1 **Starting Soon: LNAPL Training Part 3: Evaluating LNAPL Remedial Technologies for Achieving Project Goals**

- ITRC LNAPLs Team Technical and Regulatory Guidance document, Evaluating LNAPL Remedial Technologies for Achieving Project Goals (LNAPL-2, 2009) at http://www.itrcweb.org/GuidanceDocuments/LNAPL-2.pdf
- Download PowerPoint file
  - Clu-in training page at https://clu-in.org/conf/itrc/LNAPLcr/
  - Under "Download Training Materials"
- Using Adobe Connect
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  - Submit questions in the lower right

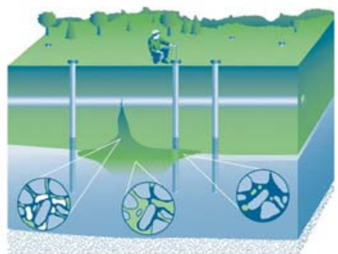
No associated notes.

2

Welcome – Thanks for joining us.
ITRC's Internet-based Training Program

LNAPL Training Part 3

ITRC Technical and Regulatory Guidance: Evaluating LNAPL Remedial Technologies for Achieving Project Goals



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

Light non-aqueous phase liquids (LNAPLs) are organic liquids such as gasoline, diesel, and other petroleum hydrocarbon products that are immiscible with water and less dense than water. Understanding LNAPLs is important because they are present in the subsurface at thousands of remediation sites across the country and are often the sole reason why a site remains open. The spectrum of sites where LNAPL assessment and remediation efforts may take place include petroleum manufacturing and handling facilities such as refineries, bulk product terminals, gas stations, airports and military bases. LNAPLs in the subsurface can be a complex problem to address, and frequently prevent or delay regulatory closure (no further action) of remediation projects.

Over the past few decades, LNAPL remedial technologies have evolved from conventional pumping or hydraulic recovery systems to a variety of innovative, aggressive, and experimental technologies that address the mobile and residual LNAPL fractions, as well as volatile and dissolved-phase plumes. Thus, many different LNAPL remedial technologies with differing site and LNAPL applicabilities and capabilities are available to remediate LNAPL releases. This can make selection of a remedial technology daunting and inefficient. To foster informed remedial technology selection and appropriate technology application, the LNAPLs Team developed the ITRC Technical and Regulatory Guidance document, Evaluating LNAPL Remedial Technologies for Achieving Project Goals (LNAPL-2, 2009). This document addresses seventeen LNAPL remedial technologies and provides a framework to streamline remedial technology evaluation and selection.

This training course is relevant for new and veteran regulators, environmental consultants, and technically-inclined site owners and public stakeholders. The training course is divided into three parts:
Part 1: An Improved Understanding of LNAPL Behavior in the Subsurface - State of Science vs.. State of Practice
Part 2: LNAPL Characterization and Recoverability - Improved Analysis
Part 3: Evaluating LNAPL Remedial Technologies for Achieving Project Goals

Part 3 uses the LNAPL conceptual site model (LCSM) approach to identify the LNAPL concerns or risks and set proper LNAPL remedial objectives and technology-specific remediation goals and performance metrics. The training course also provides an overview of the LNAPL remedial technology selection framework. The framework uses a series of tools to screen the seventeen remedial technologies based on site and LNAPL conditions and other important factors. LNAPL Training Part 1 and 2 are recommended pre-requisites for this Part 3 training course. Archives are available at http://cluin.org/live/archive.cfm?sort=title#itrc (note: courses are listed alphabetically, you will have to scroll down to find the course of interest).

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3

Housekeeping

- Course time is 2¼ hours
- This event is being recorded
- Trainers control slides
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- 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

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.

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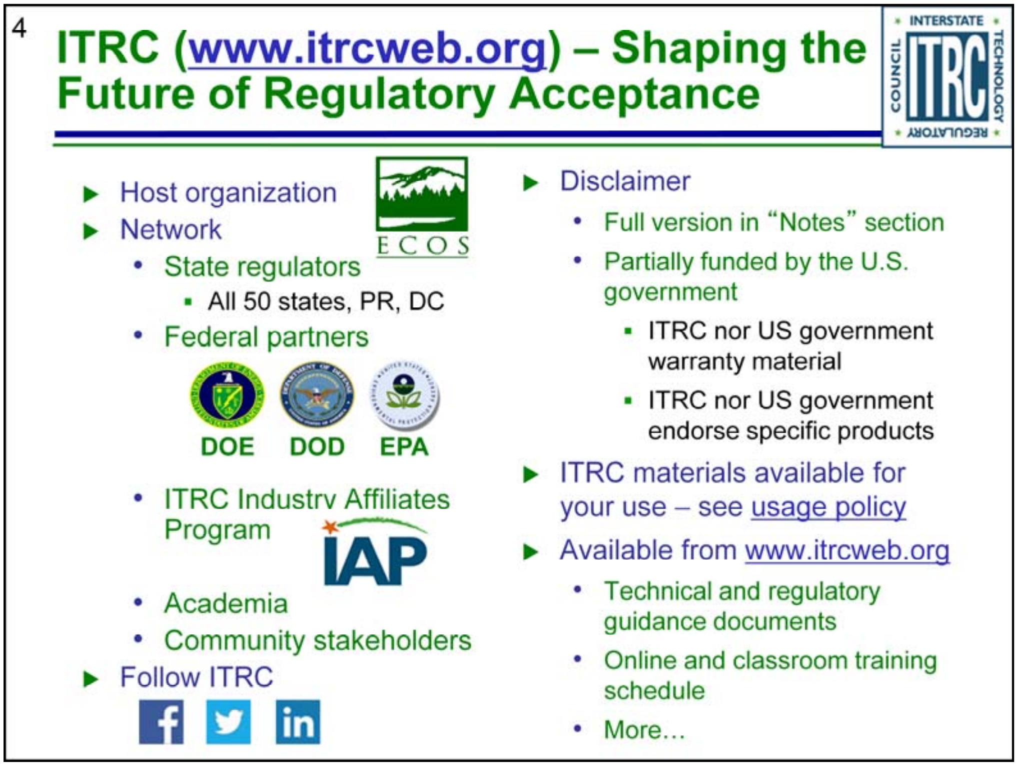

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For a state to be a member of ITRC their environmental agency must designate a State Point of Contact. To find out who your State POC is check out the "contacts" section at www.itrcweb.org. Also, click on "membership" to learn how you can become a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

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5

Meet the ITRC Trainers

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Erik Gessert is the Supervisor of the Petroleum Remediation Program for the Colorado Division of Oil and Public Safety and has worked for the State of Colorado since 2010. In this role Erik has focused on incorporating state of the science technologies into the program, including green and sustainable practices, advanced characterization techniques and conceptual site model developments. Additionally, with Erik's involvement, the Petroleum Program has placed emphasis on the value of clear and concise communication to all parties involved in release remediation. Prior to joining the State, Erik worked as an environmental consultant specializing in petroleum remediation and was responsible for managing projects and budgets, performing technical evaluations and implementing corrective action plans. He earned a bachelor's degree in Environmental Engineering (with a minor in Environmental Studies) from the University of Wisconsin-Madison in 2001. Erik obtained his Professional Engineering license from the State of Colorado in 2007.

Ian Hers is a Senior Associate Engineer with Golder Associates located in Vancouver, British Columbia and has worked for Golder since 1988. He has 20 years professional experience in environmental site assessment, human health risk assessment and remediation of contaminated lands. Ian is a technical specialist in the area of LNAPL and DNAPL source characterization, monitored natural attenuation and source zone depletion, vapour intrusion, and vapour-phase *in situ* remediation technologies, and directs or advices on projects for Golder at petroleum-impacted sites throughout North America. He has developed guidance on LNAPL assessment and mobility for the BC Science Advisory Board for Contaminated Sites (SABCS) and the BC Ministry of Environment. Ian joined the ITRC LNAPL team in March 2008. Ian earned a bachelor's degree in 1986 and master's degree in 1988 in Civil Engineering from the University of British Columbia in Vancouver, BC. He then completed a doctoral degree in Civil Engineering from University of British Columbia in 2004. He is on the Board of Directors of the SABCS, is a Contaminated Sites Approved Professional in BC, and is a sessional lecturer at the University of British Columbia.

Rick Ahlers is a Technical Expert with Arcadis, located in San Diego, California. He has been practicing groundwater and vadose-zone hydrology for more than 21 years. At Arcadis since 2002, he has worked for many Oil and Gas clients on sites ranging from service stations to pipelines to bulk terminals to refineries as well as for Industrial clients where LNAPL and chlorinated DNAPL source zones are the concern. Using emerging assessment techniques for petroleum hydrocarbon sites including natural source zone depletion (NSZD), natural attenuation of hydrocarbon and oxygenate groundwater plumes, and NAPL transmissivity allows him to evaluate alternative endpoints for NAPL management. He also uses experience gained across many sites with more common remediation technologies such as AS/SVE, MPE, and skimming, to select the best technology for the site and project and guide implementation to efficiently achieve remedial goals. Rick leads the global NAPL management community of practice in Arcadis' Technical Knowledge and Innovation network. Rick started his career at Lawrence Berkeley National Laboratory characterizing and modeling multi-phase flow in porous and fractured media. Rick has been active in the ITRC since 2006 first as a member of the BioDNAPL team and then as a member of the LNAPL team. He is also a member of the scientific advisory board for the AEHS West Coast International Conference on Soil, Water, Energy, and Air. Rick earned a bachelor's degree in physics from Occidental College in Los Angeles, California in 1990 and a master's degree in Civil Engineering specializing in groundwater hydrology from the University of California, Berkeley in 1994. Rick is a California Registered Civil Engineer.

