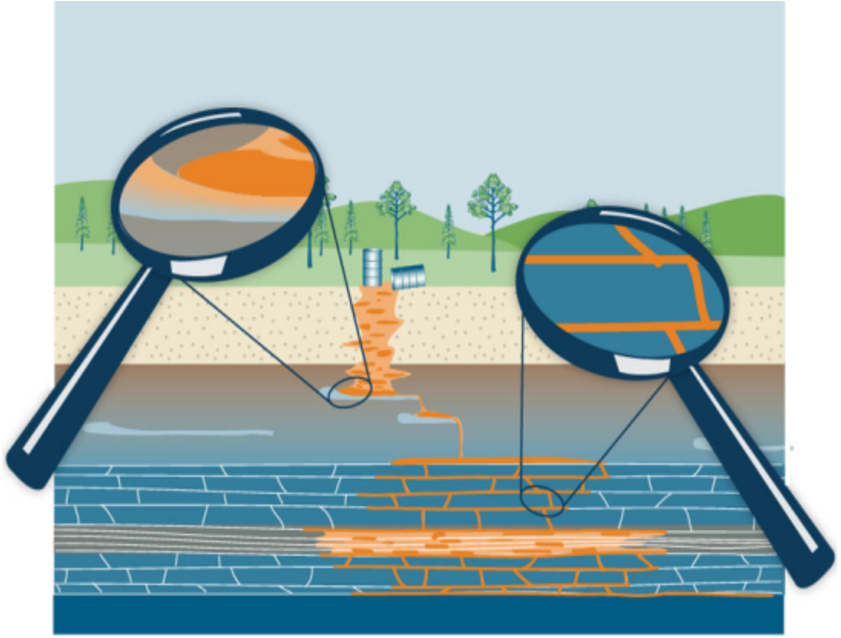
Characterizing sites contaminated with DNAPLs needs to take into account

- 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

BREAK

Training Overview

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



ISC-1, Chapter 4

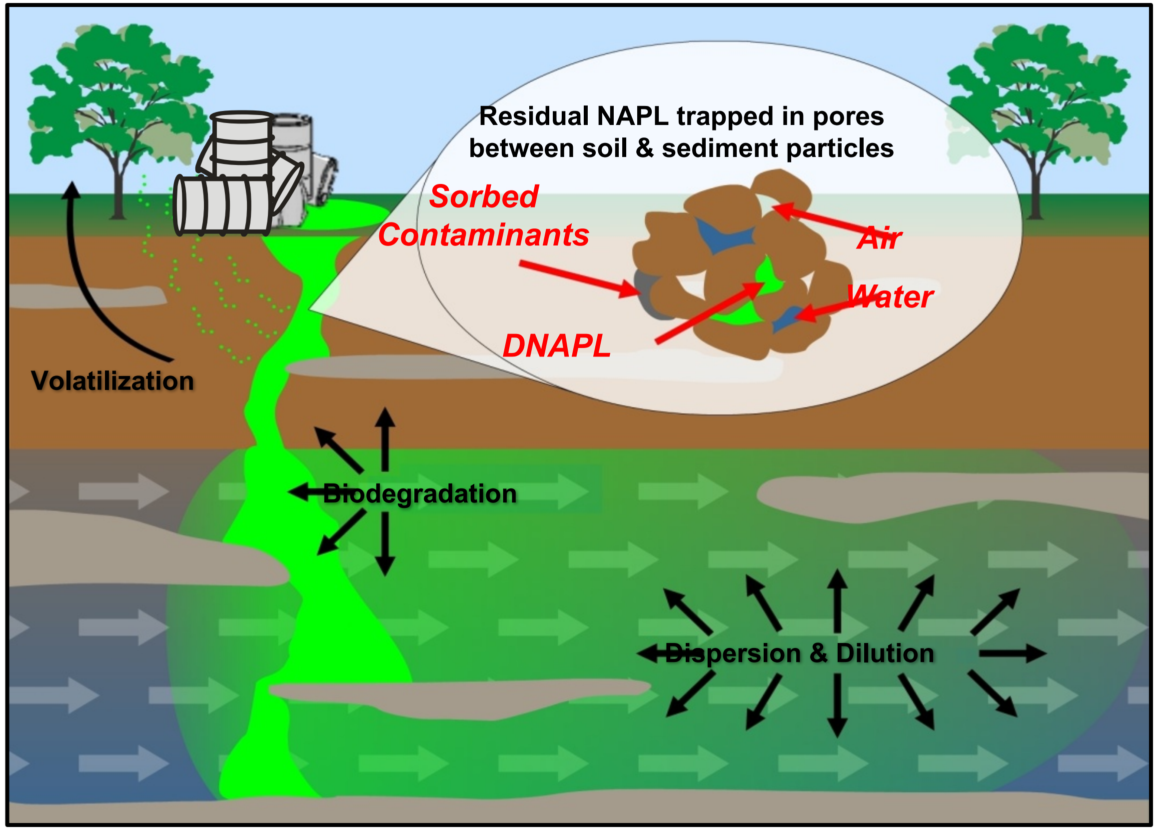
Integrated Site Characterization

Integrated site characterization (ISC) is a process to improve the efficiency and effectiveness of site characterization efforts at NAPL sites.

- It encourages collection of sufficient resolution site characterization data
- It provides an understanding of the controlling heterogeneities that effect contaminant distribution, fate, and transport, and remediation effectiveness
- It supports the development and refinement of an integrated, three-dimensional CSM that distinguishes among transport and storage zones and identifies relevant contaminant mass

Goal of Integrated Site Characterization

- Develop a CSM with sufficient depth and clarity so that risks can be accurately assessed and appropriate remediation strategies developed.



Integrated Site Characterization

New Concepts Regarding Contaminant Fate and Transport

- Heterogeneity replaces homogeneity
- Anisotropy replaces isotropy
- Diffusion replaces dispersion
- Back-diffusion is a significant source
- Lognormal replaces Gaussian
- Transient-state replaces steady-state
- Non-linear sorption replaces linear sorption
- Non-ideal sorption replaces ideal sorption

Integrated Site Characterization

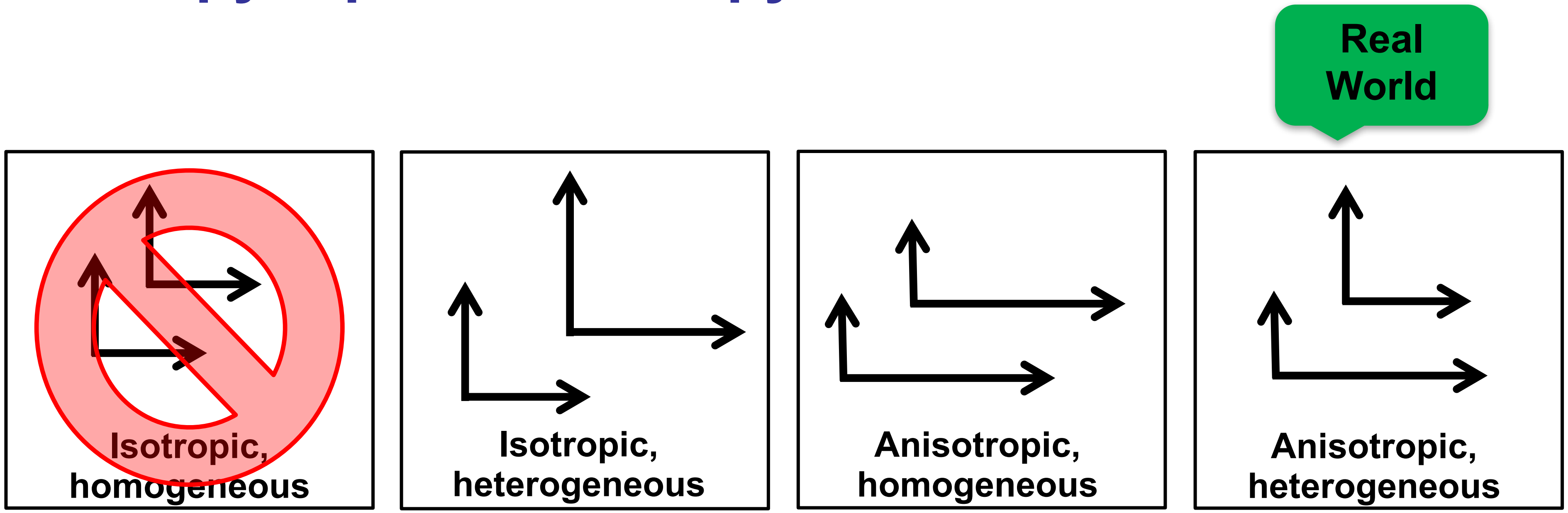
Heterogeneity replaces homogeneity

- Theis (1967): “I consider it certain that we need a new conceptual model, containing the known heterogeneities of natural aquifers, to explain the phenomenon of transport in groundwater.”

Photo: USGS

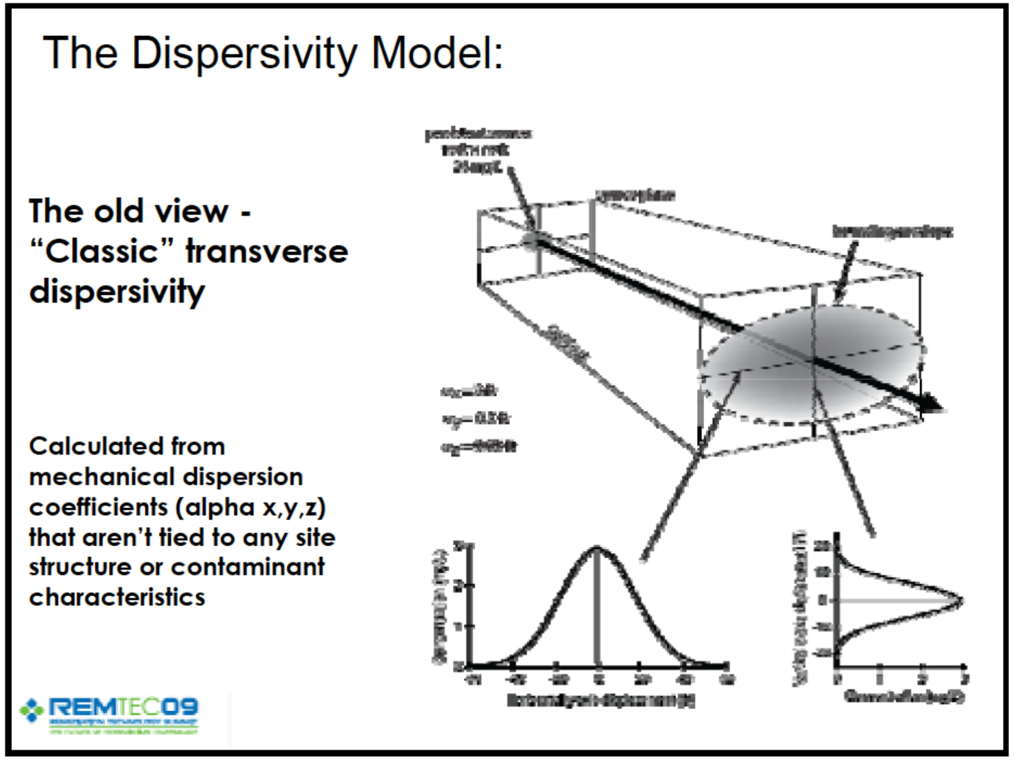
Integrated Site Characterization

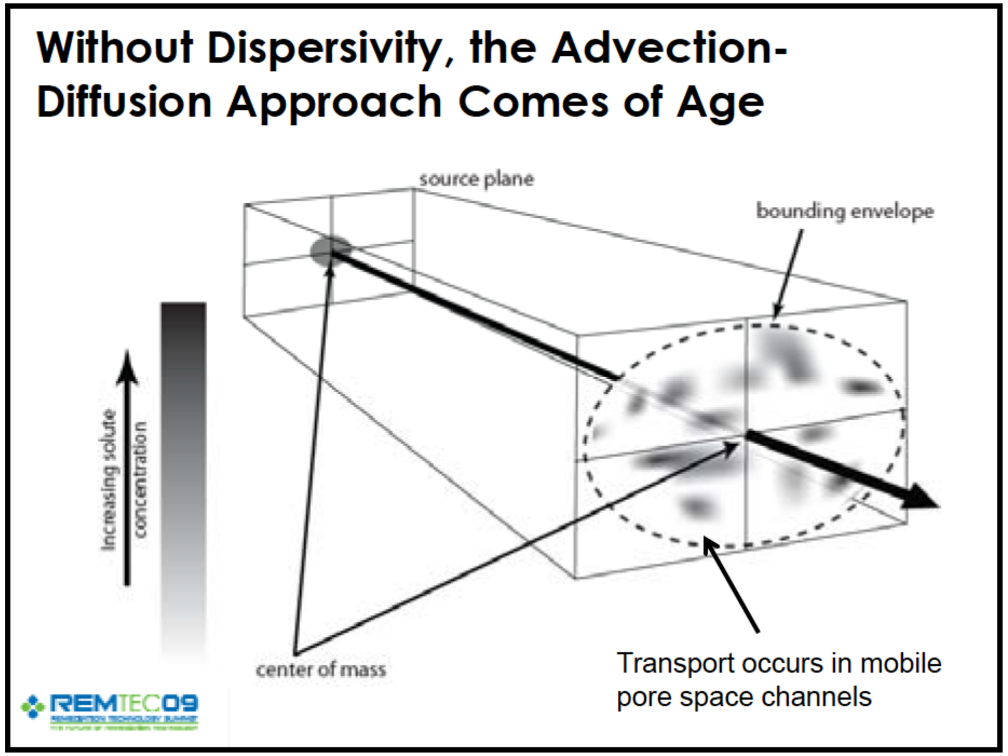
- Heterogeneity replaces homogeneity
- Anisotropy replaces isotropy



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

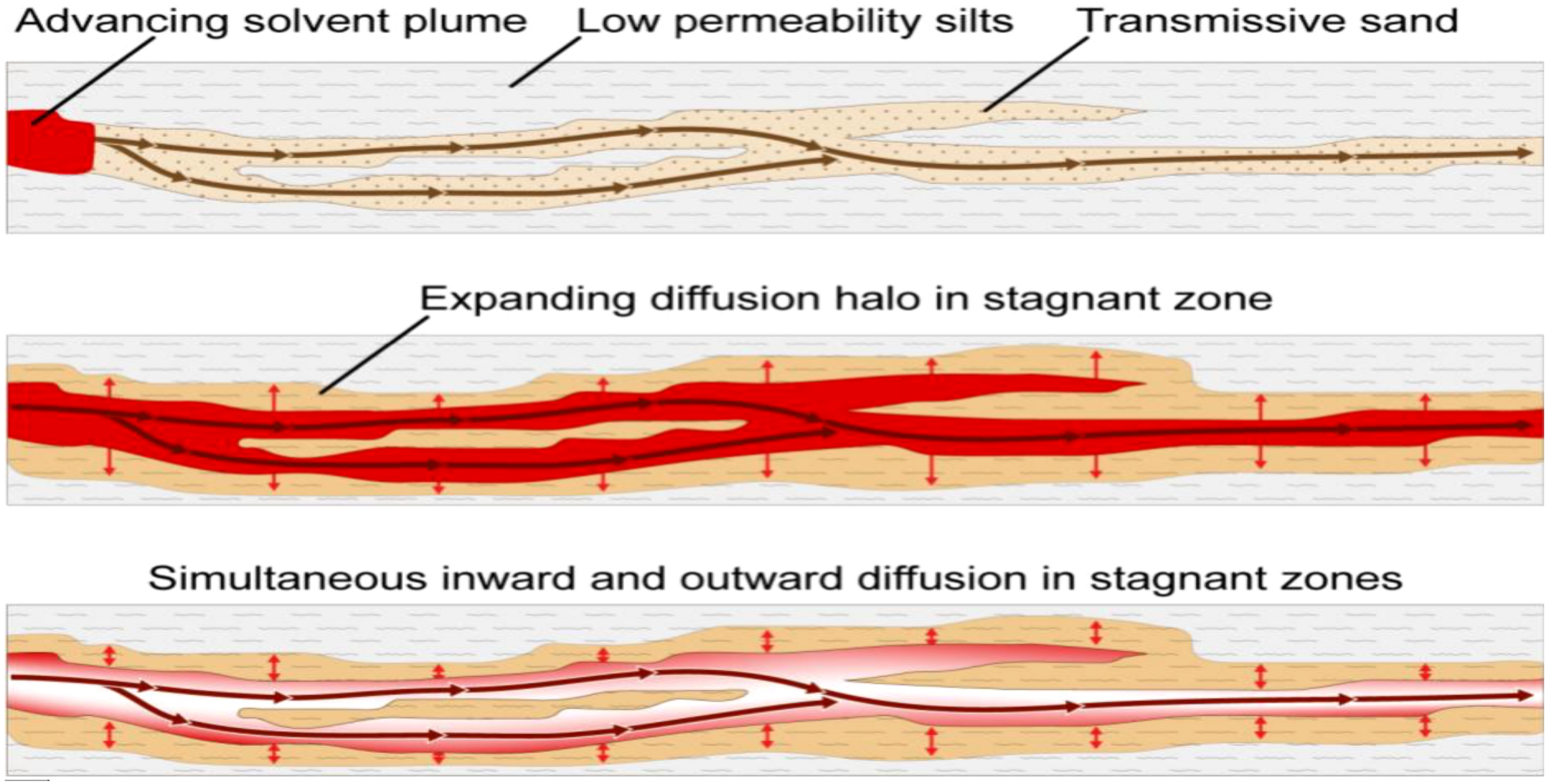




Figures courtesy of Fred Payne, Arcadis

Integrated Site Characterization

Back-diffusion is a significant source at older sites



Integrated Site Characterization

Lognormal replaces Gaussian

Geologic deposits are not distributed in a Gaussian or *normal* distribution.

Transient-state replaces steady-state

While conditions at a site may appear to be in steady state at times during the site life-cycle, at most we can expect a **dynamic equilibrium** that will change as the plume migrates, ages, degrades, as source materials are depleted or migrate, and as new geologic features are encountered by migrating contamination.

