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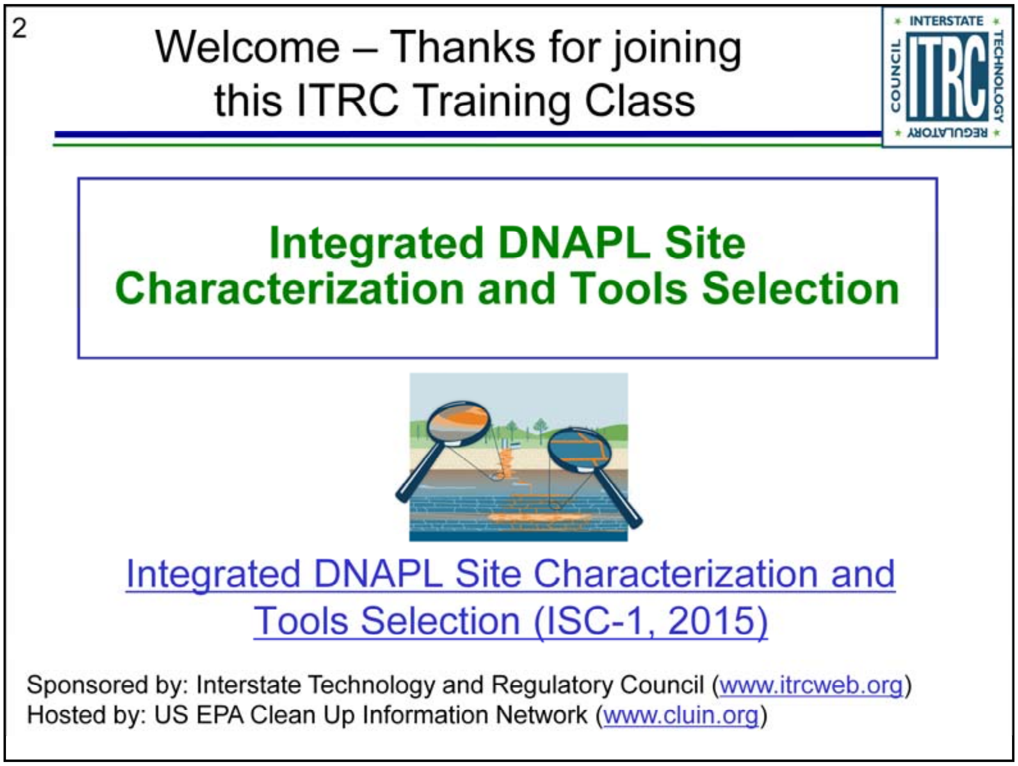
Starting Soon: Integrated DNAPL Site Characterization

- 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
- Using Adobe Connect
  - Related Links (on right)
    - Select name of link
    - Click "Browse To"
  - Full Screen button near top of page
- Follow ITRC

No associated notes.



Sites contaminated with dense nonaqueous phase liquids (DNAPLs) and DNAPL mixtures present significant environmental challenges. Despite the decades spent on characterizing and attempting to remediate DNAPL sites, substantial risk remains. Inadequate characterization of site geology as well as the distribution, characteristics, and behavior of contaminants -- by relying on traditional monitoring well methods rather than more innovative and integrated approaches -- has limited the success of many remediation efforts.

The Integrated DNAPL Site Characterization Team has synthesized the knowledge about DNAPL site characterization and remediation acquired over the past several decades, and has integrated that information into a new document, Integrated DNAPL Site Characterization and Tools Selection (ISC-1, 2015). This guidance is a resource to inform regulators, responsible parties, other problem holders, consultants, community stakeholders, and other interested parties of the critical concepts related to characterization approaches and tools for collecting subsurface data at DNAPL sites. After this associated training, participants will be able to use the ITRC Integrated DNAPL Site Characterization and Tools Selection (ISC-1, 2015) guidance to develop and support an integrated approach to DNAPL site characterization, including:

- Identify what site conditions must be considered when developing an informative DNAPL conceptual site model (CSM)
- Define an objectives-based 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

For reference during the training class, participants should have a copy of Figure 4-1, the integrated site characterization flow diagram from the ITRC Technical and Regulatory Guidance document: Integrated DNAPL Site Characterization and Tools Selection (ISC-1, 2015) and available as a PDF at http://www.cluin.org/conf/itrc/IDSC/ITRC-ISC-Figures.pdf.

ITRC (Interstate Technology and Regulatory Council) www.itrcweb.org

Training Co-Sponsored by: US EPA Technology Innovation and Field Services Division (TIFSD) (www.clu-in.org)

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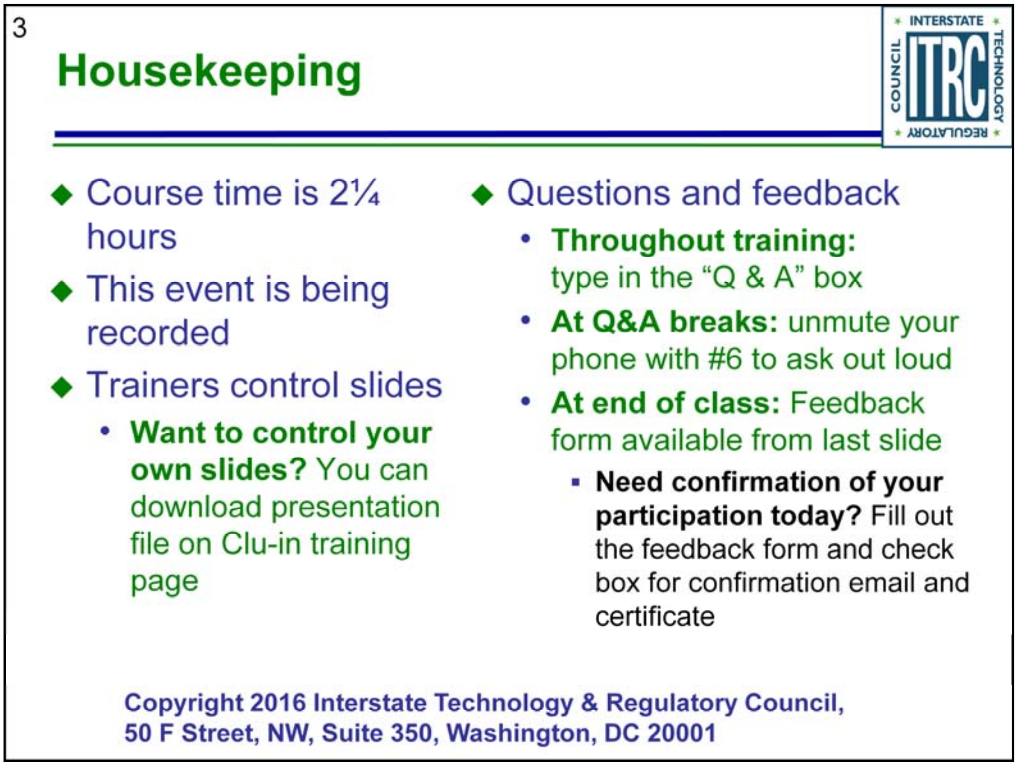
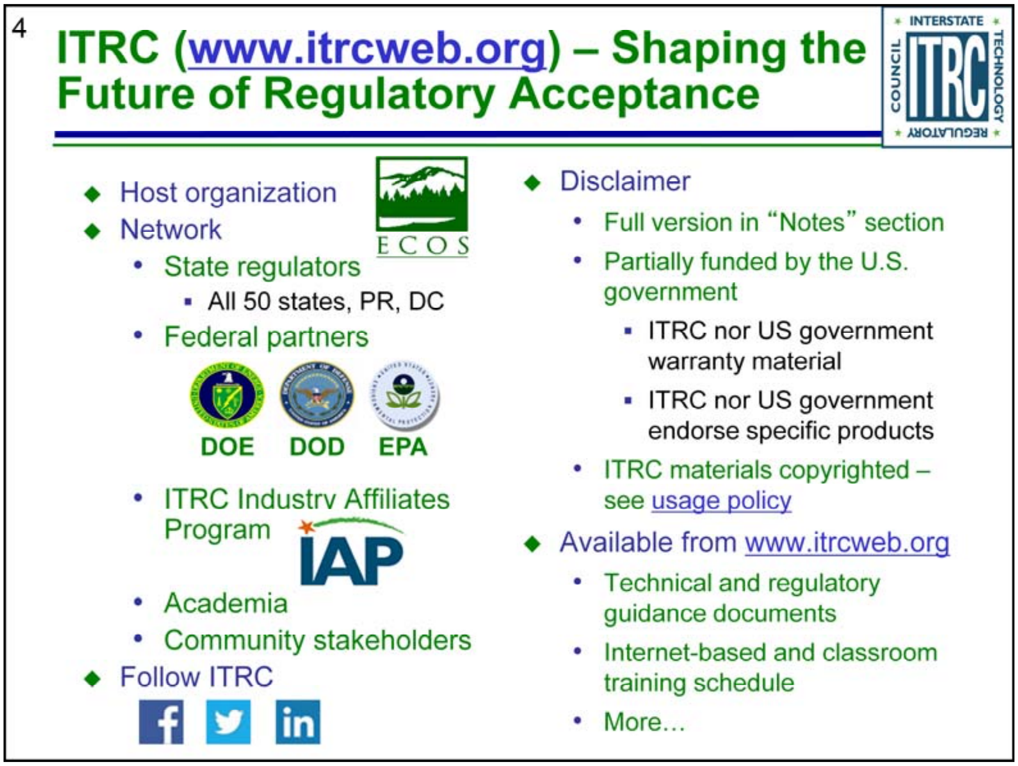


Although I'm sure that some of you are familiar with these rules from previous CLU-IN events, let's run through them quickly for our new participants.

We have started the seminar with all phone lines muted to prevent background noise. Please keep your phone lines muted during the seminar to minimize disruption and background noise. During the question and answer break, press #6 to unmute your lines to ask a question (note: *6 to mute again). Also, please do NOT put this call on hold as this may bring unwanted background music over the lines and interrupt the seminar.

Use the "Q&A" box to ask questions, make comments, or report technical problems any time. For questions and comments provided out loud, please hold until the designated Q&A breaks.

Everyone – please complete the feedback form before you leave the training website. Link to feedback form is available on last slide.



The Interstate Technology and Regulatory Council (ITRC) is a state-led coalition of regulators, industry experts, citizen stakeholders, academia and federal partners that work to achieve regulatory acceptance of environmental technologies and innovative approaches. ITRC consists of all 50 states (and Puerto Rico and the District of Columbia) that work to break down barriers and reduce compliance costs, making it easier to use new technologies and helping states maximize resources. ITRC brings together a diverse mix of environmental experts and stakeholders from both the public and private sectors to broaden and deepen technical knowledge and advance the regulatory acceptance of environmental technologies. Together, we're building the environmental community's ability to expedite quality decision making while protecting human health and the environment. With our network of organizations and individuals throughout the environmental community, ITRC is a unique catalyst for dialogue between regulators and the regulated community.

For a state to be a member of ITRC their environmental agency must designate a State Point of Contact. To find out who your State POC is check out the "contacts" section at www.itrcweb.org. Also, click on "membership" to learn how you can become a member of an ITRC Technical Team.

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Meet the ITRC Trainers

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Michael B. Smith has worked for the Vermont Department of Environmental Conservation in Montpelier as a hydrogeologist and technical expert since 1986. He manages the characterization and remediation of numerous hazardous sites including chlorinated solvent sites, manufactured gas plants, industrial sites, and petroleum sites. He also serves as a technical resource to staff, works on regulation development, develops Standard Operating Procedures, and acts as an Expert Witness for the State in various enforcement actions. Prior to working in the environmental hydrogeology field, he worked in mining, oil and gas exploration and production, and as a private consultant. In his role with the State, Michael has also represented the State in the Interstate Technology Regulatory Council (ITRC) since 2001. He was the training coordinator on the ITRC Board from 2004 through 2011. He has been a member and a contributing writer in all DNAPL teams since joining the organization. He is the co-chair of the DNAPL Site Characterization, and Remediation and Characterization of Fractured Bedrock teams. Michael earned a BS in Geology from Marietta College in Marietta, Ohio in 1978, and an MS in Hydrogeology and an MA in Climatology from Ohio University in Athens, Ohio in 1985.

Tamzen Macbeth is an Associate Engineer at CDM Smith out of Helena, Montana. She has worked for CDM since 2009. Previously, she worked for 7 years at North Wind Inc. Tamzen is an environmental engineer with an interdisciplinary academic and research background in microbiology and engineering. She specializes in the development, demonstration and application of innovative, cost-effective technologies for contaminated groundwater. Specifically, she is experienced in all aspects of remedies from characterization to remediation for DNAPLs, dissolved organic, inorganic, and radioactive contaminants under CERCLA and RCRA regulatory processes. She has expertise in a variety of chemical, biological, thermal, extraction and solidification/stabilization remediation techniques as well as natural attenuation. Her current work focuses developing combined technology approaches, and innovative characterization techniques such as mass flux and mass discharge metrics. Since 2004, Tamzen has contributed to the ITRC as a team member and instructor for the ITRC's Bioremediation of DNAPLs, Integrated DNAPL Site Strategy, Molecular Diagnostics and DNAPL Characterization teams. Tamzen earned a bachelor's degree in Microbiology in 2000 and a master's degree in Environmental Engineering in 2002 both from Idaho State University in Pocatello, Idaho, and a doctoral degree from in Civil and Environmental Engineering in 2008 from the University of Idaho in Moscow, Idaho.

Trevor King, P.E., is a Senior Project Manager / Technology Lead based in Warrington, Pennsylvania. Since 1993, Trevor has planned, implemented, and managed a wide variety of environmental projects in New Jersey, Pennsylvania, Florida and Puerto Rico. His experience includes project management, developing conceptual site models in support of remedy selection, developing remedial objectives and site closure strategies for remediation projects, and regulatory and client interface. Trevor has two pneumatic fracturing technology patents. His current company-wide responsibilities include project management and remedial strategy and technology evaluations at a national as well as the regional level. Trevor has been active in the ITRC since 2007 and has contributed, as a team member, to three ITRC DNAPL documents. He earned a bachelor's degree in mechanical engineering from the University of Wolverhampton in Wolverhampton, England in 1983 and a master's degree in environmental engineering from New Jersey Institute of Technology in Newark, New Jersey in 1993. He is a Professional Engineer in environmental engineering in Delaware.

Jeremy Musson is the Principal for Innovation and Optimization at Pinyon Environmental, Inc., based in Lakewood, Colorado with multiple offices in Colorado and Arizona. Jeremy has worked for Pinyon Environmental, Inc. since 2007 and in the environmental field since 1998. He has experience in the design of site characterization and remediation plans, using innovative state-of-the-art methods, for Brownfield, VCRA, UST, and RCRA/CERCLA projects. Jeremy has been a member of the Interstate Regulatory Council (ITRC) since 2011 on the Green and Sustainable Remediation, Dense Non-Aqueous Phase Liquids (DNAPL) Integrated Site Characterization, and Characterization and Remediation of Fractured Bedrock teams. He is a trainer for the Integrated DNAPL Site Characterization course. Additionally, Jeremy serves on the Environmental, Energy, Water Resources, and Scholarship committees for the American Council of Engineering Companies (ACEC) of Colorado. Jeremy earned a bachelor's degree in Marine Geology from Eckerd College in St. Petersburg, Florida in 1998, and has been a listed consultant with the Colorado Department of Labor and Employment, Division of Oil and Public Safety (Listing No 6155) since 2007.

Heather Rectanus, Ph.D., is a Principal Research Scientist at Battelle in Madison, WI. She has worked in the Environmental Restoration and Infrastructure section of Battelle since 2007 where she manages environmental restoration projects and serves as the section's bioremediation technical specialist. Heather's interests reside in technology transfer to integrate the state of the science with field applications. To that end, she manages the remedial innovative technology seminar series for the Navy and has served as Co-chairs for the Tenth International In Situ and On-Site Bioremediation Symposium (May 2009) and the International Symposium on Bioremediation and Sustainable Environmental Technologies (June 2011). Additionally, Heather has worked on projects ranging from biobarrier installation, biosparging designs, MNA utilization, DNAPL remediation strategies. Prior to joining Battelle, she was a post-doctoral researcher in the Charles E. Via Civil and Environmental Engineering Department at Virginia Tech where she investigated the impact of nanoparticle size on Raman spectroscopy and instructed the Introduction to Fluid Mechanics course. Heather joined the IDSS team in 2009 to help complete the Mass Flux/Mass Discharge guidance document, then served as a co-lead on a chapter for the IDSS document. Heather earned a B.S. in Nuclear Engineering and a B.A. in German from Kansas State University in Manhattan, KS in 1998, and continued at Virginia Tech in Blacksburg, Virginia to earn an M.S. in Civil Engineering with a Geoenvironmental Engineering emphasis in 2000 and a Ph.D. in Civil Engineering in 2006.

6

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

Restoring sites contaminated by chlorinated solvents to typical regulatory criteria (low parts-per-billion concentrations) within a generation (~20 years) has proven exceptionally difficult, although there have been successes. Site managers must recognize that complete restoration of many of these sites will require prolonged treatment and involve several remediation technologies. To make as much progress as possible requires a thorough understanding of the site, clear descriptions of achievable objectives, and use of more than one remedial technology. Making efficient progress will require an adaptive management approach, and may also require transitioning from one remedy to another as the optimum range of a technique is surpassed. Targeted monitoring should be used and re-evaluation should be done periodically.

7

Poll Question

Poll Question

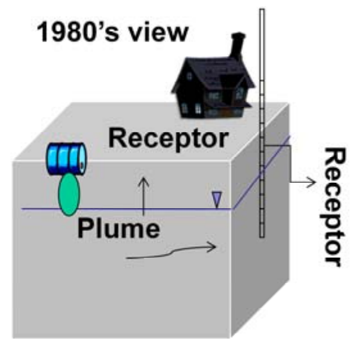
- For sites that you work on, what year did cleanup activities begin?
  - Please provide a short answer

No associated notes.

8

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



When we began to address subsurface contamination in the 1970's, many practitioners came from the water supply industry

We used a series of during site characterization and remedial design.