6

Overview of Today's Training

- LNAPL remedial objectives
- LNAPL remedial technologies
- LNAPL remedial technology selection
- ITRC LNAPL Technical and Regulatory guidance

•Today's training is the third and final part of ITRC's LNAPL internet-based training.

•In today's training, we will present:

- information on setting LNAPL remedial objectives,
- an overview of several LNAPL remedial technologies,
- information on how to select the most appropriate LNAPL remedial technology for your project, and
- an overview on how to use of the ITRC Technical and Regulatory Guidance document titled: Evaluating LNAPL Remedial Technologies for Achieving Project Goals" dated December 2009.
- Referred to as the "Tech/Reg."

7

ITRC LNAPL Technical/Regulatory Guidance, December 2009

Evaluating LNAPL Remedial Technologies for Achieving Project Goals

- Framework for implementing LNAPL remediation
- Framework for LNAPL remedial technology selection

- Applicable to any LNAPL site regardless of size or current/future use
- Hands on tools – guides to conclusions or critical questions or data needs

- The Tech/Reg:
  - Provides a framework for selecting an appropriate LNAPL remedial technology.
  - Provides guidance for setting LNAPL remedial objectives, remediation goals, and performance metrics for any size LNAPL site.
  - Is a hands-on tool to guide you through the LNAPL remedial selection process and will help you determine additional data needs that should be addressed in order to achieve your project goals.

8

Goals & Issues for the Team

- Re-evaluate State regulatory LNAPL paradigms
- Objective-driven (begin with end in mind) remedial technology selection strategy, but objectives may or may not be risk-based
- Need good LNAPL Conceptual Site Model (LCSM)!
- Addressing "maximum extent practicable" important team goal – metric to determine when met
- Conveying science understanding, but maintaining tool-focused purpose

•During the development of the Tech/Reg, the ITRC LNAPL team examined existing State regulatory LNAPL paradigms.

•The team wanted the Tech/Reg to present an objective-driven remedial technology selection strategy.

•As discussed in previous training sessions, you need a good LNAPL Conceptual Site Model (LCSM) in order to evaluate risks and target your remediation technology to address those risks.

•You also need to keep in mind your site's regulatory framework, and for LUST sites, that means federal regulation 40CFR Part 280.64: "removal of free product to the maximum extent practicable as determined by the local implementing agency."

•Finally, how do you mesh the current LNAPL science with your site's regulatory framework?

9

ITRC LNAPL Team

- ITRC LNAPL Team was formed in July 2007
- Collaborative effort involving:
  - 11 state regulators from Arkansas, Delaware, Georgia, Kansas, Missouri, Montana, Pennsylvania, South Carolina, Texas, Utah and Wyoming
  - 2 stakeholders and academic representatives
  - 5 federal stakeholders from the U.S. Army Corps of Engineers, U.S. Naval Facilities Engineering Command, and the U.S. Environmental Protection Agency
  - 25 professionals from the petroleum industry and environmental consulting

- The ITRC process is unique because it puts regulators, consultants, and industry representatives together in the same room to hash out topics and come to a consensus in the final Tech/Reg document.

10

Why Focus on LNAPL?

- LNAPL is an issue at thousands of sites
- Perceived as a significant environmental threat
- Technical and regulatory complexities
- 2008 ITRC LNAPLs Team State Survey – States requested training!
- Better understanding facilitates better decision making
- LNAPL policies and regulations frequently are not science-based, feasible, beneficial, or practical
- Foster coupling of remedial objectives and goals with remedial technology selection
- Promote holistic consideration of LNAPL in the context of overall site corrective action objectives – address the "LNAPL disconnect in RBCA states"

•What do we mean by the "LNAPL disconnect in RBCA states?"

•It is the idea that any LNAPL poses a "risk," and that all LNAPL should be removed to specific "in-well product thicknesses," regardless of actual risk or practicality.

•For example, many States require removal of free product to 1/8 inch thicknesses in monitor wells.

•Is there any difference in actual risk between 1/8 inch and 6 inches?

•It depends on site-specific conditions.

11

ITRC LNAPL Team Approach

- Provide LNAPL "Basics" online training
  - Part 1: An Improved Understanding of LNAPL Behavior in the Subsurface
  - Part 2: LNAPL Characterization and Recoverability
  - Prerequisites for LNAPLs Part 3
- ITRC Technology Overview: *Evaluating Natural Source Zone Depletion at Sites with LNAPL* (LNAPL-1, 2009)
- ITRC Technical/Regulatory Guidance: *Evaluating LNAPL Remedial Technologies for Achieving Project Goals* (LNAPL-2, 2009)
- Provide LNAPL Part 3 online training to foster understanding and use of the Technical Regulatory Guidance
- Provide LNAPL Classroom Training
- ***Current ITRC team***: LNAPL Update (started in 2016)

- We have given 12 classes:
  - September 2011 in Minneapolis, Minnesota
  - April 2012 in Boston, Massachusetts
  - October 2012 in Novi, Michigan
  - April 2013 in King of Prussia, Pennsylvania
  - June 2013 in Springfield, Illinois
  - October 2013 in Garden Grove, California
  - April 1-2, 2014 in Kansas City, Missouri
  - June 3-4, 2014 in Lexington, Kentucky
  - October 29-30, 2014 in Richmond, Virginia
  - April 7-8, 2015 in Denver, Colorado
  - September 15-16, 2015 in Seattle, Washington
  - November 18-19, 2015 in Austin, Texas

- We will be giving 1 or 2 classes in 2016
  - April 5-6, 2016 in Atlanta (area), GA
  - Potentially an additional location in 2016

Regulatory Context

- Maximum Extent Practicable (MEP) – various definitions by the various States
- Decision-making frameworks
- Unclear and inconsistent methods for setting objectives
- Unclear and inconsistent terminology
- Science-based regulatory initiatives
- Non-degradation drivers

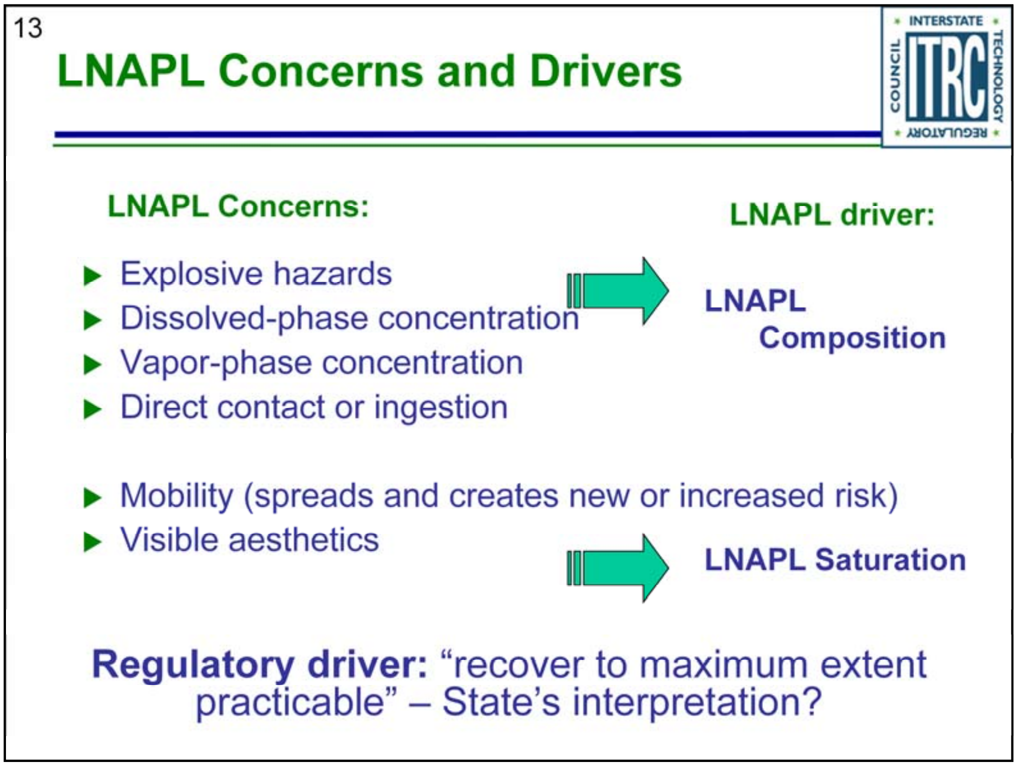
•As mentioned earlier, there is a disconnect regarding the state-of-the-science and state-of-the-practice with regards to LNAPL.