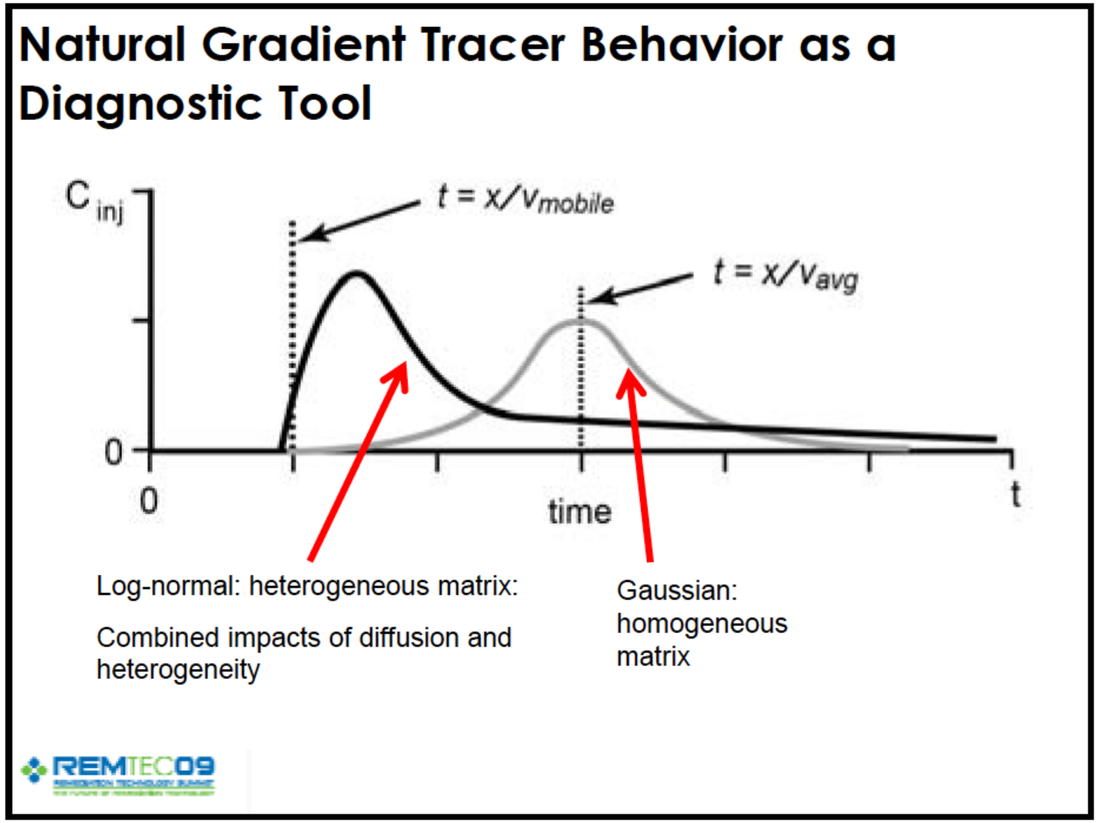


Figure Courtesy of Fred Payne, Arcadis

Integrated Site Characterization

Non-linear sorption replaces linear sorption

Some models predict DNAPL contaminant fate and transport assuming linear sorption of reactive solutes.

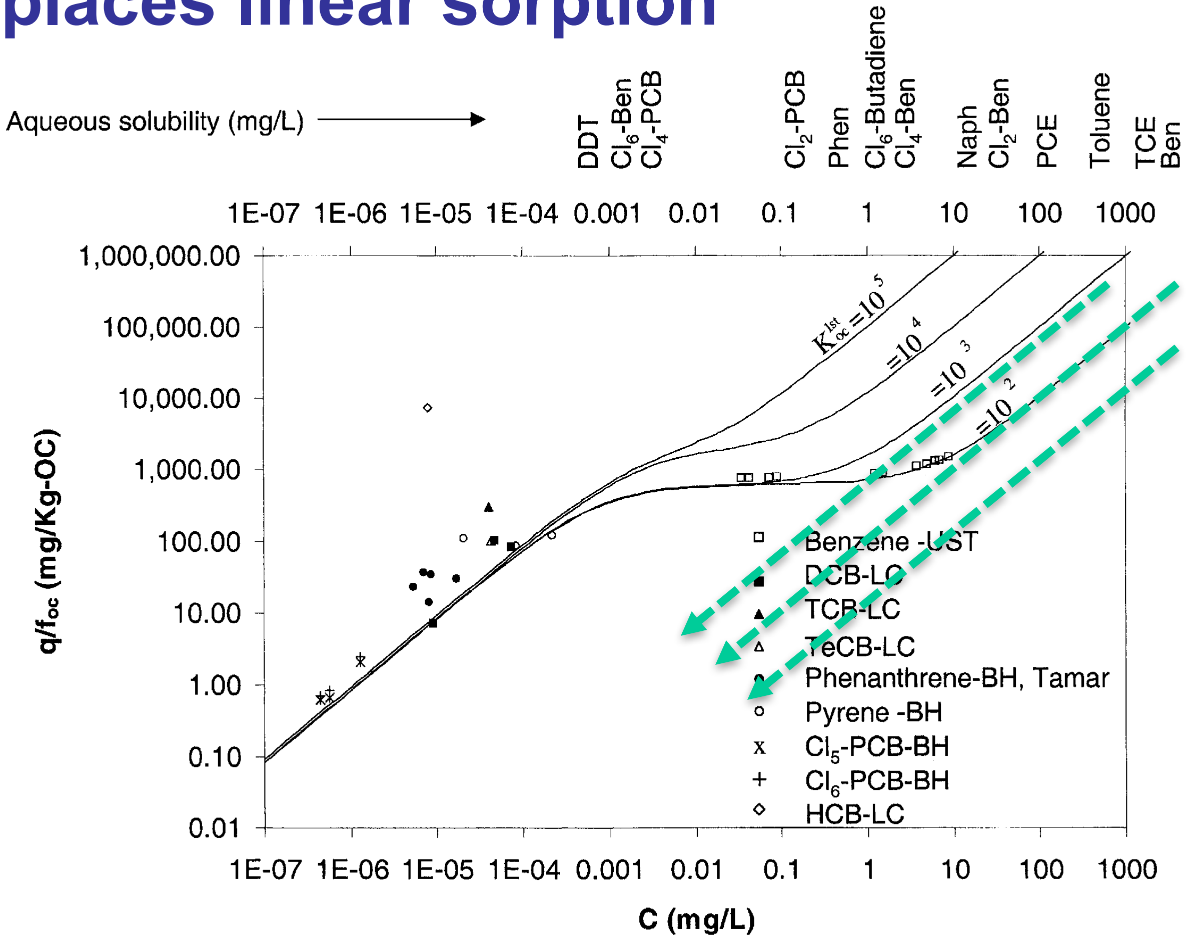


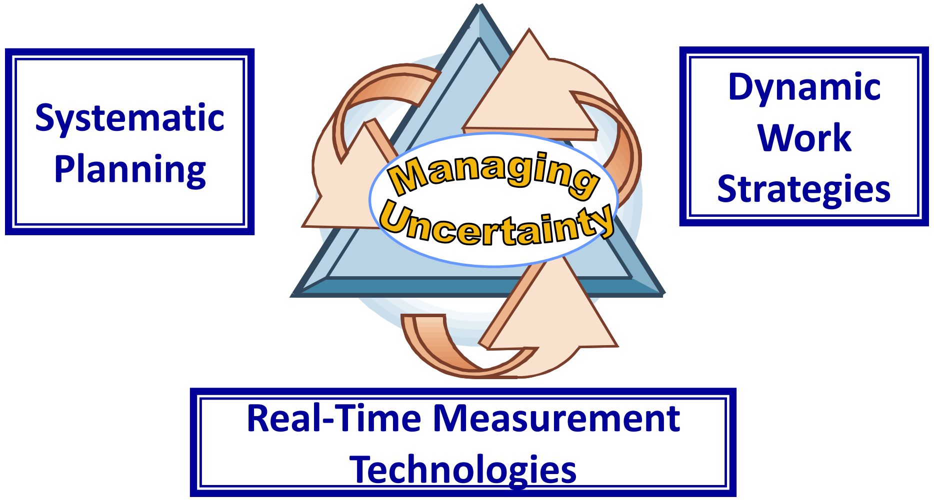
Figure: Dual Equilibrium Based Model of Non-linear sorption. Green arrows show linear isotherms; dual equilibrium model shows divergence due to non-linear sorption

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:



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

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)

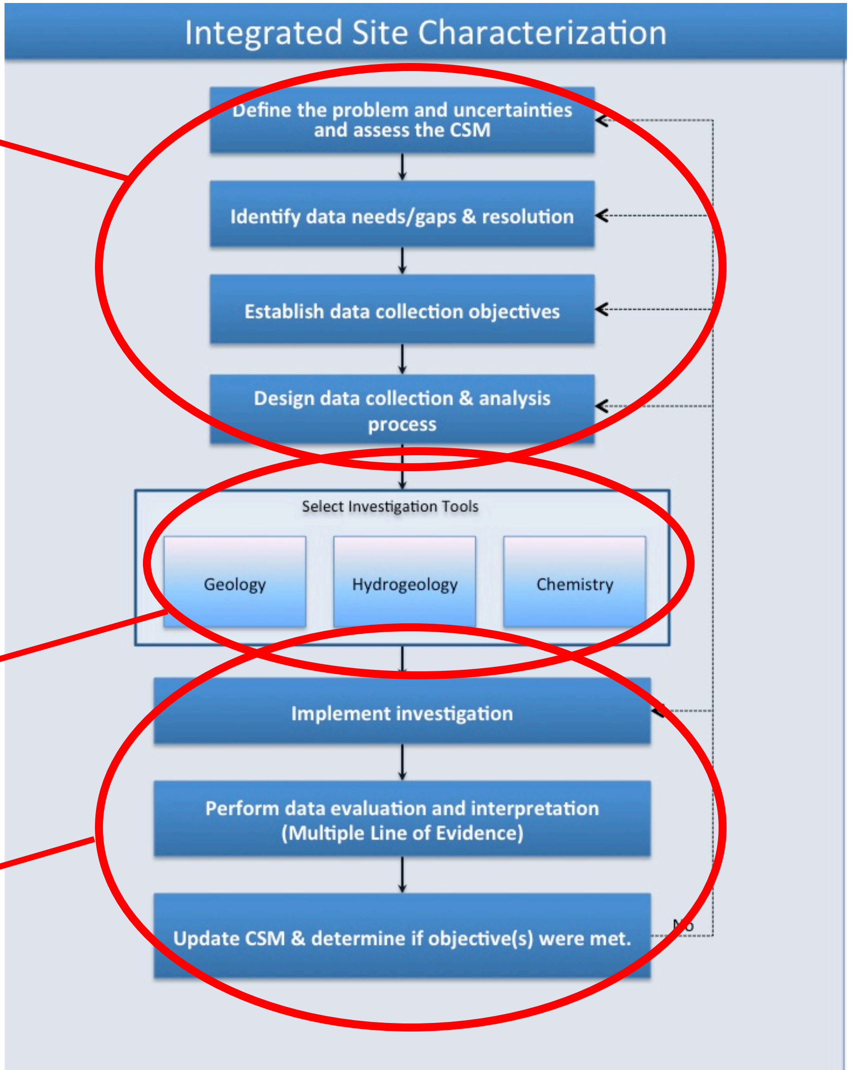


Figure 4-1 Integrated Site Characterization

Data Quality Objectives are "Built in"

USEPA Data Quality Objectives

- Step 1: State Problem
- Step 2: Identity Goal of Study
- Step 3: Identify Information Inputs
- Step 4: Define Boundaries of Study
- Step 5: Develop Analytical Approach
- Step 6: Specify Performance or Acceptance Criteria
- Step 7: Develop Plan for Obtaining Data

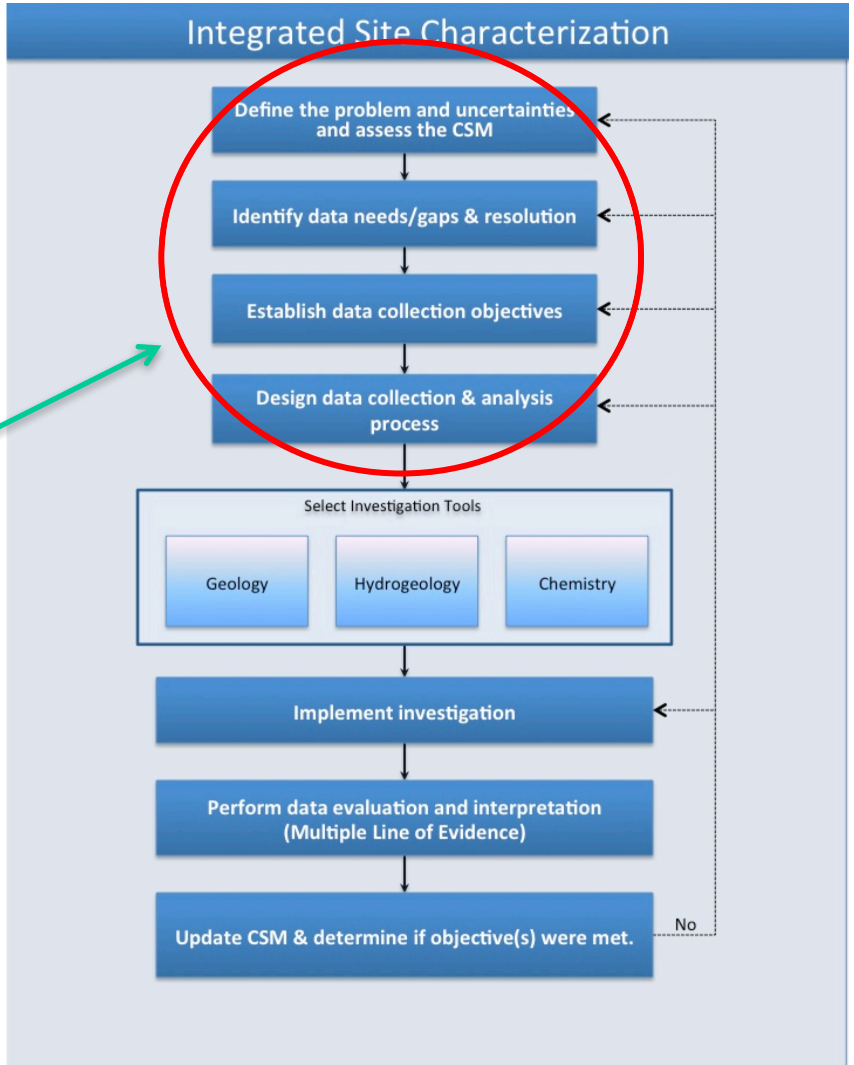


Figure 4-1 Integrated Site Characterization

Step 1: Define Problem and Assess CSM Uncertainties

- Assess existing CSM
- Define problem
- Define uncertainties

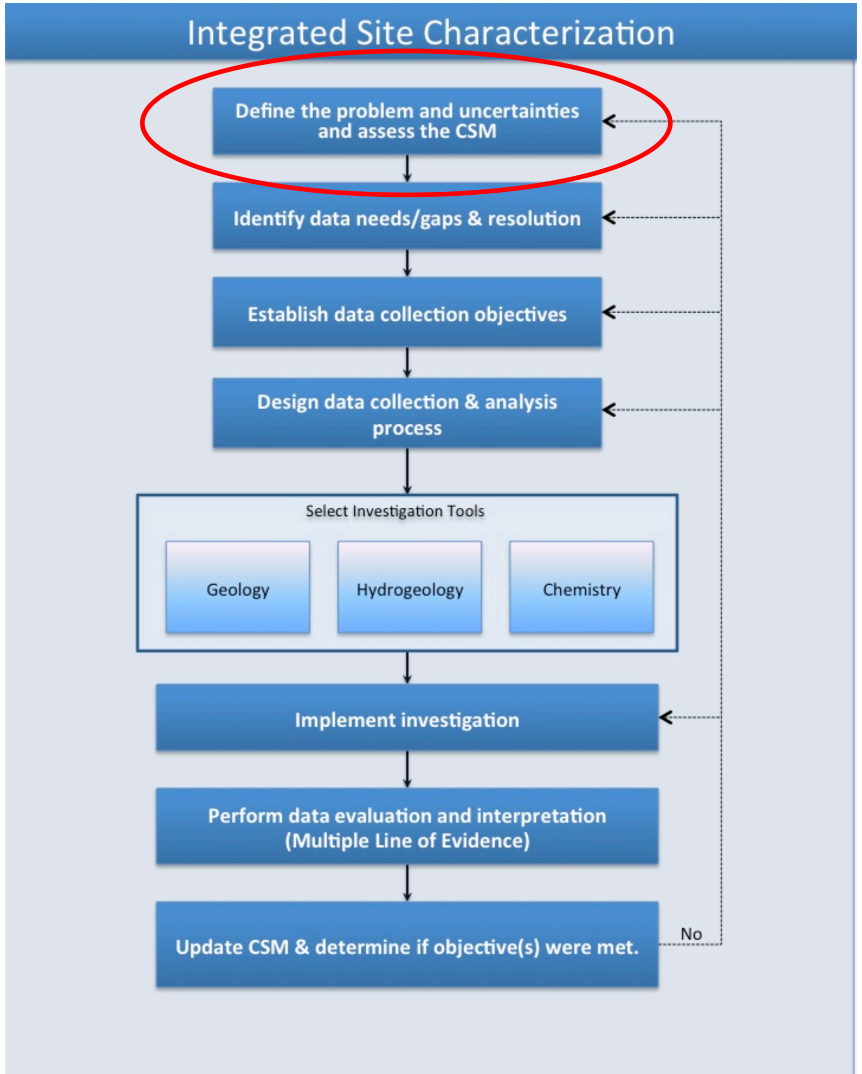
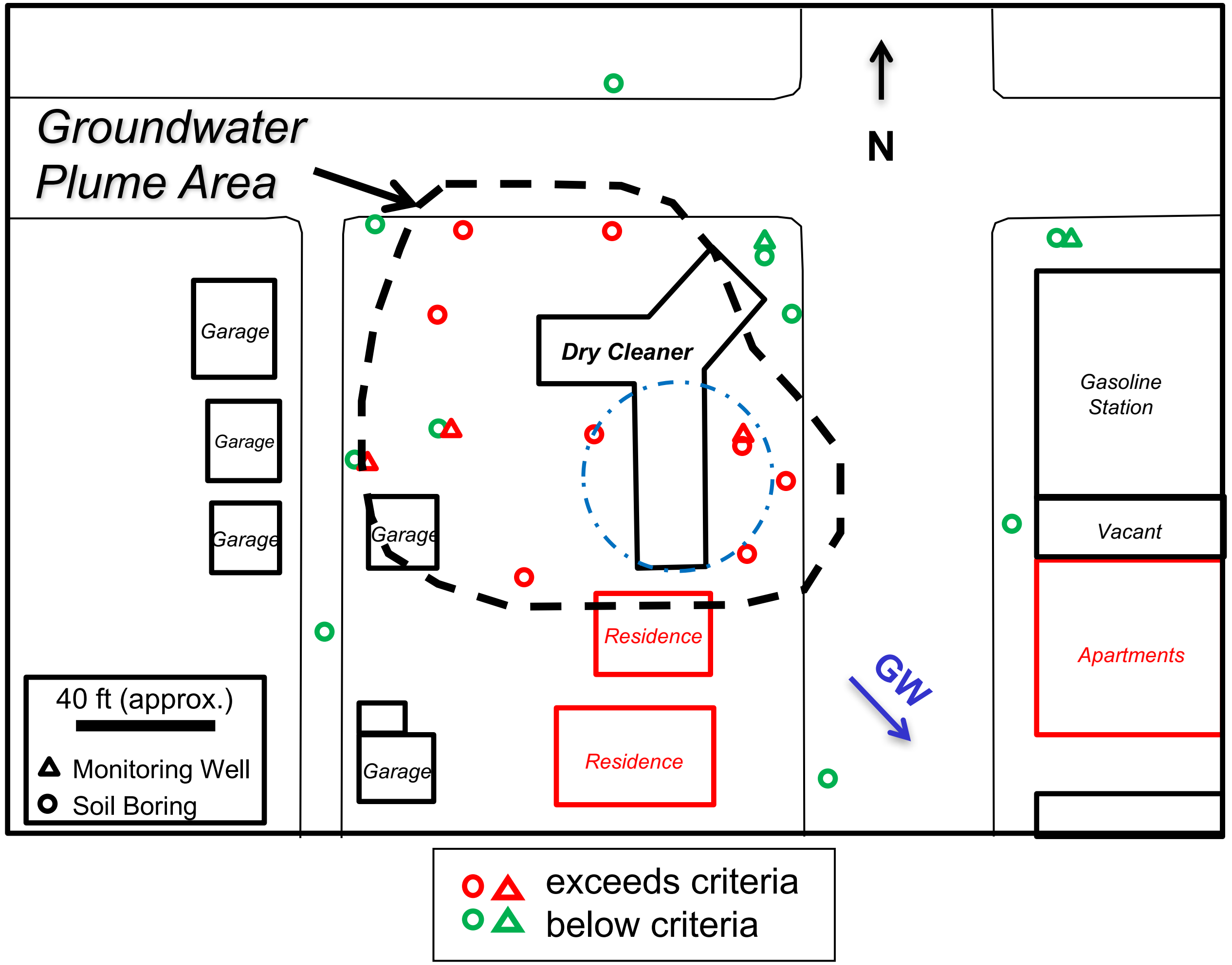