These simplifications in many cases led to inadequate characterization of the site geologic heterogeneity and distribution, characteristics, and behavior of contaminants

This approach has helped to limit the success of many site remediation activities

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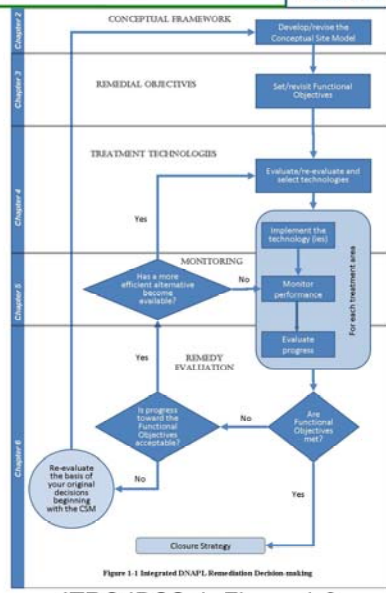
The Solution: An Integrated DNAPL Site Strategy

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

ITRC's Integrated Dense Nonaqueous Phase Liquid Site Strategy (IDSS-1, 2011) technical and regulatory guidance document will assist site managers in development of an integrated site remedial strategy. This course highlights five important features of an IDSS including:

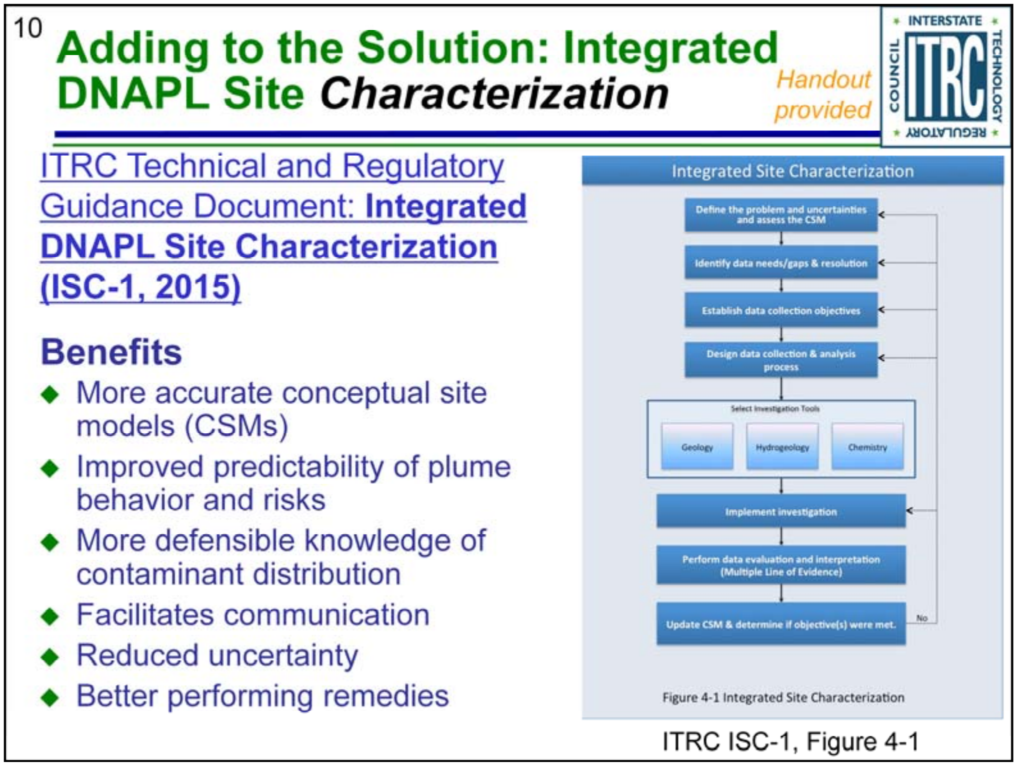
A conceptual site model (CSM) that is based on reliable characterization and an understanding of the subsurface conditions that control contaminant transport, reactivity, and distribution

Remedial objectives and performance metrics that are clear, concise, and measureable

Treatment technologies applied to optimize performance and take advantage of potential synergistic effects

Monitoring based on interim and final cleanup objectives, the selected treatment technology and approach, and remedial performance goals

Reevaluating the strategy repeatedly and even modifying the approach when objectives are not being met or when alternative methods offer similar or better outcomes at lower cost



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

Better performing remedies and improved predictability of plume behavior and risks.

Increased spatial precision and accuracy of characterization data, leading to more accurate CSMs.

More defensible knowledge of contaminant distribution.

Improved selection of remedial measures to address subsurface zones that feed plumes and drive up potential exposure.

Use of real-time field screening tools for site characterization that may minimize the number of permanent monitoring wells, thus providing more optimal use of available personnel and financial resources.

Facilitates communication of site conditions and improves enhanced stakeholder understanding and involvement.

Reduced uncertainty in risk evaluation, remedy selection, and site management decisions, leading to better reductions in risk and protection of natural resources.

Use of real-time field screening tools for site characterization that may minimize the number of permanent monitoring wells, thus providing more optimal use of available personnel and financial resources.

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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

No associated notes.

12

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

No associated notes.

13

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

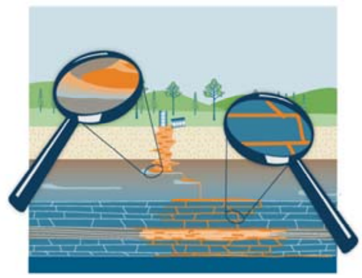
Photo Courtesy of Fred Payne, Arcadis, Inc

ISC-1, Chapter 2

No associated notes.

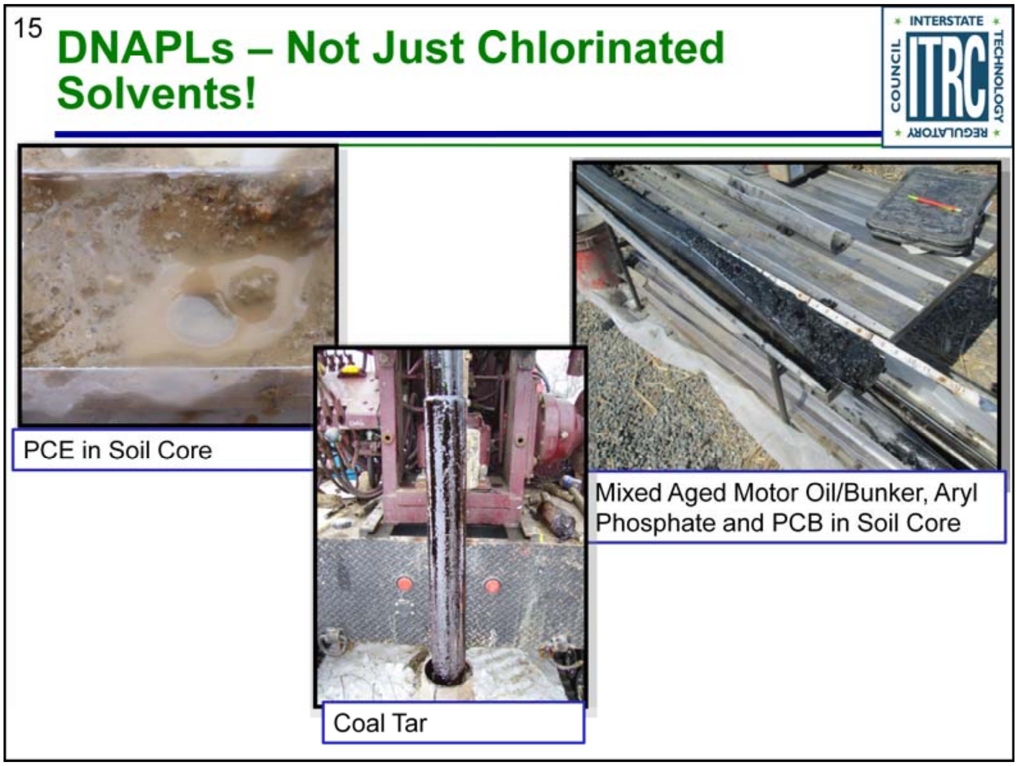
Training Overview

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



ISC-1, Chapter 2

Understanding the subsurface behavior of DNAPLs is technically-challenging and methods for site characterization have evolved. The objective of this document is to describe the tools and resources that can improve the identification, collection, and evaluation of appropriate site characterization data to prepare more accurate CSMs. This guidance describes how, with the current understanding of subsurface contaminant behavior, both existing and new tools and techniques can be used to measure physical, chemical, and hydrologic subsurface parameters to better characterize the subsurface. The expected results of using this guidance are more accurate site-specific CSMs, which can then be applied in the ITRC Integrated DNAPL Site Strategy (ITRC 2011).



Heterogeneity replaces homogeneity. Anisotropy replaces isotropy.

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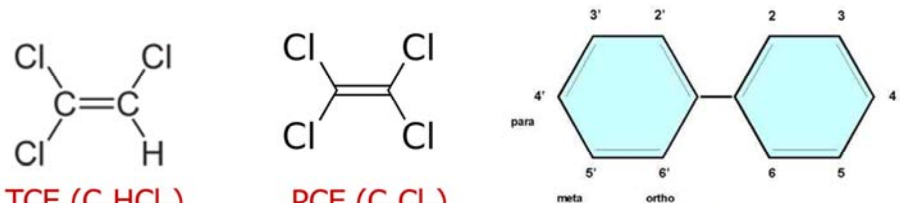
DNAPL Types

- 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

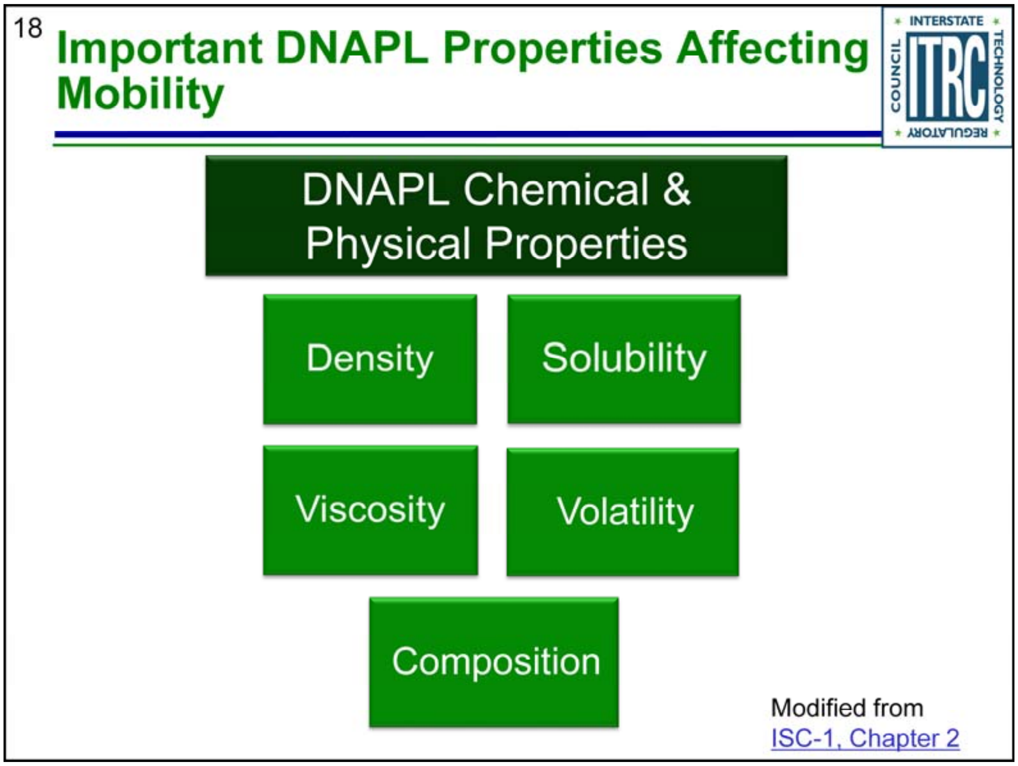
Chapter 2 of this document reviews DNAPL types and the characteristics that control their distribution, fate, and transport in the subsurface. Although these issues are addressed in peer-reviewed literature, they are also summarized in this document because they are crucial to designing an adequate characterization program.

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

Physical properties of
Example NAPLs & reference fluids



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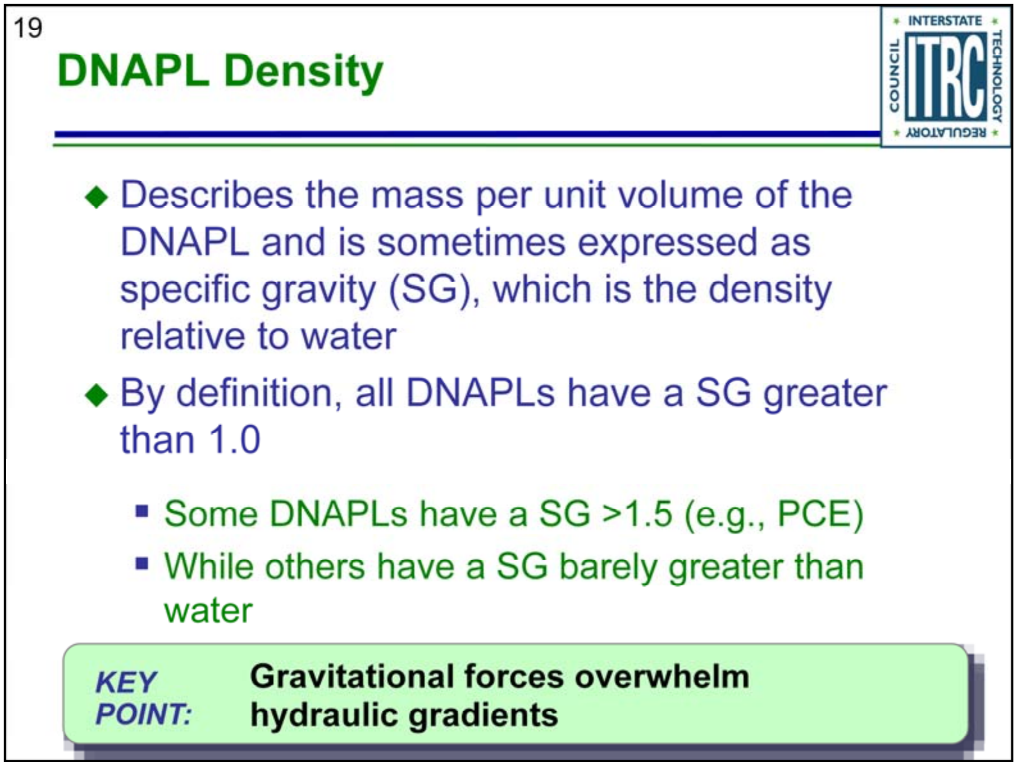

Higher density DNAPLs have a greater driving force for downward movement, while in other cases other DNAPLs may be almost neutrally buoyant.

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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**

Mention effects of pure vs mixed DNAPLs: effect on dissolution etc

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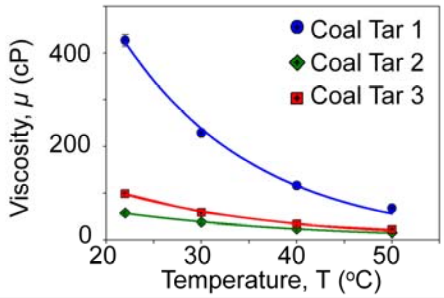
DNAPL Viscosity (Dynamic)

- 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



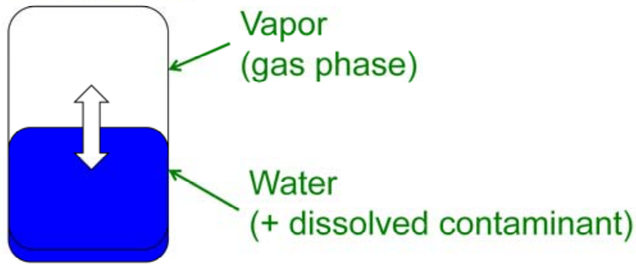
KEY POINT: **Influences mobility in the subsurface**

No associated notes.

22

DNAPL Volatility

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

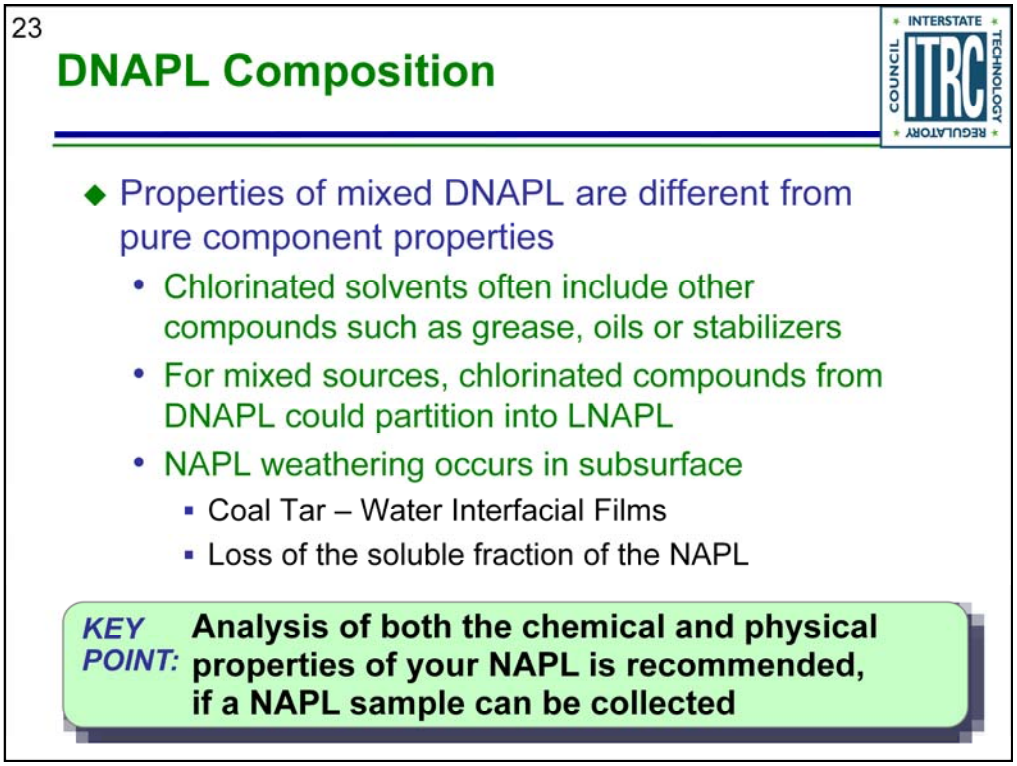


- See also ITRC's Vapor Intrusion Pathway: A Practical Guideline (VI-1, 2007)

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

- Vapor Pressure (VP_{sat} or P_0) Maximum amount of a pure compound that can exist in the gas phase

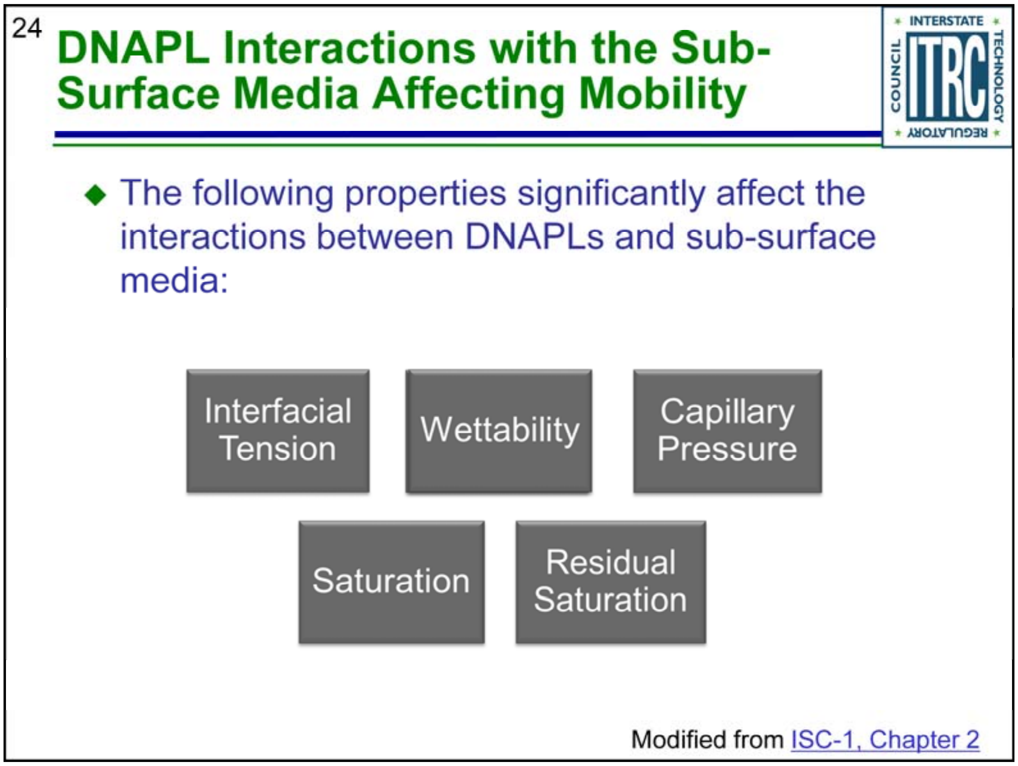
- Henry's Law (K_H)
  - Amount of dissolved organic contaminant that will exist in the gas phase



The properties we have just discussed can “be found” in published literature.

