

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   

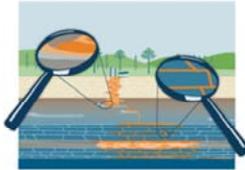
No associated notes.

2

Welcome – Thanks for joining
this ITRC Training Class



Integrated DNAPL Site Characterization and Tools Selection



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

Sponsored by: Interstate Technology and Regulatory Council (www.itrcweb.org)
Hosted by: US EPA Clean Up Information Network (www.cluin.org)

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)

ITRC Training Program: training@itrcweb.org; Phone: 402-201-2419

Housekeeping



- ▶ Course time is 2¼ hours
- ▶ This event is being recorded
- ▶ Trainers control slides
 - **Want to control your own slides?** You can download presentation file on Clu-in training page
- ▶ Questions and feedback
 - **Throughout training:** type in the “Q & A” box
 - **At Q&A breaks:** unmute your phone with #6 to ask out loud
 - **At end of class:** Feedback form available from last slide
 - **Need confirmation of your participation today?** Fill out the feedback form and check box for confirmation email and certificate

Copyright 2019 Interstate Technology & Regulatory Council,
50 F Street, NW, Suite 350, Washington, DC 20001

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.

4 **ITRC (www.itrcweb.org) – Shaping the Future of Regulatory Acceptance**



- ▶ Host organization 
- ▶ Network
 - State regulators
 - All 50 states, PR, DC
 - Federal partners




 - ITRC Industry Affiliates Program 
 - Academia
 - Community stakeholders
- ▶ Follow ITRC




- ▶ Disclaimer
 - Full version in “Notes” section
 - Partially funded by the U.S. government
 - ITRC nor US government warranty material
 - ITRC nor US government endorse specific products
- ▶ ITRC materials available for your use – see [usage policy](#)
- ▶ Available from www.itrcweb.org
 - Technical and regulatory guidance documents
 - Online and classroom training schedule
 - More...

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.

Disclaimer: This material was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof and no official endorsement should be inferred.

The information provided in documents, training curricula, and other print or electronic materials created by the Interstate Technology and Regulatory Council (“ITRC” and such materials are referred to as “ITRC Materials”) is intended as a general reference to help regulators and others develop a consistent approach to their evaluation, regulatory approval, and deployment of environmental technologies. The information in ITRC Materials was formulated to be reliable and accurate. However, the information is provided “as is” and use of this information is at the users’ own risk.

ITRC Materials do not necessarily address all applicable health and safety risks and precautions with respect to particular materials, conditions, or procedures in specific applications of any technology. Consequently, ITRC recommends consulting applicable standards, laws, regulations, suppliers of materials, and material safety data sheets for information concerning safety and health risks and precautions and compliance with then-applicable laws and regulations. ITRC, ERIS and ECOS shall not be liable in the event of any conflict between information in ITRC Materials and such laws, regulations, and/or other ordinances. The content in ITRC Materials may be revised or withdrawn at any time without prior notice.

ITRC, ERIS, and ECOS make no representations or warranties, express or implied, with respect to information in ITRC Materials and specifically disclaim all warranties to the fullest extent permitted by law (including, but not limited to, merchantability or fitness for a particular purpose). ITRC, ERIS, and ECOS will not accept liability for damages of any kind that result from acting upon or using this information.

ITRC, ERIS, and ECOS do not endorse or recommend the use of specific technology or technology provider through ITRC Materials. Reference to technologies, products, or services offered by other parties does not constitute a guarantee by ITRC, ERIS, and ECOS of the quality or value of those technologies, products, or services. Information in ITRC Materials is for general reference only; it should not be construed as definitive guidance for any specific site and is not a substitute for consultation with qualified professional advisors.

Meet the ITRC Trainers



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



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



Tamzen Macbeth
CDM Smith
Helena, MT
208-904-0238
Macbethtw
@cdmsmith.com



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



Trevor King
AECOM
Warrington, PA
610-832-3566
trevor.king@aecom.com

Read trainer bios at
[https://clu-
in.org/conf/itrc/IDSC/](https://clu-in.org/conf/itrc/IDSC/)

Alec Naugle is a Senior Engineering Geologist in the Groundwater Protection Division at the California Regional Water Quality Control Board, San Francisco Bay Region where he has worked since 1999. Alec leads a unit that oversees solvent and petroleum hydrocarbon cleanups at Department of Energy laboratories and closed military bases, many of which are undergoing conversion for civilian use. He is also co-chair of the Region's technical groundwater committee, which supports the Board's planning activities related to groundwater quality and beneficial use. Prior to joining the Board, Alec worked as a consultant on various military and private sites in California and the Northeast and as a regulator in the UST program. Alec has been a member of ITRC since 2000 participating in the Permeable Reactive Barriers, Enhanced Attenuation: Chlorinated Organics, and Integrated DNAPL Site Strategy teams. Alec earned a bachelor's degree in chemistry and geology from Marietta College in Marietta, Ohio in 1986 and a master's degree in groundwater hydrology from the University of California at Davis in 2001. Alec is a Registered Professional Geologist in California.

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 is a Remediation Technical Lead with AECOM DNAPL team in Pennsylvania. He has global experience in the planning, implementing and management of environmental and DNAPL remediation projects. He has extensive experience in the development of characterization and closure strategies for soil and groundwater remediation projects, and implementing cost effective remedial actions. 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 **Ryan A. Wymore, P.E.**, rejoined CDM Smith in Denver, CO in 2015. He serves as a national resource for evaluation, selection, and implementation of remediation strategies and solutions. Ryan has specialized in innovative groundwater remediation technologies, particularly bioremediation, monitored natural attenuation and chemical oxidation. Previously, he work at Geosyntec Consultants in 2014-2015, CDM Smith from 2005-2013, at North Wind Inc. from 2001-2005, and at the Idaho National Laboratory from 1998-2001. He has given over eighty presentations at various local, regional, national, and international symposia and meetings. Since 2002, he has worked with various ITRC teams that addressed DNAPLs, bioremediation, enhanced attenuation, and Environmental Molecular Diagnostics. He was an instructor on the ITRC Internet-based training courses: DNAPL Performance Assessment, Bioremediation of DNAPLs, and Integrated DNAPL Site Strategy. Ryan earned a bachelor's degree in Biological Systems Engineering from the University of Nebraska-Lincoln in 1997 and a master's degree in Civil/Environmental Engineering from the University of Idaho in Moscow, Idaho in 2003. He is a registered Professional Engineer in the state of Idaho and Colorado in the environmental discipline.

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.

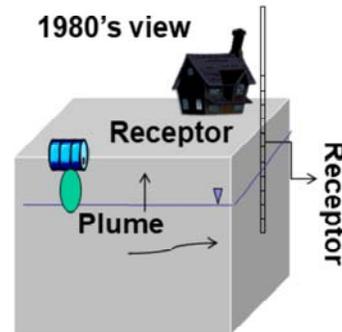
Poll Question

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

No associated notes.

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.

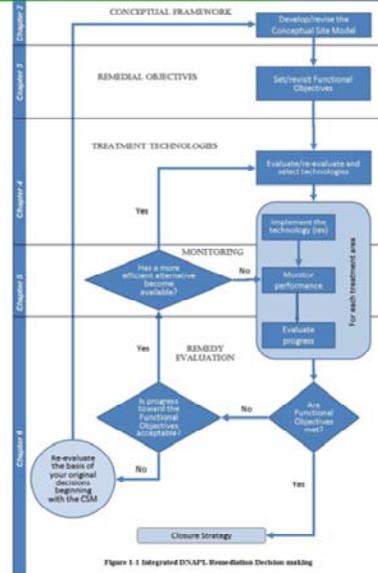
These simplifications in many cases led to inadequate characterization of the site geologic heterogeneity and distribution, characteristics, and behavior of contaminants

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

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 measurable
- 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

Adding to the Solution: Integrated DNAPL Site Characterization

Handout
provided



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

Benefits

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

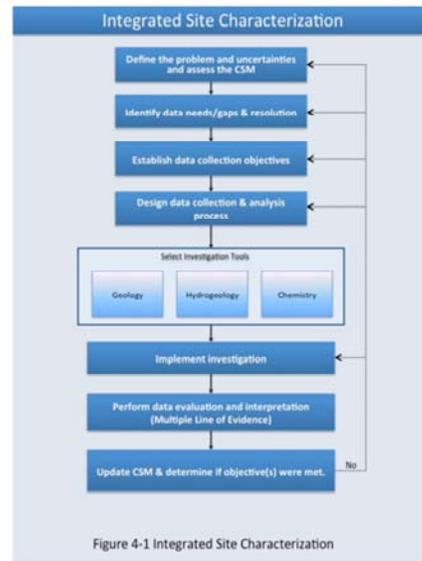


Figure 4-1 Integrated Site Characterization

ITRC ISC-1, Figure 4-1

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.

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.

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.

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



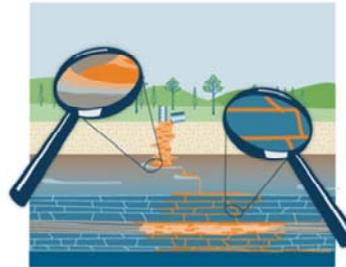
Photo Courtesy of Fred Payne, Arcadis, Inc

[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



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).

DNAPLs – Not Just Chlorinated Solvents!



PCE in Soil Core



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



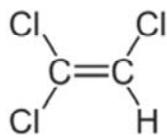
Coal Tar

Heterogeneity replaces homogeneity. Anisotropy replaces isotropy.