Figure 4-1 Integrated Site Characterization

Case Example – Dry Cleaner Site

Case Example

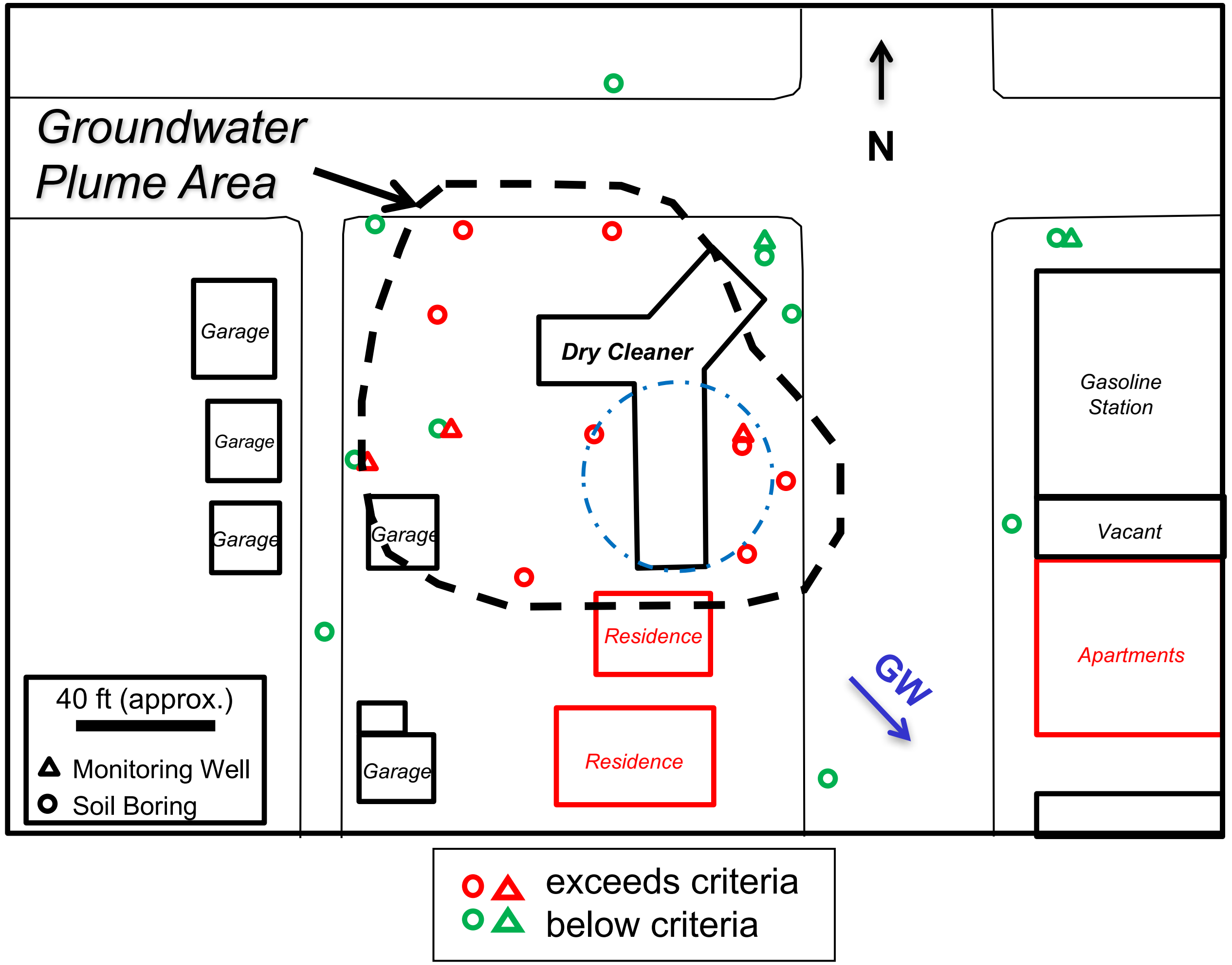
1. Commercial & residential location
2. Shallow groundwater (<20’ bgs)
3. Five MWs; 10-ft screens
4. 18 soil borings; 5-ft samples
5. No soil-gas evaluation
6. In situ chemical oxidation (ISCO) & enhanced in situ bioremediation (EISB) injections in source area & plume



Step 1: Define Problem and Assess Uncertainties

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

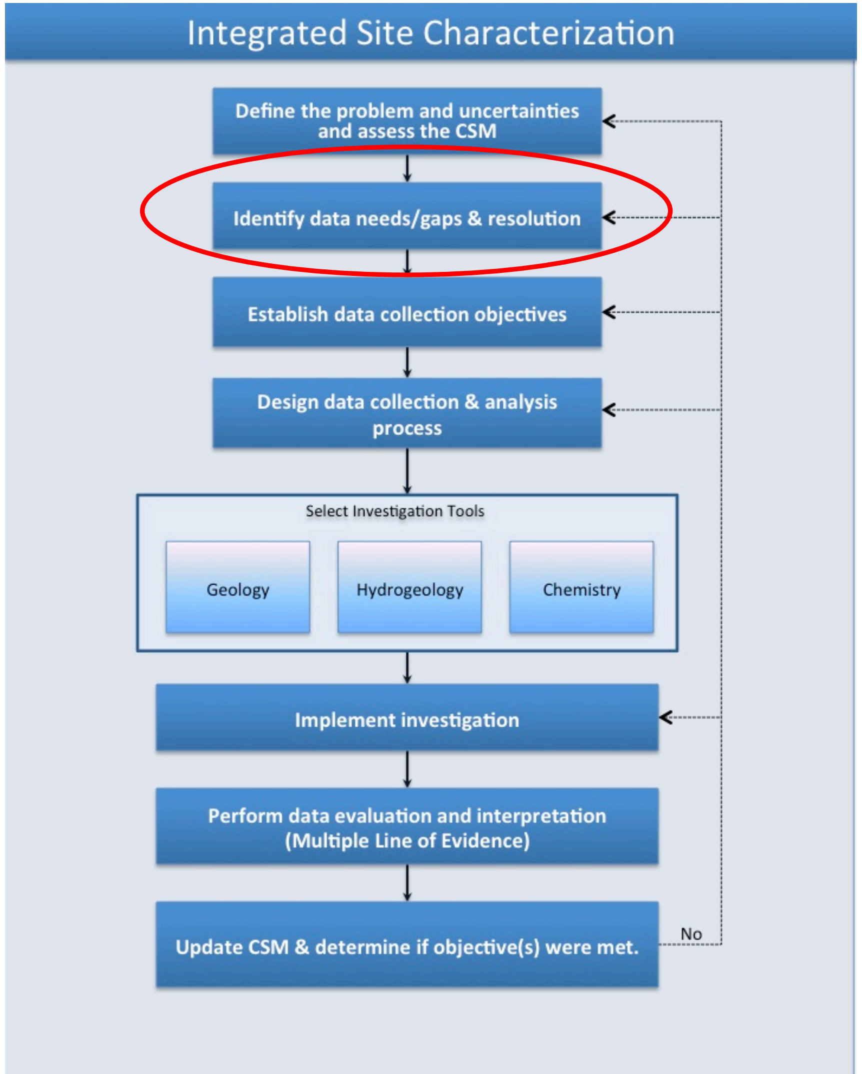
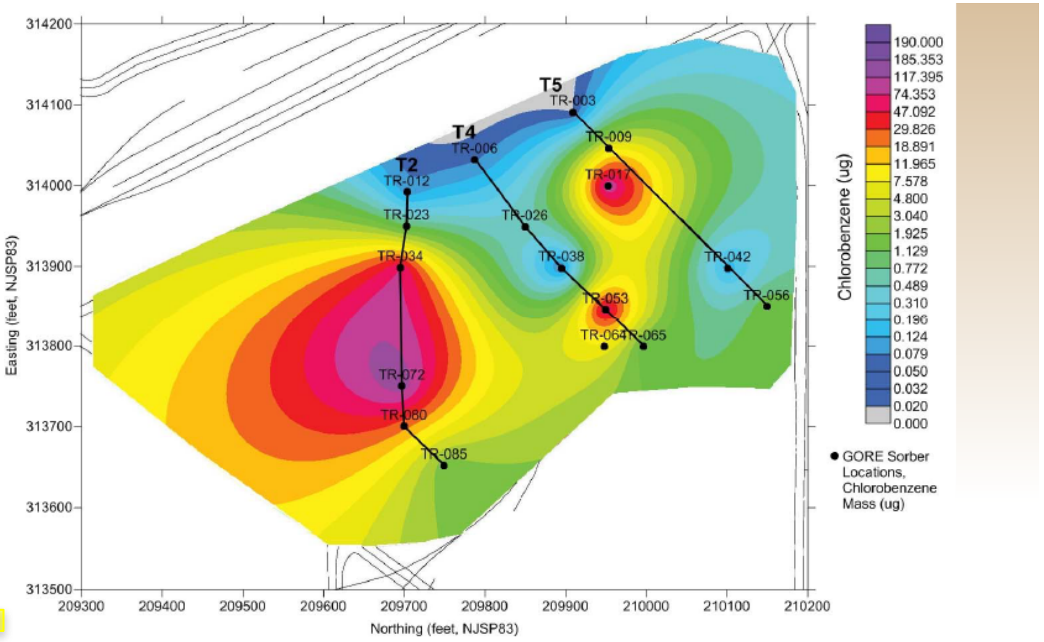


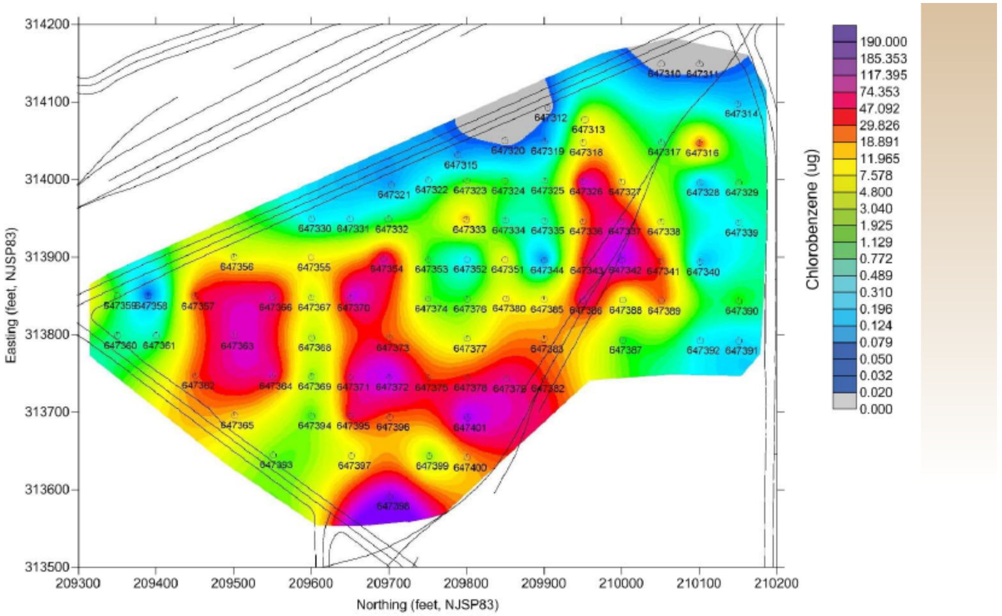
Figure 4-1 Integrated Site Characterization

Step 2. Identify Data Needs / Gaps and Resolution

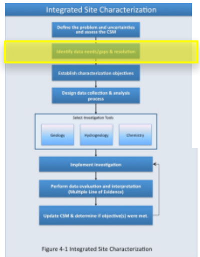
- Once the uncertainties in the existing CSM are recognized, specific data needs (e.g., type, location, amount, and quality) as well as data resolution (i.e., spacing or density) can be described. Spatial resolution should be assessed laterally and vertically.



STONE ENVIRONMENTAL INC



STONE ENVIRONMENTAL INC



Step 2. Identify Data Needs / Gaps and Resolution

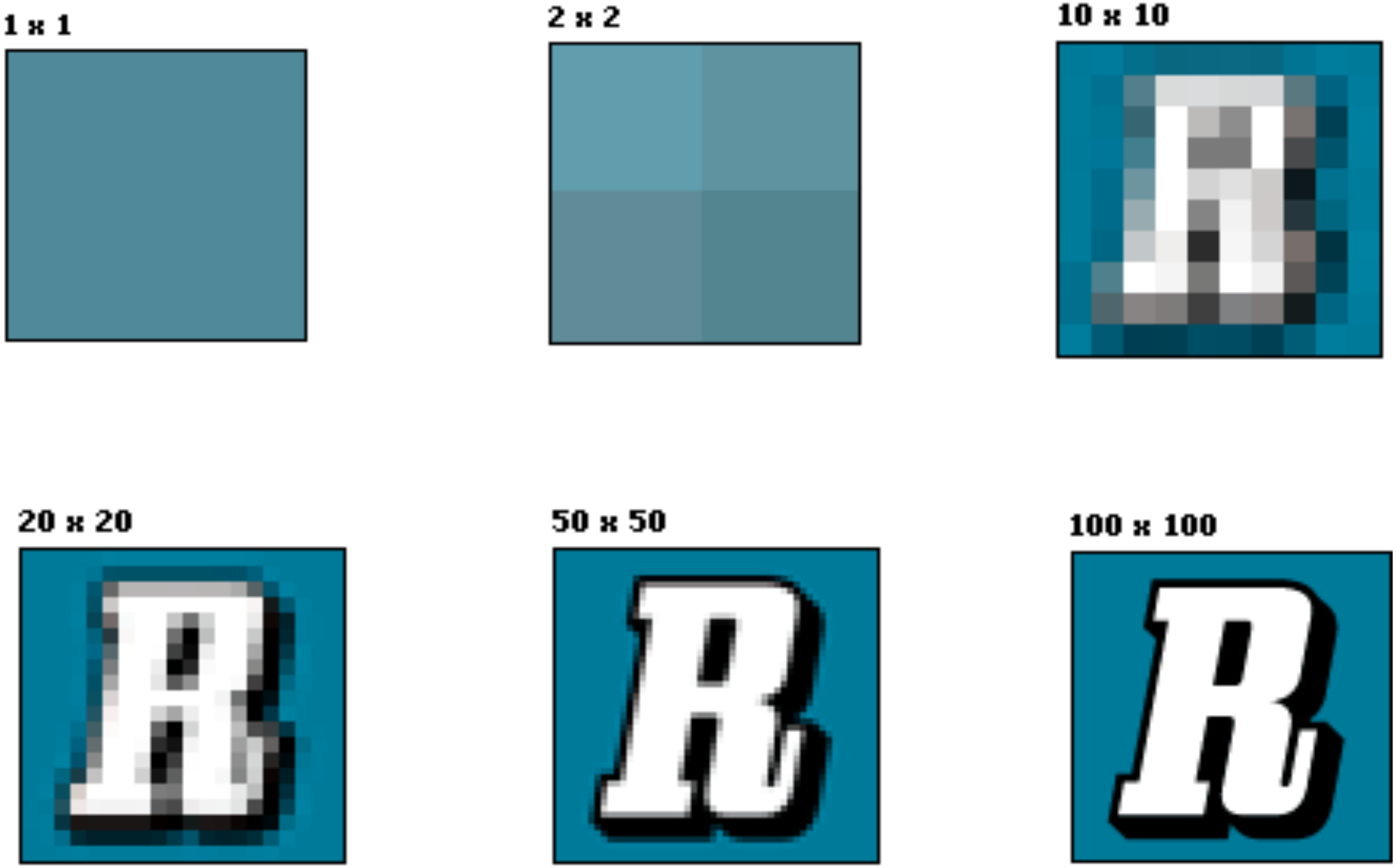
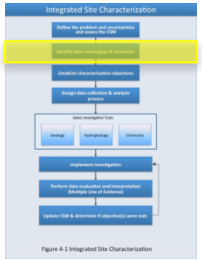
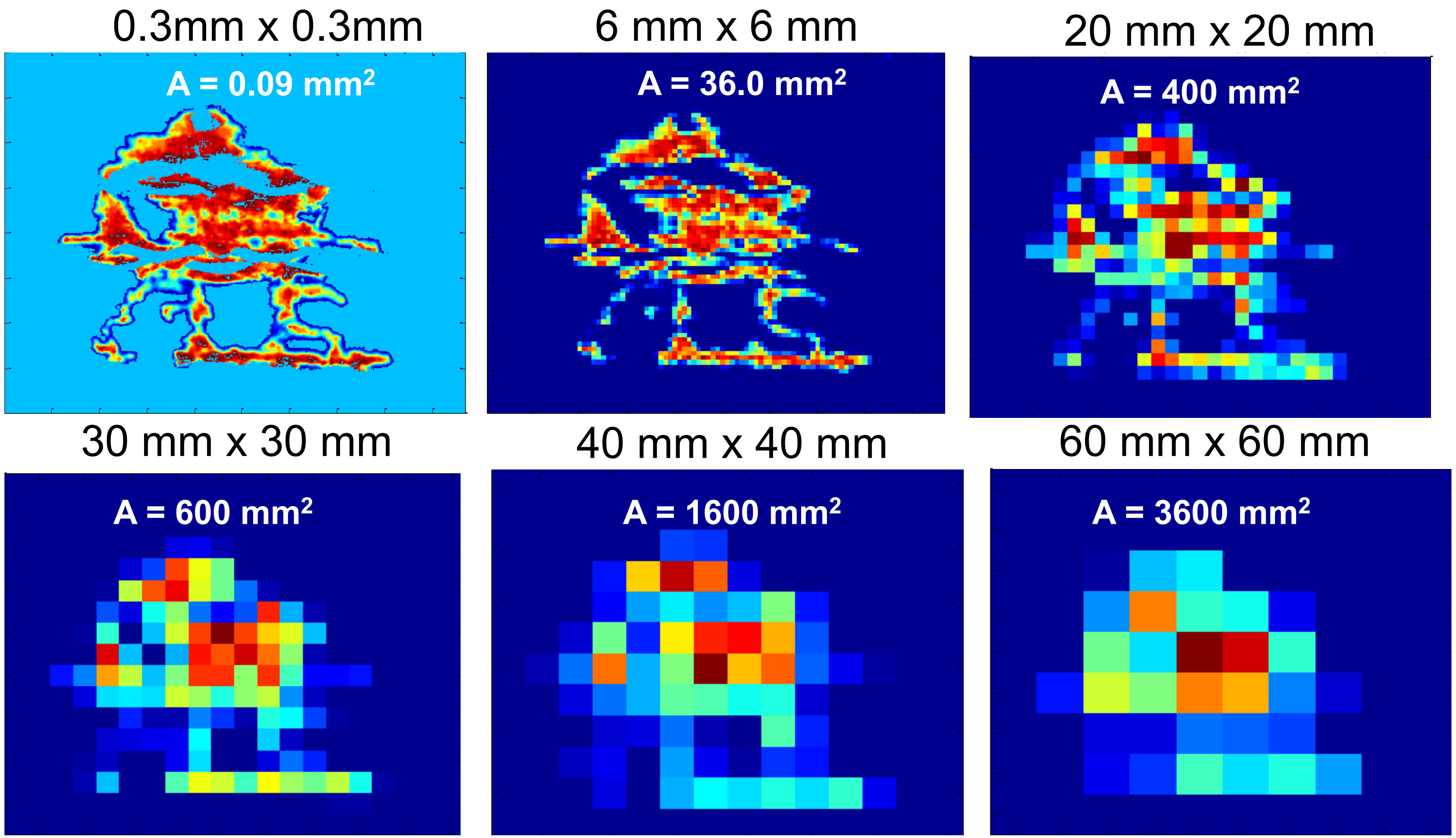