HOWEVER

It is important to stress that the properties of pure laboratory grade chemicals can be very different from what may be present at a site.

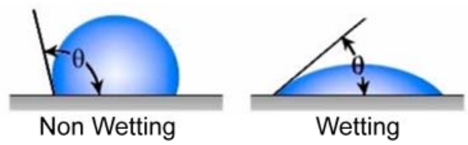


DNAPL Migration is to a large extent controlled by the following DNAPL Properties and the DNAPL interactions with the Sub-Surface Media

25

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**

Wettability

Represents whether a fluid is wicked into or repelled out of the subsurface media, defined by the contact angle θ of the DNAPL fluid against the matrix materials in the presence of water.

Wettability is a combined property of the NAPL and the subsurface formation materials, chemistry, presence of co-contaminants

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

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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

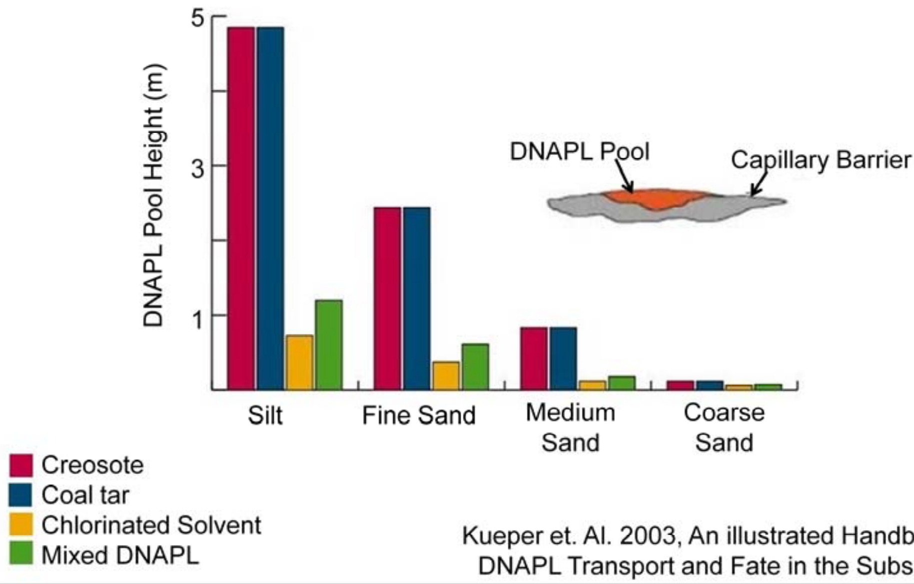
(Lenhard and Parker, 1987)

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

No associated notes.

27

Capillary Pressure of Coarser Layers and DNAPL Entry



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

No associated notes.

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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**

No associated notes.

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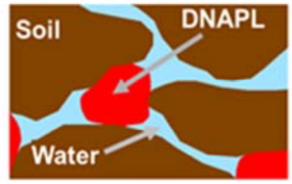
NAPL Saturation and Mobility

- 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)

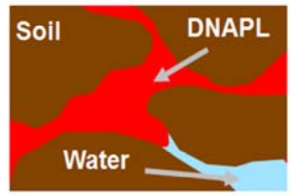


Figure modified from ISC-1, Chapter 2

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

No associated notes.

30

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)

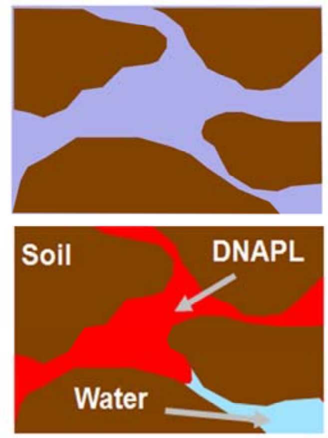


figure modified from ISC-1, Chapter 2

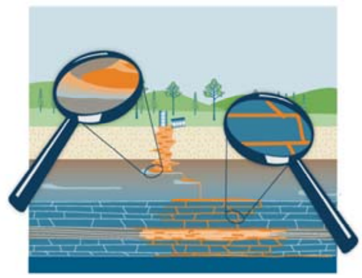
KEY POINT: **The presence of NAPL reduces the effective hydraulic conductivity of the media**

No associated notes.

31

Training Overview

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

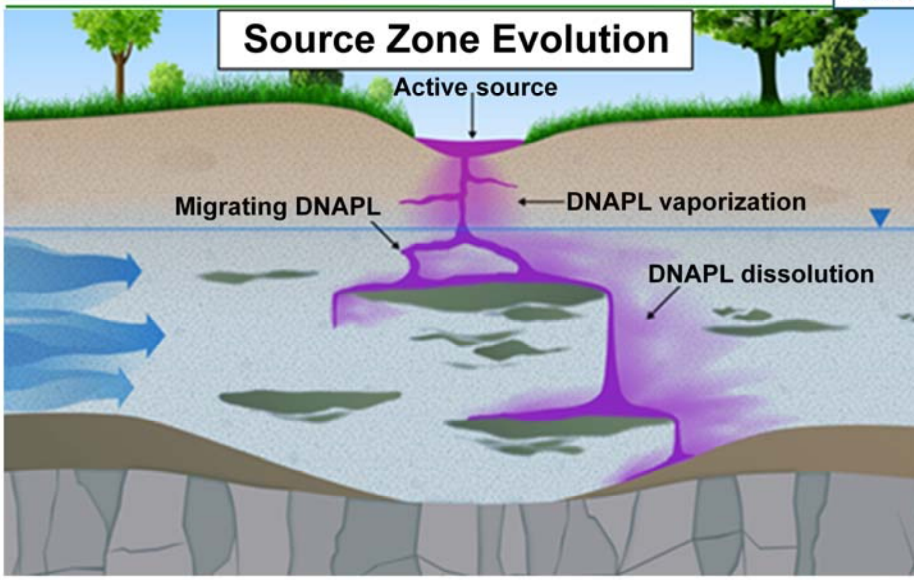


ISC-1, Chapter 3

Understanding the subsurface behavior of DNAPLs is technically-challenging and methods for site characterization have evolved. The objective of this document is to describe the tools and resources that can improve the identification, collection, and evaluation of appropriate site characterization data to prepare more accurate CSMs. This guidance describes how, with the current understanding of subsurface contaminant behavior, both existing and new tools and techniques can be used to measure physical, chemical, and hydrologic subsurface parameters to better characterize the subsurface. The expected results of using this guidance are more accurate site-specific CSMs, which can then be applied in the ITRC Integrated DNAPL Site Strategy (ITRC 2011).

32

DNAPL Life Cycle – Classical Model



Kueper et al., 2013

No associated notes.

33

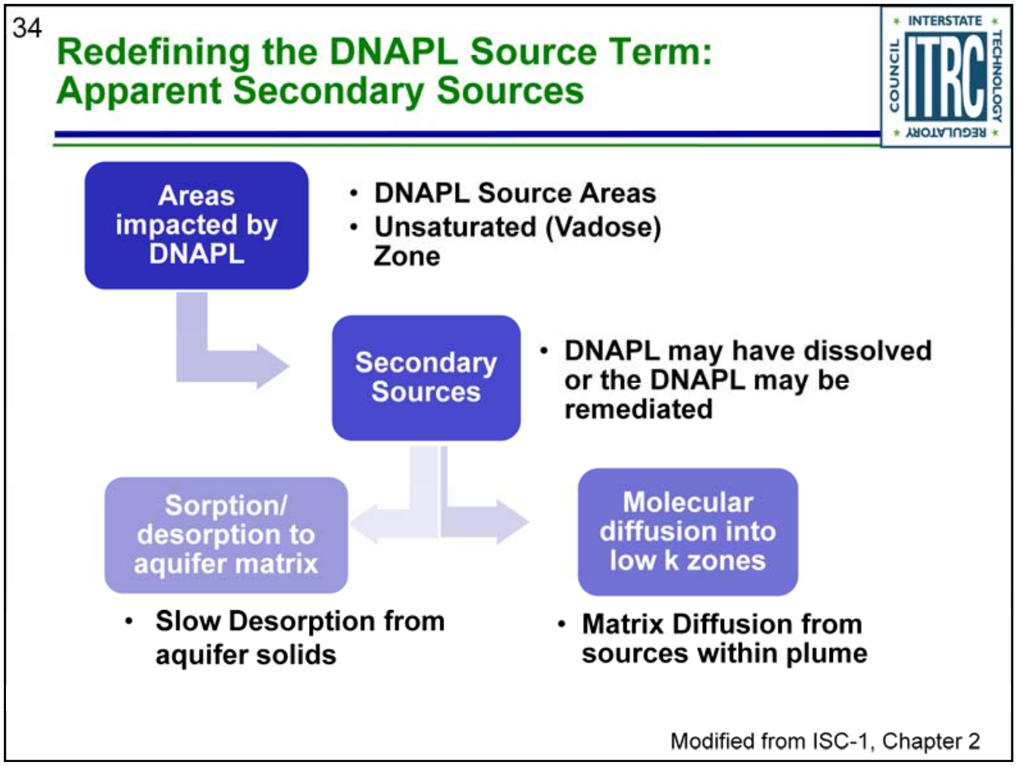
Secondary Sources within Groundwater Plumes

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

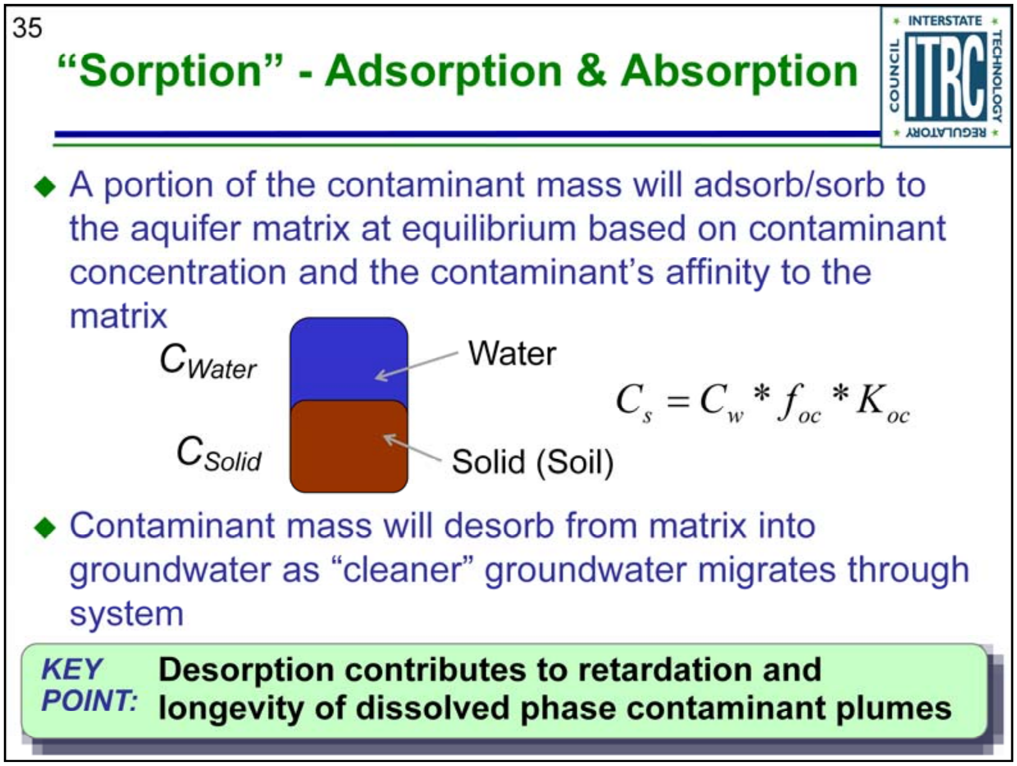
- The hunt for DNAPL is often distracting
- DNAPL is no longer considered the only source of groundwater contamination
  - Sorption/desorption from aquifer matrix
  - Matrix diffusion into/out of low K zones

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

No associated notes.



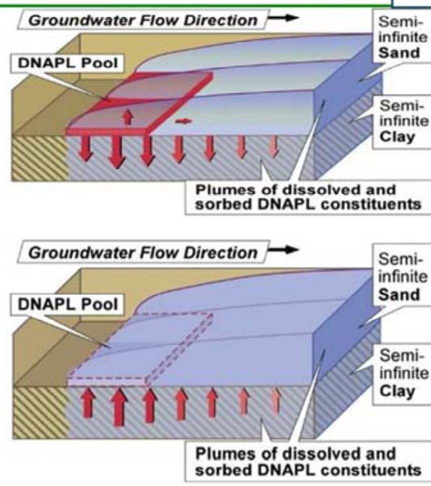
These actions may control the longevity long term migration of the dissolved phase plumes at DNAL sites



Chapter 2 of this document reviews DNAPL types and the characteristics that control their distribution, fate, and transport in the subsurface. Although these issues are addressed in peer-reviewed literature, they are also summarized in this document because they are crucial to designing an adequate characterization program.

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**

No associated notes.

37

Controlling Role of Geology in Matrix Diffusion

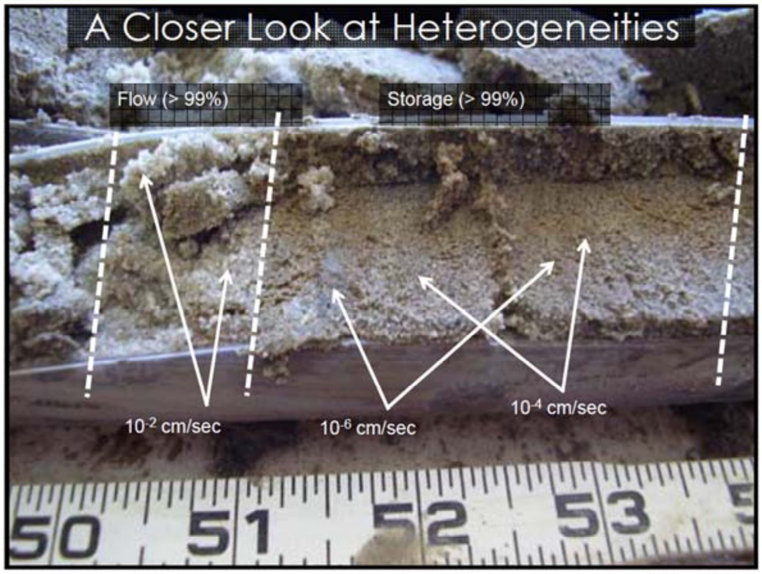
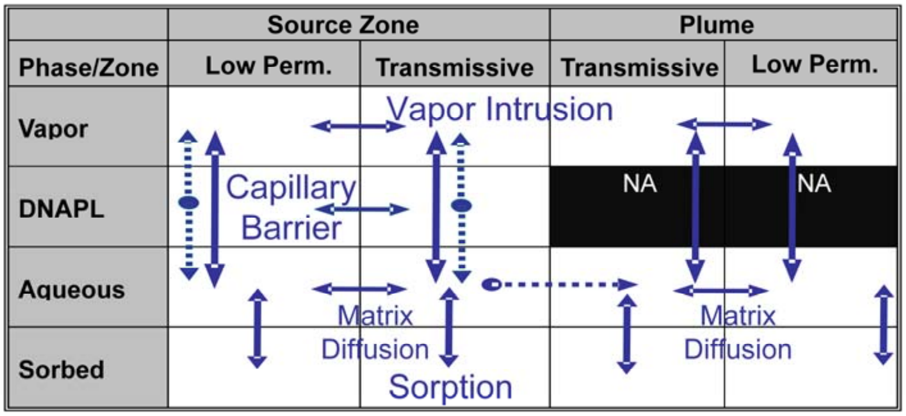


Figure courtesy of Fred Payne, Arcadis

No associated notes.