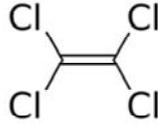
DNAPL Types

► Common types of DNAPLs

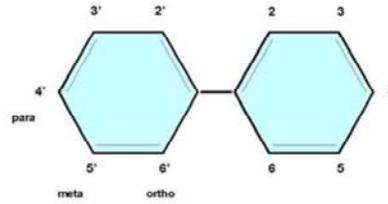
- Chlorinated solvents
- Coal tar
- Creosote
- Heavy petroleum such as some #6/Bunker fuel oil products
- Oils containing Polychlorinated biphenyls (PCBs)



TCE (C₂HCl₃)
trichloroethene
trichloroethylene



PCE (C₂Cl₄)
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

Important DNAPL Properties Affecting Mobility

DNAPL Chemical & Physical Properties

Density

Solubility

Viscosity

Volatility

Composition

Modified from
[ISC-1, Chapter 2](#)

No associated notes.

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

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

DNAPL Aqueous Solubility (C_w, 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 ₂ SO 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

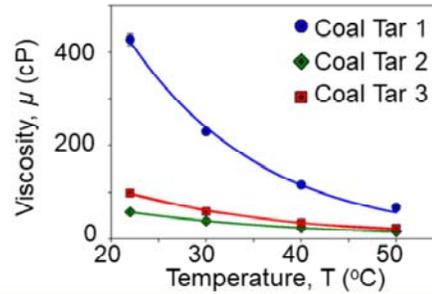
DNAPL Viscosity (Dynamic)

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



- ▶ Temperature dependent

- $\mu_w = 0.894$ cP 25 °C
- $\mu_w = 1.002$ cP 20 °C

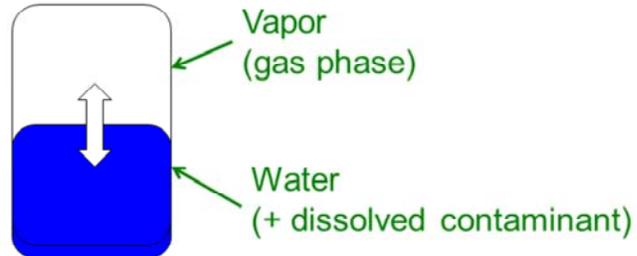


KEY POINT: Influences mobility in the subsurface

No associated notes.

DNAPL Volatility

- ▶ Volatility - Henry's Constant (K_H)
- ▶ 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

DNAPL Composition

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

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

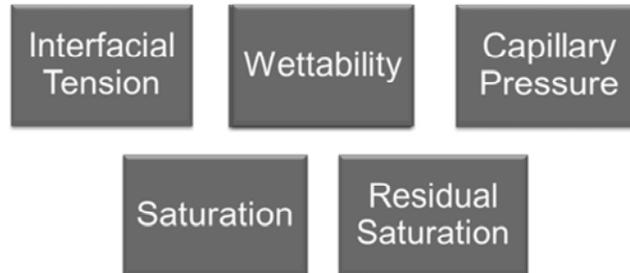
The properties we have just discussed can “be found” in published literature.

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 Interactions with the Sub-Surface Media Affecting Mobility

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

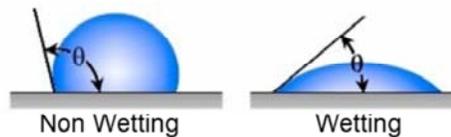


Modified from [ISC-1, Chapter 2](#)

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

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

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

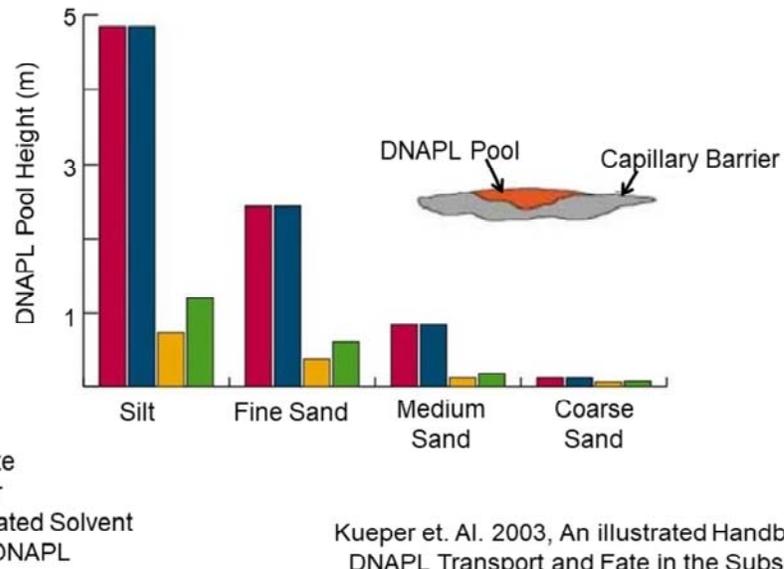
- ▶ P_c is a non-linear function of S , with P_c increasing at greater saturation of the non-wetting fluid

(Lenhard and Parker, 1987)

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

No associated notes.

Capillary Pressure of Coarser Layers and DNAPL Entry



No associated notes.

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.

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)

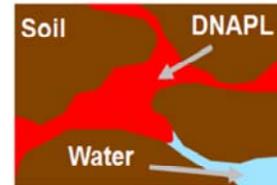
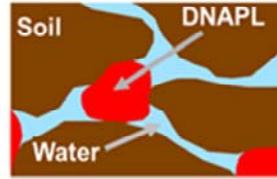


Figure modified from ISC-1, Chapter 2

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.

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)

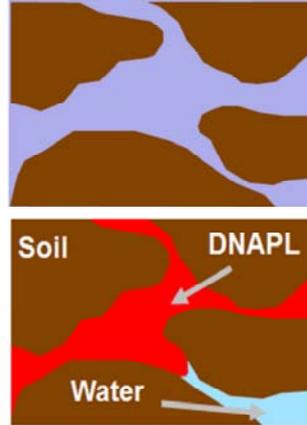


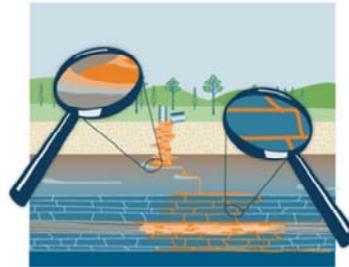
figure modified from ISC-1, Chapter 2

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

No associated notes.

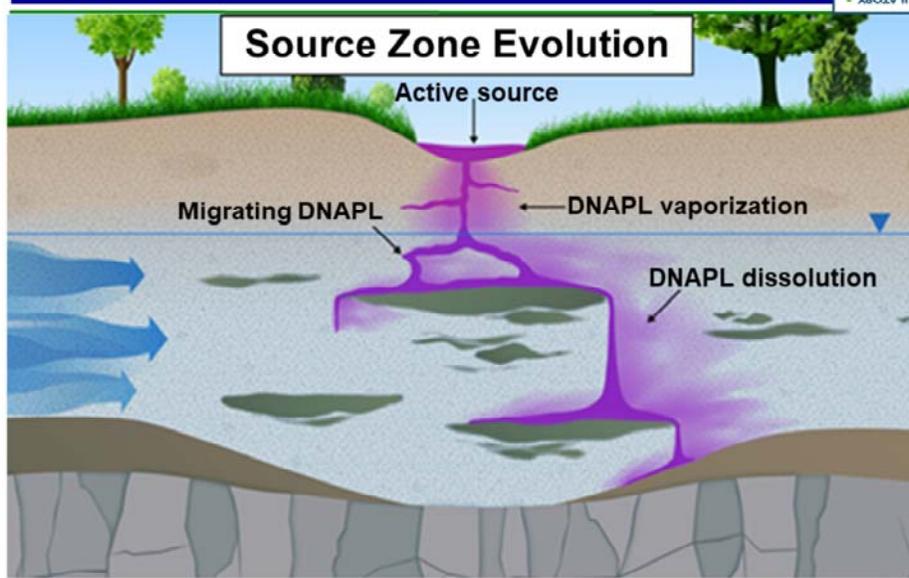
Training Overview

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



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).

DNAPL Life Cycle – Classical Model



Kueper et al., 2013

No associated notes.

Secondary Sources within Groundwater Plumes

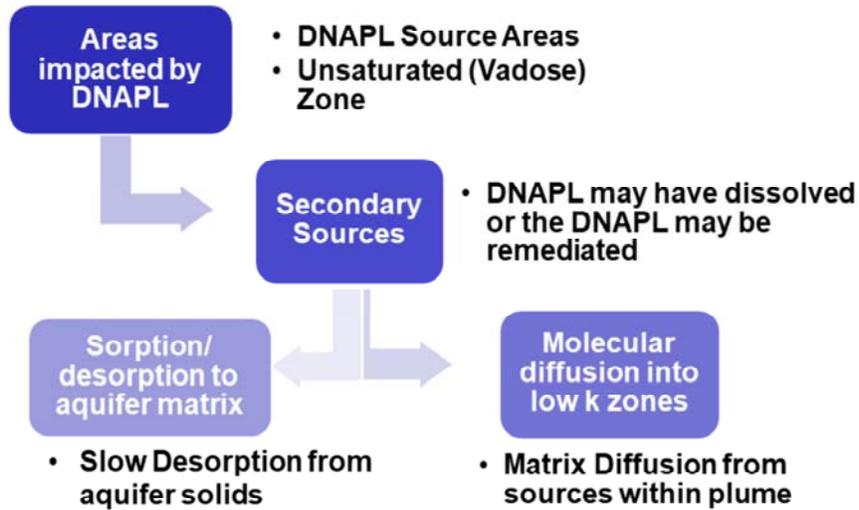
We are now revising our definition of “DNAPL Source Zone”

- ▶ 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.