Figure courtesy of Seth Pitkin

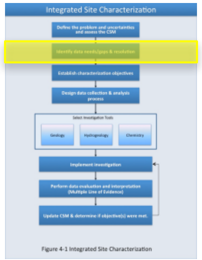


Step 2. Identify Data Needs / Gaps and Resolution

- Adequate Resolution: Averaging window size – fixed grid

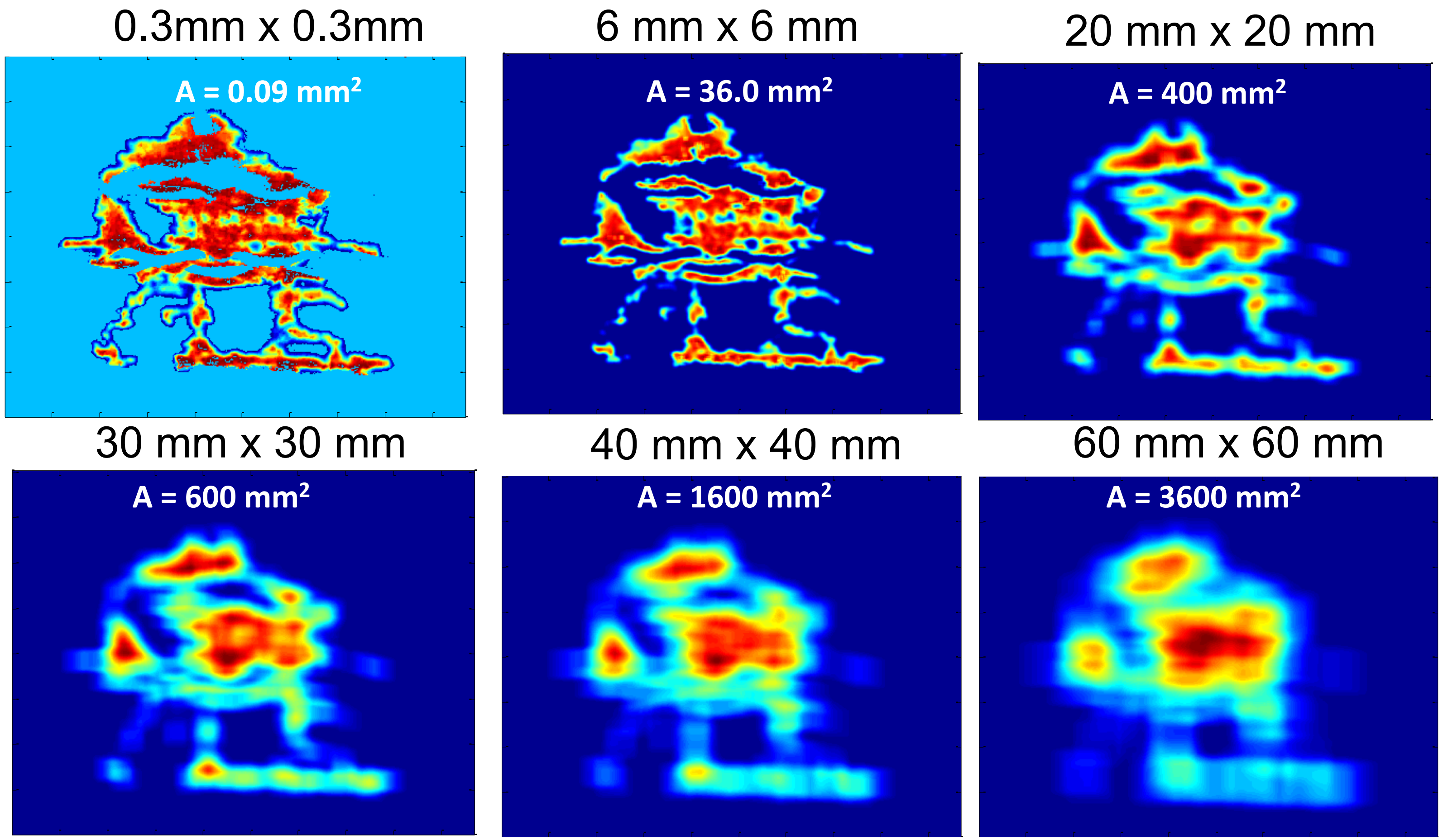


Christ et al., 2012, WRR

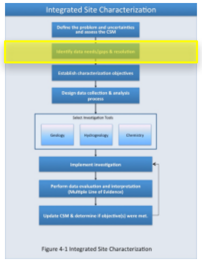


Step 2. Identify Data Needs / Gaps and Resolution

Adequate Resolution Data: Averaging window size-overlapping



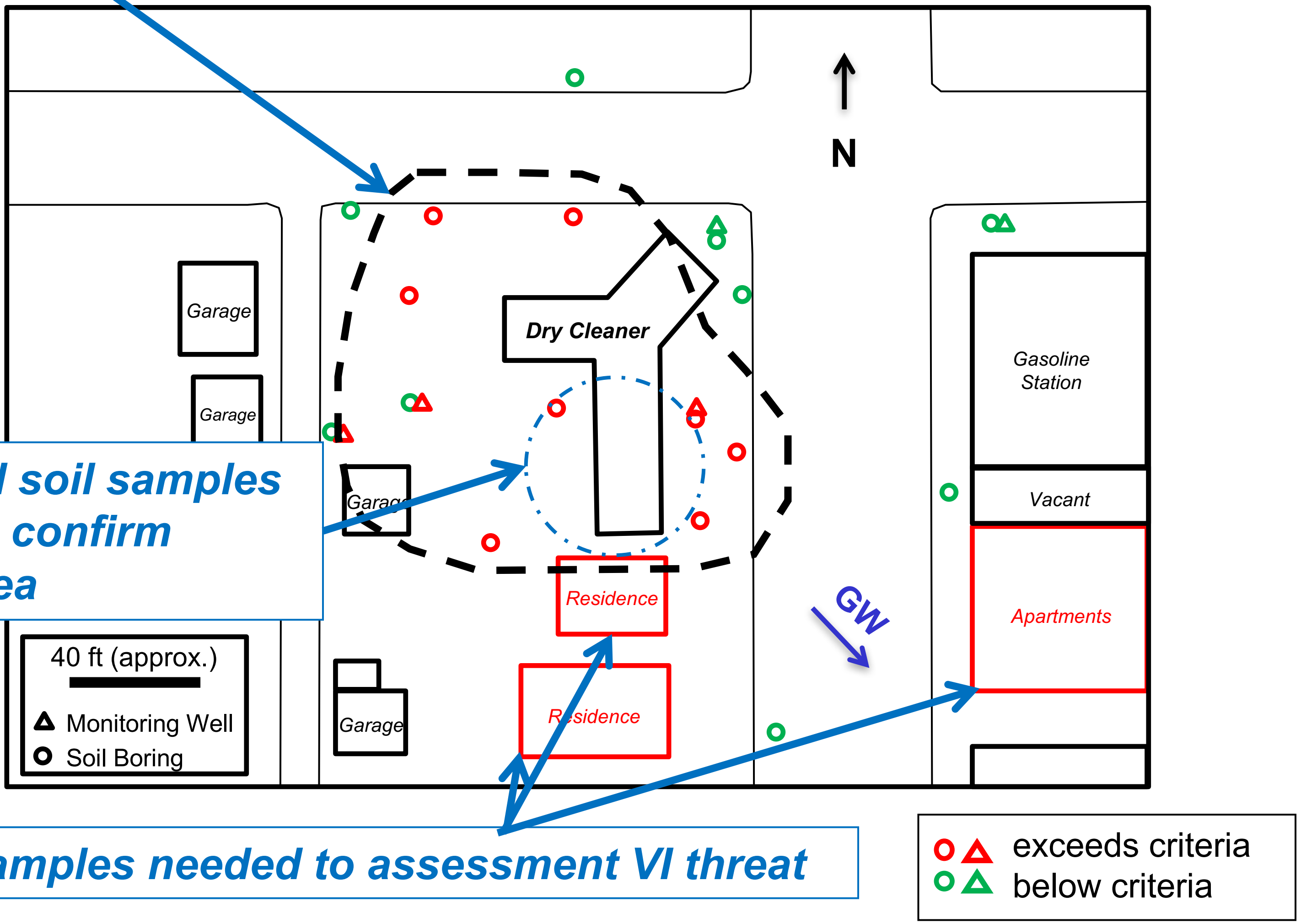
Christ et al., 2012, WRR



Step 2: Identify Data Needs & Spatial Resolution

Case Example

Additional groundwater samples needed to define plume extent

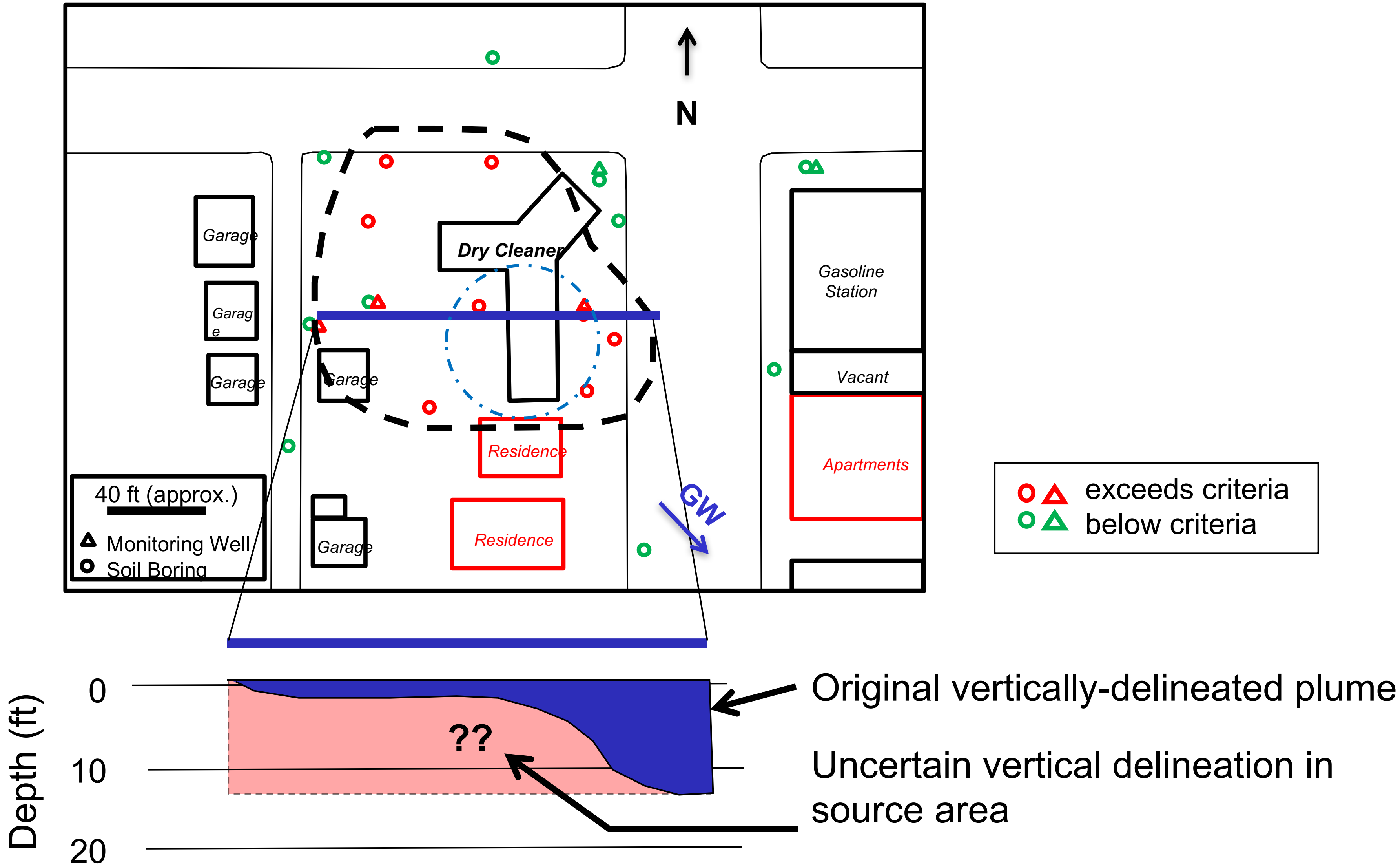


Additional soil samples needed to confirm source area

Soil-gas samples needed to assessment VI threat

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

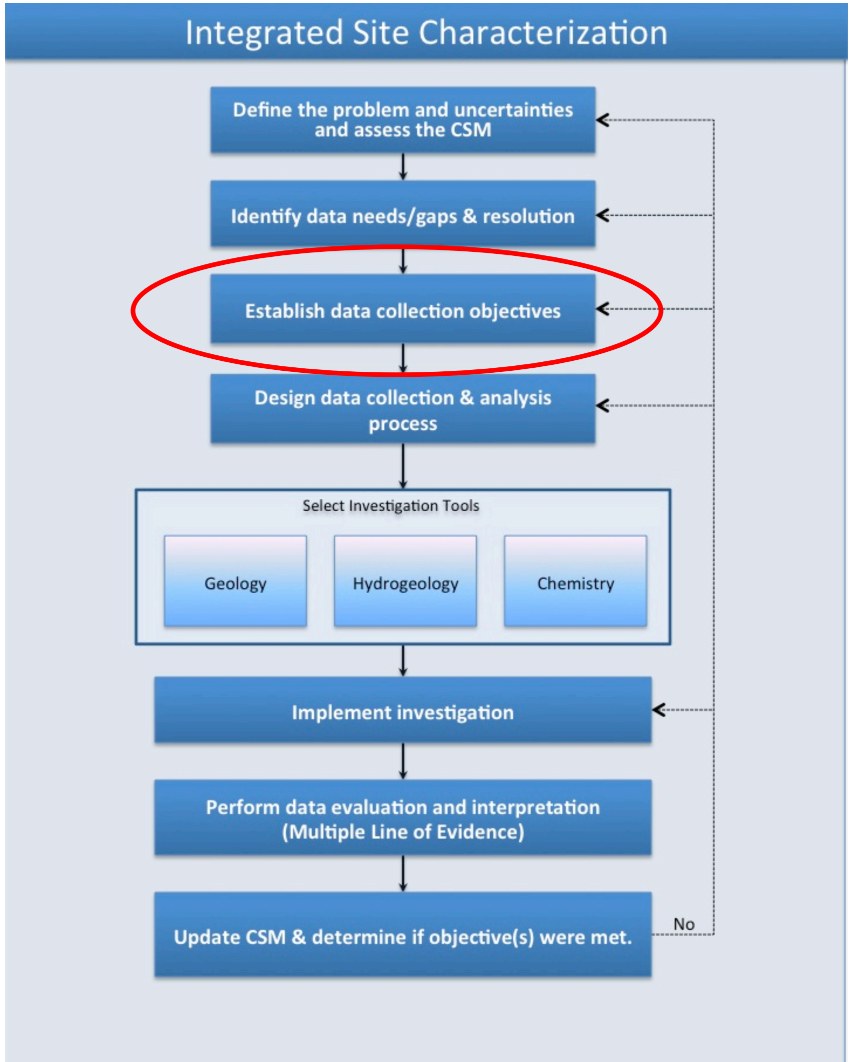


Figure 4-1 Integrated Site Characterization

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

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

Step 4: Data Collection & Analysis Plan

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

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

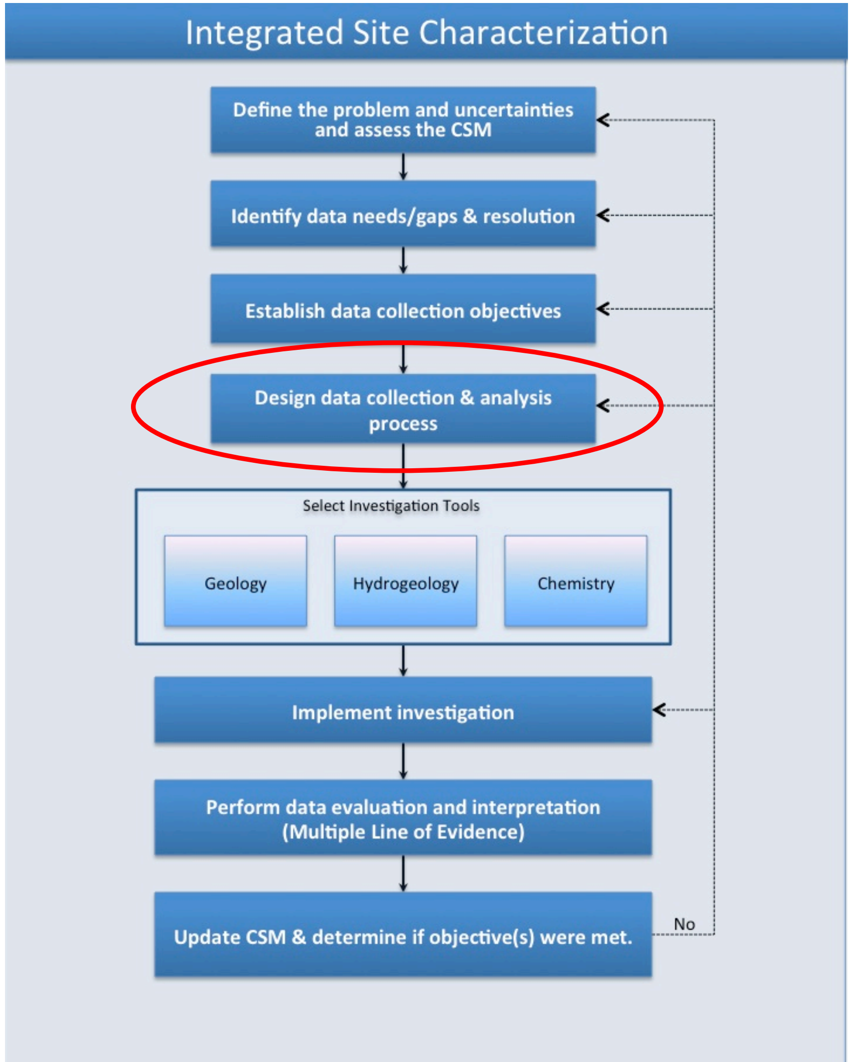
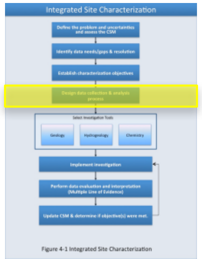


Figure 4-1 Integrated Site Characterization

Step 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., µg/L, ppm, and µg/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.