38

14-Compartment Model: Phase Distribution and Mass Transfer



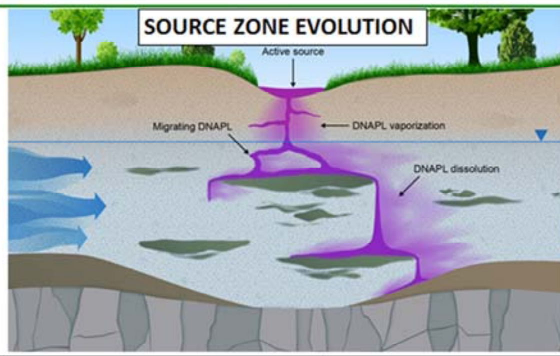
ITRC IDSS-1, Table 2-2 from Sale and Newell 2011

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

No associated notes.

39

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

No associated notes.

40

Prolonged Early Stage Behavior

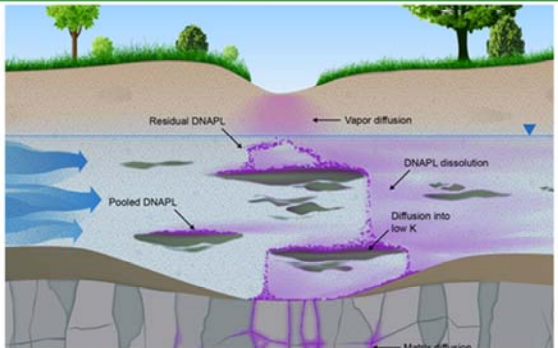
- Low solubility and high viscosity DNAPLs
- High DNAPL saturations and still immobile.
- Highly DNAPL saturation causes flow by-passing

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

No associated notes.

41

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

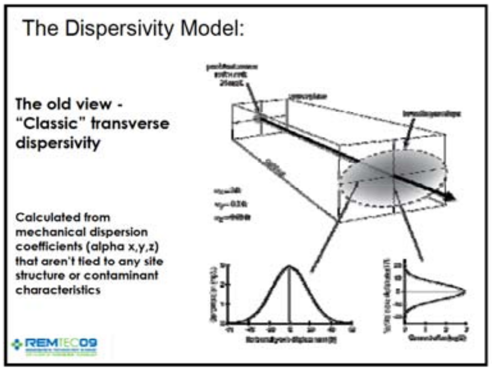
Kueper et al., 2013

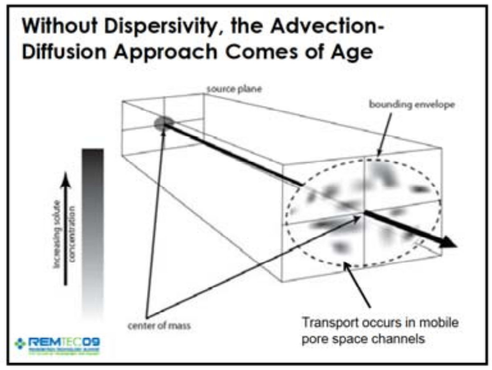
No associated notes.

42

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

Diffusion replaces dispersion.

43

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

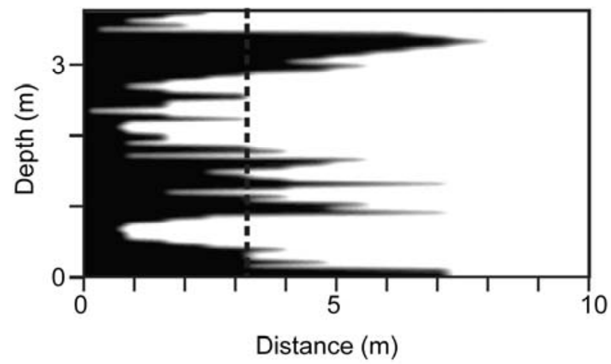


Figure courtesy of Fred Payne, Arcadis

Anisotropy replaces isotropy
Heterogeneity replaces homogeneity

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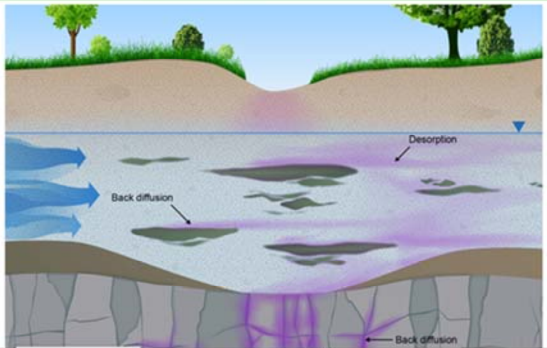
DNAPL Life Cycle – Late Stage



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

No associated notes.

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Poll Question

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

No associated notes.

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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

No associated notes.

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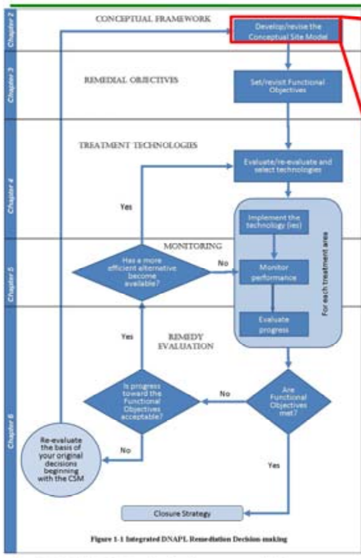
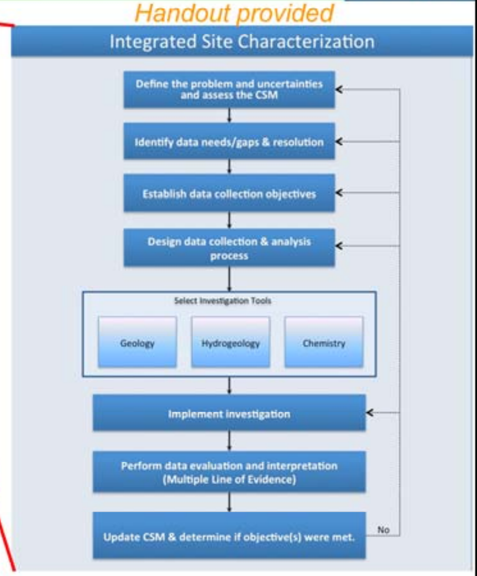
Q&A

Follow ITRC

Handout provided



ITRC IDSS-1, Figure 1-2



ITRC ISC-1, Figure 4-1

No associated notes.

Training Overview

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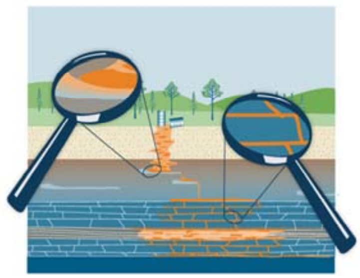
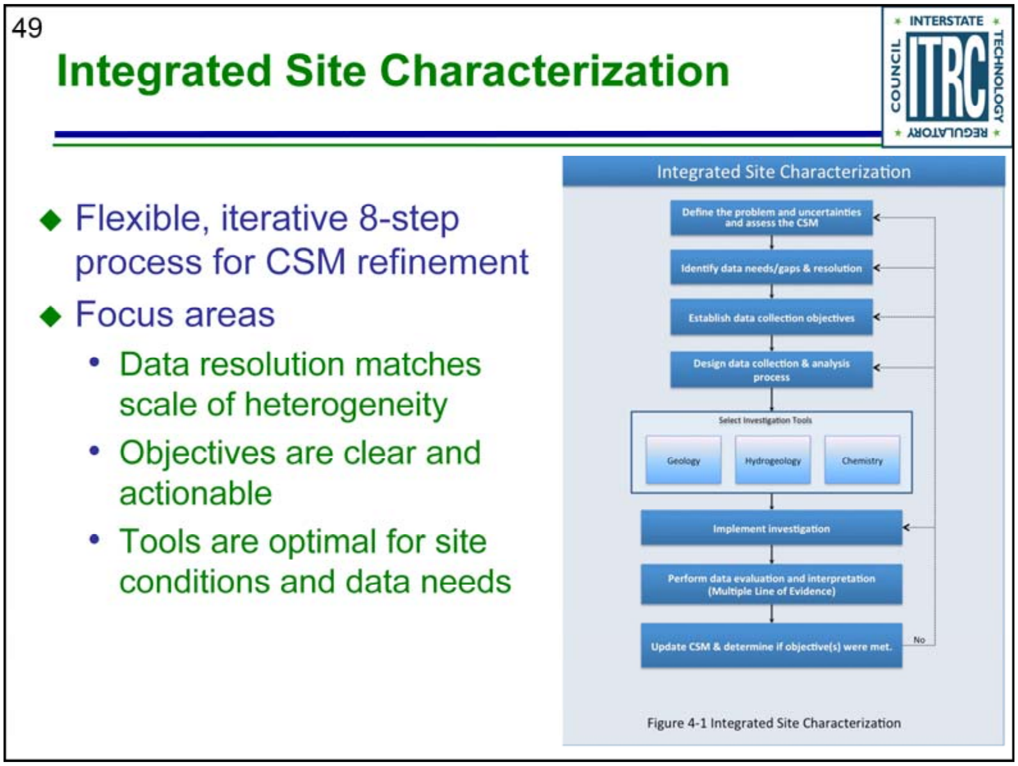


Now that you've heard about DNAPL characteristics and the life cycle of a DNAPL site, we want to discuss a process that we're calling integrated site characterization for DNAPL sites. It's a process that integrates the planning, collection, and evaluation of characterization data. One major highlight of this process is a module on new and existing data collection tools and techniques for DNAPL sites, including the physical, chemical, and hydrologic parameters that they measure.

The integrated site characterization process is presented in Chapters 4 through 6 in pour guidance document. The purpose is to help users prepare more accurate conceptual site models. And that translates to a more effective Integrated DNAPL Site Strategy, which was the subject of our 2011 guidance.



So, what is integrated site characterization?

Well, basically it's

- A Flexible, iterative, 8-step process to encourage refinement of the Conceptual Site Model over the project lifecycle with information obtained during any phase. That's what's shown in the roadmap on the right side.
- The process was developed to focus on particular aspects that are common to DNAPL site characterization. This includes matching spatial data resolution with the scale of subsurface heterogeneity that is controlling contaminant distribution and movement. As discussed earlier, discounting the effects of heterogeneity on contaminant distribution and matrix diffusion, is a major issue for DNAPL sites and why remedies fail.
- It also includes:
    - developing clear, actionable data collection objectives, and
    - selecting appropriate tools for optimal data collection considering site conditions and data needs

I should take a moment to emphasize that data collection objectives are not to be confused with remedial action objectives. Data collection objectives are the reasons why you are collecting the data, what kind of data, how much data, and the quality of the data in order to answer specific questions about site characterization. Remedial action objectives are all about the reasons why remediation is needed and the specific goals for implementing it.

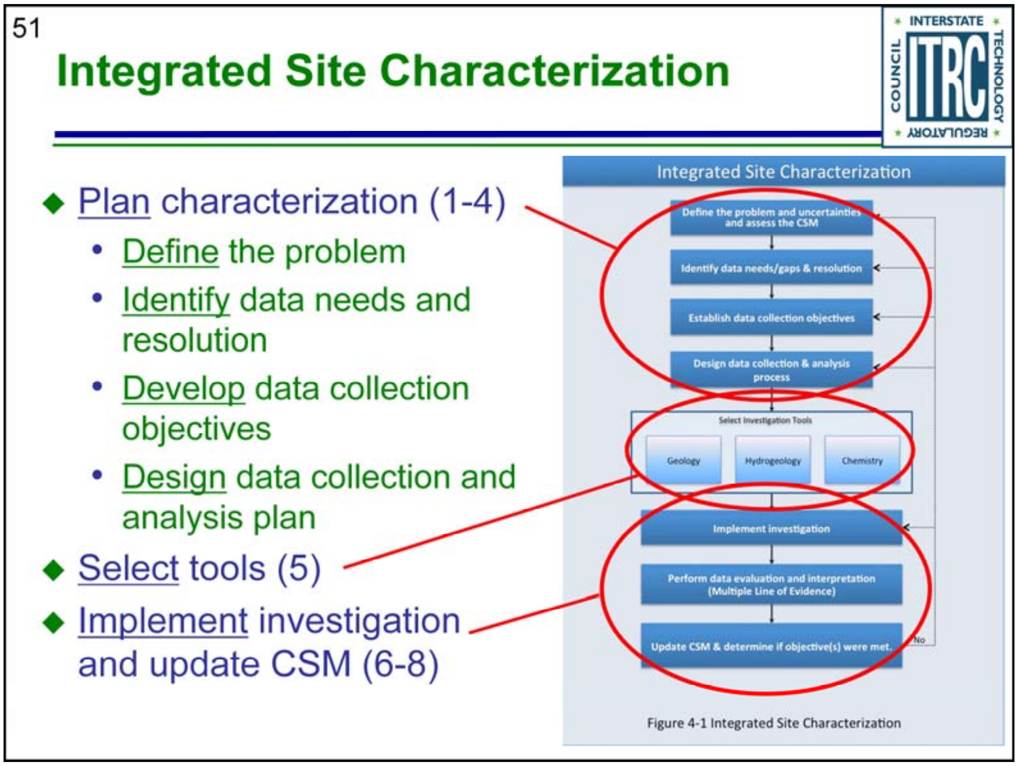
****

NEW CONCEPTS FOR CONTAMNANT FATE AND TRANSPORT

- Heterogeneity replaces homogeneity
- Anisotropy replaces isotropy
- Diffusion replaces dispersion
- Matrix back diffusion must be evaluated as a source
- Lognormal replaces gaussian
- Transient replaces steady state conditions
- Non-linear replaces linear sorption
- Non-ideal replaces ideal sorption

The benefits of integrated site characterization are best understood in light of common problems with DNAPL sites. Often the controlling heterogeneities have not been fully characterized, which has led to inadequate data resolution and undervaluing the need to fully assess contaminant distribution, particularly in storage zones that account for back diffusion. And that has lead to many remedy failures. So the benefits include:

- Reducing uncertainty and enabling development of more accurate Conceptual Site Models
- Improving identification, collection, and evaluation of site characterization data to develop appropriate and achievable remedial objectives and more efficient remedies. The ITRC's Integrated DNAPL Site Strategy document does a good job summarizing why developing appropriate and achievable objectives is so critical…and it is worth noting that the integrated site characterization approach we're discussing today is really part of an overall Integrated DNAPL Site Strategy. So if you are not familiar with our 2012 document, you can download it from the ITRC's website.
- Another major benefit is what we call "avoiding costly do-overs" prompted by ineffective remedies. As I said, too often this is the result of *insufficient* data resolution, data gaps, or unfocused characterization objectives.

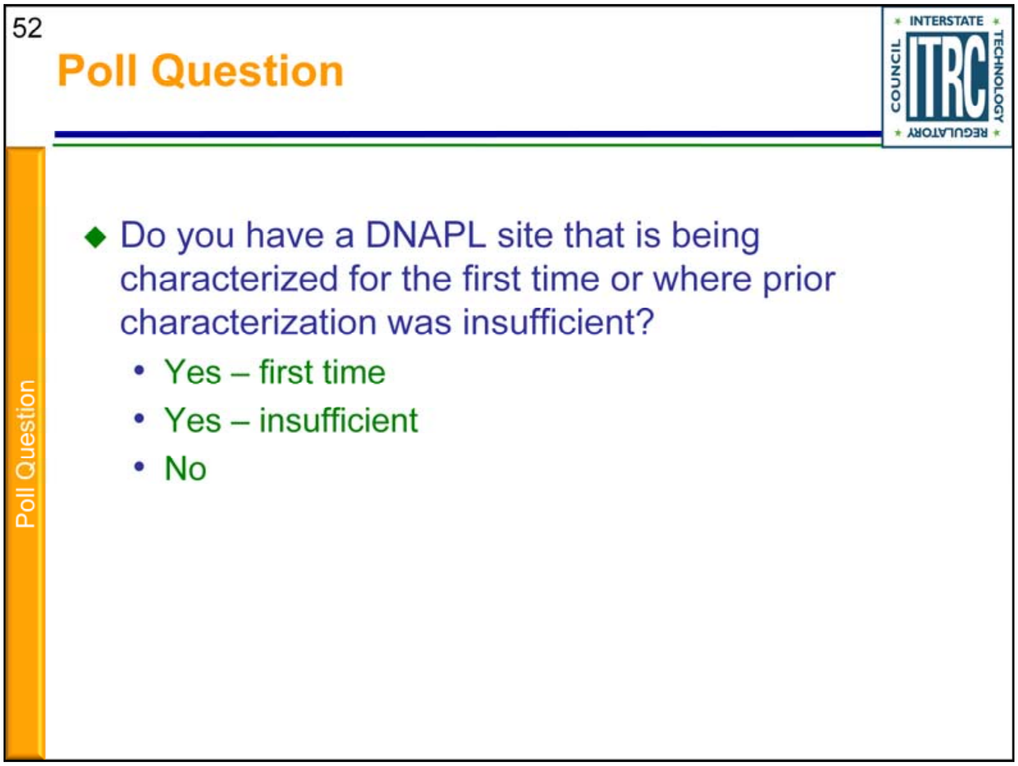


In this training we're going to present the 8-step approach as three modules. The first is a module for planning your site characterization, which is covered by the first four steps of the ISC module that are shown here. I'll go into more detail about each step later on, but for now I just want to preview what the planning module includes.

1. Defining the uncertainties and deficiencies in the Conceptual Site Model
2. Identifying data needs and resolution appropriate for site conditions
3. Developing clear, actionable data collection objectives
4. Designing a data collection and analysis plan

The second module is for selecting your investigation tools, which is based on your data needs and the hydrogeologic environment. Nathan/Jeremy will present that module after I'm done.

The third module is about implementing the investigation. This also includes evaluating and interpreting the data and then circling back to update the Conceptual Site Model. Heather/Ryan will present that module after the Tools Selection module.