Redefining the DNAPL Source Term: Apparent Secondary Sources

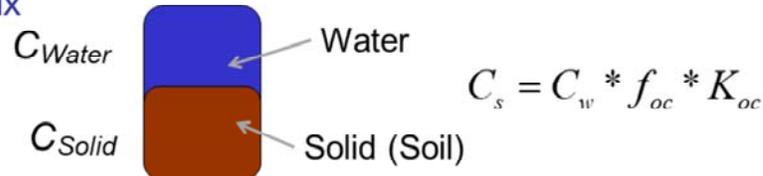


Modified from ISC-1, Chapter 2

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

“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



- ▶ Contaminant mass will desorb from matrix into groundwater as “cleaner” groundwater migrates through system

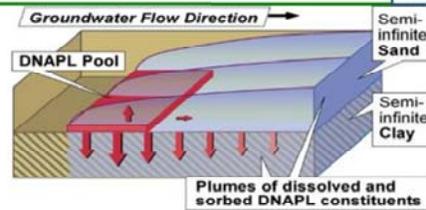
KEY POINT: Desorption contributes to retardation and longevity of dissolved phase contaminant plumes

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”

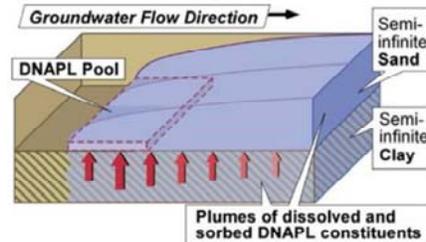
► Early time

- 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.

Controlling Role of Geology in Matrix Diffusion

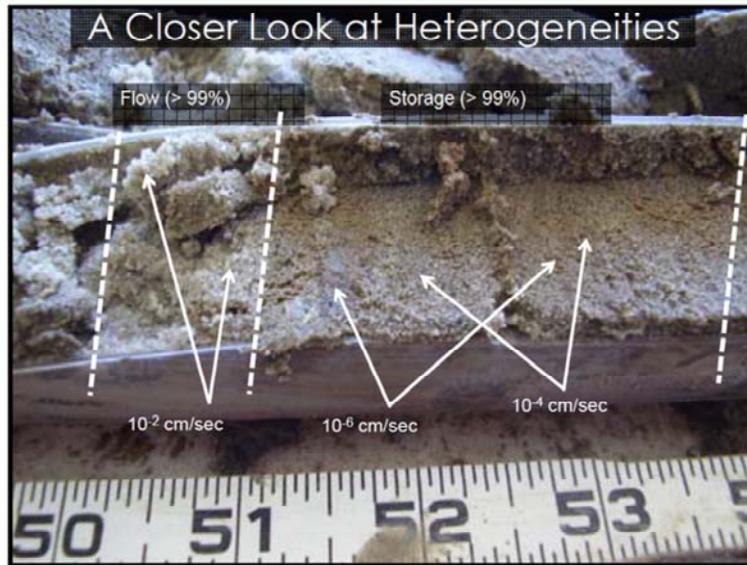
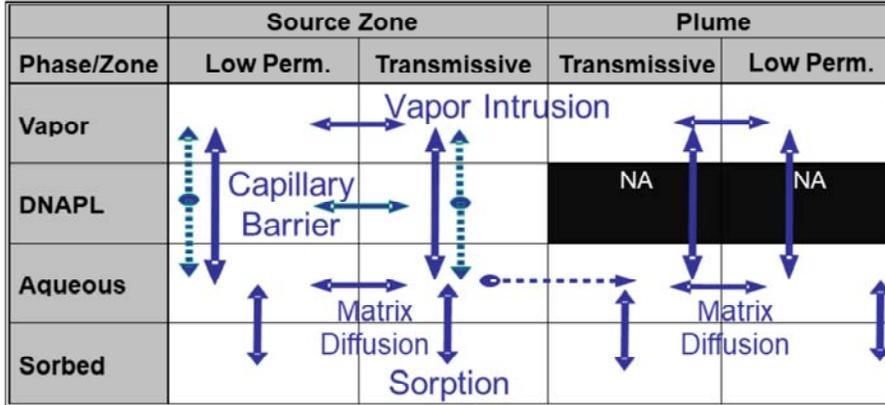


Figure courtesy of Fred Payne, Arcadis

No associated notes.

14-Compartment Model: Phase Distribution and Mass Transfer

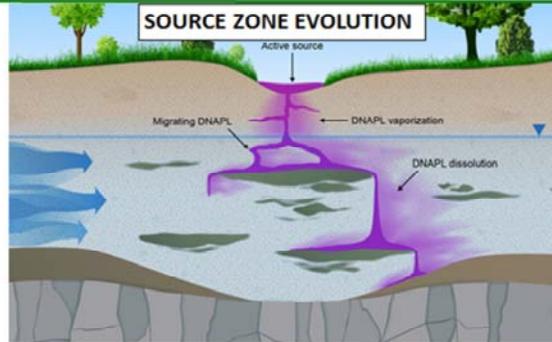


ITRC IDSS-1, Table 2-2 from Sale and Newell 2011

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

No associated notes.

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.

Prolonged Early Stage Behavior

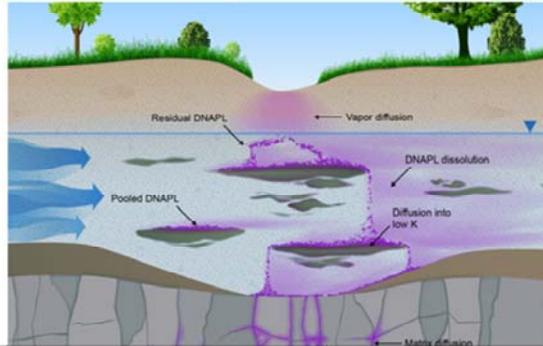
- ▶ Low solubility and high viscosity DNAPLs
- ▶ High DNAPL saturations and still immobile.
- ▶ Highly DNAPL saturation causes flow by-passing



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

No associated notes.

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.

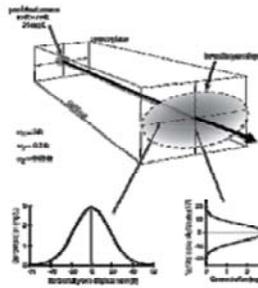
Diffusion Replaces Dispersion in Dissolved Phase Plumes

- ▶ 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

The Dispersivity Model:

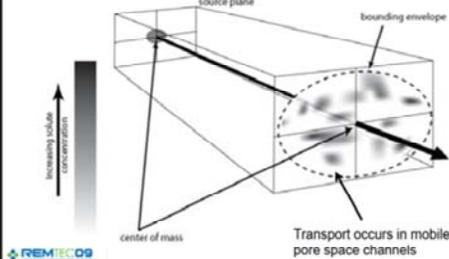
The old view -
"Classic" transverse
dispersivity

Calculated from
mechanical dispersion
coefficients ($\alpha_x, \alpha_y, \alpha_z$)
that aren't tied to any site
structure or contaminant
characteristics



REMTECOS
Remediation Technology

Without Dispersivity, the Advection-Diffusion Approach Comes of Age



REMTECOS
Remediation Technology

Figures courtesy of Fred Payne, Arcadis

Diffusion replaces dispersion.

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

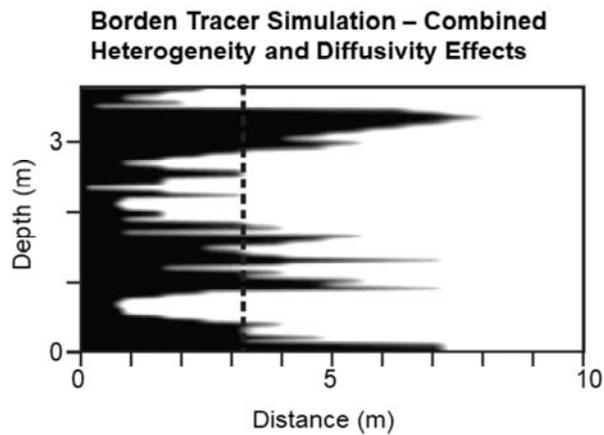
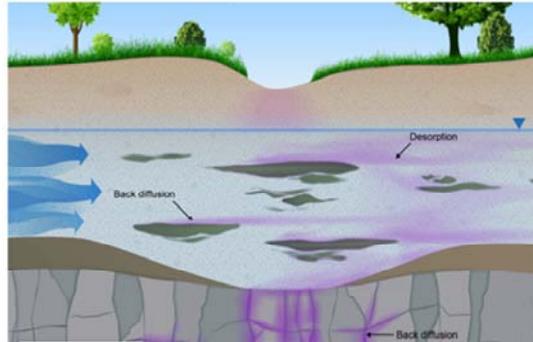


Figure courtesy of Fred Payne, Arcadis

Anisotropy replaces isotropy
Heterogeneity replaces homogeneity

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.

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.

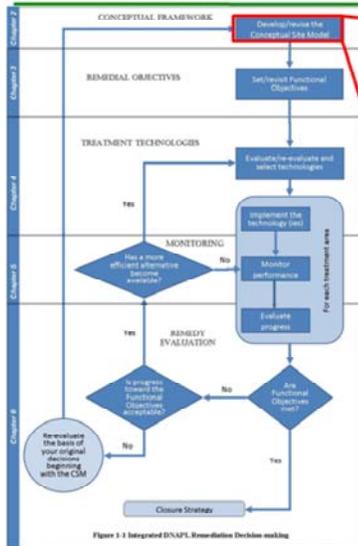
Understanding Your DNAPL CSM



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

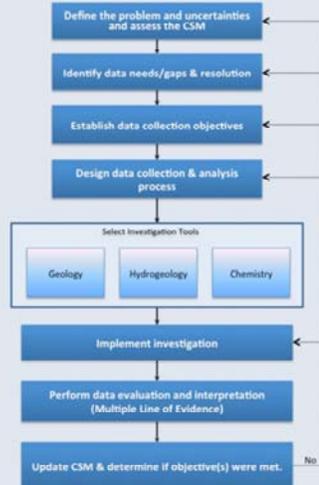
No associated notes.