Step 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

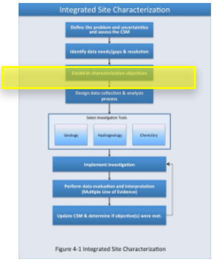
Precision:

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

Step 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

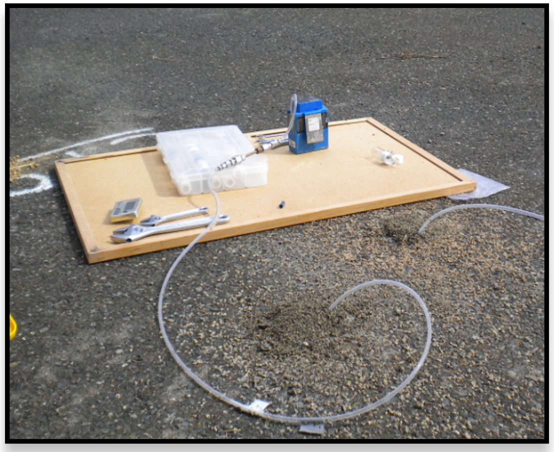


Step 4: Drycleaner Site Data Collection & Analysis Plan

MISSOURI WASTE CONTROL COALITION

INTERSTATE TECHNOLOGY REGULATORY COUNCIL ITRC

Case Example



Soil vapor sampling

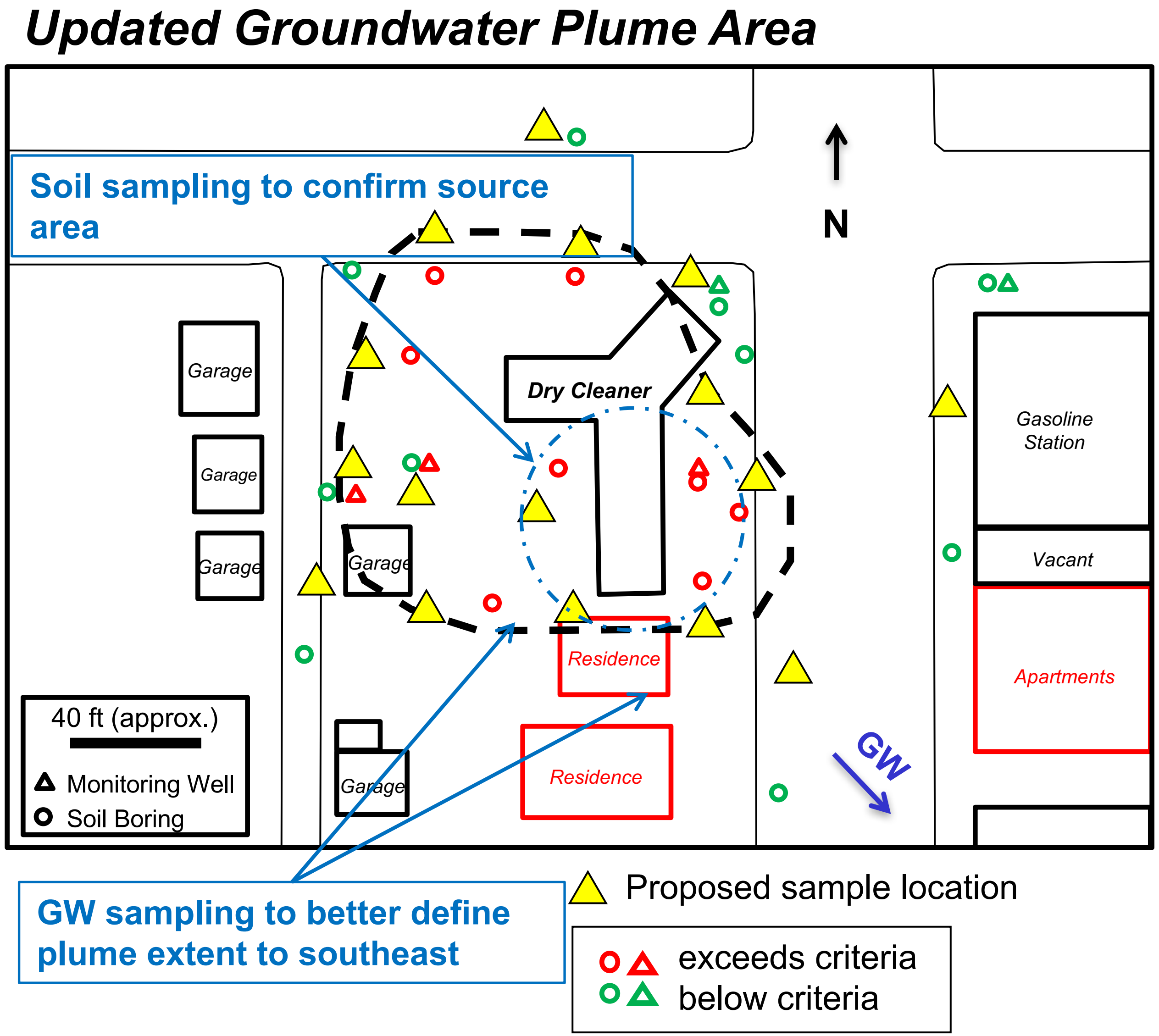
Triad ES mobile lab and Geoprobe

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)

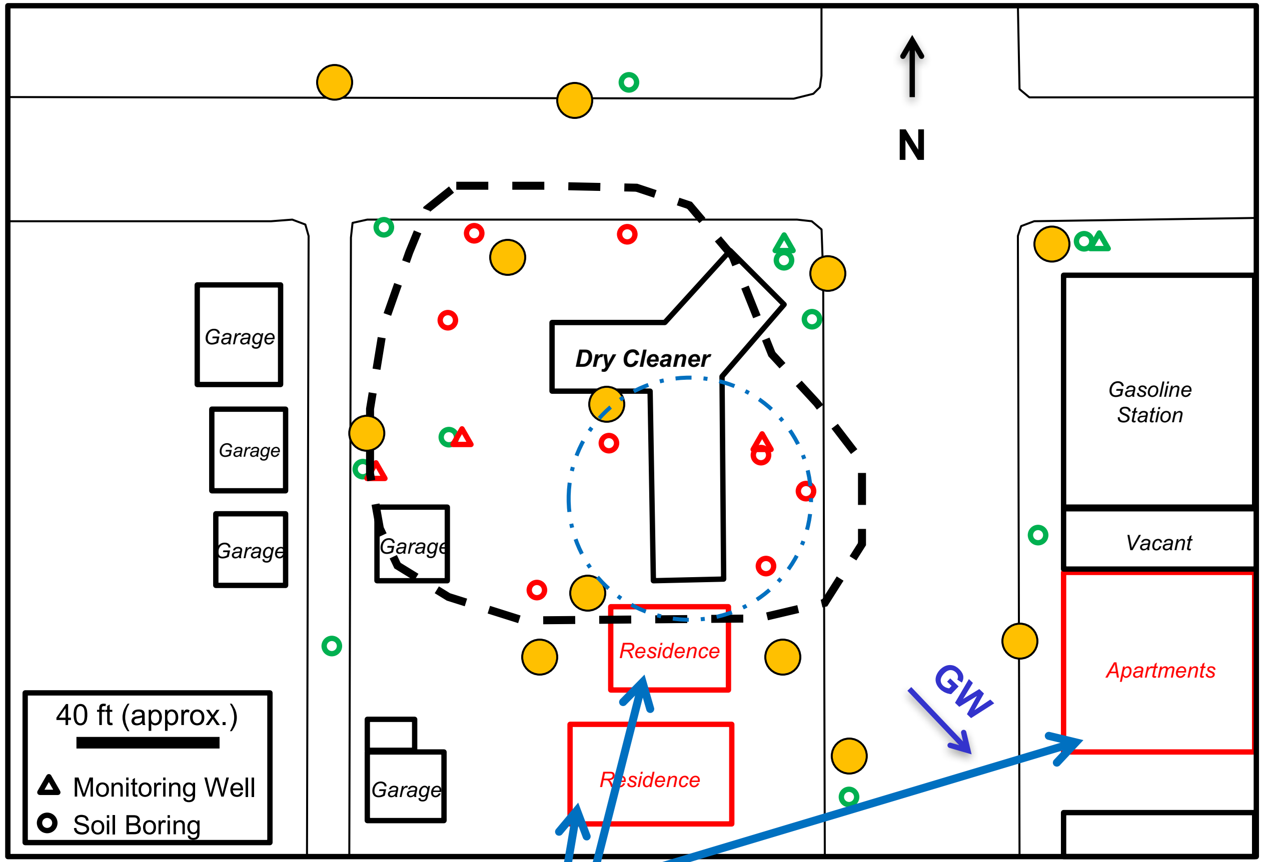


Step 4: Data Collection & Analysis Plan

Case Example

- Soil gas
  - 12 points
  - 24 samples

Shallow soil vapor results

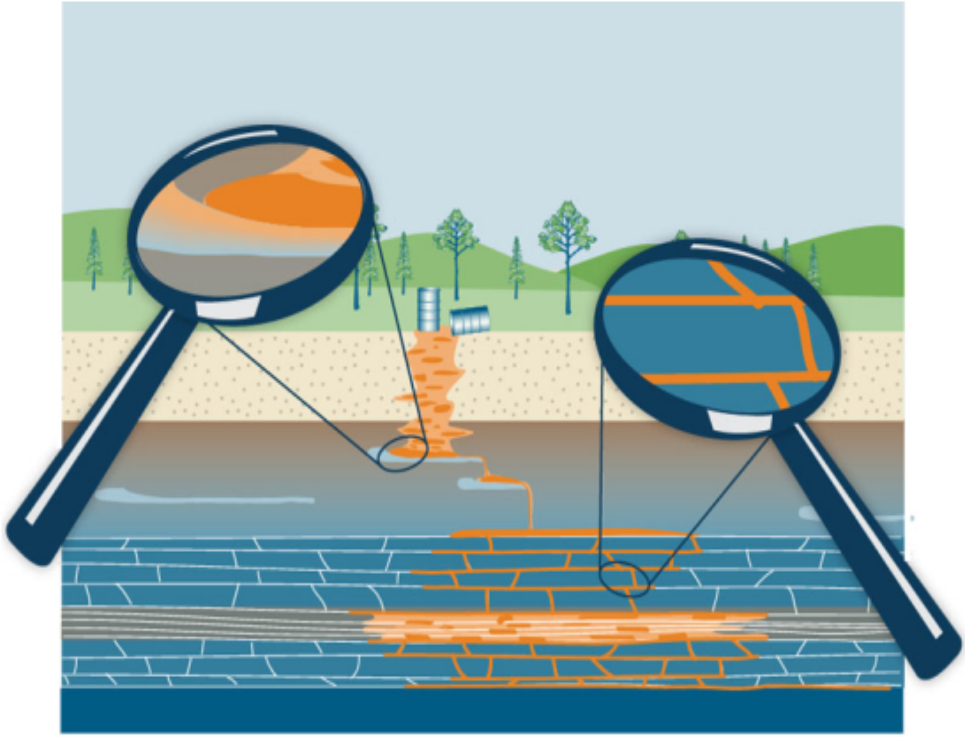


Soil-gas samples needed to assessment VI threat

Proposed soil-gas sample location

Training Overview

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



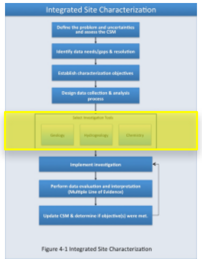
ISC-1, Chapter 4

Tools Selection Process: Contents of this Section

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

5. Tools Selection

- Categories of Tools:
  - Geophysics
    - Surface Geophysics
    - Down-Hole Testing
  - Hydraulic Testing
    - Single Well Tests
    - Cross Borehole Testing
    - Flow Metering
  - Sample Collection
    - Sediment/Rock
    - Groundwater
    - Soil Vapor



5. Tools Selection

- 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
  - Multilevel Sampling
- DNAPL Presence
- Chemical Screening

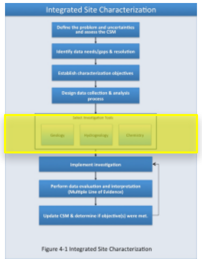


Figure 4-1 Integrated Site Characterization

Tools Matrix Format and Location

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

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

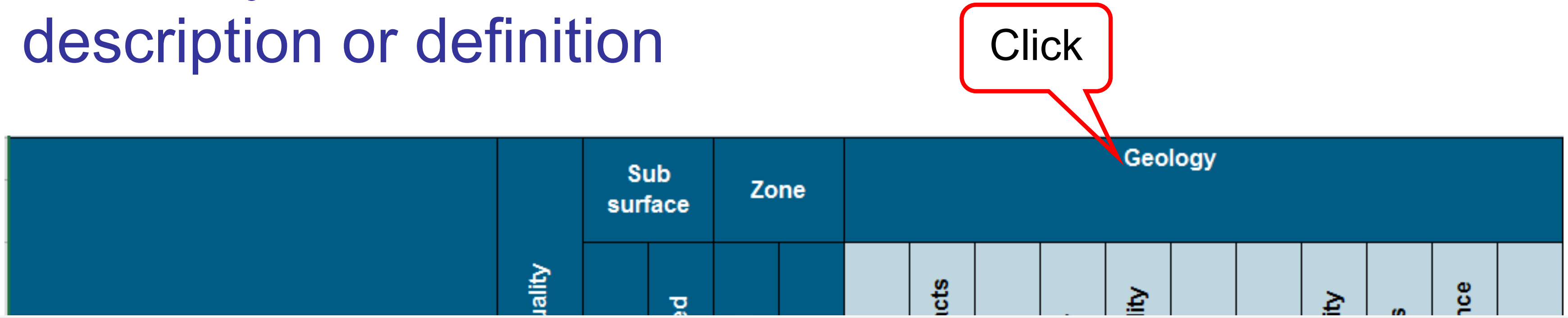
Orientation to the Tools Matrix

- 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



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

Tool	Data Quality	Sub surface		Zone	
		Bedrock	onsolidated	nsaturated	Saturated

Click

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		Zone		Geology										
		Bedrock	Unconsolidated	Unsaturated	Saturated	Lithology	Lithology Contacts	Porosity	Permeability	Dual Permeability	Faults	Fractures	Fracture Density	Fracture sets	Rock Competence	Mineralogy
Geophysics																
Surface Geophysics																
Ground Penetrating Radar (GPR)	QL - 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																

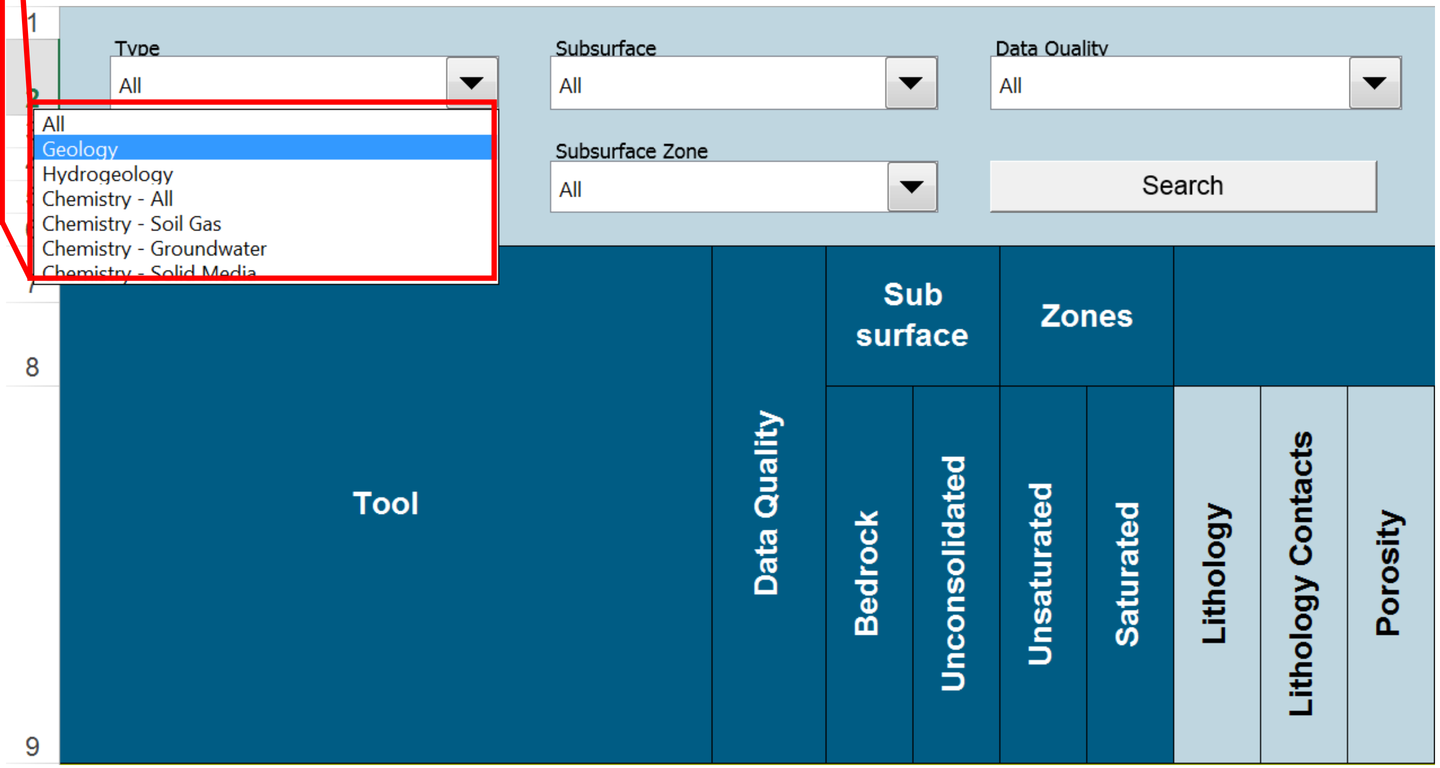
Green shading indicates that tool is applicable to characterization objective