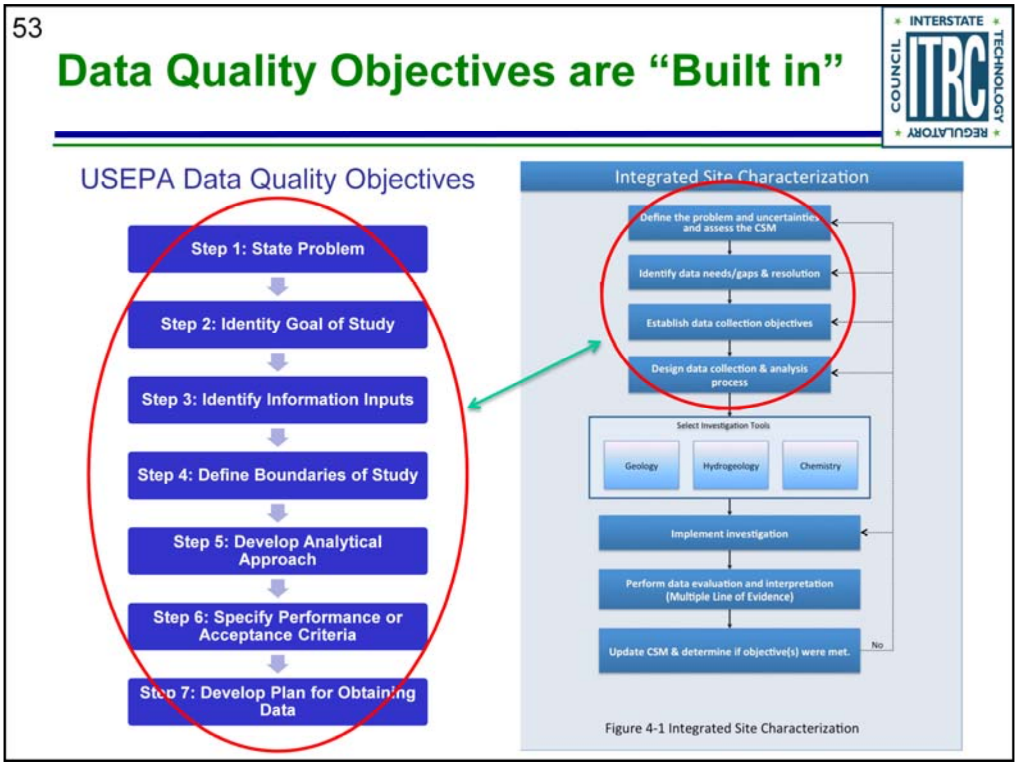


So before we go any further, please take a few moments to respond to our poll question.

“Do you have a DNAPL site that is being characterized for the first time or where prior characterization was insufficient?”

There are three possible responses – Yes, I have a site that is being characterized for the first time; or, Yes, my site is being re-characterized, perhaps because it’s just a second or third iteration that as planned, or perhaps you’re at the remedial design stage and need to have better delineation for targeting the source zone; or perhaps because the initial resolution was insufficient or there were unanswered questions. Or maybe you don’t have a site that’s being characterized.

Either way, this guidance provides an optimal planning approach for planning a DNAPL site characterization, and minimizing the chances of collecting insufficient or inadequate data.

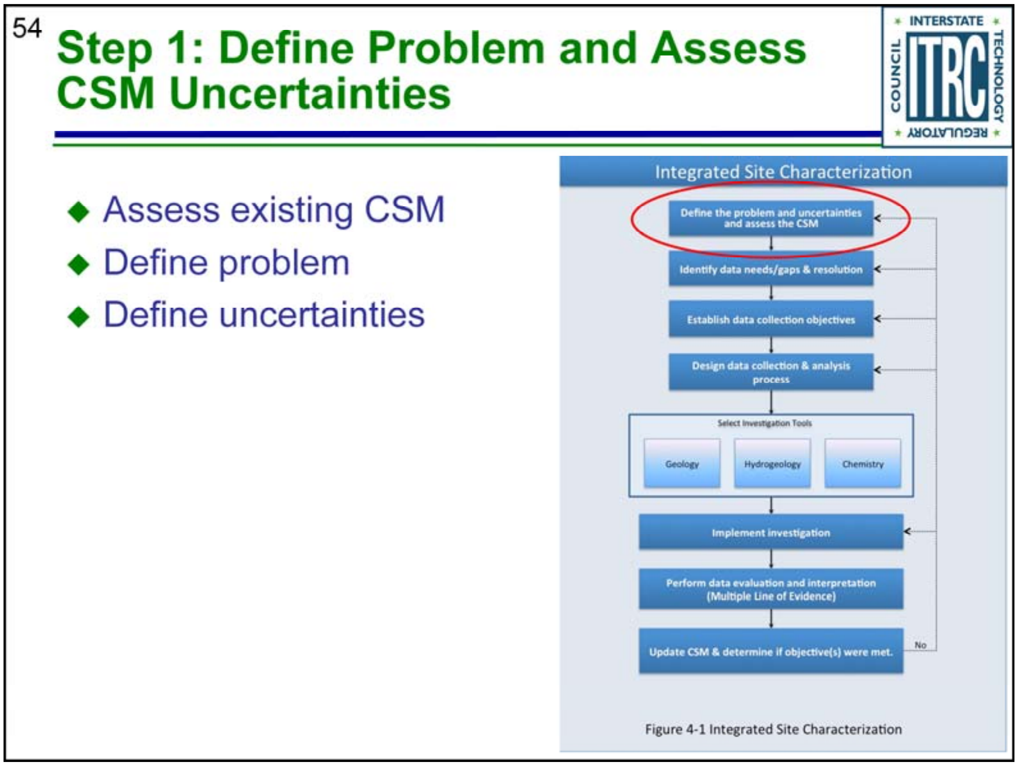


Most of us are familiar with U.S. Environmental Protection Agency's seven step Data Quality Objectives Process. And you might be thinking that integrated site characterization sounds a lot like data quality objectives.

So this slide simply shows that the Data Quality Objectives process is meant to be fully captured within the planning module of integrated site characterization. It's just that we wanted to design an approach that would focus attention on specific DNAPL site problems, such as insufficient data resolution and lack of appropriate objectives.

******

Directly from EPA "The DQO Process may be applied to all programs involving the collection of environmental data and apply to programs with objectives that cover decision making, estimation, and modeling in support of research studies, monitoring programs, regulation development, and compliance support activities. When the goal of the study is to support decision making, the DQO Process applies systematic planning and statistical hypothesis testing methodology to decide between alternatives. When the goal of the study is to support estimation, modeling, or research, the DQO Process develops an analytic approach and data collection strategy that is effective and efficient."



Now I'm going to walk through the first four steps of integrate site characterization. In between each step I'm going to switch to a case example of a small drycleaner site that illustrates how each step was applied.

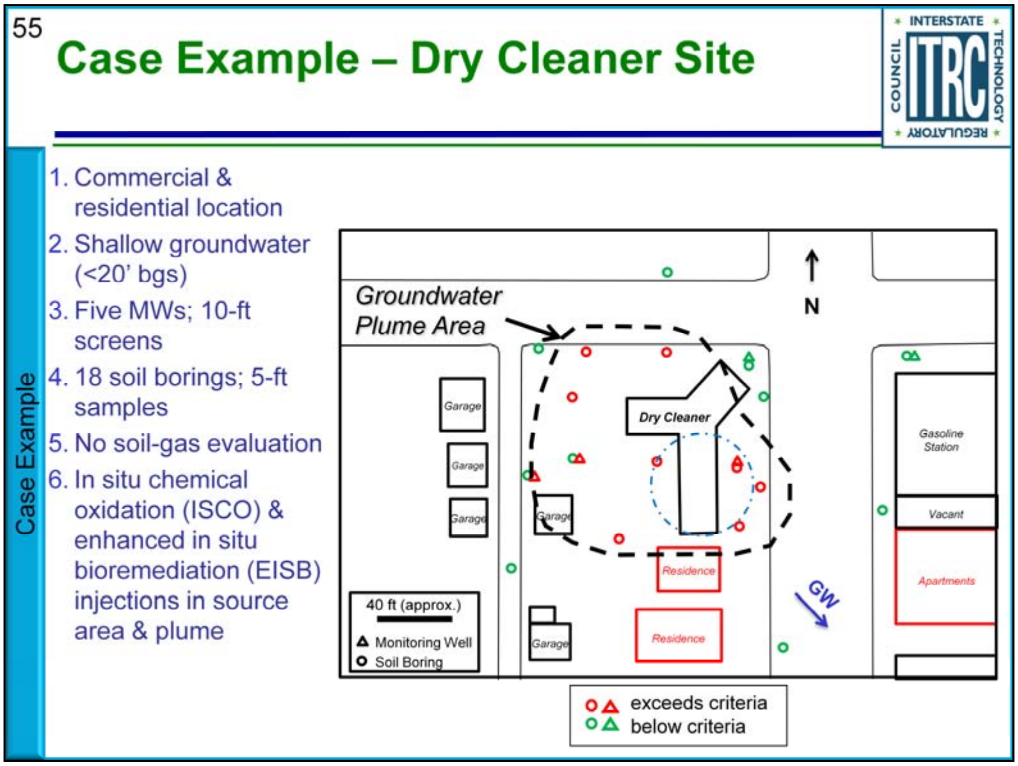
Step 1 is about defining the problem and assessing the uncertainties with the Conceptual Site Model. The challenge is to define the problem in terms of uncertainties to better understand what's missing and what's needed. For example, if the problem is that the extent of contamination is not fully defined, the uncertainty might about low data density in a particular direction, or misunderstanding of groundwater flow direction. If the problem is about ineffective remediation, then their may be uncertainty about the true extent of the source area or presence of undefined preferential pathways.

Critically review existing information:

If your site has already been characterized to some degree, and many DNAPL sites have, then it's critical to review what is known or suspected and assess the existing data quality and data gaps. Some of the key areas you'll want to focus on include:

- Lithologic and structural heterogeneity – that's what's controlling groundwater flow and contaminant distribution and movement. For example, it includes soil type, permeability, presence or absence of buried channels and aquitards, fractures, fracture density, and depth to base units.
- Vertical sampling resolution – for example, was continuous coring done for soil? Were different groundwater intervals sampled? What are the well screen lengths? What are the gaps?
- Historic sources, including the contaminants, and the nature of the source and source area – for example was it a mixture or pure NAPL release? Is there any data to suggest the remaining presence of DNAPL?
- Chemical signatures in the groundwater data – for example, what's the relative abundance of parent and daughter contaminants at different locations. Does that suggest anything about the source, distribution, or attenuation?

As you heard earlier, the use of tools such as the 14-compartment model can help assess the relative strengths and weaknesses of existing data for each compartment….which can help identify uncertainties and data needs.



In this case example, a dry cleaner site in was initially investigated with 18 soil borings and 5 monitoring wells from 2004 through 2007. Groundwater flow is toward the southeast, and there are commercial and residential buildings nearby. Soil borings were sampled every five feet and monitoring wells were set with ten-foot screens from 15 to 25 feet below ground surface.

The small circles represent soil borings and the triangles are monitoring wells. Red indicates that the results exceeded compliance standards, green means the results were below standards. The black dashed line represents the initial interpretation of the gw plume area. The blue dashed line represents the initial interpretation of the source area.

In 2008, remediation was performed on both the source and plume areas using in-situ chemical oxidation (in the source area) and enhanced in-situ bioremediation (in the plume area). But in 2010, the monitoring data showed that the plume still remained above standards.

So the first problem is that while this may seem like a relatively high number of sample locations, no attempt was made to match the sample resolution with the scale of the controlling heterogeneities. Furthermore, groundwater was sampled using 10-ft well screens, which may not be sufficient to provide sufficient vertical delineation. In our guidance document we caution against the use of monitoring wells for DNAPL site characterization because they tend to average concentrations over large vertical distances, they're an expensive compared to other characterization methods, and once installed, they usually required to be monitored and can bias the site characterization picture for a long time to come. Monitoring wells are best used to monitor contaminants trends once delineation is complete, not for characterization.

The second problem is that no effectiveness evaluation was planned after remediation was conducted in 2008. So when monitoring data showed that the groundwater plume remained above standards two years after remediation, there was no consensus about where the problem lay.

The third problem is that the vapor intrusion pathway had not been assessed despite the existence of nearby residential buildings. This was probably because vapor intrusion has been an evolving concern in recent years and may not have been given much thought when the investigation began in 2004. But now it's a big concern.

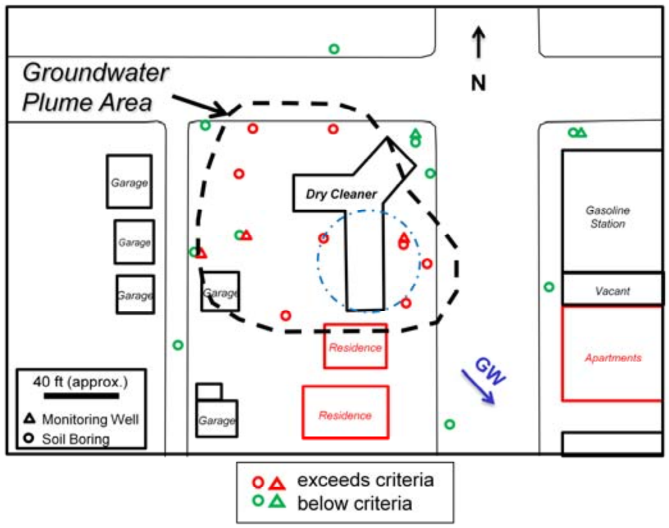
In 2011 when the site was revisited, uncertainties remained about the completeness of source and plume delineation, remedy effectiveness, and vapor intrusion threats to nearby residential and commercial building occupants.

56

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



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In 2011 when the site was revisited, uncertainties remained about the completeness of source and plume delineation, remedy effectiveness, and vapor intrusion threats to nearby residential and commercial building occupants.

57

Step 2: Identify Data Needs & Spatial Resolution

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

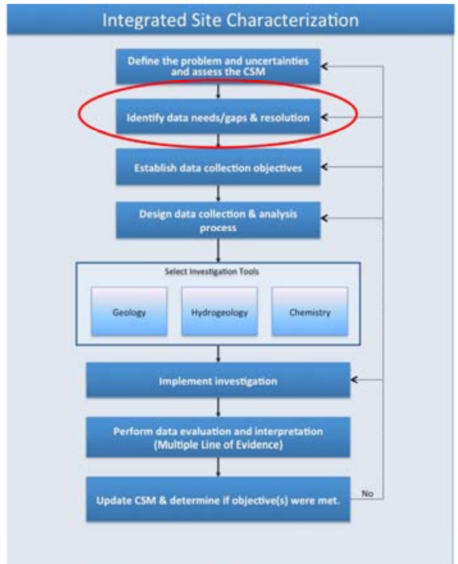


Figure 4-1 Integrated Site Characterization

Step 2 in the integrated site characterization planning process is about identifying specific data needs and the spatial resolution needed for data collection.

The first concern is to translate the uncertainties in the conceptual site model into data needs. This is typically straight forward. For example, if there is uncertainty in the contaminant distribution, it might be because you're lacking soil or groundwater data in a particular direction or depth. If plume stability is uncertain, you might need more time-series groundwater data.

The second concern is to determine sufficient spatial resolution. This is a bit more challenging because you may not know the scale of the controlling heterogeneities at your site. What you want is spatial resolution that enables you to assess the nature of the subsurface heterogeneity that is effectively controlling contaminant distribution and transport.

For DNAPL sites it's particularly important to distinguish among transport and storage zones to determine if there may a matrix diffusion problem.

Also, we're using the concept of sufficient resolution rather than saying you must have high resolution. That's because once you have captured the appropriate resolution and know where to look, you may find that you don't need the same resolution everywhere.

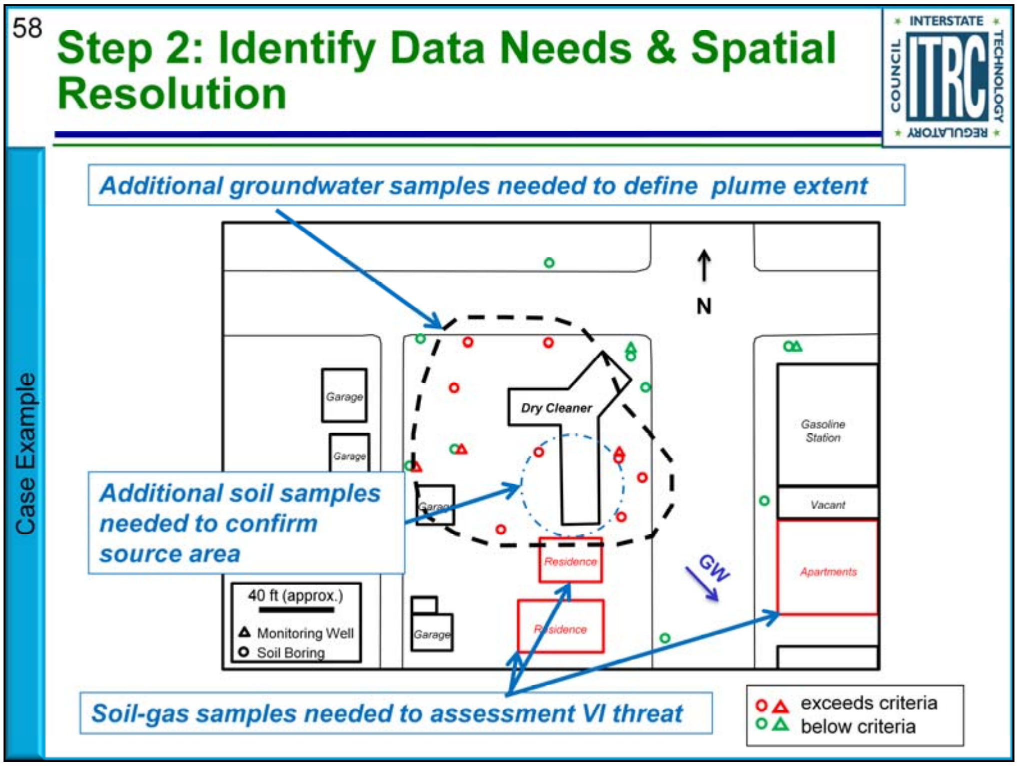
The big question is how do I know what level of resolution to characterize to? Ans: While there may be many techniques, including use of geophysical methods, you'll never really know until you've tried. So one way is to pick a small, off-source area and do what is typically considered high resolution, to get a spot assessment of the heterogeneity scale. Keep in mind that contaminant distribution in DNAPL source areas can vary widely over small distances and can easily be missed.

****

My site has been characterized using conventional techniques. Do I need to redo this work using the higher resolution methods?

If you think your existing site conceptual model is sound and the site management strategy has been successful, an extensive supplemental site characterization program is not needed.

If questions remain about key components of the site conceptual model—e.g., hydrogeology; contaminant distribution, fate, and transport properties; and risk—additional characterization using high-resolution techniques can be both beneficial and cost-effective. Some sites may not have been precisely delineated by conventional characterization methods (e.g., soil borings and monitoring wells); in such cases, high-resolution techniques can provide clarity on how to move forward in the site remediation/ management process.