•LNAPL remediation projects often fail to achieve State cleanup standards and get an NFA letter.

•For example, removal of free product to 1/8-inch thicknesses in monitor wells may not be possible due to soil type, incomplete LNAPL characterization, and poorly targeted remedial strategies.

•However, even if you do everything perfectly, LNAPL is difficult and expensive to remediate when it gets into subsurface soils.

•It is the ITRC LNAPL Team's philosophy that actual LNAPL concerns must be addressed, LNAPL should be removed to the extent PRACTICAL (scientifically and technically feasible), long-term stewardship should be considered (Environmental Covenants, deed restrictions, institutional controls), and then LNAPL sites should be considered for no further action at this time.



•On the left side of this slide, some LNAPL concerns are listed.

•The right side of the slide shows whether a concern is based on LNAPL composition or saturation.

•Most State regulatory programs adequately address composition concerns (toxicity or risk) with science-based regulations, i.e., soil and groundwater cleanup standards (MCLs).

•However, many State regulatory programs do not clearly address LNAPL saturation concerns with a clear regulatory framework that incorporates the current LNAPL science.

•For example, removal of free product to 1/8-inch thicknesses in monitor wells may not be possible and may not be necessary if the LNAPL is not migrating and poses no current risk.

•Another LNAPL regulatory driver for LUST sites is 40CFR 280.64 – "recover free product to the maximum extent practicable as determined by the implementing agency."

•Because the definition of LNAPL recovery to the maximum extent practicable is determined by the implementing agency, there are many different interpretations of this federal regulation.

•One of the goals of this training is to determine what "maximum extent practicable" is based on site-specific factors and the current science.

14

LNAPL Remedial Technology Selection (Yesterday)

Where are we?

Why are we here?

Will it work?

It might work, maybe not….???

Are we there yet?

•With the various interpretations of "removal to the maximum extent practicable," there is no clear guidance on how to adequately manage LNAPL sites.

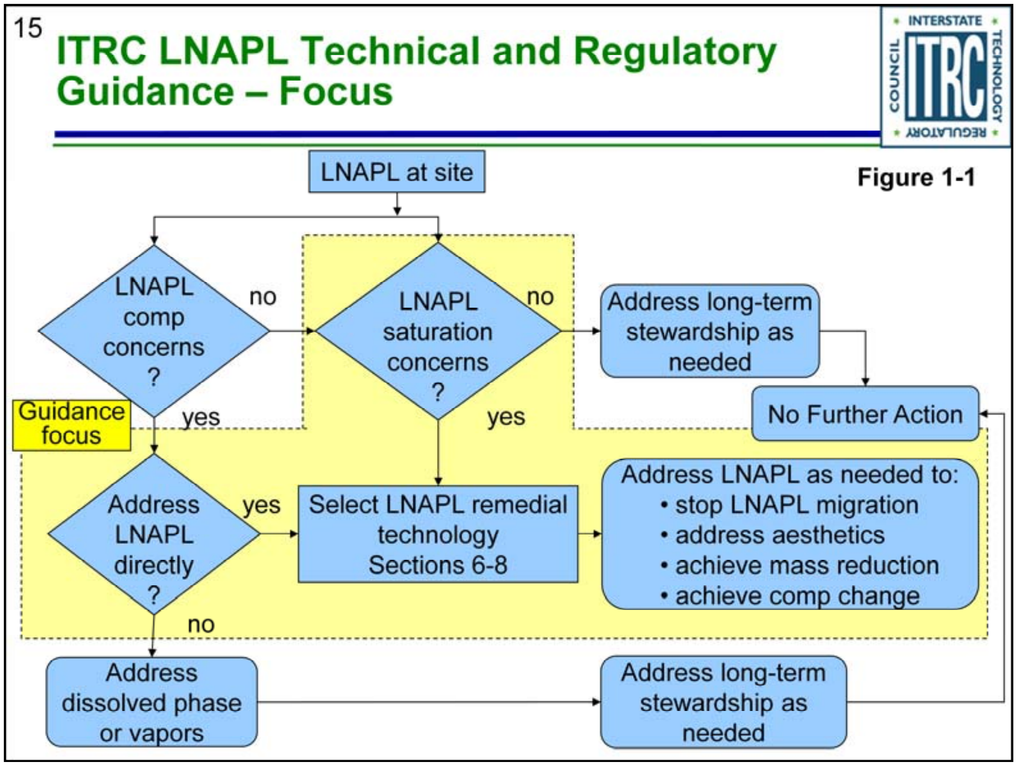
•Because there is no clear path, one is often left with some questions:

- What will work?
- How many things do we try?
- How long do we do it?
- When are we done?

•If we don't have a clear understanding of regulations in the context of subsurface LNAPL behavior and the current science, how can we select an appropriate remedial technology?

•One is often left with trying several technologies and still having 1/8-inch of LNAPL in monitor wells.

•A lot of money is spent and the site is no closer to NFA than when you started.



- This flow chart is from page 2 of the Tech/Reg.
- First identify your site-specific LNAPL composition and saturation concerns.
- If there are none, address long-term stewardship and go to NFA.
- If there are concerns, apply appropriate LNAPL remedial technologies to abate those concerns:
    - Stop LNAPL migration
    - Reduce LNAPL mass to reduce the time for natural biodegradation to finish remediating the site.
    - Change the LNAPL composition to reduce risk from contaminated groundwater plumes and/or vapor intrusion.

16

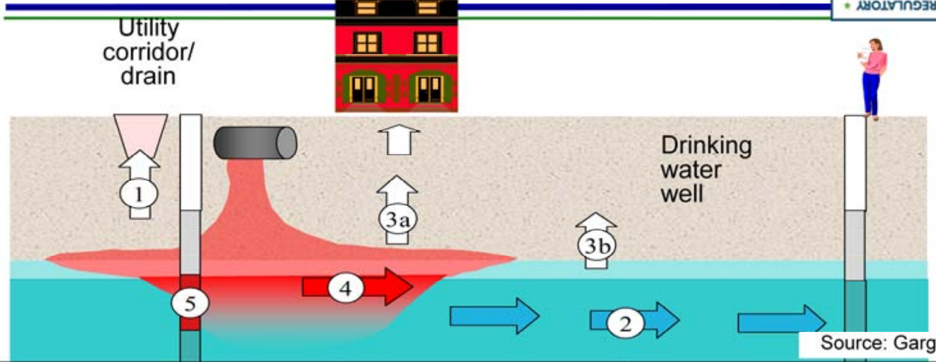
ITRC LNAPL Technical and Regulatory Guidance – Issues Addressed

- Promotes principles that facilitate timely and successful LNAPL remediation
  - Characterize the LNAPL site by preparing an LNAPL Conceptual Site Model
  - Establish achievable remedial objectives
  - Establish metrics for each remedial objective
  - Develop a remedial strategy to achieve the objectives
  - Hopefully, achieve an acceptable outcome
- Provides a framework to set LNAPL remedial objectives and match to goals/metrics for potentially applicable technologies
- Promotes technology understanding and applicability and aids in the selection of an appropriate remedial technology

17

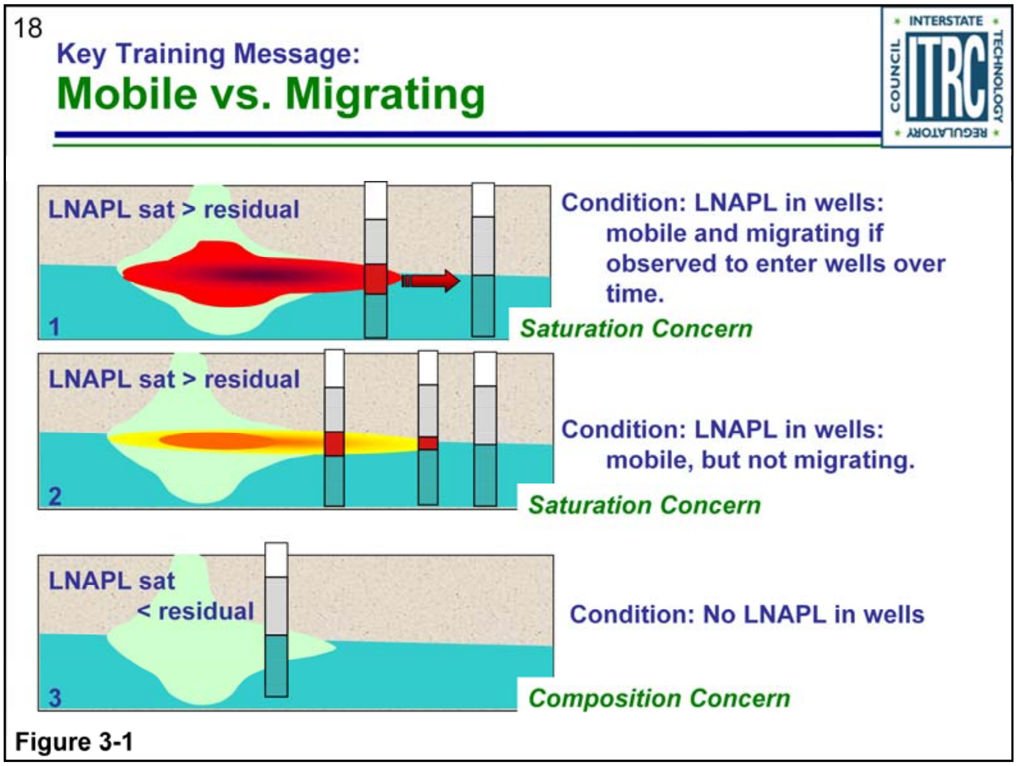
Key Training Message:

Understand the LNAPL Concerns



LNAPL emergency issues when LNAPL in the ground	LNAPL considerations when LNAPL in the ground (evaluated using standard regulations)	Additional LNAPL considerations when LNAPL in wells (not evaluated using standard regulations)
(1) Vapor accumulation in confined spaces causing explosive conditions ***Not shown*** - Direct LNAPL migration to surface water ***Not shown*** - Direct LNAPL migration to underground spaces	(2) Groundwater (dissolved phase) (3a) LNAPL to vapor (3b) Groundwater to vapor ***Not shown -*** Direct skin contact	(4) LNAPL potential mobility (offsite migration, e.g. to surface water, under houses) (5) LNAPL in well (aesthetic, reputation, regulatory)
LNAPL **Composition**		LNAPL **Saturation**

- This cross-section illustrates several LNAPL concerns and divides them into composition concerns and saturation concerns, as shown in orange at the bottom of the slide.
- LNAPL composition concerns are associated with toxicity and risk, such as risks posed by vapor intrusion (1, 3a, and 3b) and risks posed by dissolved contaminants in groundwater (2).
- Composition concerns can be mitigated by changing the LNAPL composition, i.e., by removing the more toxic, volatile, and soluble compounds (such as benzene) from the LNAPL body.
- LNAPL saturation concerns are associated with movement or migration of the LNAPL body (4 and 5).
- Saturation concerns can be mitigated by removing LNAPL itself, reducing the LNAPL head and saturation, and stopping the migration of the LNAPL body.
- The Tech/Reg will guide you from the LNAPL concerns to establishing remedial objectives for each concern.
- Each remedial objective may then have several technologies that are applicable.



•This figure is from page 10 of the Tech/Reg.

•Cross-section 1 shows a situation in which LNAPL is still migrating – the LNAPL release is ongoing. The LNAPL body is migrating due to the high LNAPL saturation and LNAPL head. LNAPL will continue to migrate laterally until the release is stopped and the LNAPL head dissipates.

•Cross-section 2 shows a situation where the LNAPL release has been stopped and the LNAPL head has dissipated. LNAPL still accumulates in monitor wells installed in the LNAPL body, but he LNAPL is no longer migrating (spreading) laterally.

•Cross-section 3 shows a situation where LNAPL is below residual saturation. LNAPL will not accumulate in a well installed in the LNAPL body (unless the water table drops and LNAPL trapped below the water table in the smear zone moves into the well).

•The first two cross-sections are focused on the migration and mobility of LNAPL, both of which are saturation concerns. To address these concerns, the LNAPL remedial technology must reduce the LNAPL saturation.

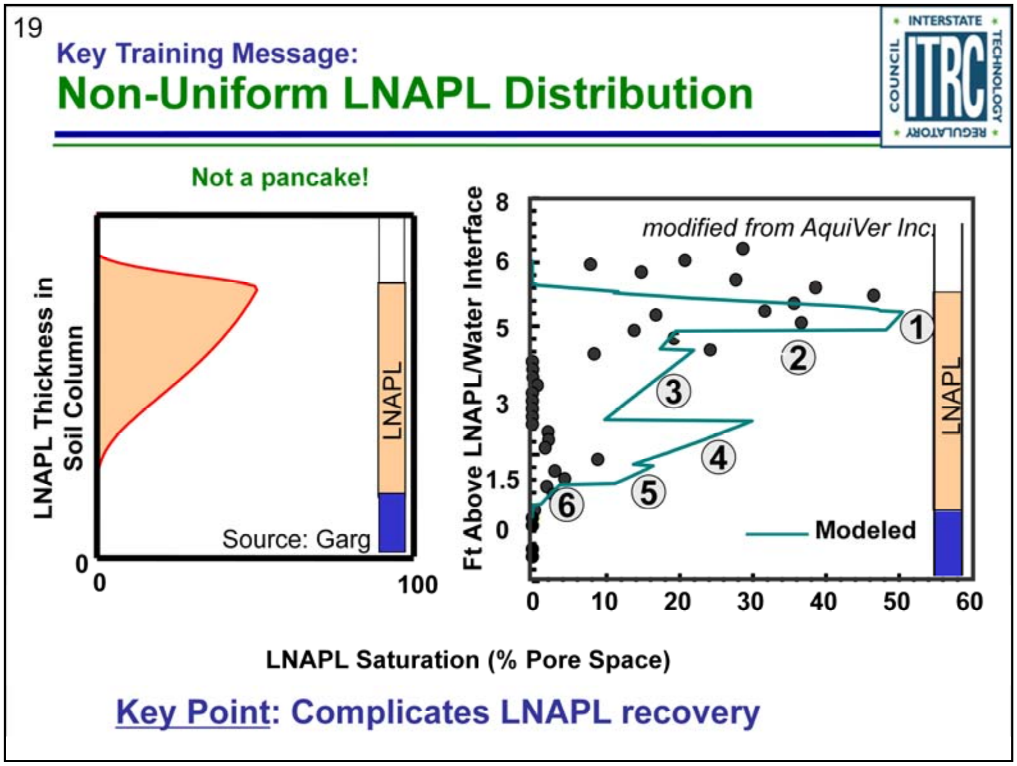
•In contrast, the third cross-section shows LNAPL at less than residual saturation. The concern here is that the residual LNAPL in soil can be a source of a dissolved contaminant plume in groundwater or pose a vapor intrusion issue. IN this case, the remedial technology should address the LNAPL composition, i.e., remove the soluble and volatile components from the residual LNAPL.

•We usually react to the presence of LNAPL in wells, but the LNAPL may not be migrating.

•Therefore, the composition concerns may be the more compelling issues, and those are typically addressed in the context of soil and groundwater cleanup levels.

•If you are concerned about LNAPL migration, you must reduce the LNAPL saturation and LNAPL head, therefore, reducing LNAPL saturation is the remedial objective.

•If you are concerned about risks posed by the LNAPL at residual saturation, you should target its composition as the remedial objective.



•This slide is from work done by G.D. Beckett (AquiVer) and Dr. David Huntley (San Diego State University).

•In the slide on the right, the black dots represent actual soil cores that were collected from a borehole and analyzed for % LNAPL saturation.

•LNAPL saturation (% of soil pore space filled with LNAPL) is on the "X" axis and thickness of LNAPL in the monitor well is on the "Y" axis.

•On the right side of both slides is a monitor well with LNAPL in it.

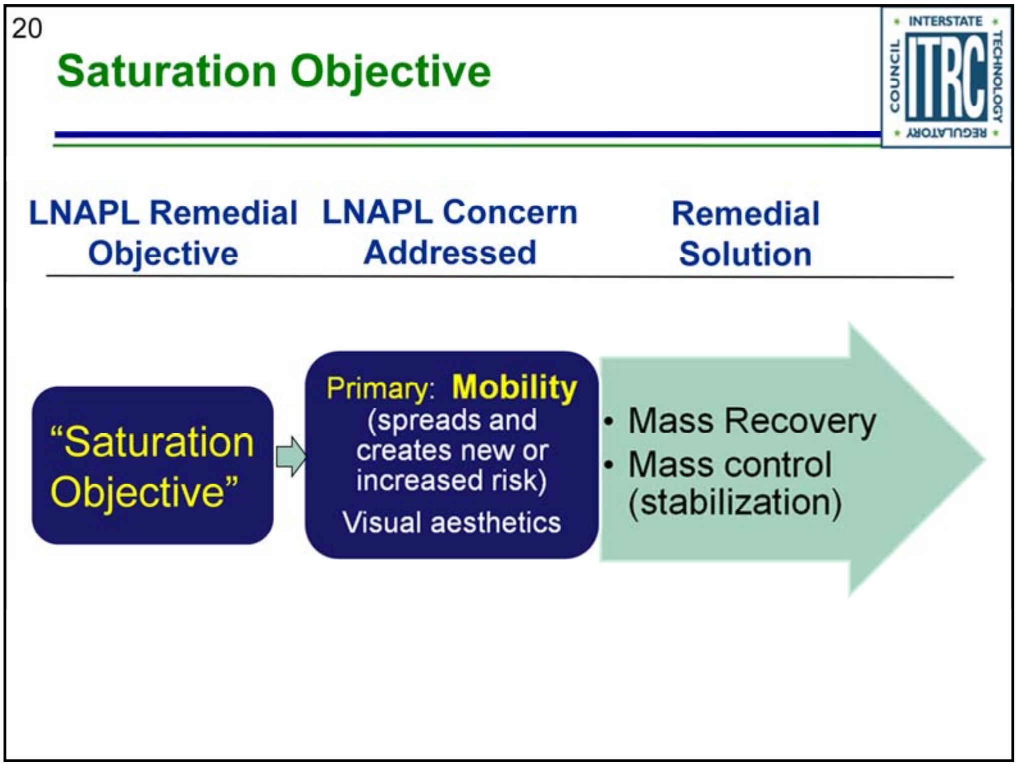
•On the left is the LNAPL distribution in soil – the "Shark Fin."