ITRC IDSS-1, Figure 1-2

Handout provided

Integrated Site Characterization

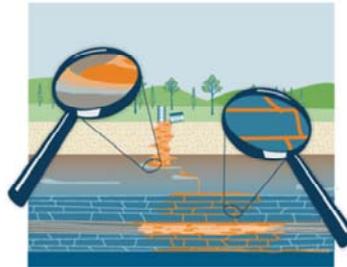


ITRC ISC-1, Figure 4-1

No associated notes.

Training Overview

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

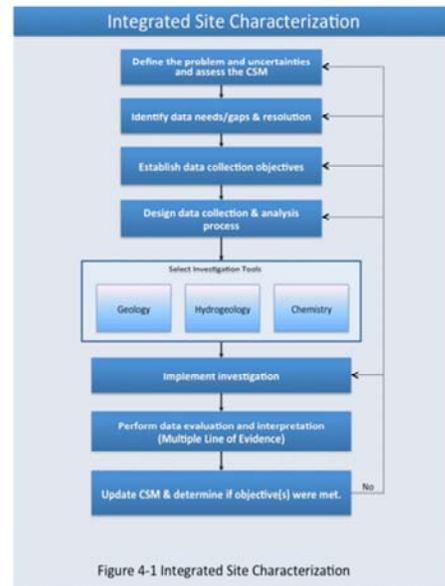


Now that you've heard about DNAPL characteristics and the life cycle of a DNAPL site, we want to discuss a process that we're calling integrated site characterization for DNAPL sites. It's a process that integrates the planning, collection, and evaluation of characterization data. One major highlight 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 our 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.

Integrated Site Characterization

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



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

Benefits of Integrated Site Characterization



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

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 led 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.

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)



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.

Poll Question



Poll Question

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

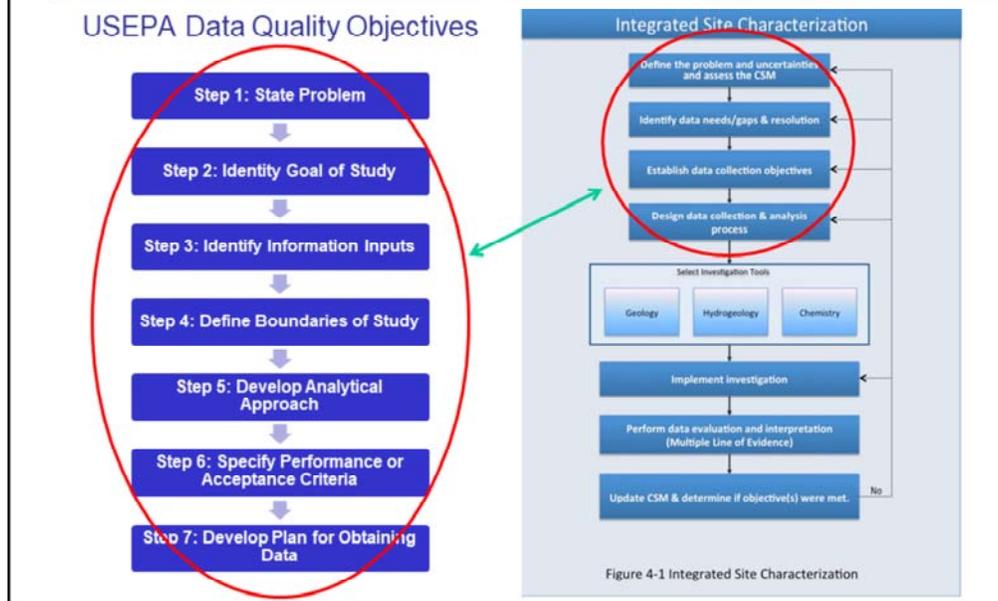
So before we go any further, please take a few moments to respond to our poll question.

“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.

Data Quality Objectives are “Built in”



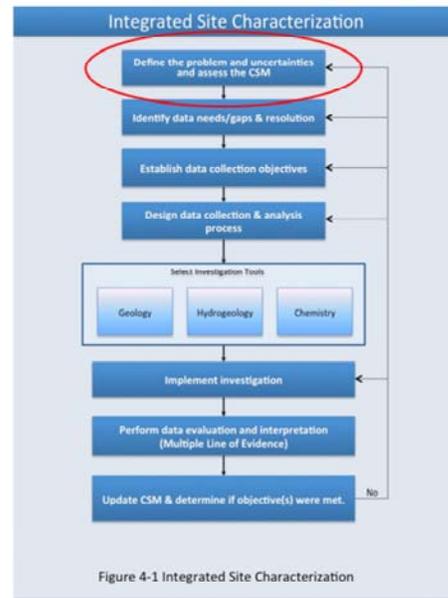
Most of us are familiar with U.S. Environmental Protection Agency’s seven step Data Quality Objectives Process. And you might be thinking that integrated site characterization sounds a lot like data quality objectives.

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.”

Step 1: Define Problem and Assess CSM Uncertainties

- ▶ Assess existing CSM
- ▶ Define problem
- ▶ Define uncertainties



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:

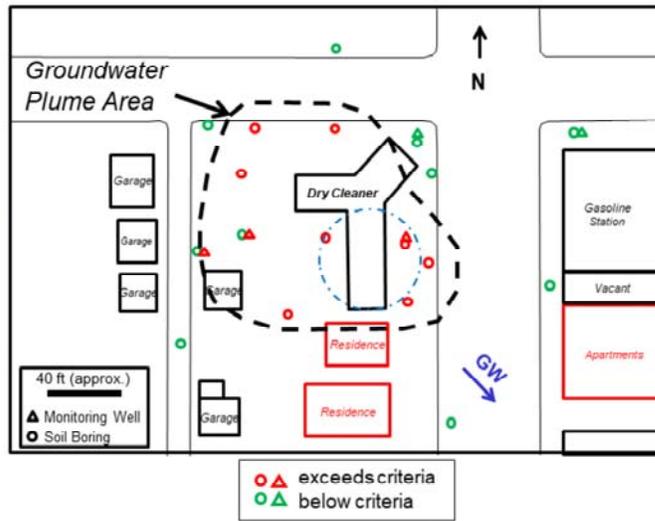
- Lithologic and structural heterogeneity – that's what's controlling groundwater flow and contaminant distribution and movement. For example, it includes soil type, permeability, presence or absence of buried channels and aquitards, fractures, fracture density, and depth to base units.
- Vertical sampling 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.

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



In this case example, a dry cleaner site 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 groundwater 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 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.

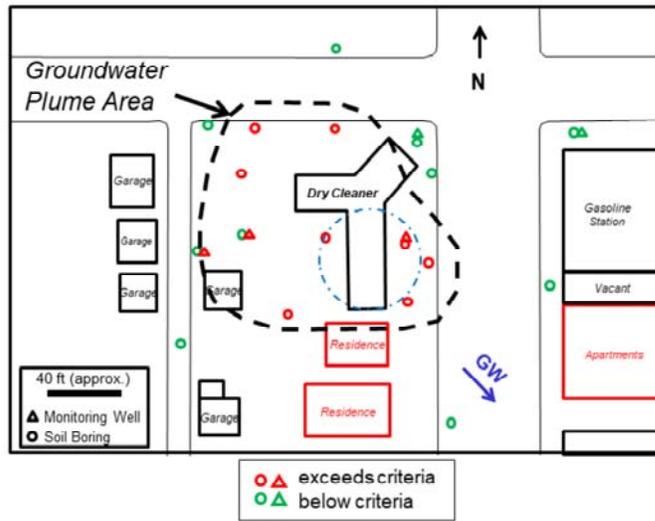
The third problem is that the vapor intrusion pathway had not been assessed despite the existence of nearby residential buildings. This was probably because vapor intrusion has been an evolving concern in recent years and may not have been given much thought when the investigation began in 2004. But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

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



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.

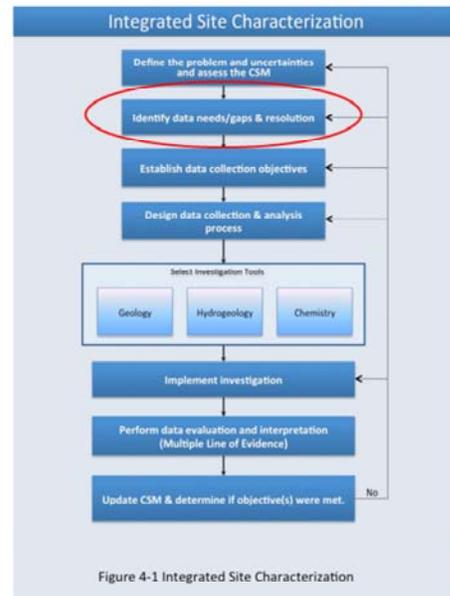
The second problem is that no effectiveness evaluation was planned after remediation was conducted in 2008. So when monitoring data showed that the groundwater plume remained above standards two years after remediation, there was no consensus about where the problem lay.

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.

Step 2: Identify Data Needs & Spatial Resolution

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



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.