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

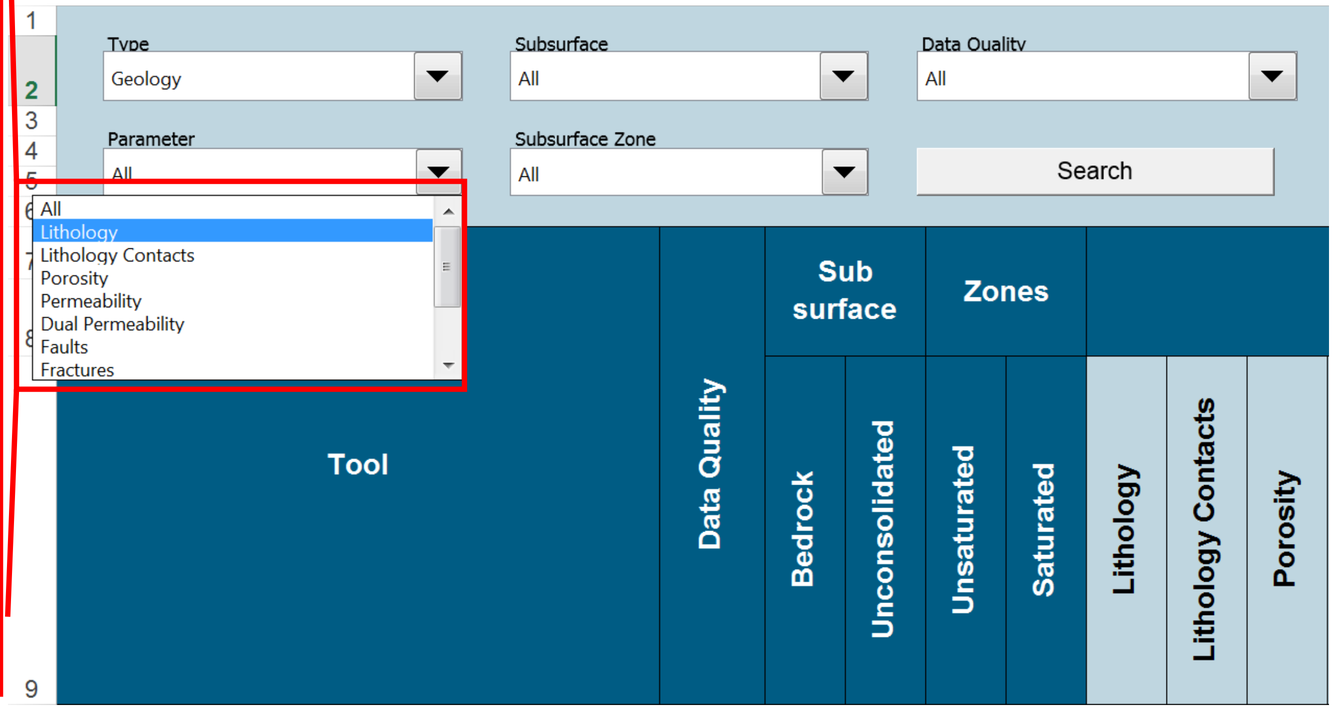
1. Select Category

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



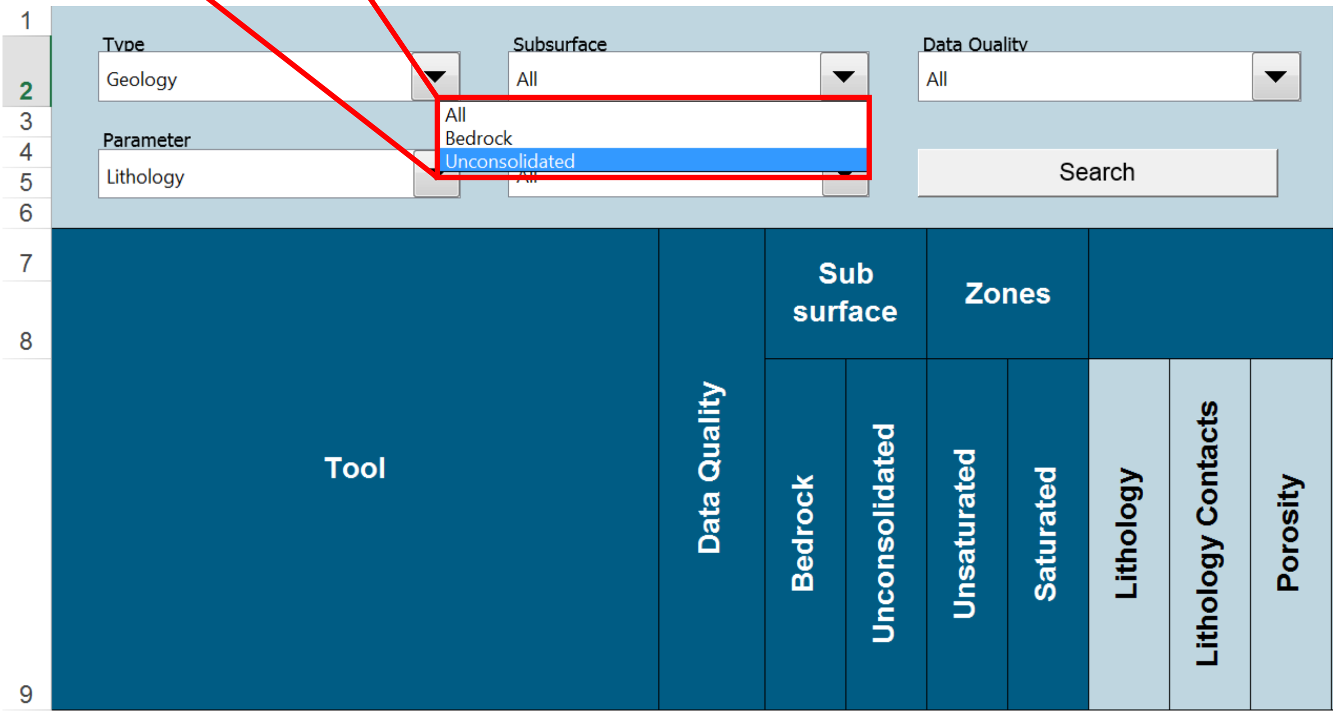
2. Select Parameters of Interest

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



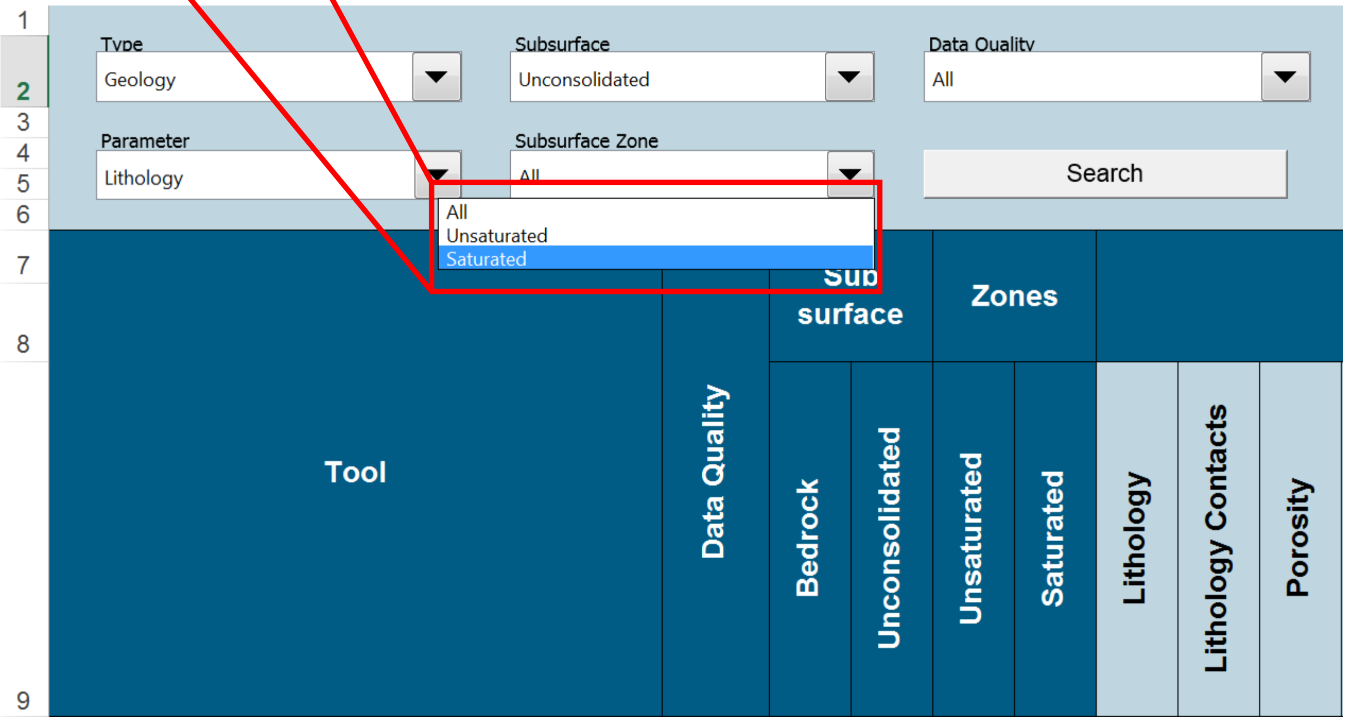
3. Identify Geologic Media

All
Bedrock
Unconsolidated



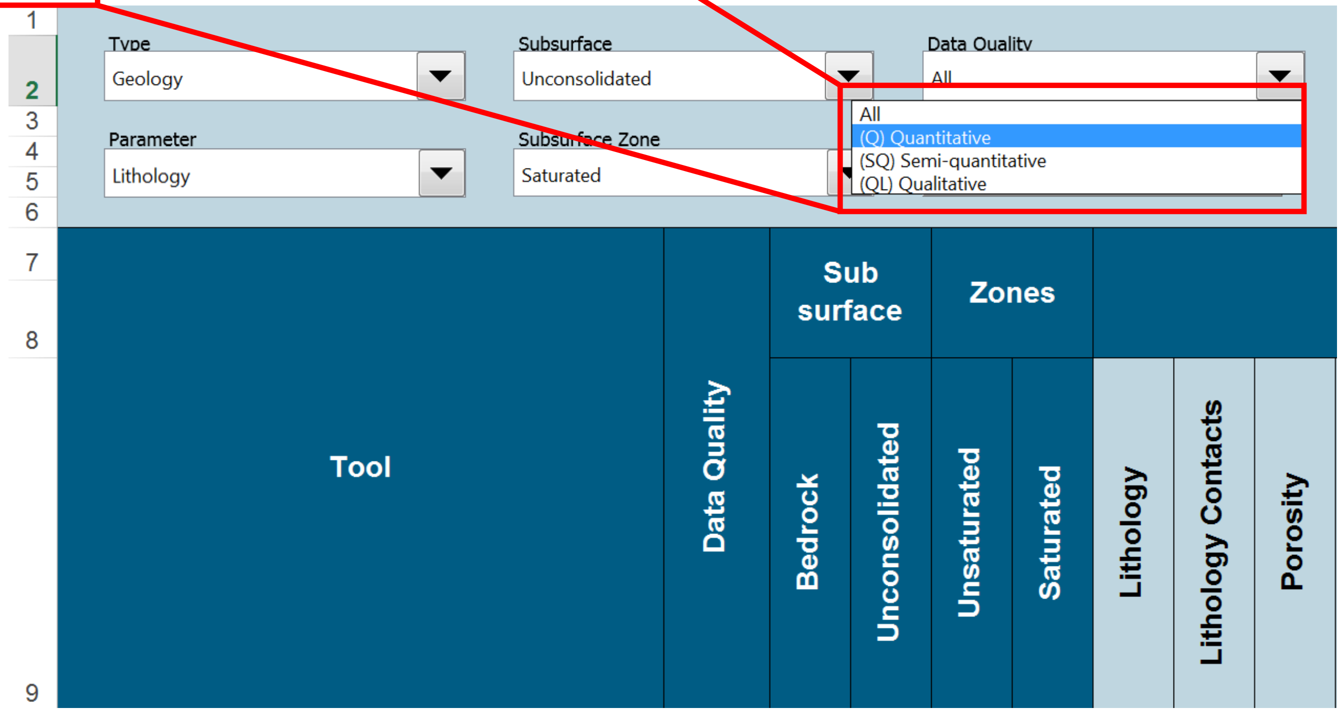
4. Identify Zone

All
Unsaturated
Saturated

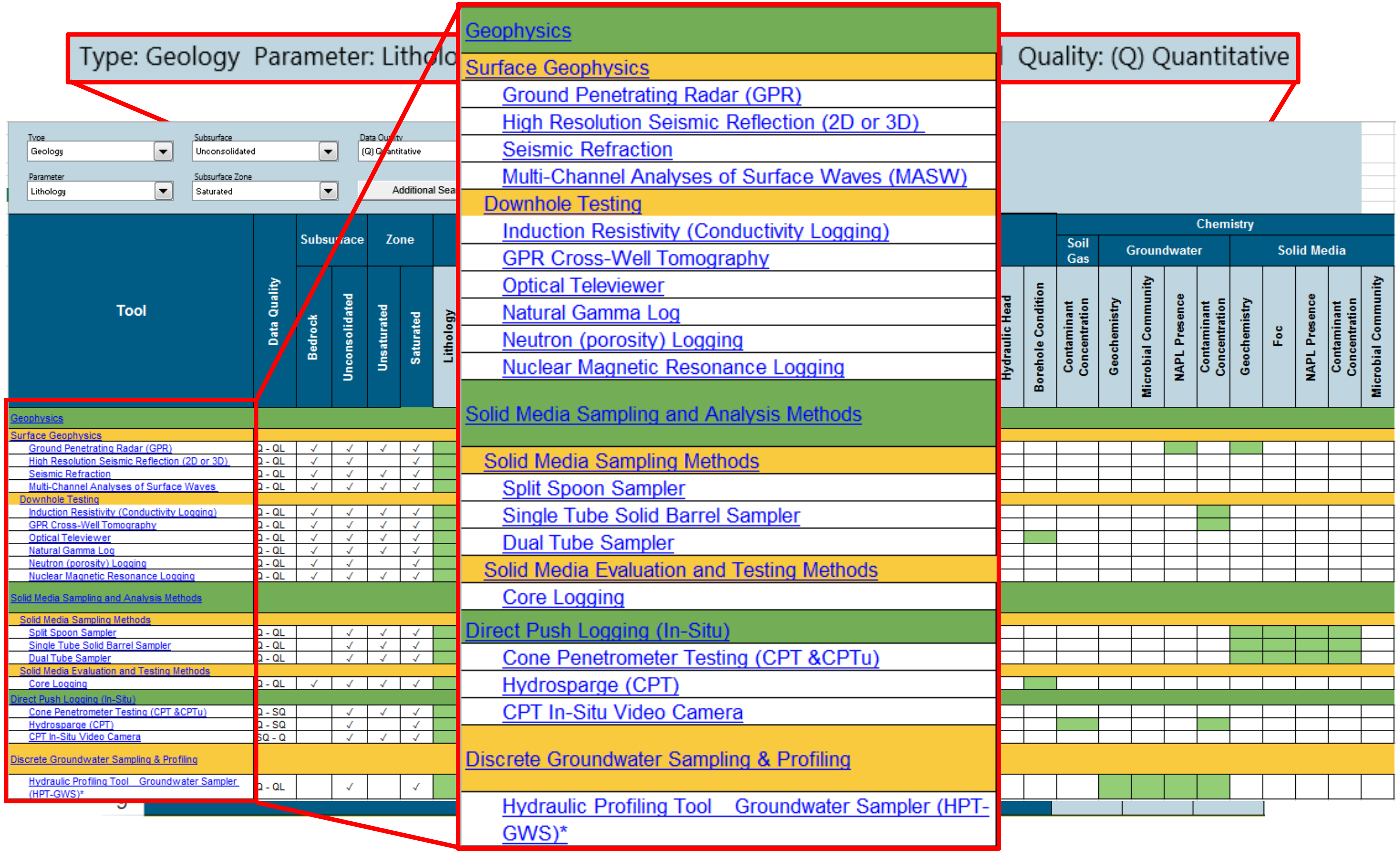


5. Choose Data Quality

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

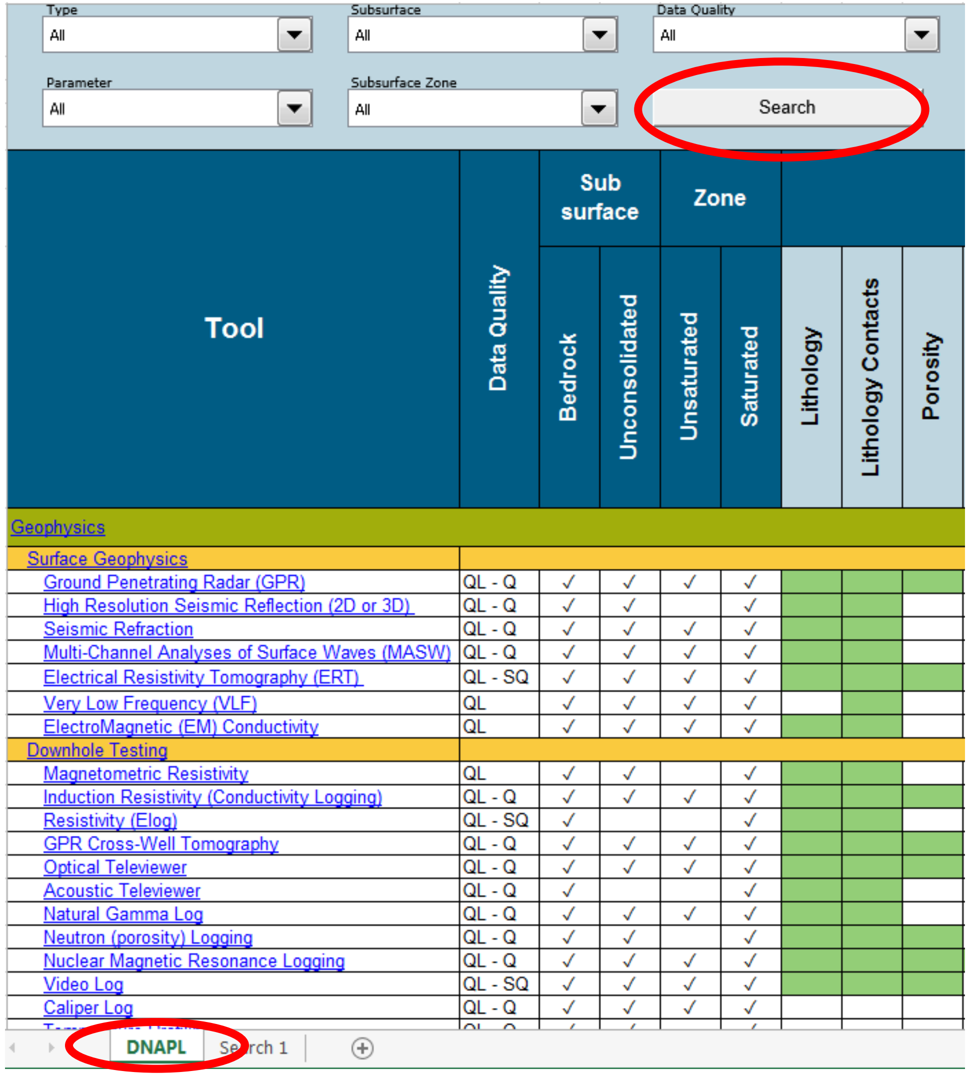


6. Apply Filters, Evaluate Tools



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: Bedrock	Sub surface: Unconsolidated	Zone: Unsaturated	Zone: 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

Type: Geology | Subsurface: Unconsolidated | Data Quality: (Q) Quantitative

Parameter: Lithology | Subsurface Zone: Saturated | Additional Search

Tool	Data Quality	Subsurface: Bedrock	Subsurface: Unconsolidated	Zone: Unsaturated	Zone: Saturated	Lithology	Lithology Contacts	Porosity
Geophysics								
Surface Geophysics								
Ground Penetrating Radar (GPR)	Q - QL	✓	✓	✓	✓			
High Resolution Seismic Reflection (2D or 3D)	Q - QL	✓	✓		✓			
Seismic Refraction	Q - QL	✓	✓	✓	✓			
Multi-Channel Analyses of Surface Waves (MASW)	Q - QL	✓	✓	✓	✓			
Downhole Testing								
Induction Resistivity (Conductivity Logging)	Q - QL	✓	✓	✓	✓			
GPR Cross-Well Tomography	Q - QL	✓	✓	✓	✓			
Optical Televiewer	Q - QL	✓	✓	✓	✓			
Natural Gamma Log	Q - QL	✓	✓	✓	✓			
Neutron (porosity) Logging	Q - QL	✓	✓		✓			
Nuclear Magnetic Resonance Logging	Q - QL	✓	✓	✓	✓			
Solid Media Sampling and Analysis Methods								
Solid Media Sampling Methods								
Split Spoon Sampler	Q - QL		✓	✓	✓			
Single Tube Solid Barrel Sampler	Q - QL		✓	✓	✓			
Dual Tube Sampler	Q - QL		✓	✓	✓			
Solid Media Evaluati[illegible] Methods								