•These slides show that LNAPL is not uniformly distributed in the soil.

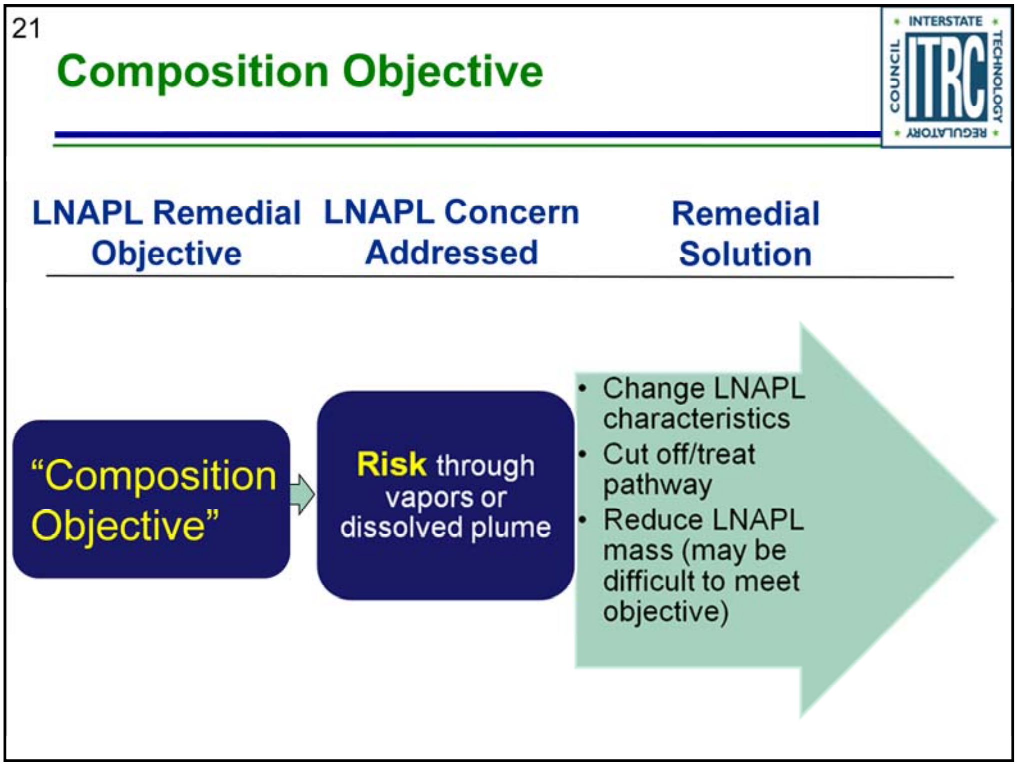
•The LNAPL saturation varies within the soil column from 5% to 50%.

•This fact makes estimations of the volume of LNAPL in the subsurface very difficult.

•Moreover, it is difficult to predict how much LNAPL is hydraulically recoverable, based on the thickness of LNAPL in monitor wells.



- If your LNAPL concern is LNAPL migration, your remedial objective is a Saturation Objective.
- You can stop LNAPL migration by recovering enough LNAPL to reduce LNAPL saturation and LNAPL head.

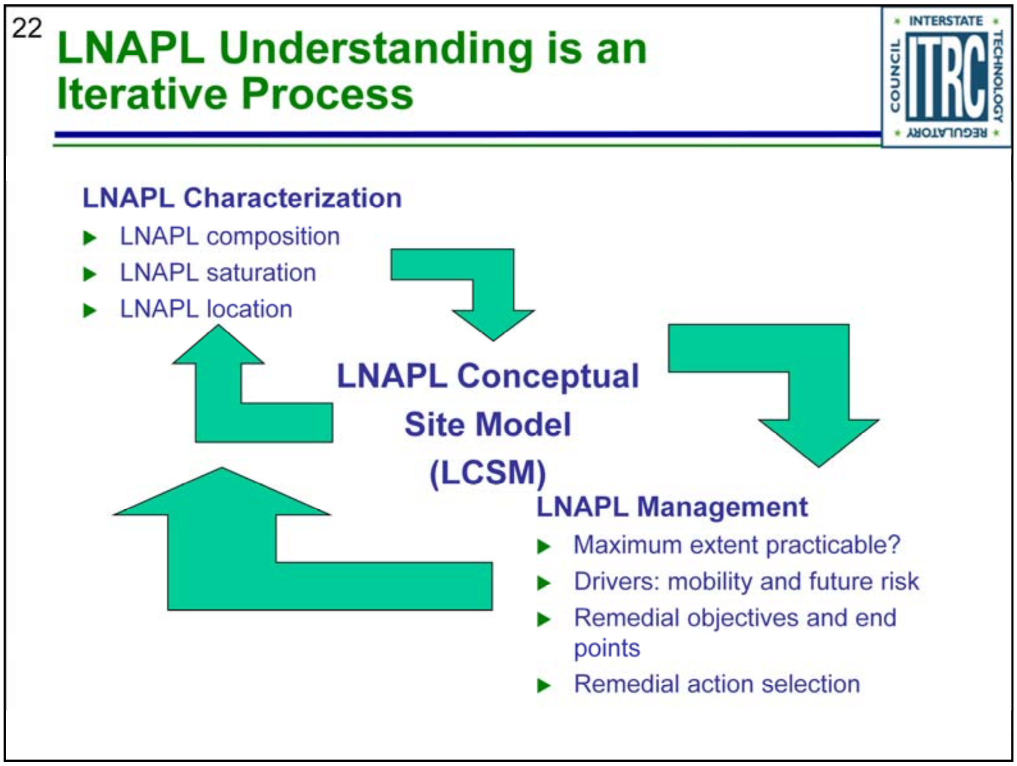


•If you have risks from vapor intrusion or a dissolved phase plume in groundwater emanating from the LNAPL body, you have a composition objective.

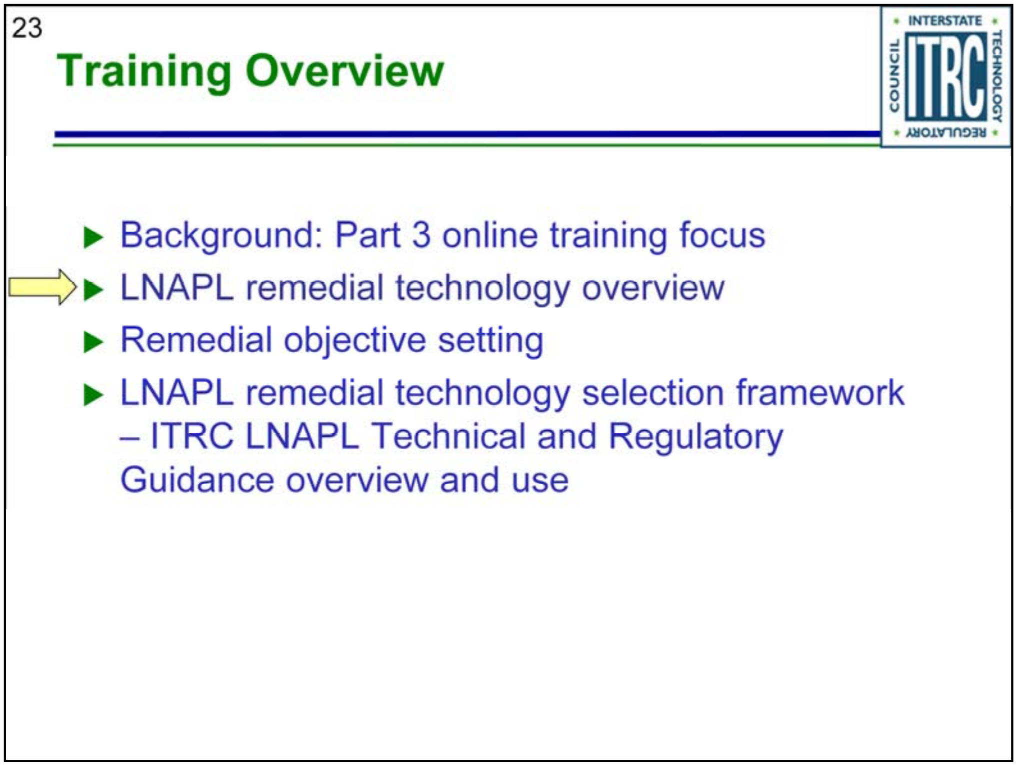
•You should select a remedial technology that removes the toxic, volatile, and soluble components of the LNAPL.

•This involves a Phase Change technology, such as Multi-Phase Extraction or air sparging/vapor extraction.

•Just pumping LNAPL out of the ground will not change the composition and will not address your "composition concerns."