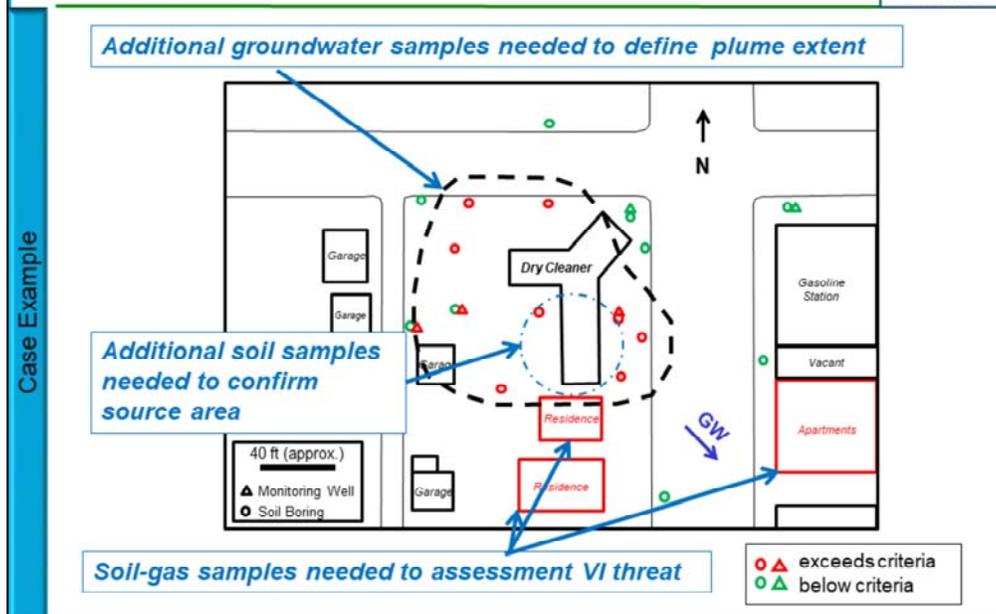
The big question is how do I know what level of resolution to characterize to? Ans: While there may be many techniques, including use of geophysical methods, you'll never really know until you've tried. So one way is to pick a small, off-source area and do what is typically considered high resolution, 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.

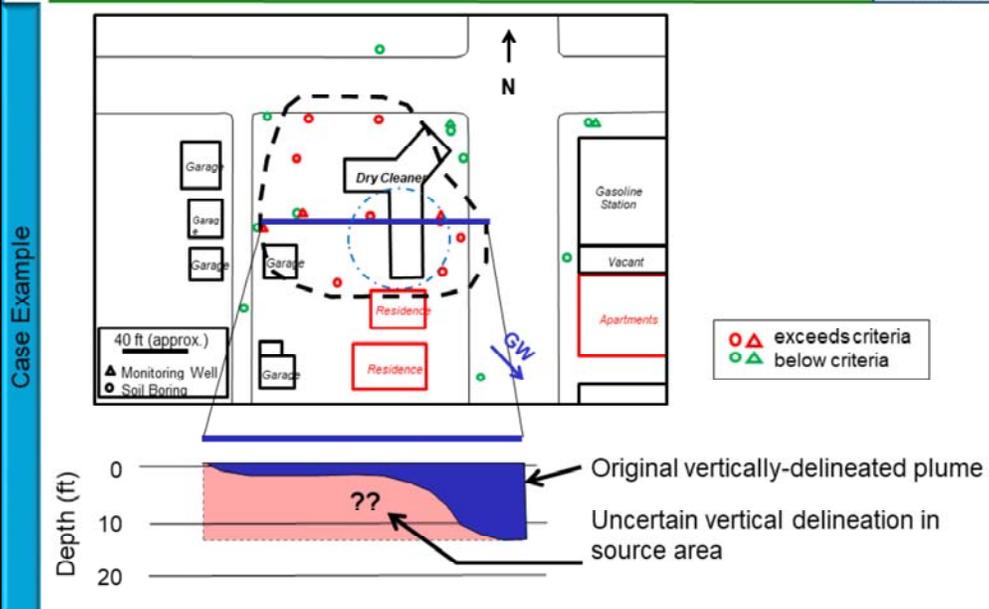
Step 2: Identify Data Needs & Spatial Resolution



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.

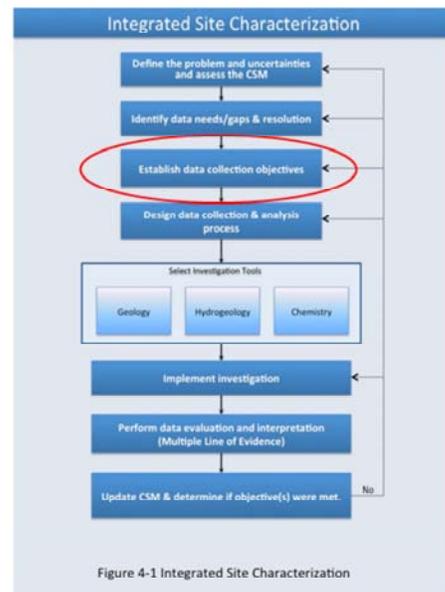
Step 2: Identify Data Needs & Spatial Resolution



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

Step 3: Establish Data Collection Objectives

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



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.

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...

Poll Question

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

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.

Step 3: Drycleaner Site Data Collection Objectives

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

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: Data Collection & Analysis Plan

► Write work plan

- Recognize data limitations
- Select data management tool
- Develop data analysis process



► Consider real-time analysis



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!

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

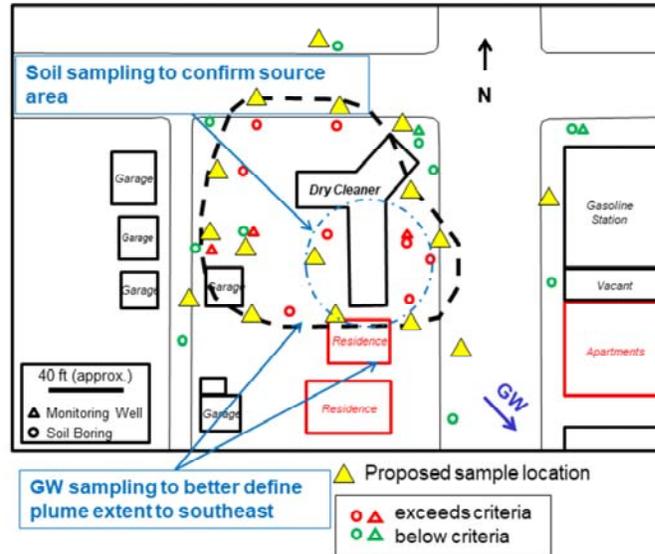
With the objectives in mind, a plan was developed for the dry cleaner site using the TRIAD approach, two Geoprobos and a mobile laboratory to collect high-resolution samples in the source area, grab groundwater samples, and soil vapor samples across the site.

Step 4: Data Collection & Analysis Plan

Case Example

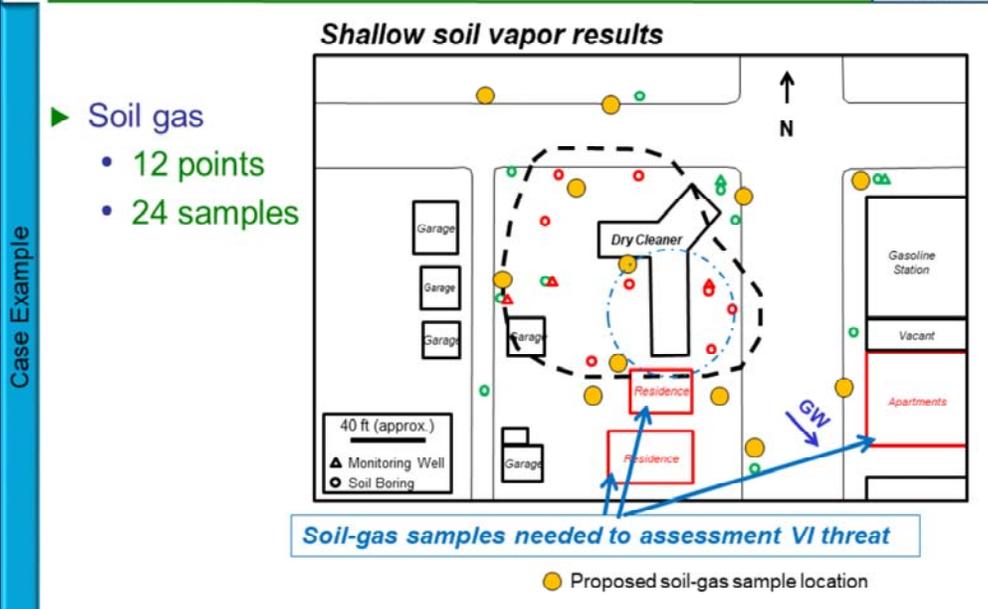
- ▶ 16 borings
- ▶ 80 soil samples (~5 per boring)
- ▶ 48 grab groundwater samples (~3 per boring)

Updated Groundwater Plume Area



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.

Step 4: Data Collection & Analysis Plan



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.

Summary – Integrated Site Characterization

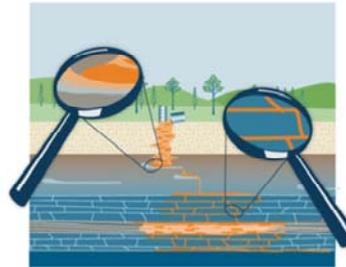


- ▶ Integrated Site Characterization flow chart
 - Planning
 - Tool Selection
 - Implementation
- ▶ Planning module
 - Step 1: Define problem and uncertainties
 - Step 2: Identify data gaps & resolution
 - Step 3: Develop data collection objectives
 - Step 4: Design data collection & analysis plan
 - 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



Tools Selection Process: Contents of this Section



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

No associated notes.

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.

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.