DNAP | Search 1

Apply Selected Tool(s)

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

Case Example – Characterization Objectives

Case Example

Returning to Case Example from prior section – **Characterization Objective:**

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

Goal:

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

Case Example – Select Tools Matrix Filters

Case Example

Filters

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

Case Example – Apply Filters

Case Example

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

Type: Chemistry - All

Subsurface: Unconsolidated

Data Quality: (Q) Quantitative

Parameter: Contaminant Concentration

Subsurface Zone: Saturated

Additional Search

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

Tool	Data Quality	Subsurface: Bedrock	Subsurface: Unconsolidated	Zone: Unsaturated	Zone: Saturated	Geology: Lithology	Geology: Lithology Contacts	Geology: Porosity	Geology: Permeability	Geology: Dual Permeability	Geology: Faults	Geology: Fractures	Geology: Fracture Density	Geology: Fracture sets	Geology: Rock Competence	Geology: Mineralogy	Hydrogeology: Open Hole Flow	Hydrogeology: Ambient Flow	Hydrogeology: Groundwater Age	Hydrogeology: Fracture Aperture	Hydrogeology: Fracture Connectivity	Hydrogeology: Hydraulic Conductivity	Hydrogeology: Hydraulic Head	Hydrogeology: Borehole Condition	Chemistry – Soil Gas: Contaminant Concentration	Chemistry – Groundwater: Geochemistry	Chemistry – Groundwater: Microbial Community	Chemistry – Groundwater: NAPL Presence	Chemistry – Groundwater: Contaminant Concentration	Chemistry – Solid Media: Geochemistry	Chemistry – Solid Media: Foc	Chemistry – Solid Media: NAPL Presence	Chemistry – Solid Media: Contaminant Concentration	Chemistry – Solid Media: Microbial Community
Geophysics																																		
Downhole Testing																																		
Induction Resistivity (Conductivity Logging)	Q - QL	✓	✓	✓	✓																													
GPR Cross-Well Tomography	Q - QL	✓	✓	✓	✓																													
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		✓		✓																													
Grab well water sampler (SNAP, Hydrasleeve)	Q - SQ	✓	✓		✓																													
Straddle packer sampling	Q	✓	✓		✓																													

Case Example – Applicable Tools

Case Example

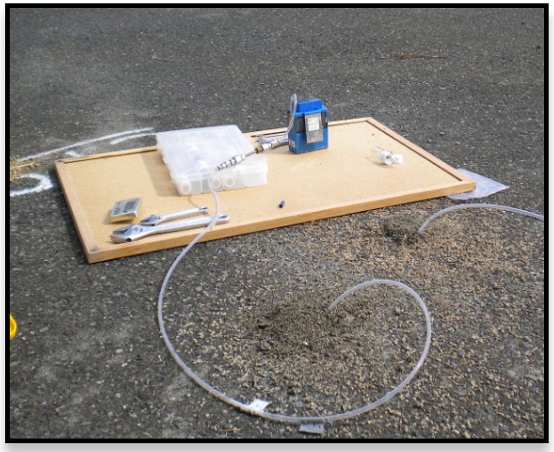
Tool	Data Quality	Subsurface: Bedrock	Subsurface: Unconsolidated	Soil Gas: Contaminant Concentration	Groundwater: Geochemistry	Groundwater: Microbial Community	Groundwater: NAPL Presence	Groundwater: Contaminant Concentration	Chemistry: Geochemistry
Geophysics									
Downhole Testing									
Induction Resistivity (Conductivity Logging)	Q - QL	✓	✓						
GPR Cross-Well Tomography	Q - QL	✓	✓						
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		✓						
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 Spectrometer	Q - SQ	✓	✓						

Geophysics
Downhole Testing
Induction Resistivity (Conductivity Logging)
GPR Cross-Well Tomography
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 Tool
Screen Point (SP) 16 Groundwater Sampling Tool
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 Spectrometer

Case Example – Tools Selection

Case Example

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



Active Soil Gas Survey

DSITMS Mobil Lab

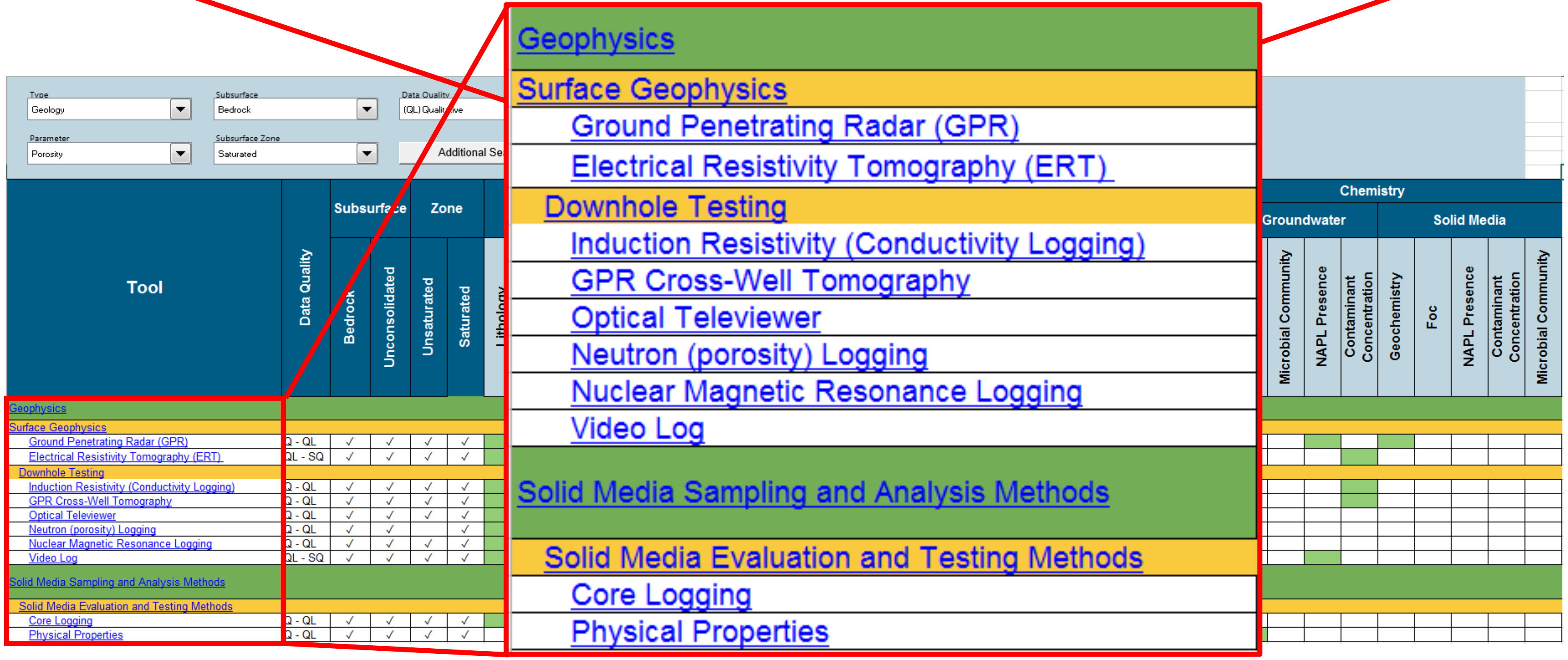
Example #2

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



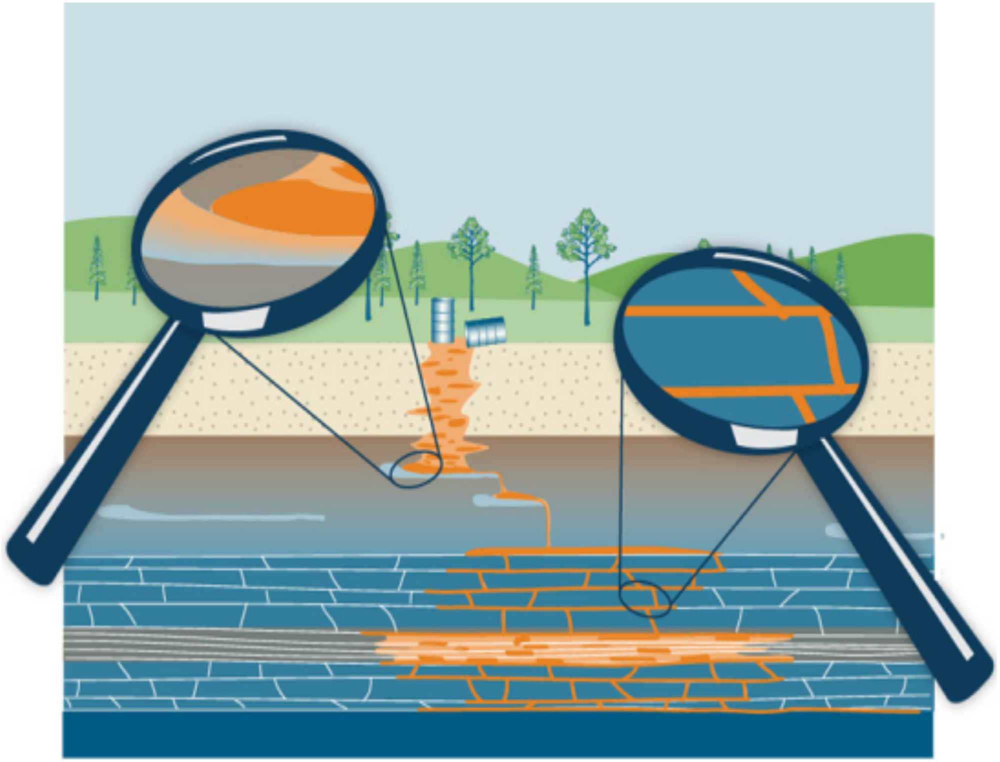
Over 100 tools distilled to 10 that are applicable to the Characterization Objective

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

- NAPL 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

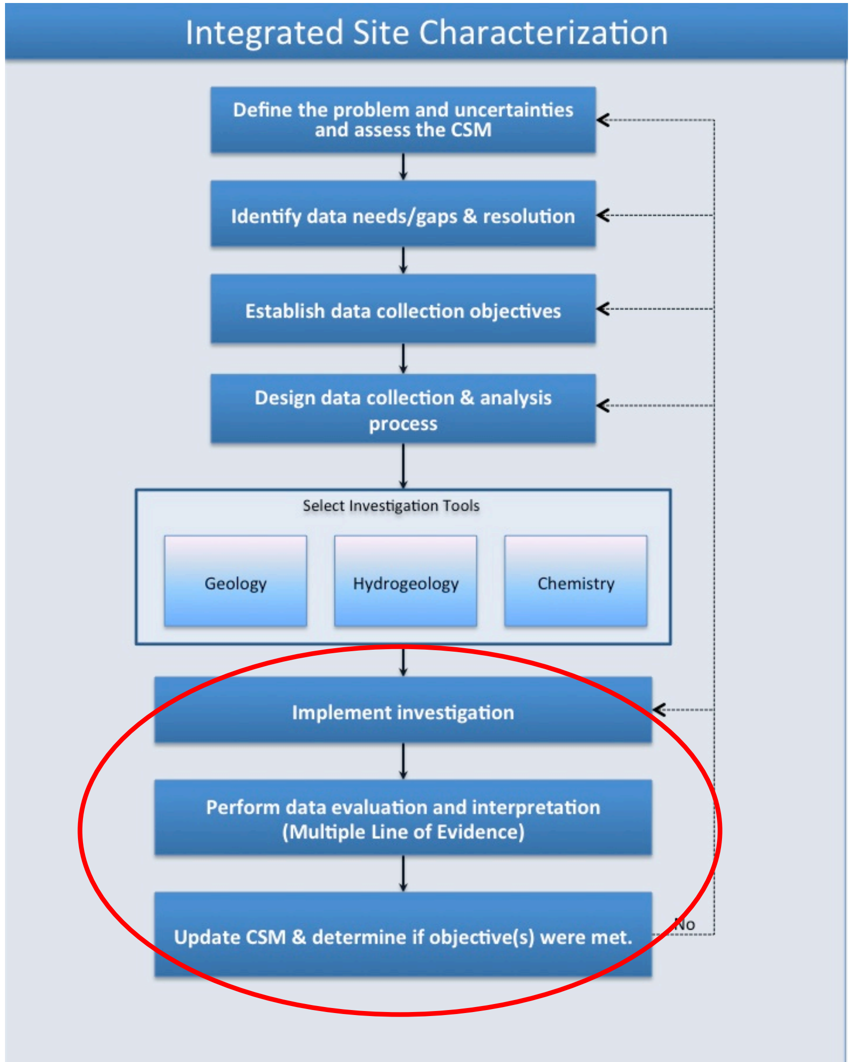


Figure 4-1 Integrated Site Characterization

Step 6. Implement Investigation

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

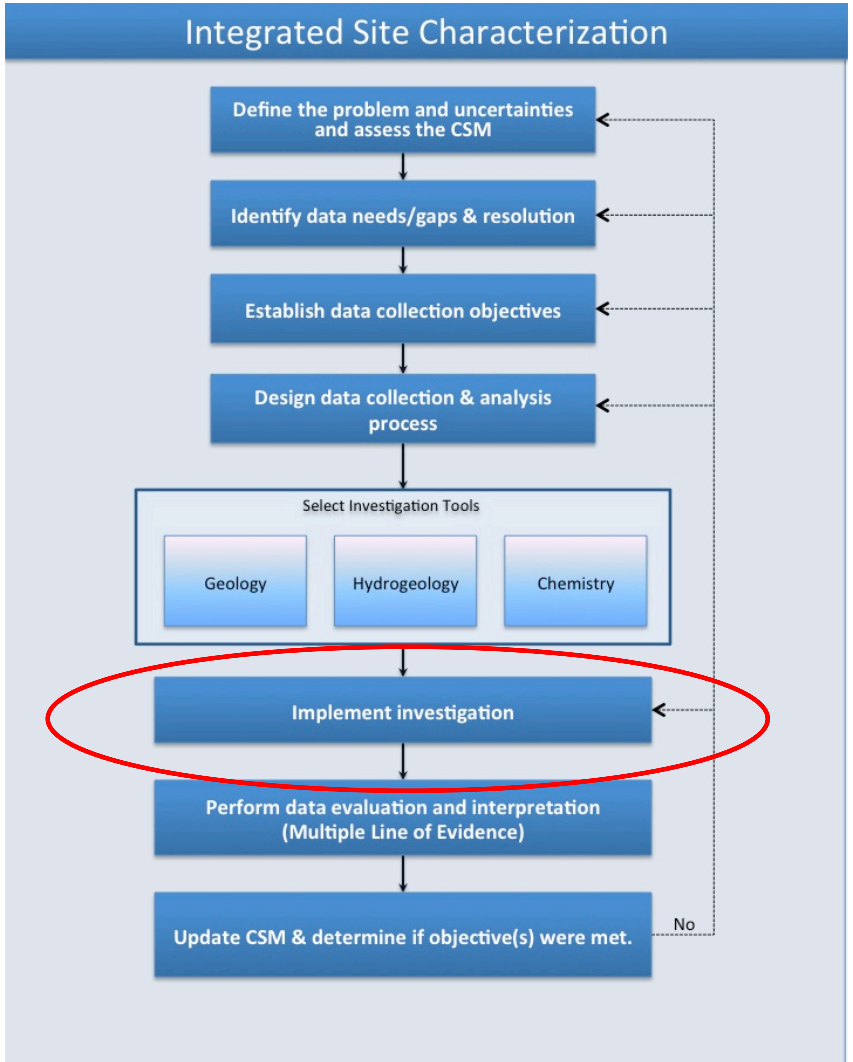


Figure 4-1 Integrated Site Characterization

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

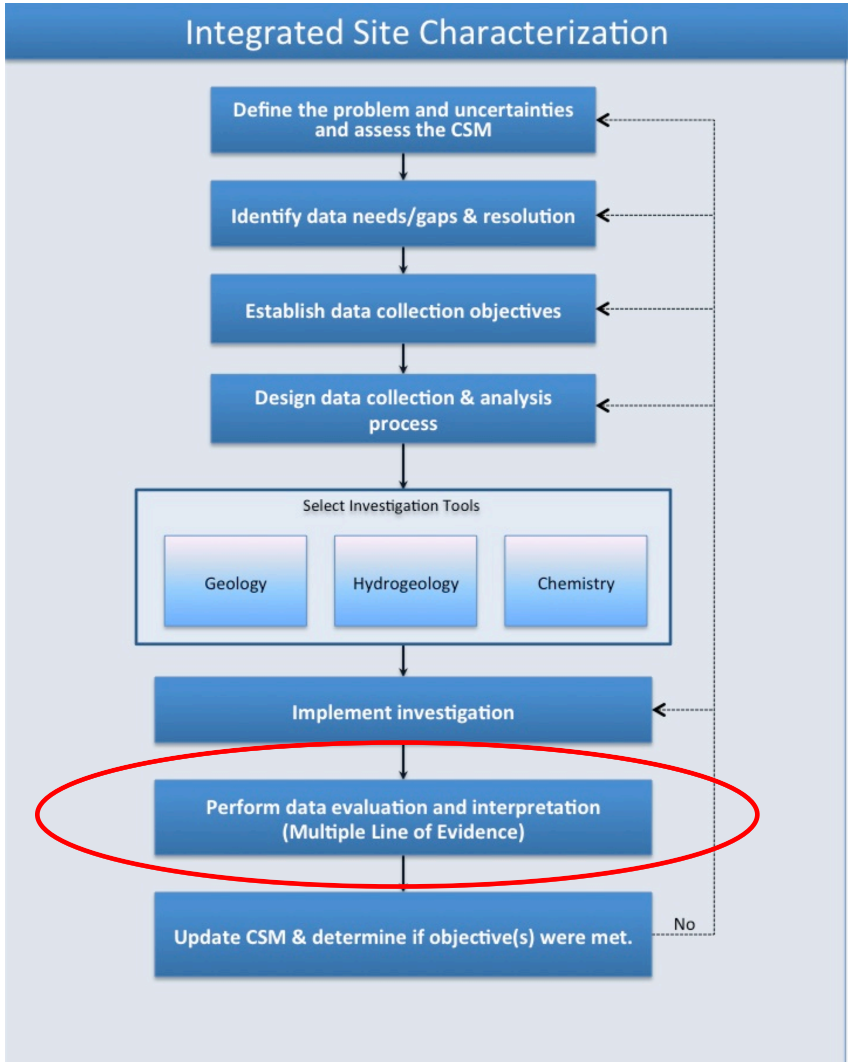
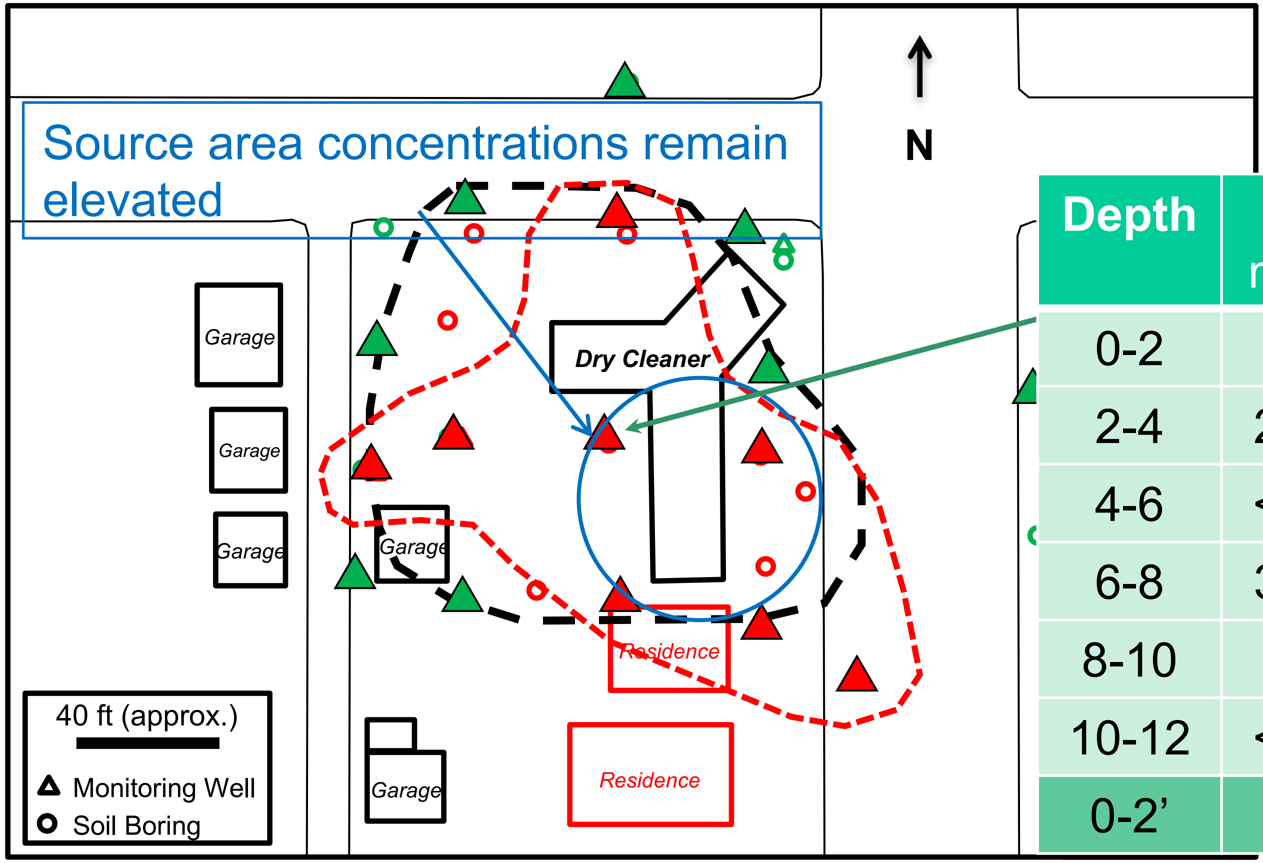