- LNAPL characterization and management is an iterative process that revolves around the LCSM.
- A complete LCSM will help you determine your LNAPL remediation objectives and goals.
- Our next speaker, Eric Nichols with Arcadis, will give us an overview of LNAPL remedial technologies.



•To recap, we have looked over some of the key terms from the earlier Internet-based trainings as well as touched on some of the concepts in the Tech/Reg Guidance document.

•Next we are going to provide an overview of LNAPL remedial technologies.

•Eric Nichols / Ian Hers of Golder Associates will present the next section of this training.

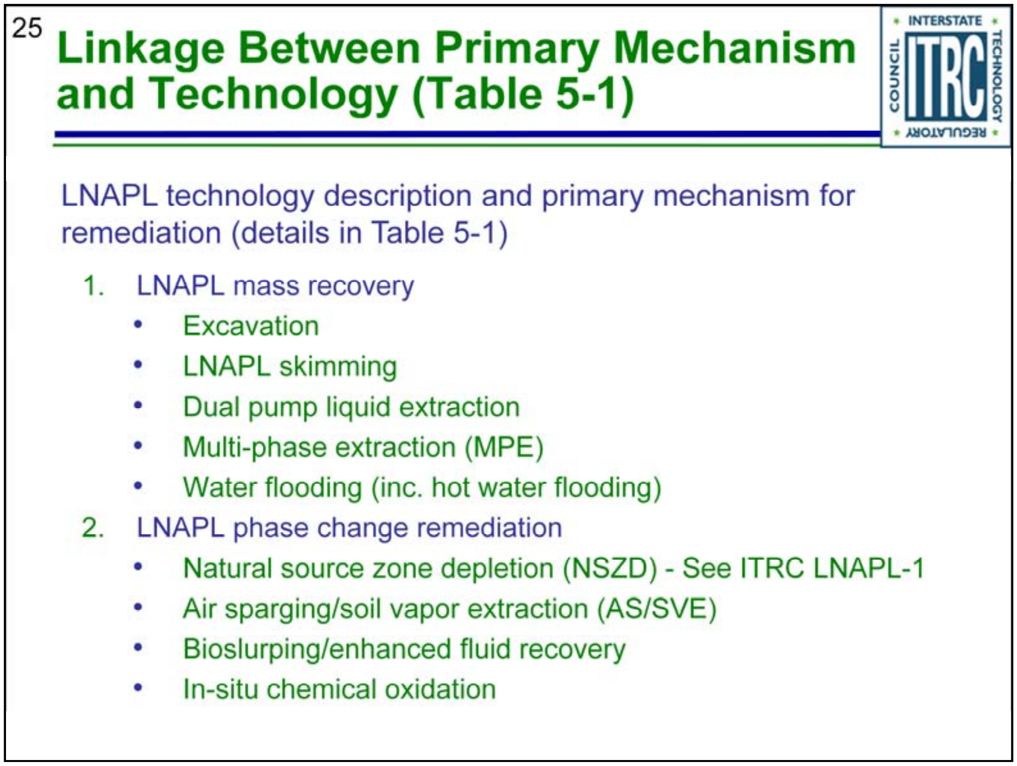
Technology Introduction

17 LNAPL remedial technologies addressed:

- Excavation
- Physical containment
- In-situ soil mixing
- Natural source zone depletion (NSZD)
- Air sparging/soil vapor extraction (AS/SVE)
- LNAPL skimming
- Bioslurping/EFR
- Dual pump liquid extraction
- Multi-phase extraction, dual pump
- Multi-phase extraction, single pump
- Water/hot water flooding
- In situ chemical oxidation
- Surfactant- enhanced subsurface remediation
- Cosolvent flushing
- Steam/hot-air injection
- Radio frequency heating
- Three and six-phase electrical resistance heating

Key Point: Who ya gonna call?

This section of the training is an overview of the 17 LNAPL remedial technologies addressed in the Technical and Regulatory Guidance focusing on the concepts addressed in Section 5 of our Guidance. We'll review the primary mechanisms or basic ways in which these technologies work followed by a framework for evaluating key technology characteristics. Several case examples that introduce different remedial technologies are presented, and key concepts addressed in Parts 1 and 2 of the internet training are reviewed.



Section 5 of the Guidance begins with a brief technology description and primary mechanism for remediation, or in simple terms, how each of the 17 technologies work. There are four primary mechanism categories, two presented on this slide, and two on the next.

The first category is LNAPL mass recovery, which can range from simple technologies such as removal through excavation to more complex technologies such as multi-phase extraction or water flooding.

The second category is LNAPL phase change where through either natural or enhanced means, there is change in phase, for example, chemicals in LNAPL may partition into overlying soil gas.

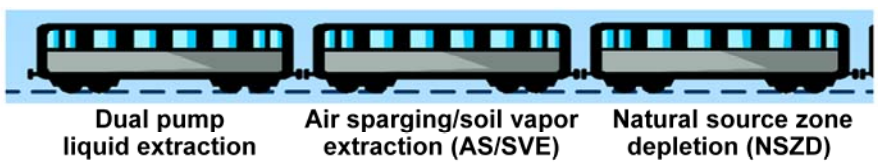
The LNAPL team published a guidance document on natural source zone depletion that is available on the ITRC web page.

26

Linkage Between Primary Mechanism and Technology (continued)

3. LNAPL mass control
   - Physical containment (barrier wall, drain)
   - Stabilization (in situ soil mixing)
4. LNAPL phase change remediation and mass recovery
   - Surfactant-enhanced subsurface remediation
   - Co-solvent flushing
   - Steam/hot-air injection
   - Radio frequency, 3- & 6-phase electrical resistance heating

▶ Consider multiple treatment technologies (“trains”)



The third primary mechanism is LNAPL mass or mobility control. This remediation approach involves controlling the movement of LNAPL either through physical containment such as barrier wall or actually stabilizing the source LNAPL mass, through for example injecting bentonite or cement-like chemicals.

The fourth category is really a combination of phase change remediation and mass recovery, and involves more innovative and aggressive technologies, where injected agents such as surfactants or heat are used to enhance phase change, and also to enhance mass recovery.

When selecting technologies consider multiple treatment technologies or treatment trains. For example, you may begin with dual pump liquid extraction to remove free-phase LNAPL. Air sparging and soil vapor extraction may then be used to further remove LNAPL mass and potentially address vapor risks. The final treatment technology may be natural source zone depletion.

27

Linkage Between Remediation Objectives and Primary Mechanism

- "Saturation objective" – mass recovery
  - ***Reduce*** LNAPL saturation by recovering LNAPL mass
- "Composition objective" – primarily phase change remediation
  - ***Change*** LNAPL characteristics by phase change
- "Containment objective" – LNAPL mass control

The linkages between different remediation objectives and primary remediation mechanism is summarized.

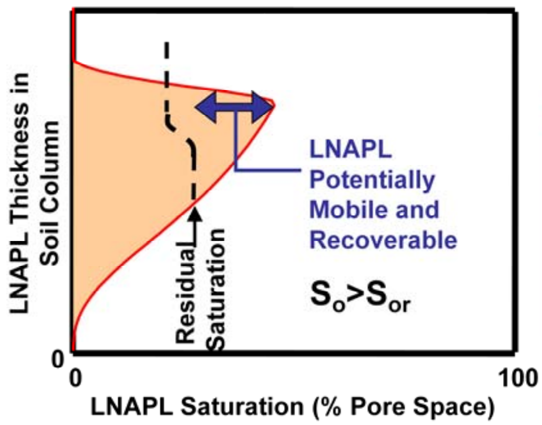
The saturation objective would be achieved by recovering LNAPL mass, example being hydraulic recovery methods.

A composition or concentration objective would be achieved primarily through phase change remediation, an example being soil vapor extraction.

The containment objective is achieved through LNAPL mass control technologies, an example being stabilization.

28

Review – Potentially Mobile Fraction of the LNAPL Distribution (Training Part 1)



Key Point: Saturation objective and reduction of mobility is only relevant when LNAPL saturation exceeds residual saturation

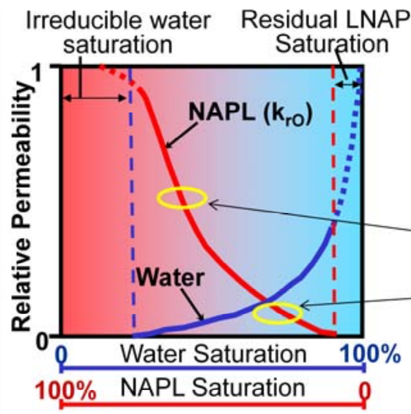
A key point in Part 1 of the training relates to the conceptual model for LNAPL mobility. This is important since at many sites remediation technologies are targeted to address the saturation objective where mobility is the key concern.

LNAPL is only potentially mobile and recoverable when the saturation exceeds the residual saturation shown in the figure as the portion of the vertical LNAPL profile, or so-called shark fin, exceeds residual saturation.