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						
Magnetostratigraphic Resistivity	QL	✓	✓	✓	✓	✓
Induction Resistivity (Conductivity Logging)	QL - Q	✓	✓	✓	✓	✓
Resistivity (Flow)	QL - SQ	✓	✓	✓	✓	✓
RFI Cross-Wall 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	✓	✓	✓	✓	✓
Gamma 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

Click

Quality	Sub surface		Zone	Geology				
	Depth	Location	Structure	Lithology	Stratigraphy	Structure	Structure	Structure

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, crystallinity, geologic contacts, bedding planes, fractures and faults, depositional environment, porosity, and permeability. Generally, numerous boreholes are drilled to determine the vertical and horizontal variability of the site-specific geology. The depositional environment and facies changes should also be mapped as much as possible, and these data may be combined with surface and 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 oversizing remediation systems. However, remedy performance success rates have been poor under such circumstances, whereas investing in adequately detailed site characterization has provided a positive return on investment in terms of improved remedy success rates and reduced life cycle costs.

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.

Detailed Tool Descriptions (Appendix D)

Click on any tool

- ▶ Additional reference material
- ▶ Description
- ▶ Applicability
- ▶ Limitations

Click

Tool	Data Quality	Sub surface		Zone	
		Bedrock	consolidated	unsaturated	Saturated
<p>Tool/References</p> <ul style="list-style-type: none"> • Ground Penetrating Radar • Annan 2005 • Bayer et al. 2011 • Beres et al. 1999 • Bradford 2006 • Bradford and Deeds 2006 • Bradford, Dickens, and Brandvik 2010 • Bradford and Babcock 2013 • Clement, Barrash, and Kholi 2006 • Guern 2005 • USEPA 2004 	<p>Description</p> <p>Ground penetrating radar (GPR) creates a cross-sectional imaging of the ground based on the reflection of an electromagnetic (EM) pulse from boundaries between layers of different dielectric properties. The quality depends on soil and water conditions as penetration is reduced by clay, water, and salinity. GPR is useful in resolving stratigraphic layers; however, independent confirmation of lithology is required.</p> <p>GPR generates a 2D profile, but it can be run with multiple lines in a grid pattern to generate a pseudo-3D image. Penetration and resolution of features depend on antenna frequency and material conductivity and 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.</p> <p>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).</p>	<p>Data Quality and Applicability/Advantages</p> <p>Data Quality</p> <ul style="list-style-type: none"> • varies with antennas and subsurface EC • relatively sharp boundaries • qualitative to quantitative depending on field conditions, prior knowledge/subsurface calibration, experimental quality, appropriate modeling <p>Applicability/Advantages</p> <ul style="list-style-type: none"> • 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) 	<p>Limitations/Difficulty</p> <ul style="list-style-type: none"> • minimal penetration in electrically conductive (silt 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.

Shaded Boxes Denote Tool Meets Objective

Tools collect these types of information

Tool	Data Quality	Sub surface				Geology										
		Bedrock	Unconsolidated	Unsaturated	Saturated	Lithology	Lithology Contacts	Porosity	Permeability	Dual Permeability	Faults	Fractures	Fracture Density	Fracture sets	Rock Competence	Mineralogy
Geophysics																
Surface Geophysics																
Ground Penetrating Radar (GPR)	QL - Q	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓			
High Resolution Seismic Reflection (2D or 3D)	QL - Q	✓	✓	✓	✓	✓	✓									
Seismic Refraction	QL - Q	✓	✓	✓	✓	✓	✓									
Multi-Channel Analysis 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.

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.

1. Select Category

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

Type	Subsurface	Data Quality
All	All	All
Subsurface Zone	Search	
All		

Tool	Data Quality	Sub surface		Zones		Lithology	Lithology Contacts	Porosity
		Bedrock	Unconsolidated	Unsaturated	Saturated			

No associated notes.

2. Select Parameters of Interest

All

Lithology

Contacts

Porosity

Permeability

Dual Permeability

Faults

Fractures

Fracture Density

Fracture Sets

Rock

Competence

Mineralogy

1	Type Geology	Subsurface All	Data Quality All
2			
3	Parameter All	Subsurface Zone All	Search
4			
5	<div style="border: 1px solid red; padding: 2px;"> <ul style="list-style-type: none"> All Lithology Lithology Contacts Porosity Permeability Dual Permeability Faults Fractures </div>		
6			
7	Tool	Data Quality	Sub surface
8		Bedrock	Zones
9		Unconsolidated	Unsaturated
		Saturated	Lithology
			Lithology Contacts
			Porosity

No associated notes.

3. Identify Geologic Media

All
Bedrock
Unconsolidated

1	Type	Subsurface	Data Quality
2	Geology	All	All
3	Parameter	All	
4	Lithology	Bedrock	
5		Unconsolidated	
6			Search
7	Tool		
8	Data Quality	Sub surface	Zones
	Bedrock	Unconsolidated	Unsat
			Saturated
			Lithology
			Lithology Contacts
			Porosity
9			

No associated notes.

4. Identify Zone

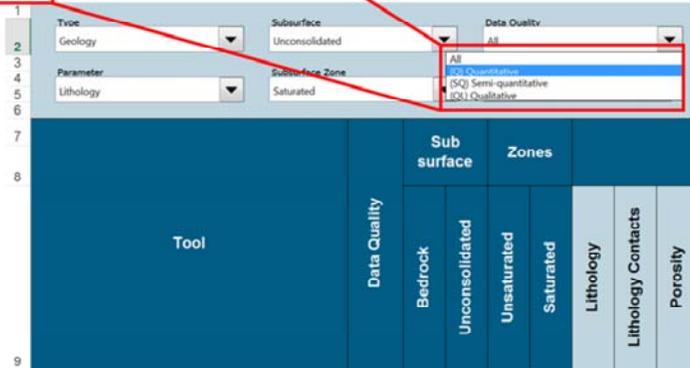
All
Unsaturated
Saturated

1	Type	Subsurface	Data Quality						
2	Geology	Unconsolidated	All						
3	Parameter	Subsurface Zone							
4	Lithology	All	Search						
5		All							
6		Unsaturated							
7		Saturated							
8	Tool	Data Quality	Bedrock	Unconsolidated	Unsaturated	Saturated	Lithology	Lithology Contacts	Porosity
9									

No associated notes.

5. Choose Data Quality

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



1	Type	Subsurface	Data Quality
2	Geology	Unconsolidated	All
3			(Q) Quantitative
4	Parameter	Subsurface Zone	(SQ) Semi-quantitative
5	Lithology	Saturated	(QL) Qualitative
6			
7	Tool		
8		Sub surface	Zones
9		Bedrock	Unconsolidated
		Unconsolidated	Saturated
		Lithology	Lithology Contacts
			Porosity

No associated notes.

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	Lithology	Lithology Contacts	Porosity
		Bedrock	Unconsolidated	Unsaturated	Saturated				
Geophysics									
Surface Geophysics									
Ground Penetrating Radar (GPR)	OL - Q	✓	✓	✓	✓	✓			
High Resolution Seismic Reflection (2D or 3D)	OL - Q	✓	✓	✓	✓	✓			
Seismic Refraction	OL - Q	✓	✓	✓	✓	✓			
Multi-Channel Analysis of Surface Waves (MASW)	OL - Q	✓	✓	✓	✓	✓			
Electrical Resistivity Tomography (ERT)	QL - SQ	✓	✓	✓	✓	✓			
Very Low Frequency (VLF)	OL	✓	✓	✓	✓	✓			
Electromagnetic (EM) Conductivity	OL	✓	✓	✓	✓	✓			
Geophysical Logging									
Magnetometric Resistivity	OL	✓	✓	✓	✓	✓			
Induction Resistivity (Conductivity Logging)	OL - Q	✓	✓	✓	✓	✓			
Resistivity (Flow)	OL - SQ	✓	✓	✓	✓	✓			
GPS Log/Wall Tomography	OL - Q	✓	✓	✓	✓	✓			
Optical Telemetry	OL - Q	✓	✓	✓	✓	✓			
Acoustic Telemetry	OL - Q	✓	✓	✓	✓	✓			
Natural Gamma Log	OL - Q	✓	✓	✓	✓	✓			
Neutron Porosity Logging	OL - Q	✓	✓	✓	✓	✓			
Nuclear Magnetic Resonance Logging	OL - Q	✓	✓	✓	✓	✓			
Videos Log	OL - SQ	✓	✓	✓	✓	✓			
Caliper Log	OL - Q	✓	✓	✓	✓	✓			
...			
DNAPL									

No associated notes.

Add Parameters to a previous search

Multiple searches can be saved on one matrix

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

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.

Case Example – Characterization Objectives



Returning to Case Example from prior section –
Characterization Objective:

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

Goal:

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

No associated notes.

Case Example – Select Tools Matrix Filters

Filters

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

No associated notes.

Case Example – Apply Filters



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

Case Example

Tool	Date Quality	Subsurface		Geology										Hydrogeology				Chemistry												
		Bedrock	Unconsolidated	Unconsolidated	Saturated	Lithology	Lithology Contacts	Porosity	Permeability	Dual Permeability	Faults	Fractures	Fracture Density	Fracture Width	Rock Competence	Mineralogy	Open Hole Flow	Arched Flow	Groundwater Age	Fracture Aperture	Fracture Connectivity	Hydraulic Conductivity	Hydraulic Head	Burial Condition	Contaminant Concentration	Geochemistry	Microbial Community	NAPL Presence Concentration	Geochemistry	Fe
Geophysics																														
Electromagnetic Induction	Q-Q																													
Induction Spectroscopy / Groundwater Logging	Q-Q																													
3D Seismic Data Interpretation	Q-Q																													
Well and Well Log Analysis	Q-Q																													
Active and gas analysis	Q-Q																													
Soil Media Sampling and Analysis Methods																														
Soil Media Collection and Testing Methods	Q-Q																													
Soil Media Analysis	Q-Q																													
Soil Phase Sampling Methods	Q-Q																													
Soil Sampling Tools	Q-Q																													
Soil and Groundwater Sampling & Profiling																														
Soil Probe (SPT) / Cone Penetration Test (CPT)	Q-Q																													
Soil Probe (SPT) / Cone Penetration Test (CPT) - Logging	Q-Q																													
Soil Probe (SPT) / Cone Penetration Test (CPT) - Logging	Q-Q																													
Soil Probe (SPT) / Cone Penetration Test (CPT) - Logging	Q-Q																													

No associated notes.