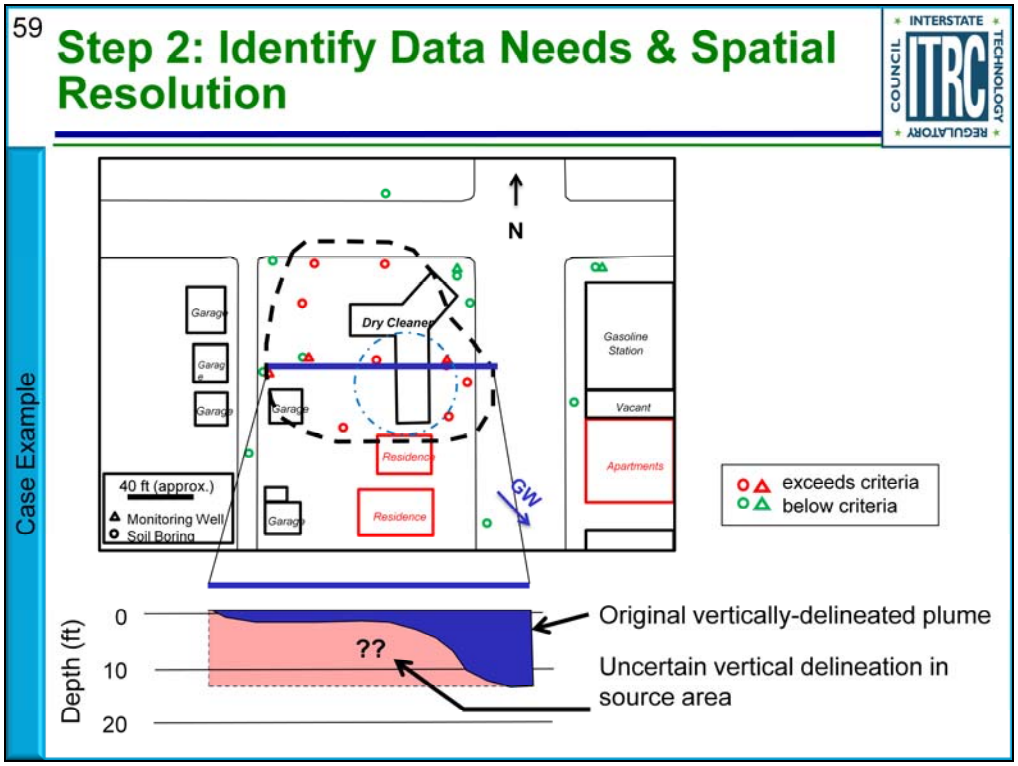


Switching back to the drycleaner case example, there were three primary data gaps identified that naturally flow from the uncertainties. Recall that the uncertainties existed about 1) completeness of source zone and plume delineation, 2) the effectiveness of the in-situ remedies that were attempted, and 3) the degree of vapor intrusion threat to occupants of nearby buildings, including commercial and residential structures. So the data gaps that were identified include:

(1) First, contaminant concentrations in soil and groundwater to bound the source area and plume both laterally and vertically. This was particularly true to the south and west because that is the direction of groundwater flow, and the initial investigation was limited by property access issues in that direction – a fence line along the southern property boundary.

(2) Second, soil and groundwater data to demonstrate the effect of the in-situ remedy. Recall that ISCO was used in the source area and EISB was used for the plume.

(3) And third, lack of soil-gas (and potentially indoor air data) to assess potential vapor intrusion threats.



This slide shows the uncertainty in the vertical directions across the plume and source area.

60

Step 3: Establish Data Collection Objectives

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

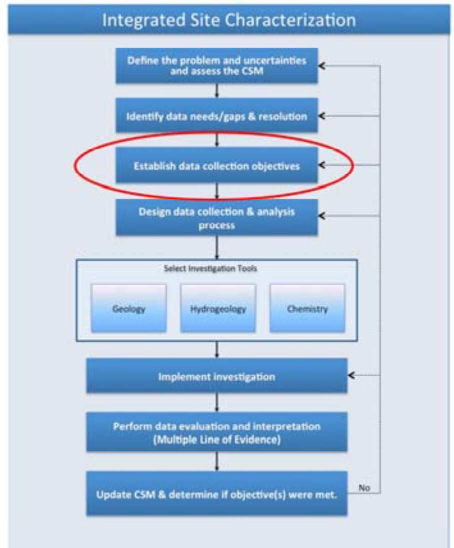


Figure 4-1 Integrated Site Characterization

Step 3 in the integrated site characterization planning process is about establishing data collection objectives. The real point here is to emphasize that objectives need to be specific, clear, and actionable, and must consider the data types, data quality, density, and spatial resolution.

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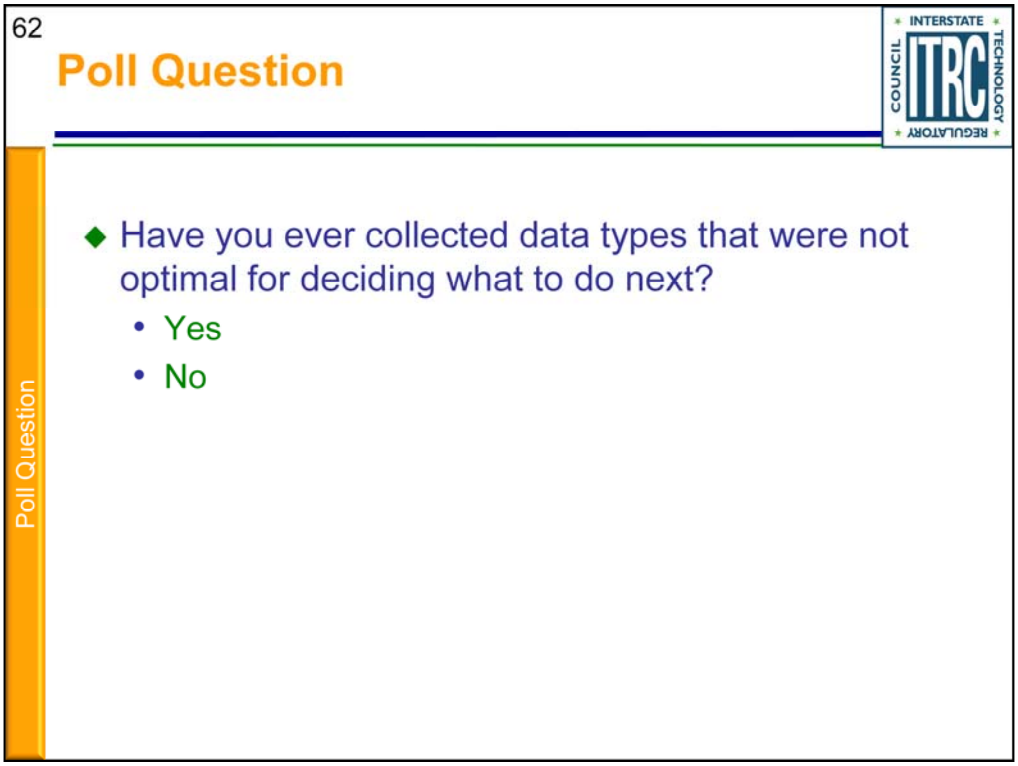
Step 3: Example Data Collection Objectives

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

The idea with developing data collection objectives is to start with a broad statement or question that you are trying to answer about what is needed. Then, continually refine it until you have something that is as clear and detailed as possible. Our IDSS document includes a section about developing remedial action objectives that are Specific, Measureable, Achievable, Relevant, and Timebound, which is what the SMART acronym means. The same idea applies to data collection objectives to make them as SMART as possible.

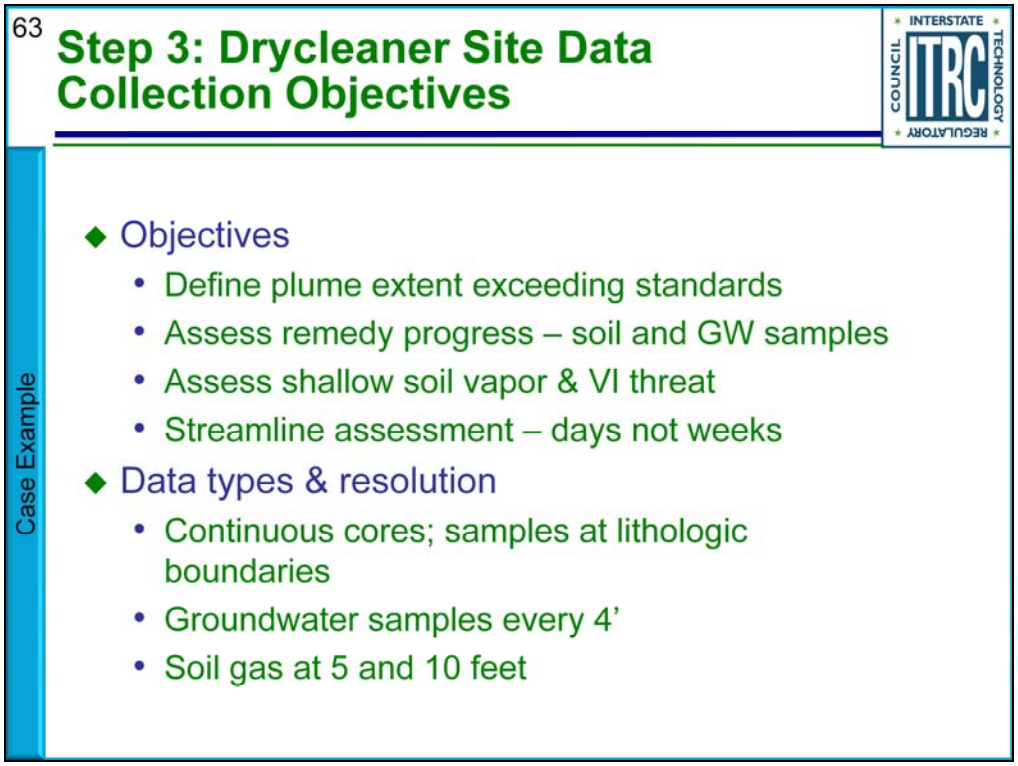
Here is an example…



Let's take a moment to respond to another poll question:

"Have you ever collected data types that were not optimal for deciding what to do next?"

This might be because your data needs weren't fully determined, as in Step 2, or because your data collection objectives were not clear or specific enough.

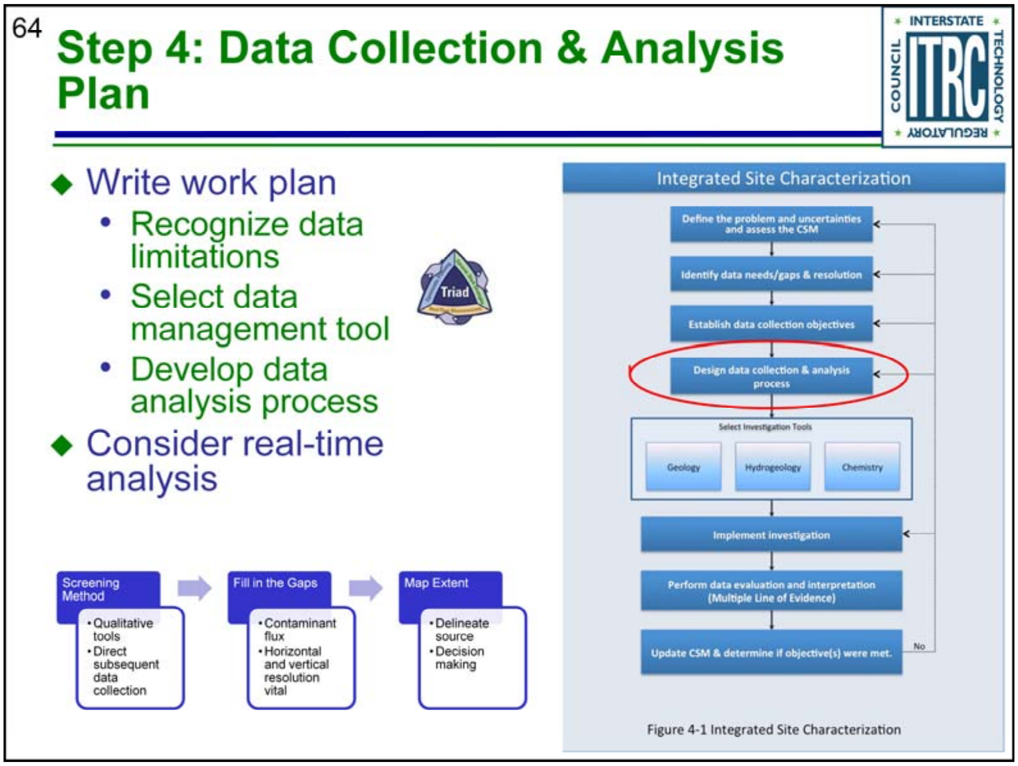


Switching back to the drycleaner case example, these are the broad objectives that were established.

- The key objectives were to define the soil and groundwater volumes exceeding the compliance standards
- Assess remedy progress to date, and
- Assess shallow soil vapor concentrations.
- A key objective was to complete the work in a short time period, not drag out the duration with multiple sampling mobilizations.

These objectives were further refined to identify the data types and resolution, including:

- Continuous coring with a direct push to a depth of about 25 feet
- Soil samples at lithologic boundaries
- Grab groundwater samples every 4’
- Shallow soil gas samples at two depths



Step 4 is where Steps 1 -3 are documented – in a work plan. Goal is to achieve your characterization objectives and manage site specific uncertainties to the point that decisions about the site can be made. Items to consider while figuring out how to collect data include:

•Recognize data limitations

•Select data management tool

•Develop data analysis process

Given the necessary dynamic nature of characterization – consider real-time analyses and how that data will be interpreted!

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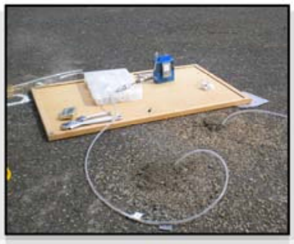
Step 4: Drycleaner Site Data Collection & Analysis Plan

Case Example



Soil vapor sampling

Triad ES mobile lab and Geoprobe

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

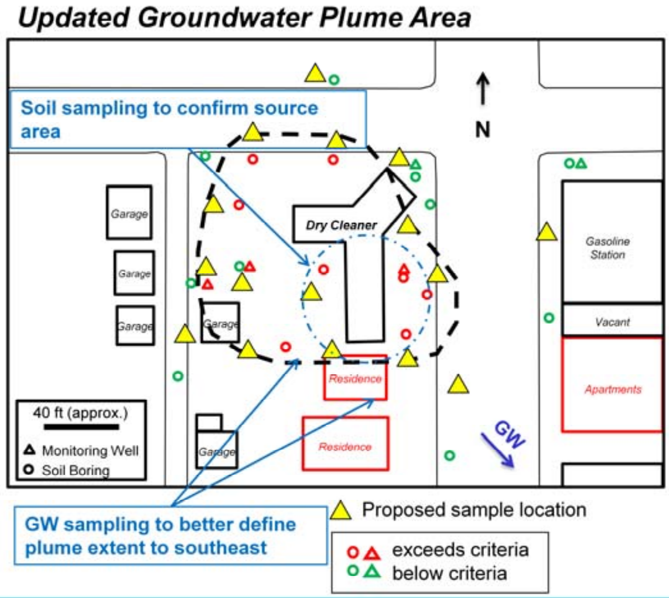
With the objectives in mind, a plan was developed for the dry cleaner site using the TRIAD approach, two Geoprobes and a mobile laboratory to collect high-resolution samples in the source area, grab groundwater samples, and soil vapor samples across the site.

66

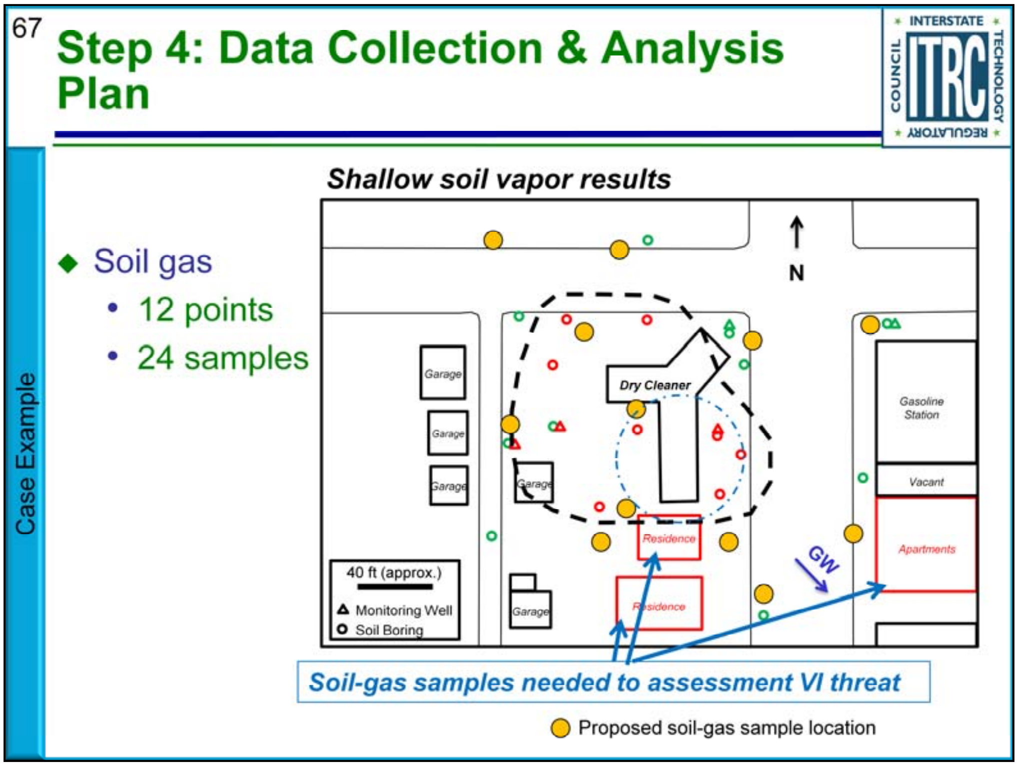
Step 4: Data Collection & Analysis Plan

Case Example

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



The drycleaner site plan included 16 direct push, continuous cored boring locations. Borings were planned for advancement to about 25 feet with soil samples to be collected at lithologic boundaries and grab groundwater samples to be collected every four feet. The planned number of soil samples to be collected for laboratory analysis was about 80, and the planned number of groundwater samples was 48.