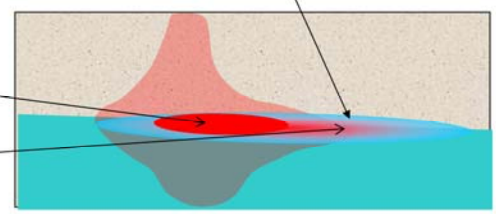
To summarize, the saturation objective and reduction of mobility is only relevant when the LNAPL saturation exceeds the residual saturation.

29

Review – Two LNAPL Mobility Concepts (Training Part 1)



- Near body edge LNAPL saturation & thickness in a well is > 0, but stable if LNAPL Pressure < Pore Entry Pressure



- Saturations/relative permeability decreases away from LNAPL body core

Key Point: LNAPL in the body core may be potentially mobile ($S_o > S_{or}$), but LNAPL body often stable – this should be considered when making remedial decisions

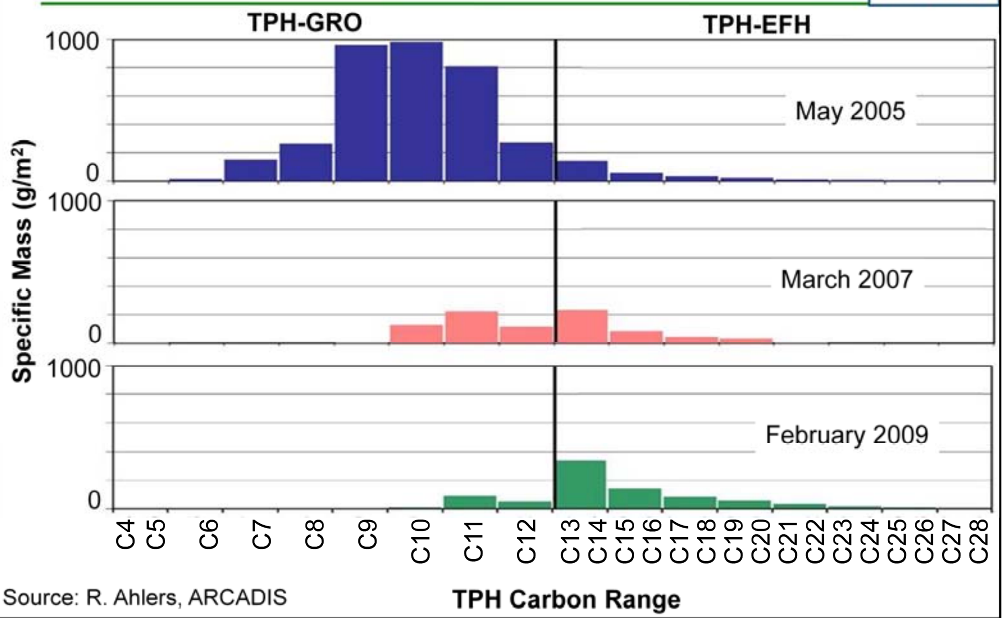
Another important concept is that although the LNAPL saturation in the core of the plume may exceed the residual saturation, the overall footprint of the LNAPL body may be stable.

To summarize, the left figure conceptually illustrates how the relative permeability increases as a function of increasing LNAPL saturation. The right figure shows that LNAPL is potential mobile within the core of plume where saturations are high but near the periphery of the LNAPL body, the LNAPL saturations are lower and the capillary pressure is less than the pore entry pressure.

As a result, the overall footprint of the LNAPL body may be stable.

The key point is that although LNAPL in the core of the plume is potentially mobile, the LNAPL body will often be stable, especially in older source zones. The LNAPL body stability may be an important consideration when evaluating the need for LNAPL remediation measures and selecting a remedy.

30 **Result of Soil Vapor Extraction (SVE) Remediation – Composition Objective Illustrated**

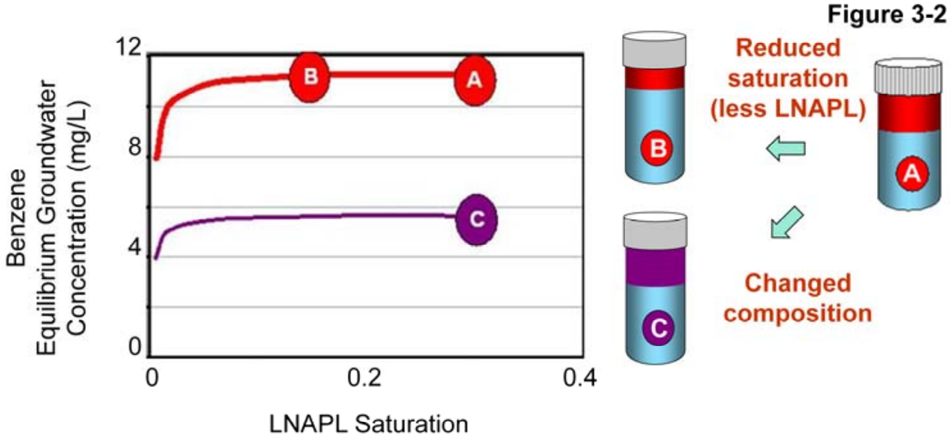


At this site, soil vapor extraction (SVE) remediation was effective for removing lighter-molecular-weight volatile hydrocarbons and thus achieving a composition objective. Time series soil sample collection and analysis was used to quantify the reduction of volatile hydrocarbons over time (May 2005 to February 2009). Because the impacts at this site were mainly gasoline-range hydrocarbons, SVE was also effective at achieving a mass-reduction objective.

31

Contrast Between Composition and Saturation Objectives

Figure 3-2



- Key Point: Dissolved or vapor concentration is dependent on change in composition (mole fraction) and not saturation (unless almost all LNAPL is removed)

The composition and saturation objectives are conceptually compared. The first scenario from A to B shows how a 50% reduction in saturation has little effect on the dissolved benzene concentration. In contrast a 50% reduction in the mole fraction of benzene from A to C has a corresponding 50% reduction in benzene concentration. The key point is that the dissolved benzene concentration is dependent on the change in composition and mole fraction. Research has shown that a reduction in saturation has little affect on the dissolved concentration unless almost all the LNAPL from a source zone is removed (e.g., see API LNAST model, publications by David Huntley)

32

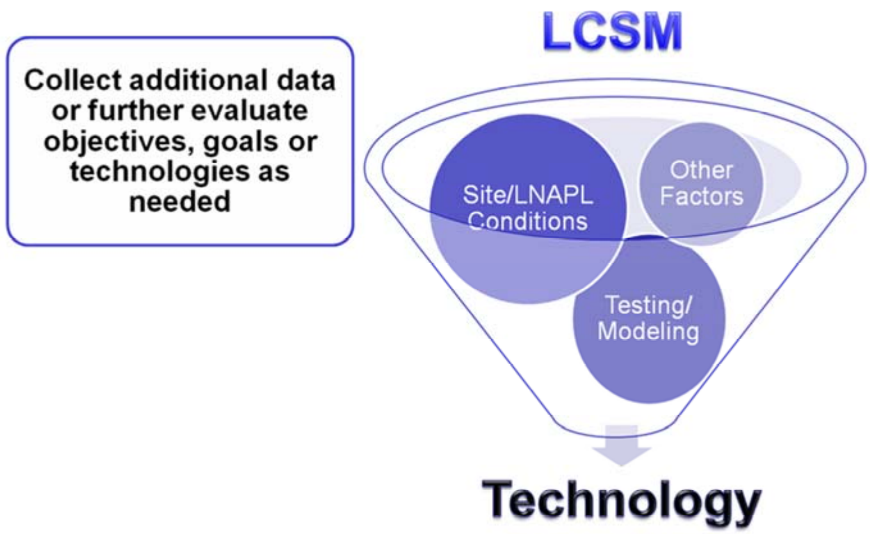
Summary Characteristics of Remedial Technologies (Table 5-2)

- LNAPL remedial technologies
  - Are applicable to specific LNAPL and site conditions - pros, cons, applicable geology, applicable LNAPL type, LNAPL remedial objective, remedial timeframe (Table 5-2 factors)
  - Many modify or exploit a particular LNAPL characteristic (saturation, transmissivity, volatility, solubility, etc.)
  - Must be matched to LNAPL and site conditions
- Important to understand how different technologies are influenced by physics and other conditions
  - Let's review some key conditions!

In Table 5-2 of our guidance, all 17 technologies are summarized with respect to pros, cons, applicable geology, LNAPL remedial objective, and remedial timeframes. The remedial technologies all act differently and apply in different ways depending on LNAPL properties and site conditions. Many technologies also modify or exploit a particular LNAPL characteristic such as saturation or volatility. To summarize, it is important to understand how different technologies are influenced by physics and by site conditions, as illustrated in subsequent slides.

33

The Technology Selection Process (Figure 5-1)



While the Site and LNAPL conditions are important factors for technology selection, there may be other considerations that influence the LNAPL conceptual site model and remedy selection, such as results of testing or modeling, bench or pilot scale tests, or other factors, including cost and liability concerns.