Case Example – Applicable Tools



Tool	Subsurface			Zone		Soil Gas		Groundwater		Contaminant	
	Data Quality	Bedrock		Unconsolidated	Unsaturated	Saturated	Constituent Concentration	Geochemistry	Microbial Community		MPL Presence
		Bedrock	Unconsolidated								
Geophysics											
Downhole Testing										Geophysics	
Induction Logging (Conductivity Logging)										Downhole Testing	
GRP Cross-Well Tomography										Induction Resistivity (Conductivity Logging)	
Vapor and Soil Gas Sampling										GRP Cross-Well Tomography	
Active soil gas surveys										Vapor and Soil Gas Sampling	
Solid Media Sampling and Analysis Methods										Active soil gas surveys	
Solid Media Evaluation and Testing Methods										Solid Media Sampling and Analysis Methods	
Contaminant Analysis										Solid Media Evaluation and Testing Methods	
Direct Push Logging (In-Situ)										Contaminant Analysis	
Hydrosparge (HPT)										Direct Push Logging (In-Situ)	
Raman Spectroscopy										Hydrosparge (HPT)	
Discrete Groundwater Sampling & Profiling										Raman Spectroscopy	
Screen Point (SPI) 22 Groundwater Sampling										Discrete Groundwater Sampling & Profiling	
Screen Point (SPI) 16 Groundwater Sampling										Screen Point (SPI) 22 Groundwater Sampling	
Hydraulic Profiling Tool - Groundwater Sampler (HPT-GWS)*										Screen Point (SPI) 16 Groundwater Sampling	
Grab well water sampler (SNAP, Hydraulic)										Hydraulic Profiling Tool - Groundwater Sampler (HPT-GWS)*	
Straddle packer sampling										Grab well water sampler (SNAP, Hydraulic)	
Hydroponch										Straddle packer sampling	
2D INFLD Hydraulic sampling system										Hydroponch	
Wellbaw										2D INFLD Hydraulic sampling system	
Chemical Screening										Wellbaw	
Direct Sampling Ion Trap Mass Spectrometer										Soling	
Environmental Molecular Diagnostics										Fast Systems (FLUTE)	
Microbial Diagnostics										GMT (Continuous Multichannel Tubing)	
Compound Specific Isotope Analysis (CSIA)										Chemical Screening	
Mobile Labs										Direct Sampling Ion Trap Mass Spectrometer	
Portable Gas Chromatograph										Environmental Molecular Diagnostics	
Portable Gas Chromatograph/Mass										Microbial Diagnostics	

No associated notes.

Case Example – Tools Selection

- ▶ Search returns 22 tools
- ▶ Considering desire to expedite the assessment, project team selected
 - Direct Push borings with continuous soil sampling and GW grab sampling on 4-foot intervals
 - Active Soil Gas Survey at two depth intervals
 - Direct Sampling Ion Trap Mass Spectrometer (DSITMS) mobile field lab



Active Soil Gas Survey



DSITMS Mobil Lab

No associated notes.

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.

Example #2 – Bedrock Porosity

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

The screenshot shows a tool selection interface with a callout box highlighting applicable tools. The callout box lists the following tools:

- Geophysics**
 - Surface Geophysics
 - Ground Penetrating Radar (GPR)
 - Electrical Resistivity Tomography (ERT)
 - Downhole Testing
 - Induction Resistivity (Conductivity Logging)
 - GPR Cross-Well Tomography
 - Optical Televiwer
 - Neutron (porosity) Logging
 - Nuclear Magnetic Resonance Logging
 - Video Log
- Solid Media Sampling and Analysis Methods**
- Solid Media Evaluation and Testing Methods**
 - Core Logging
 - Physical Properties

The background interface shows a table with columns for 'Tool', 'Dist Quality', 'Subsurface', and 'Zone'. The 'Subsurface' column is filtered to 'Bedrock' and the 'Zone' column is filtered to 'Saturated'. The 'Tool' column lists various geophysical and sampling methods.

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.

Example #3 – Hydraulic Conductivity

Type: Hydrogeology Parameter: Hydraulic Conductivity Consolidated Zone: Saturated Quality: All

Tool	Cost Category	Subsurface Zone	Zone	Quality
		Unconsolidated	Consolidated	Unconsolidated
Geophysics				
Downhole Testing				
Nuclear Magnetic Resonance Logging				
Hydraulic Testing				
Single well tests				
Packer Testing				
FLUTE™ Profiling				
Borehole Dilution				
Flow Metering				
Pumping and Recovery Tests				
Slug Tests				
Constant Head Step Test				
Cross Borehole Testing				
Tracer testing				
Hydraulic Tomography				
Flow Metering				
Pumping and Recovery Tests				
Slug Tests				
Solid Media Sampling and Analysis Methods				
Solid Media Evaluation and Testing Methods				
Physical Properties				
Direct Push Logging (In-Situ)				
Hydraulic Profiling Tool (HPT)				
Electrical Conductivity (EC) Logging				
Cone Penetrometer Testing (CPT & CPTu)				
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)™				
Waterloo Advanced Profiling System (Waterloo APS)™				

21 tools returned. Can we refine?

No associated notes.

Example #3 – Hydraulic Conductivity (refined)



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

Tool	Data Quality	Subsurface			Zone	Chemistry						
		Beltsch	Unconsolidated	Saturated		Groundwater		Solid Media				
					Microbial Community	MFP, Presence	Concentration	Geochemistry	Fit	MFP, Presence	Concentration	Microbial Community
Geophysics												
Downhole Testing												
Nuclear Magnetic Resonance Logging												
Solid Media Sampling and Analysis Methods												
Solid Media Evaluation and Testing Methods												
Physical Properties												
Direct Push Logging (In-Situ)												
Hydraulic Profiling Tool (HPT)												
Electrical Conductivity (EC) Logging												
Discrete Groundwater Sampling & Profiling												
Screen Point (SP) 22 Groundwater Sampling Tool												
Screen Point (SP) 16 Groundwater Sampling Tool												
Hydraulic Profiling Tool - Groundwater Sampler (HPT-GWS)*												

Change data quality to QL 7 tools returned

No associated notes.

ITRC Tools Matrix Summary

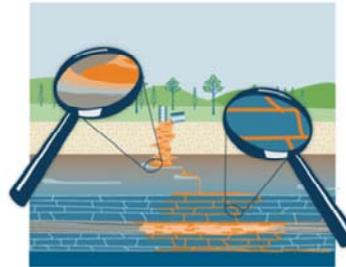


- ▶ Characterization objectives guide selection of tools
- ▶ Interactive tools matrix - over 100 tools with links to detailed descriptions
- ▶ A systematic tools selection process
- ▶ Select tools, implement work plan, evaluate results
- ▶ Align data gaps with characterization objectives, update CSM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

No associated notes.

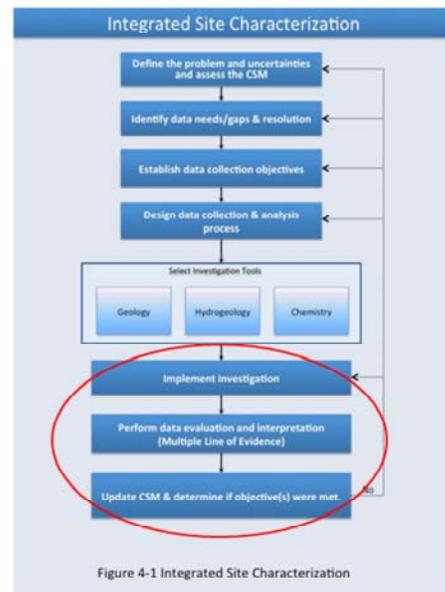
Training Overview

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



Conducting

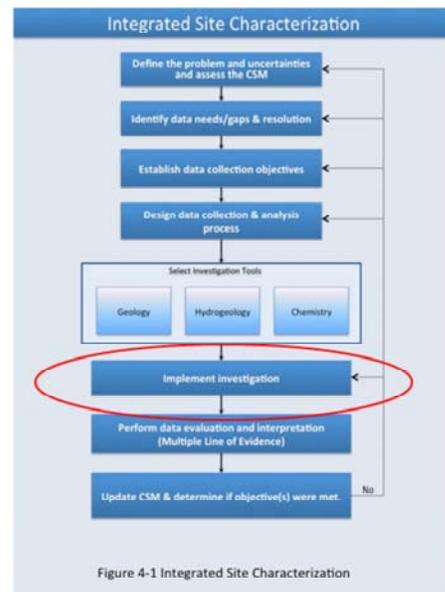
- ▶ Step 6: Implement investigation
- ▶ Step 7: Perform data evaluation and interpretation
- ▶ Step 8: Update CSM



No associated notes.