The plan also included shallow soil gas collection at two depths at 12 locations. Samples depths would be about 5 and 10 feet.

So the overall data collection plan for the drycleaner site was fairly robust. But that's what was needed to capture the effects of the subsurface variability on the distribution of the contaminants in the soil. Groundwater, and soil gas.

Keep in mind, this was essentially do-over. So this planning phase benefited from a lot of prior knowledge about the site, such as lithology, groundwater flow direction, and some initial understanding of contaminant distribution, albeit somewhat in error. This kind of planning done from the start would almost certainly have saved time and money, particularly when it came to the remediation.

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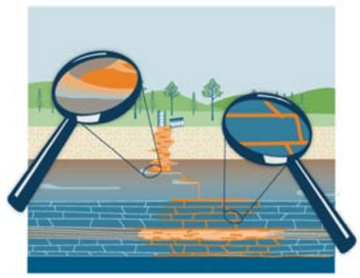
Summary – Integrated Site Characterization

- 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

No associated notes.

Training Overview

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



ISC-1, Chapter 4

No associated notes.

70

Tools Selection Process: Contents of this Section

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

No associated notes.

71

Poll Question

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)

No associated notes.

72

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

No associated notes.

73

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	✓			✓

No associated notes.

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.

No associated notes.

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Detailed Tool Descriptions (Appendix D)

INTERSTATE TECHNOLOGY REGULATORY COUNCIL ITRC

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])

No associated notes.

76

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

No associated notes.

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Using the Tools Matrix

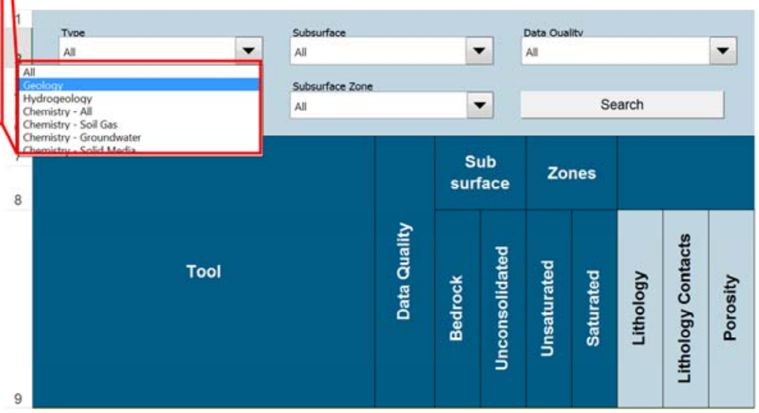
- Down-selecting appropriate tools to meet your characterization objectives
- A systematic process
  - Select your categories: geology, hydrogeology, chemistry
  - Select parameters of interest
  - Identify geologic media (e.g., unconsolidated, bedrock)
  - Select saturated or unsaturated zone
  - Choose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

No associated notes.

78

1. Select Category

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

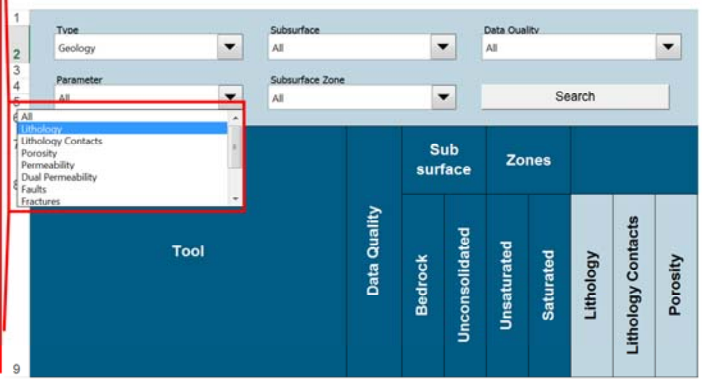


No associated notes.

79

2. Select Parameters of Interest

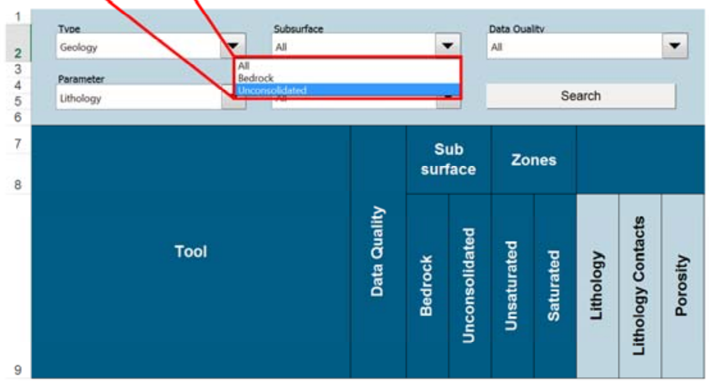
All
Lithology
Contacts
Porosity
Permeability
Dual Permeability
Faults
Fractures
Fracture Density
Fracture Sets
Rock
Competence
Mineralogy



No associated notes.

3. Identify Geologic Media

All
Bedrock
Unconsolidated

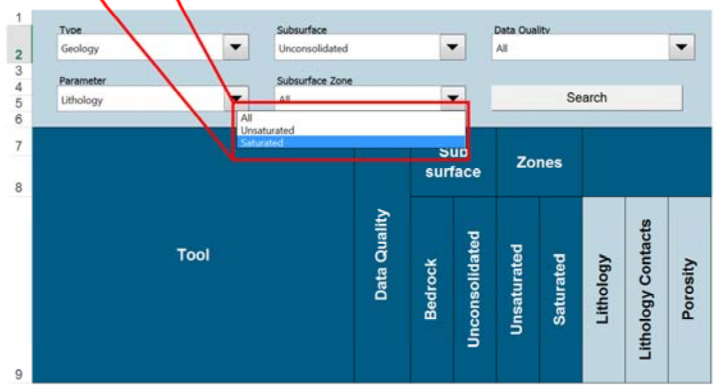


No associated notes.

81

4. Identify Zone

All
Unsaturated
Saturated

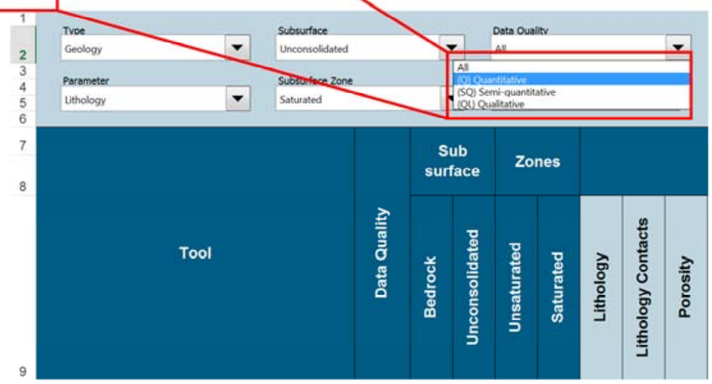


No associated notes.

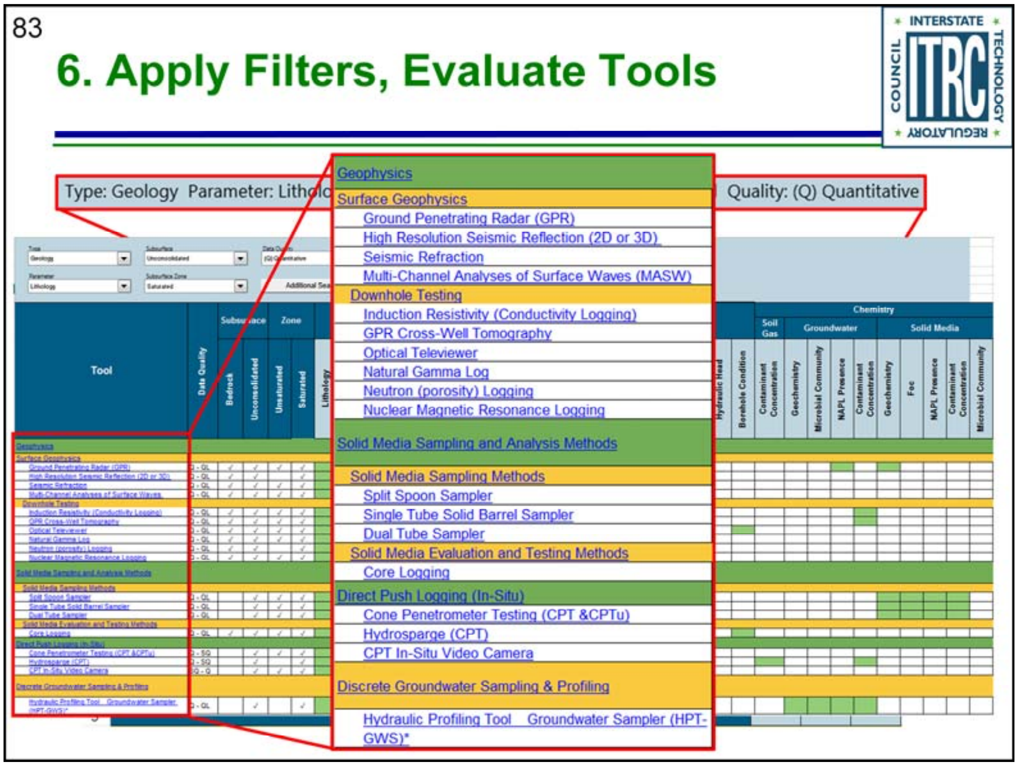
82

5. Choose Data Quality

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



No associated notes.

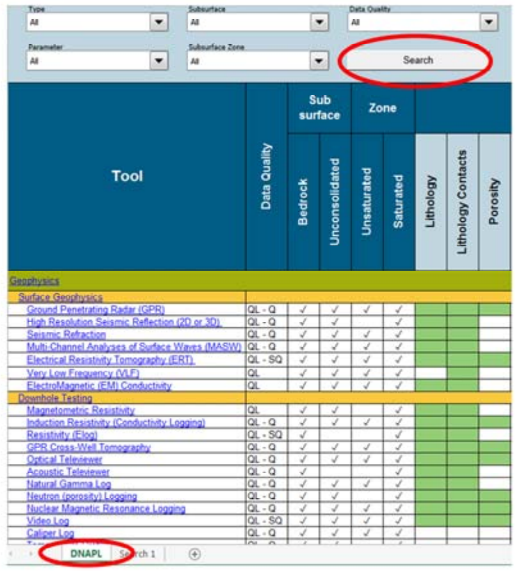


No associated notes.

84

Perform Additional Searches to Find More Tools for Different Objectives

Additional parameters can be added or removed from any given 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	✓	✓	✓	✓			

No associated notes.

85

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		✓	✓	✓			

DNA | Search 1

No associated notes.

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

No associated notes.

87

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

No associated notes.

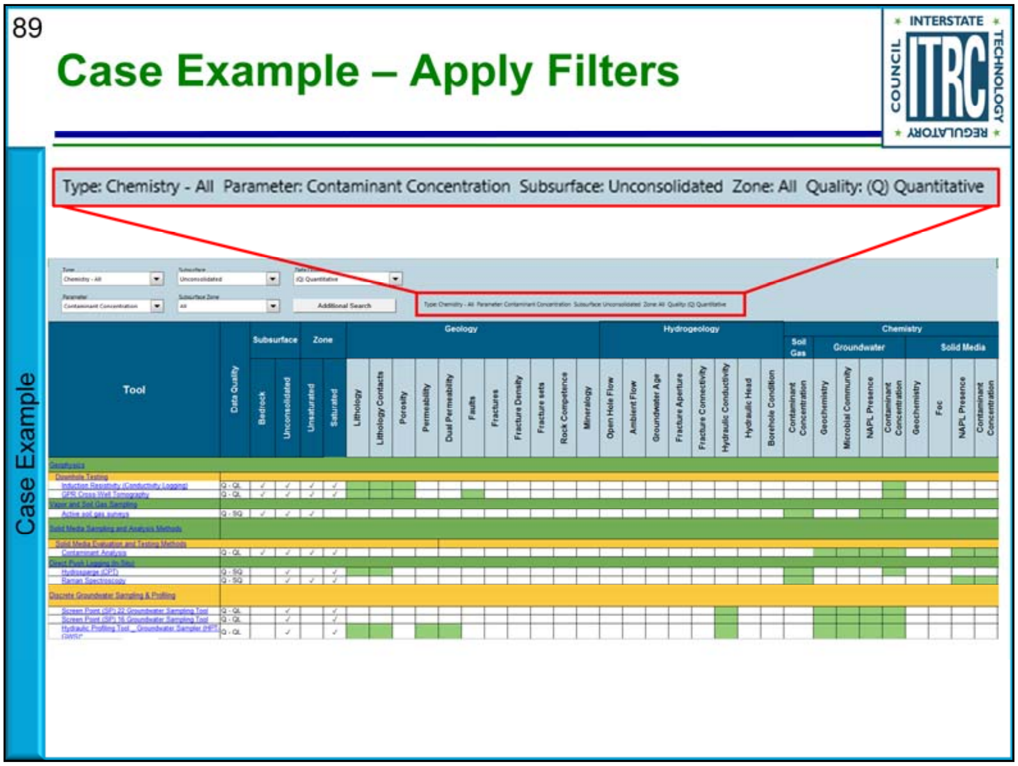
Case Example – Select Tools Matrix Filters

Case Example

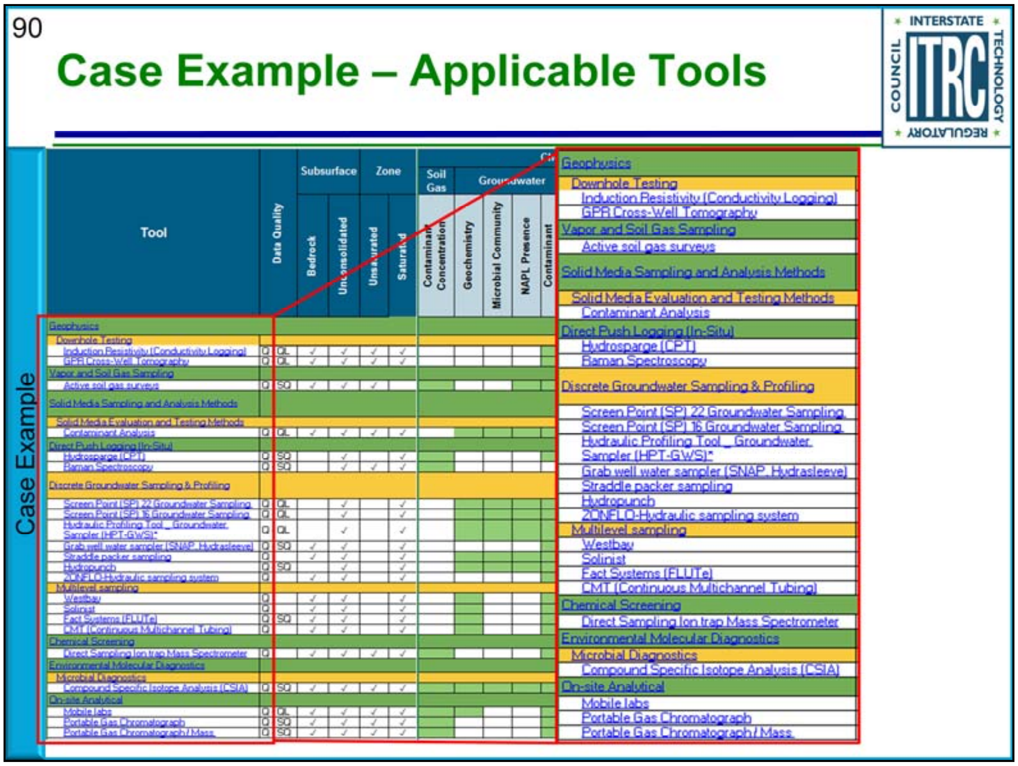
Filters

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

No associated notes.



No associated notes.



No associated notes.

Case Example – Tools Selection

Case Example

- 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

No associated notes.

92

Example #2

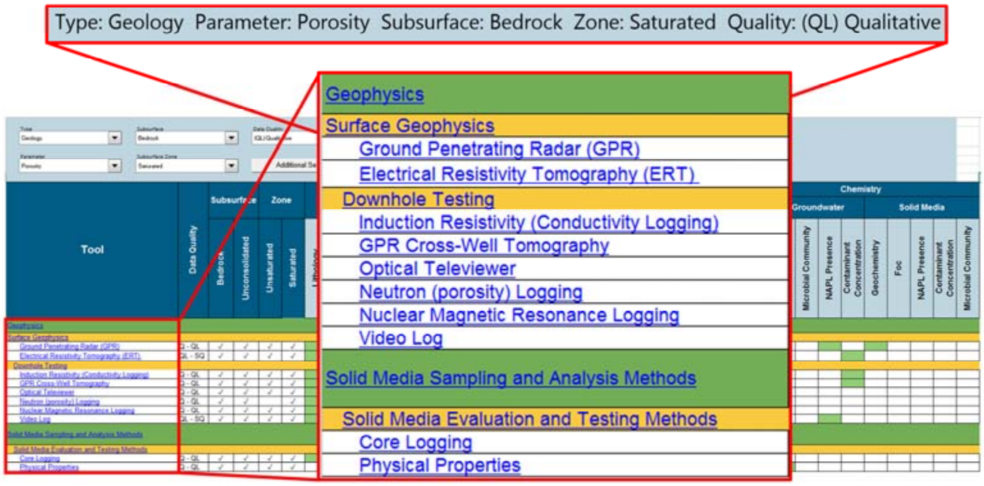
Characterization Objective – Determine the porosity of a fractured bedrock formation in a DNAPL source zone to evaluate the potential storage capacity of the rock

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

No associated notes.

93

Example #2 – Bedrock Porosity



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

No associated notes.