Figure 4-1 Integrated Site Characterization

Step 7. Soil and Groundwater Data Evaluation and Interpretation

Case Example

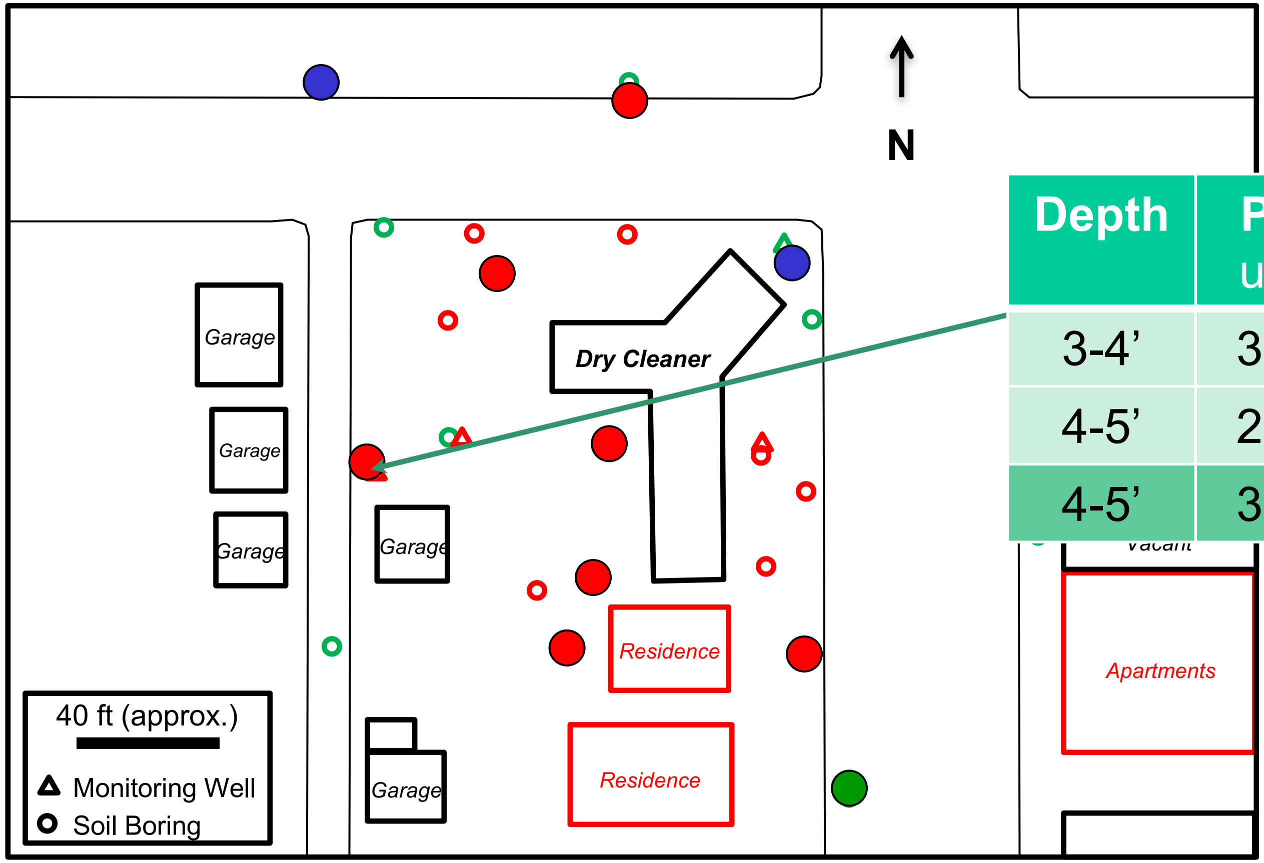


Depth	PCE mg/kg	Lab
0-2	3.25	Mobile
2-4	2.232	Mobile
4-6	<0.37	Mobile
6-8	3.298	Mobile
8-10	11.5	Mobile
10-12	<0.37	Mobile
0-2’	21	Fixed

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

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

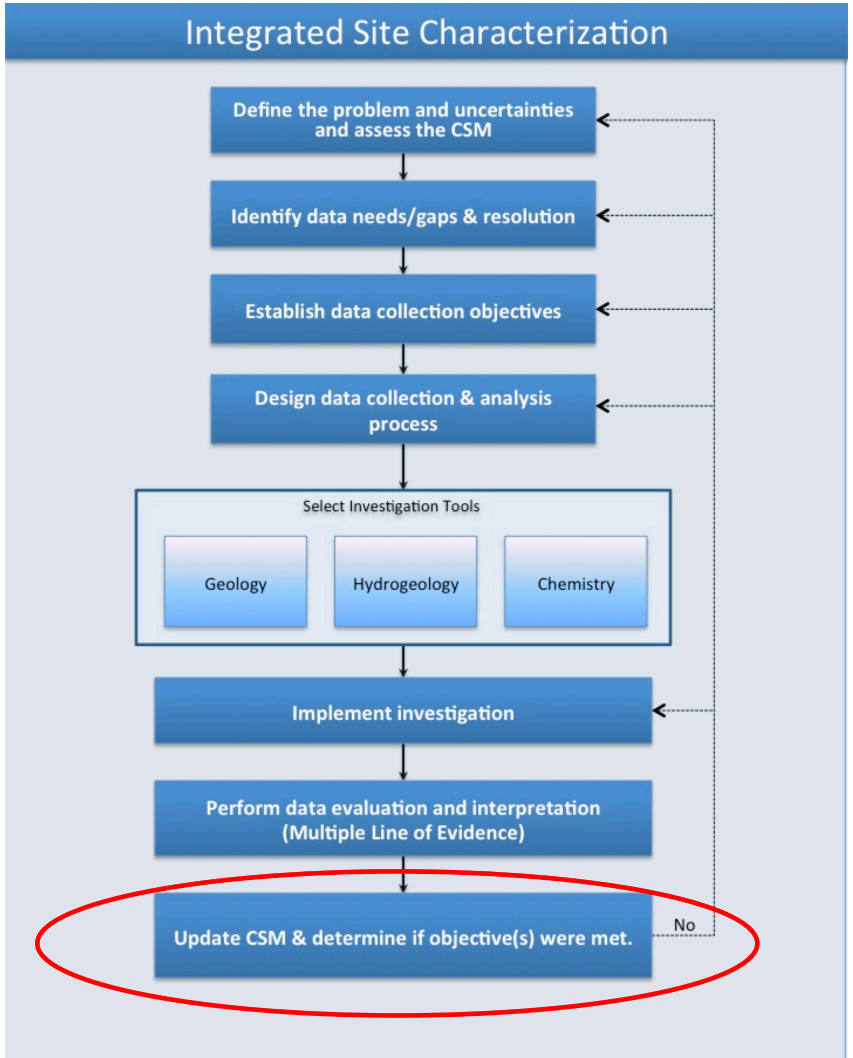
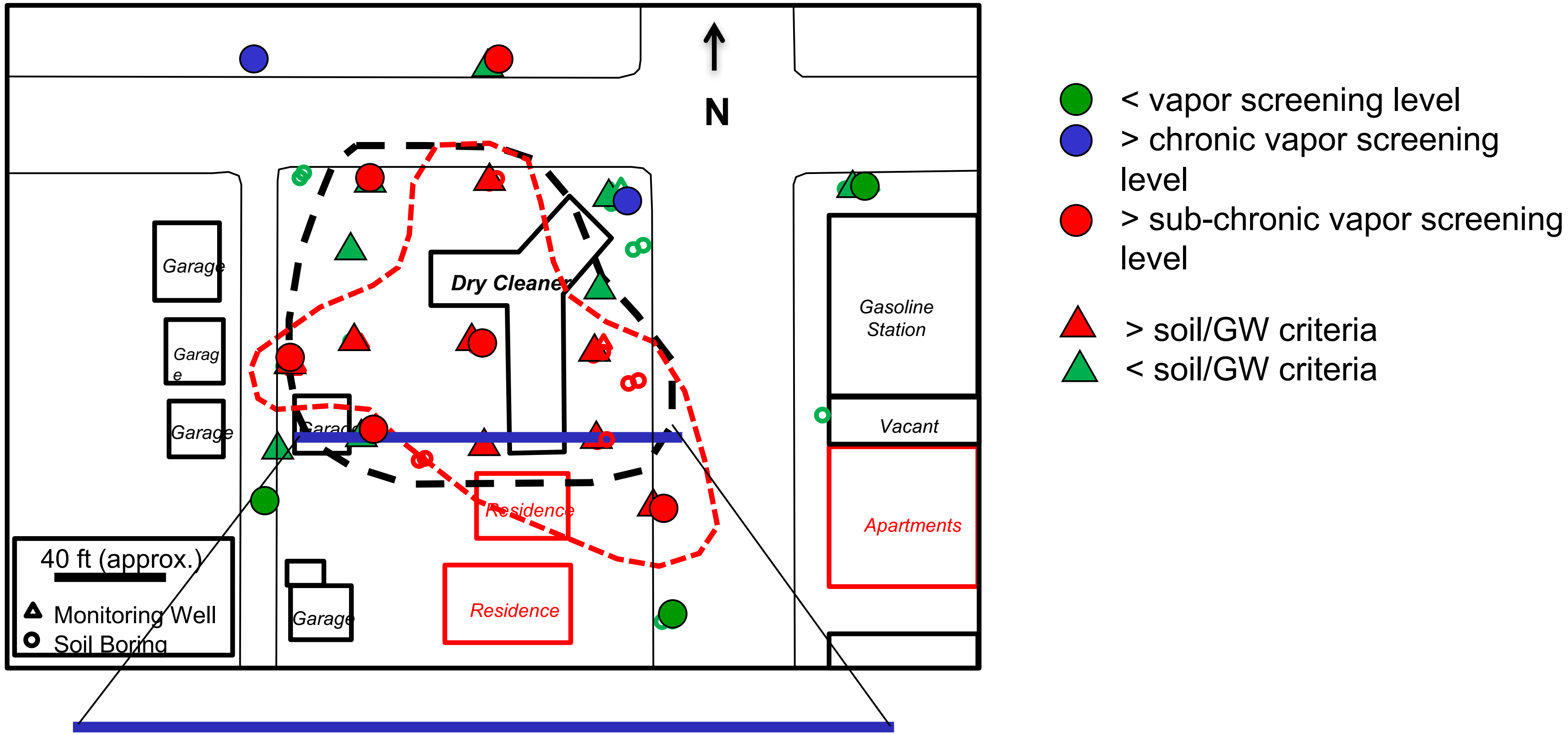
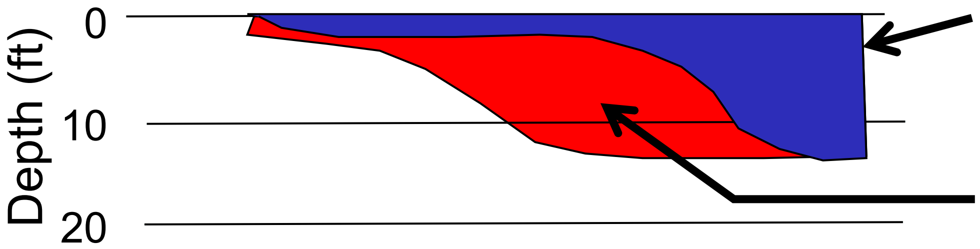


Figure 4-1 Integrated Site Characterization

Step 8: Dry Cleaners – CSM Update

Case Example





Original vertically-delineated plume

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

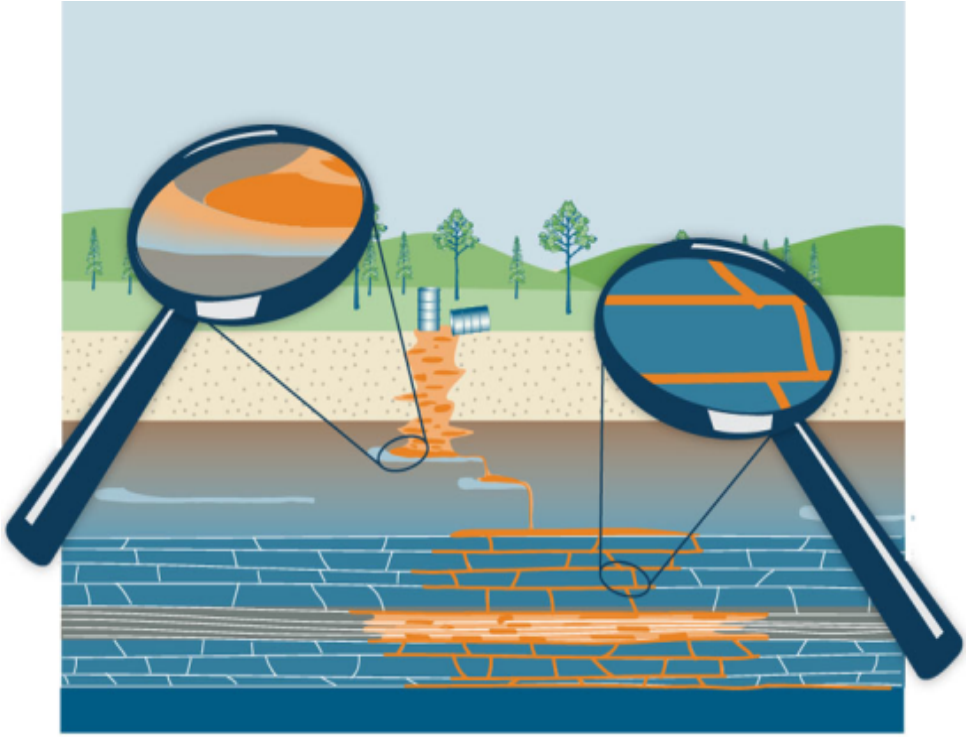
Integrated Site Characterization Benefits for Dry Cleaners Sites

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%)

Training Overview

- NAPL Characteristics
- Life Cycle of a DNAPL Site
- Integrated Site Characterization
- Summary



Summary: Integrated Site Characterization

- Planning
- Tools selection
- Implementation

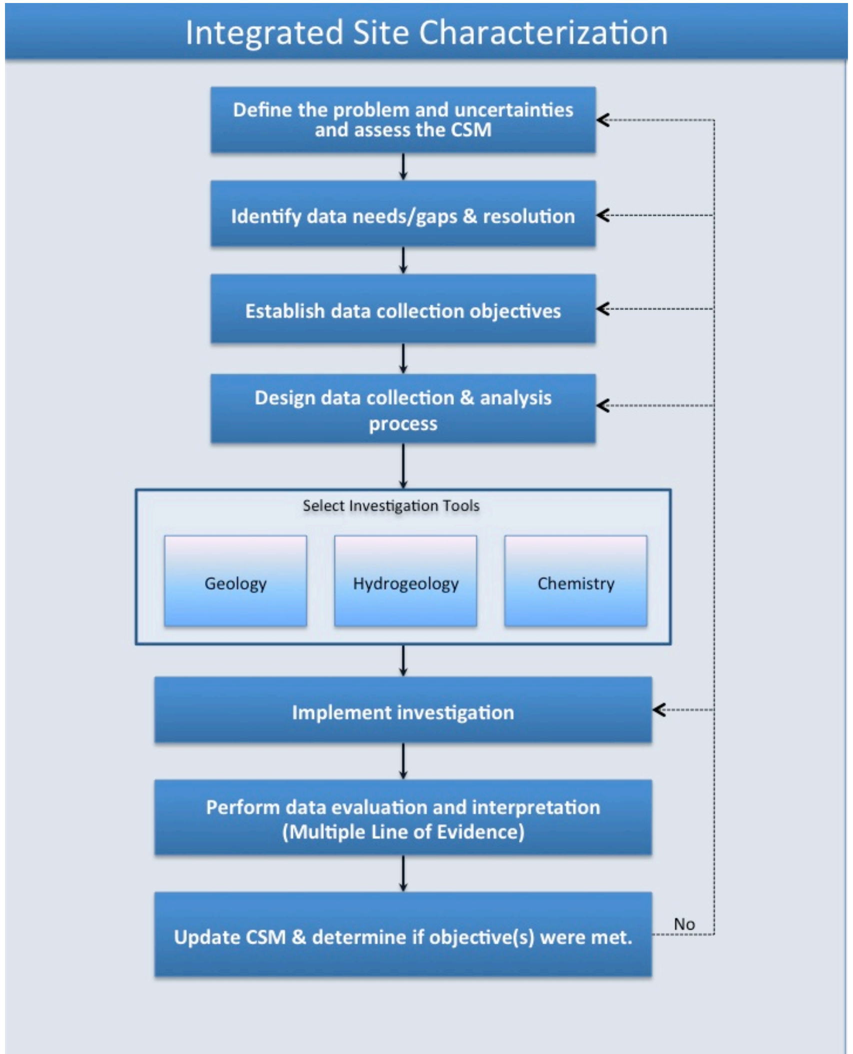


Figure 4-1 Integrated Site Characterization

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 for Participating