Step 6. Implement Investigation

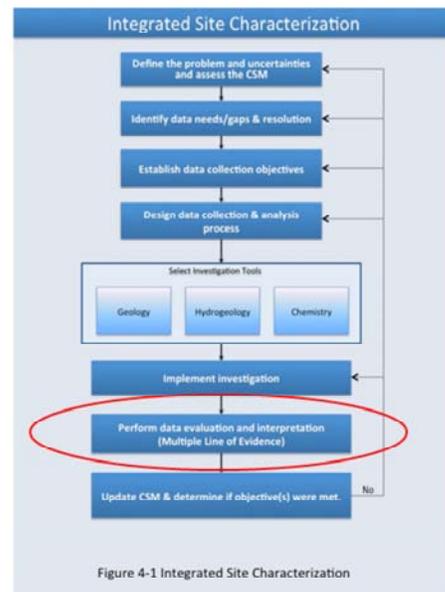
- ▶ Time to conduct the investigation
 - Go into field
 - Use flexible plan
 - Collect data
- ▶ Often concurrent with data evaluation (Step 7)



No associated notes.

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

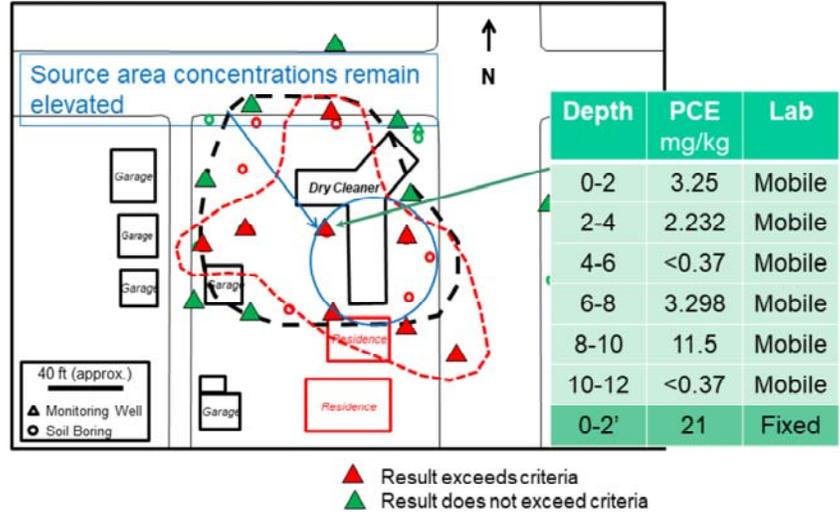


No associated notes.

Step 7. Soil and Groundwater Data Evaluation and Interpretation



Case Example

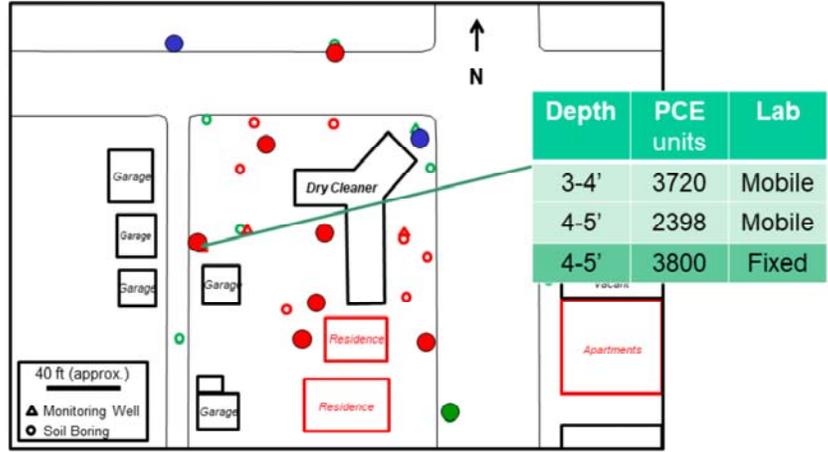


No associated notes.

Step 7. Soil Vapor Data Evaluation and Interpretation



Case Example



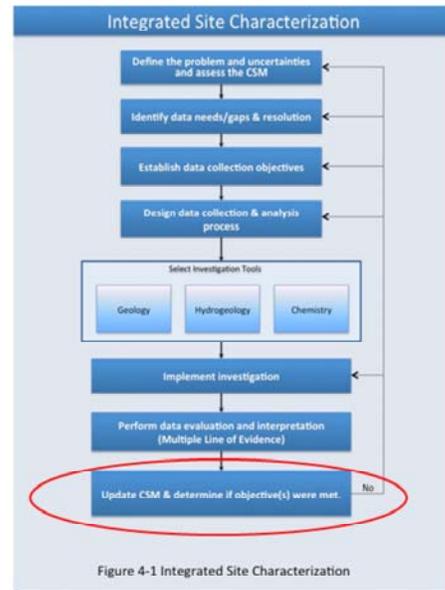
Shallow soil vapor results

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

No associated notes.

Poll Question

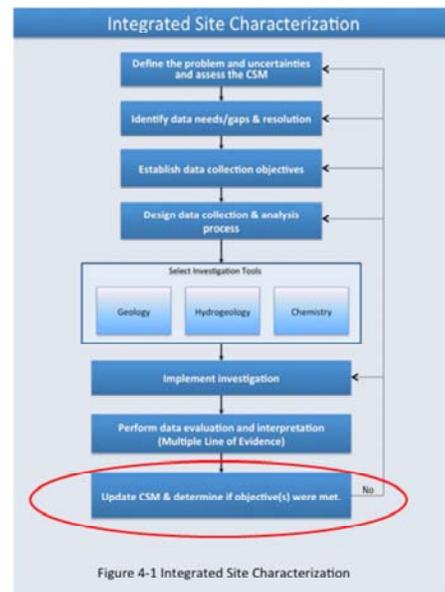
- When do you typically update your CSM at sites where you work?
- Whenever new data is collected
 - When a remedial technology fails
 - Whenever the CSM is determined to be inaccurate
 - Every five years
 - Never



No associated notes.

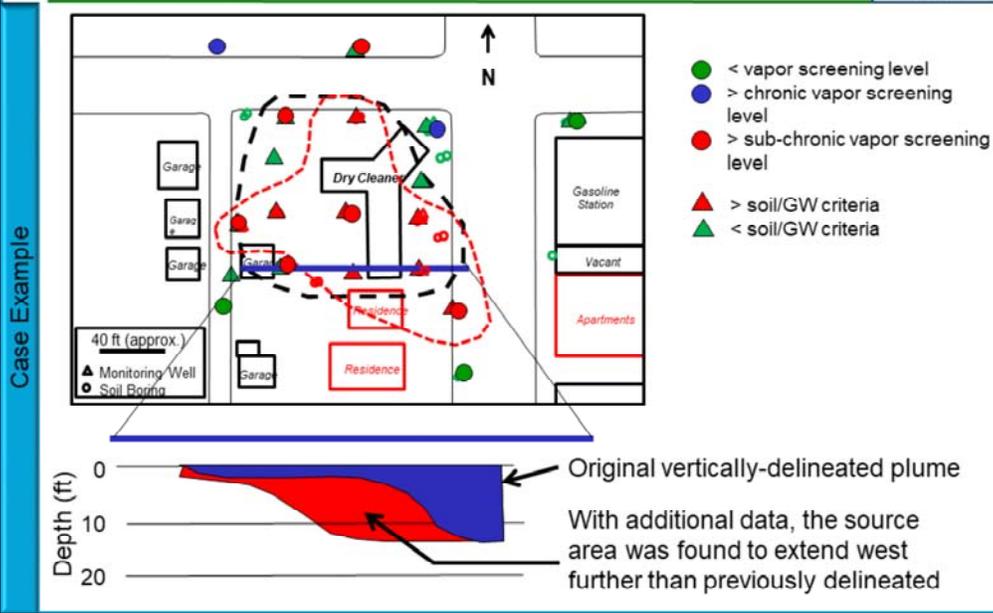
Step 8. Update the CSM

- ▶ 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



No associated notes.

Step 8: Dry Cleaners – CSM Update



No associated notes.

Integrated Site Characterization Benefits for Dry Cleaners Sites



Case Example

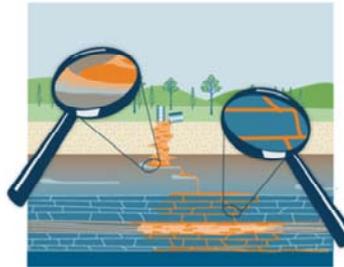
- ▶ Confirmed need for residential indoor air evaluation and VI mitigation for commercial buildings
- ▶ Optimized data density in specific areas; avoided unnecessary / inconclusive data collection
- ▶ Accurately determined source zone and remediation target area
- ▶ Completed ahead of schedule; saved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

No associated notes.

Training Overview

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

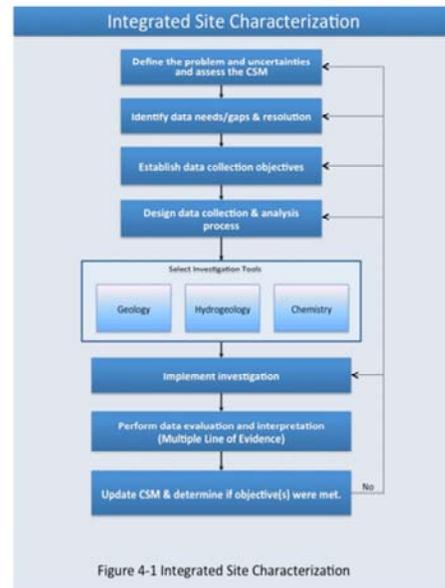
➔ Summary



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).

Summary Integrated Site Characterization

- ▶ Planning
- ▶ Tools selection
- ▶ Implementation



No associated notes.

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

Thank You

Follow ITRC



Poll Question

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

View Your
Participation
Certificate (PDF)



Need confirmation of your participation today?

Fill out the feedback form and check box for confirmation email and certificate.

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