Example #3

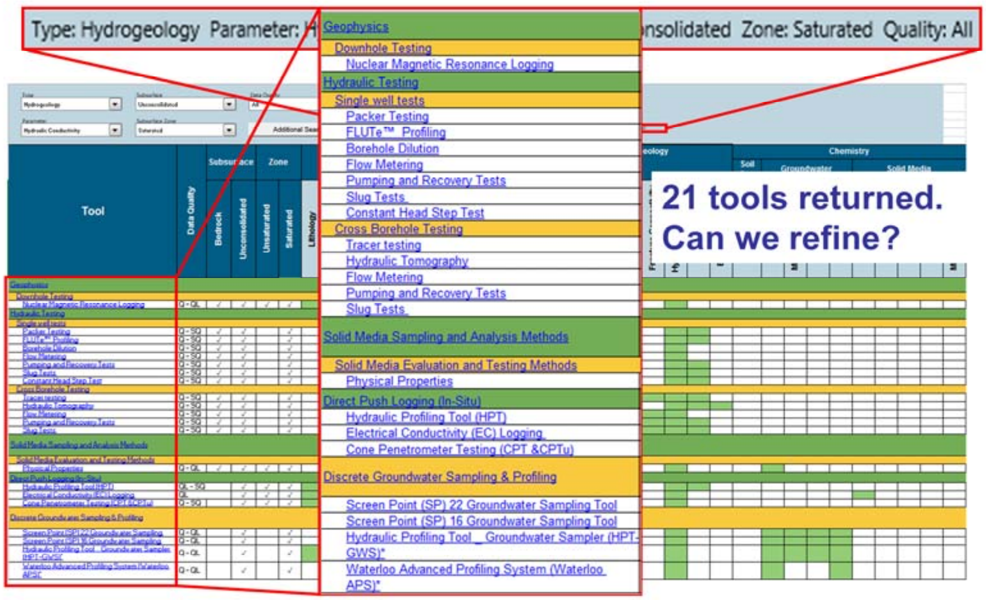
Characterization Objective – Evaluate potential matrix diffusion issues associated with variations in hydraulic conductivity

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

No associated notes.

95

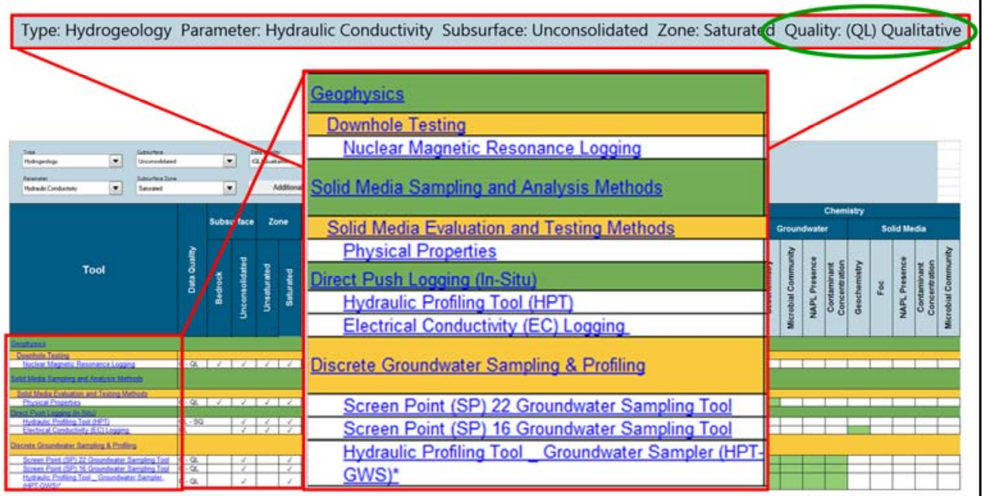
Example #3 – Hydraulic Conductivity



No associated notes.

96

Example #3 – Hydraulic Conductivity (refined)



Change data quality to QL 7 tools returned

No associated notes.

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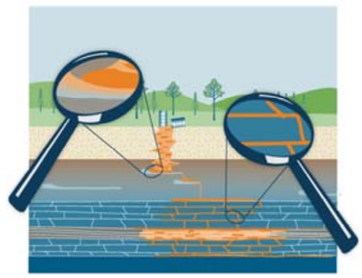
ITRC Tools Matrix Summary

- 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

No associated notes.

Training Overview

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



ISC-1, Chapter 4

No associated notes.

Conducting

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

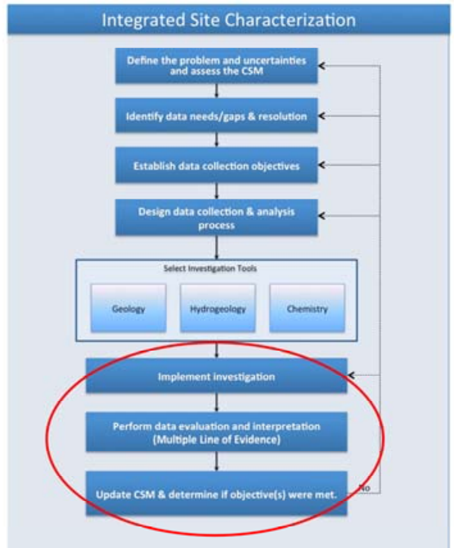


Figure 4-1 Integrated Site Characterization

No associated notes.

100

Step 6. Implement Investigation

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

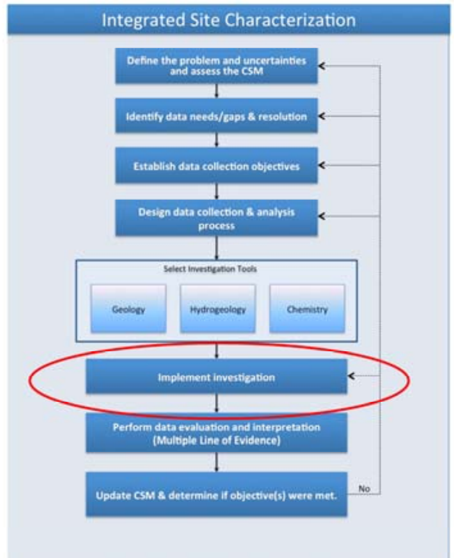


Figure 4-1 Integrated Site Characterization

No associated notes.

101

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

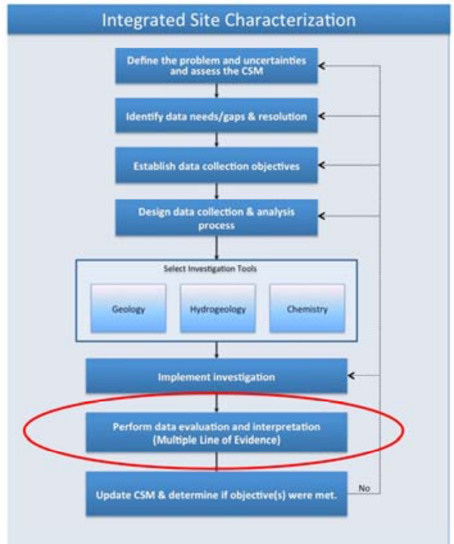


Figure 4-1 Integrated Site Characterization

No associated notes.

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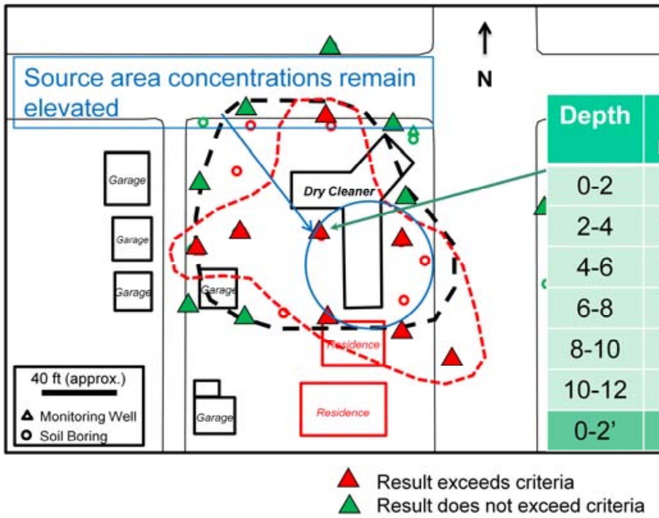
Step 7. Soil and Groundwater Data Evaluation and Interpretation

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

No associated notes.

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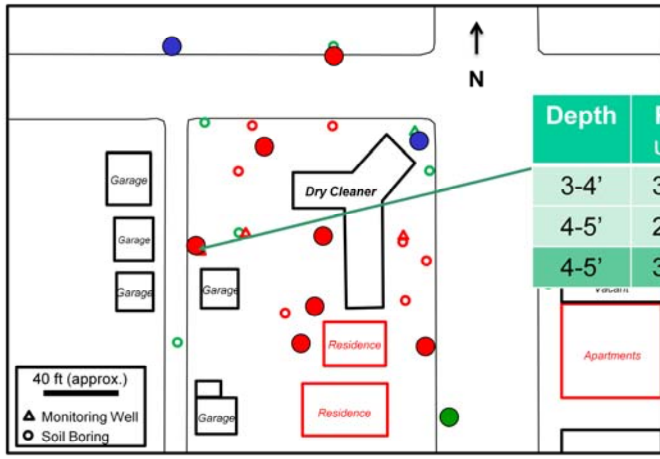
Step 7. Soil Vapor Data Evaluation and Interpretation

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

No associated notes.

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Poll Question

Poll Question

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

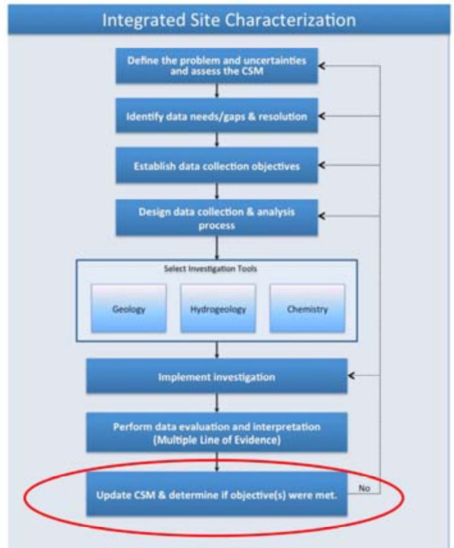

Figure 4-1 Integrated Site Characterization

No associated notes.

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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

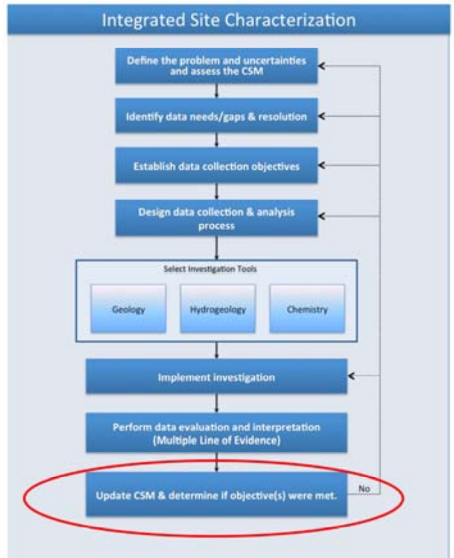
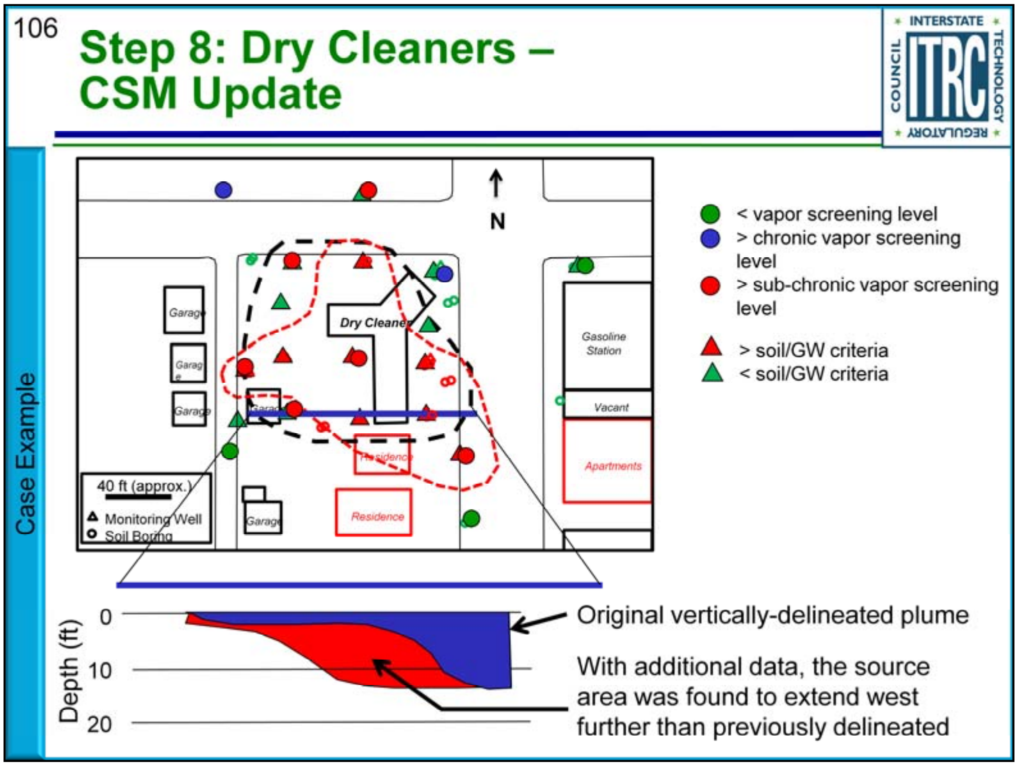


Figure 4-1 Integrated Site Characterization

No associated notes.



No associated notes.

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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%)

No associated notes.

Training Overview

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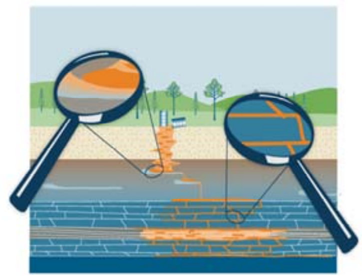

Understanding the subsurface behavior of DNAPLs is technically-challenging and methods for site characterization have evolved. The objective of this document is to describe the tools and resources that can improve the identification, collection, and evaluation of appropriate site characterization data to prepare more accurate CSMs. This guidance describes how, with the current understanding of subsurface contaminant behavior, both existing and new tools and techniques can be used to measure physical, chemical, and hydrologic subsurface parameters to better characterize the subsurface. The expected results of using this guidance are more accurate site-specific CSMs, which can then be applied in the ITRC Integrated DNAPL Site Strategy (ITRC 2011).

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Summary Integrated Site Characterization

- Planning
- Tools selection
- Implementation

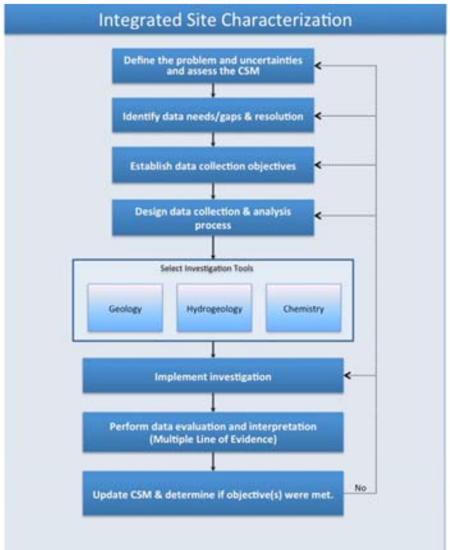

Figure 4-1 Integrated Site Characterization

No associated notes.

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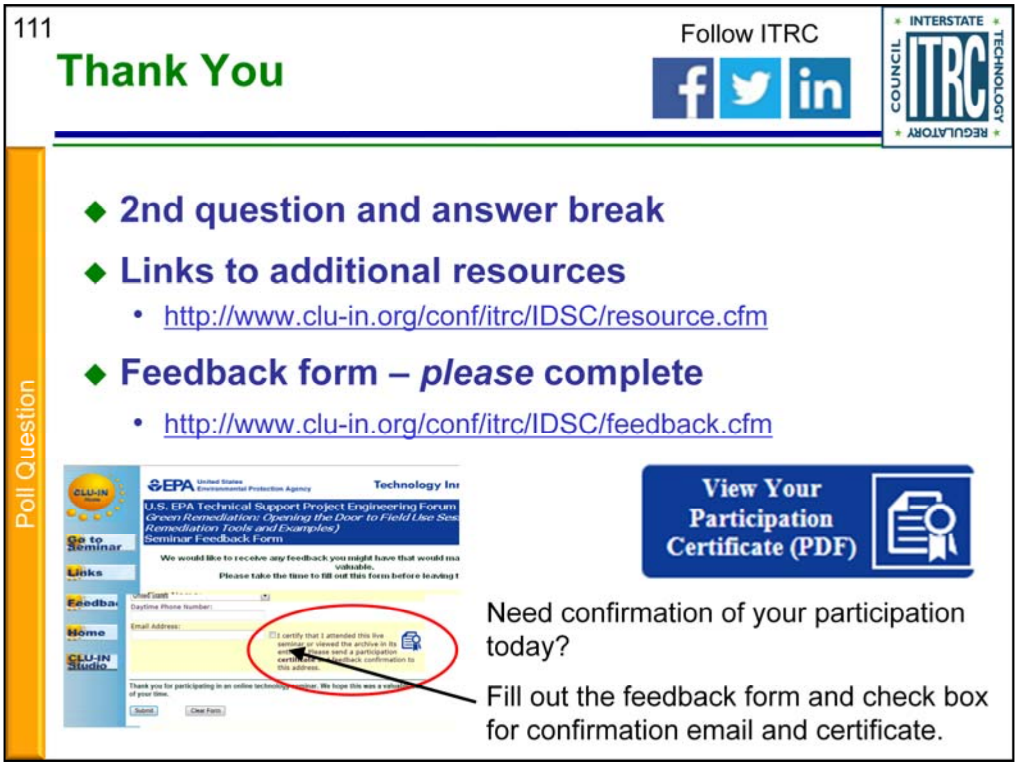
Integrated Site Characterization is the Path Forward

- 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

Better characterization builds trust and confidence in site decisions:

Stakeholder participation
Risk mitigation; site restoration
Cost optimization



Links to additional resources:
http://www.clu-in.org/conf/itrc/IDSC/resource.cfm

Your feedback is important – please fill out the form at:
http://www.clu-in.org/conf/itrc/IDSC/feedback.cfm

The benefits that ITRC offers to state regulators and technology developers, vendors, and consultants include:

✓Helping regulators build their knowledge base and raise their confidence about new environmental technologies

✓Helping regulators save time and money when evaluating environmental technologies

✓Guiding technology developers in the collection of performance data to satisfy the requirements of multiple states

✓Helping technology vendors avoid the time and expense of conducting duplicative and costly demonstrations

✓Providing a reliable network among members of the environmental community to focus on innovative environmental technologies

How you can get involved with ITRC:

✓Join an ITRC Team – with just 10% of your time you can have a positive impact on the regulatory process and acceptance of innovative technologies and approaches

✓Sponsor ITRC's technical team and other activities

✓Use ITRC products and attend training courses

✓Submit proposals for new technical teams and projects