34

Key Considerations for Technologies

- Site Conditions
  - Grain size distribution
  - Depth below grade and access
  - Depth to water table
  - Unsaturated zone versus saturated zone
- LNAPL Conditions
  - Saturation
  - Composition (single chemical or multi-component mixture)
  - Volatility
  - Solubility
  - Viscosity
  - Interfacial tension
  - Biodegradation

Let's look at some example technologies within this general framework

Several key considerations for LNAPL technology evaluation are listed on this slide with respect to site and LNAPL conditions (see Table 5-2 and Appendix A of the Guidance). The relative importance of each consideration or factor listed will vary depending on the technology.

An example of how a site condition could affect a technology is that when the water table is deep, a technology such as multiphase extraction may become less efficient or become not feasible. An example of how a LNAPL condition could affect a technology is that hydraulic pumping rates will be faster for low viscosity product such as gasoline compared to a higher viscosity product such as diesel.

In subsequent slides, selected technologies are evaluated in greater detail through case examples discussed within this general framework.

35

Excavation – LNAPL Mass Recovery

- Key site conditions
  - Depth below grade, access
  - Depth to water table
  - Unsaturated vs. saturated zone
- Advantages include very short timeframe, complete mass removal where accessible
- Disadvantages include access restrictions, cost and de-watering below water table
- Sustainability may also be an issue (safety, carbon footprint)

The first technology illustrated excavation of LNAPL, which involves the mass recovery mechanism. This slide illustrates a site where the goal was to remove a LNAPL source zone through excavation.

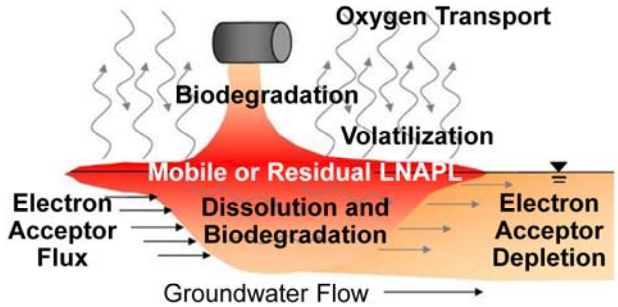
At this site, the depth to LNAPL was greater than anticipated and the excavation required de-watering. The areal extent of contamination was also larger than anticipated. Fortunately at this site, there was good access which allowed for expansion of the excavation and removal of contamination. At some sites this will not be the case. This case study illustrates the importance of good site investigation data and a solid LNAPL conceptual site model.

The advantages of excavation include very short time frame and complete LNAPL removal, where accessible. Disadvantages include access restrictions, cost and de-watering below the water table. Sustainability may also be an issue for this technology, for example when a large volume of soil needs to removed and transported long distances to a disposal site. Emissions from vehicles and safety on-site and on-road may be other factors to consider.

36

Natural Source Zone Depletion (NSZD) – LNAPL Phase Change

- Key LNAPL conditions
  - Composition
  - Volatility
  - Solubility
  - Biodegradation



- Low intensity remedial solution
- Advantages include no disruption, low carbon footprint
- Disadvantages include very long time frame, may not meet saturation (mobility) or composition objective

ITRC's Evaluating Natural Source Zone Depletion at Sites with LNAPL (LNAPL-1, 2009)

Natural source zone depletion involves processes such as volatilization, dissolution and biodegradation. The relative importance of these processes will depend on the type of LNAPL. For example, the dissolution rate will be slow for heavier petroleum products such as diesel or oil since the solubility will be lower. Natural source zone depletion is a low intensity remedial solution and advantages include no disruption and low carbon footprint. The disadvantage is that it occurs slowly over very long time frames and may require long-term monitoring. This technology may also not meet saturation or composition objectives for a site in an acceptable timeframe.

37

Barrier Wall – LNAPL Mass Control

- Key site conditions
  - Grain size distribution
  - Depth below grade, access
  - Unsaturated vs. saturated zone
  - Depth to water table

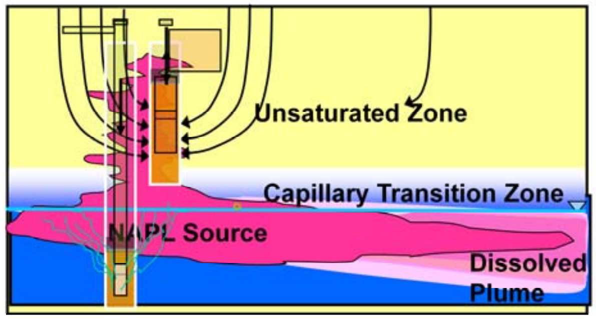
- Advantages controls LNAPL and dissolved plume mobility
- Disadvantages long time frame monitoring, potentially costly remedial approach

LNAPL containment through construction of a barrier wall is intended to achieve LNAPL mass control. The case example presented in this slide shows the construction of a low permeability soil-bentonite wall to prevent the off-site movement of LNAPL. The photo to the right shows the trench under construction, which involves excavation and filling the trench with a slurry to keep it open, and then filling it with a soil-bentonite mixture. This trench was constructed to 20 to 30 feet depth and keyed into a confining layer (often bedrock, but in this case an aquitard). There are some examples of cut-off trenches being constructed to 60 or 70 feet depth below ground, although walls to such depths become relatively costly. An advantage of this technology is that it can provide effective control of LNAPL and dissolved plume mobility. A disadvantage is that the LNAPL is not treated, but managed inward of the containment wall. Construction of barrier walls can also be relatively costly and slow down the rate of NSZD.

38

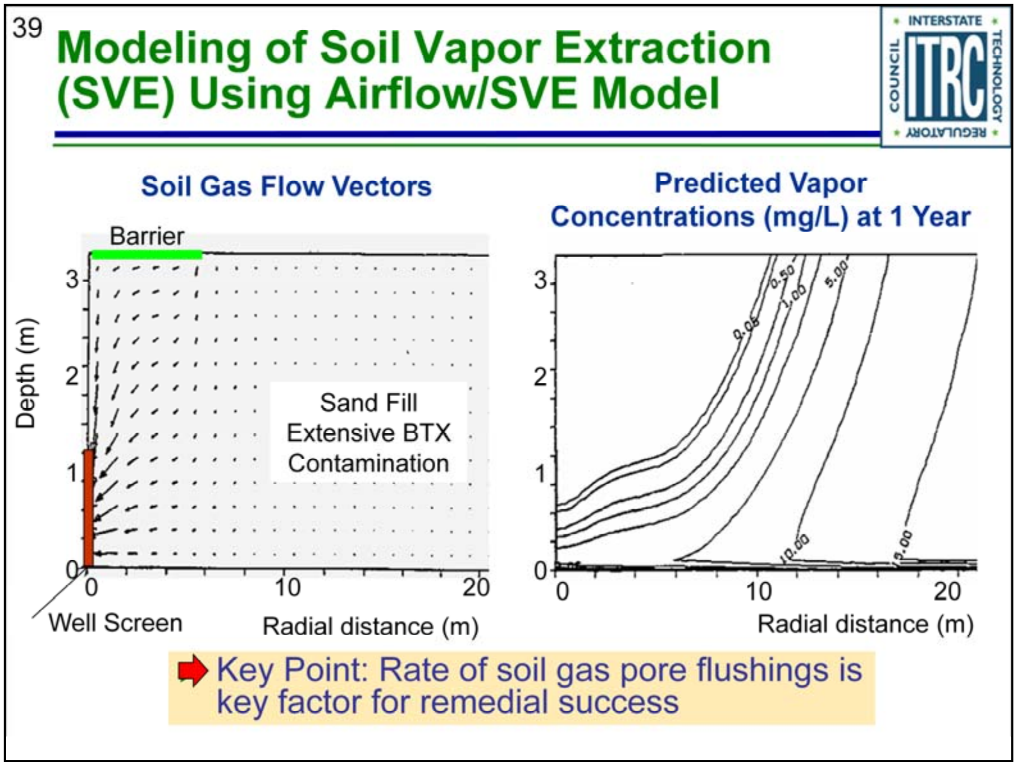
Air Sparging/Soil Vapor Extraction (AS/SVE) – LNAPL Phase Change

- Key site conditions
  - Grain size distribution and permeability
  - Unsaturated zone vs. saturated zone
  - Water content
- Key LNAPL conditions
  - Composition
  - Volatility



- AS/SVE target LNAPL above & below water table, targets volatile compounds, more effective for coarse-grained soils
- Advantage is AS/SVE can be effective technology to address composition objective
- Disadvantage is less effective as mass removal technology

Air sparging and soil vapor extraction involves the LNAPL phase change mechanism. Above the water table, LNAPL is removed through soil vapor extraction, while below the water table air sparging removes LNAPL. Since soil vapor extraction relies on soil gas flow to remove hydrocarbon constituents that are volatilized, the permeability and the moisture content of the soil are important, since this will affect rate at which pore flushing and hydrocarbon removal will occur. The volatility of LNAPL is another important factor. Volatile products such as gasoline will be removed much faster than for example diesel, for which a significant fraction is non-volatile and will not be removed by soil vapor extraction. A potential advantage of air sparging and soil vapor extraction is that it may be effective in achieving a composition objective depending on site conditions, but it is a less efficient technology for LNAPL mass removal. This is particularly the case when there are significant quantities of free-product present, which is a scenario where other technologies such as hydraulic recovery could be used to initially target LNAPL mass recovery.

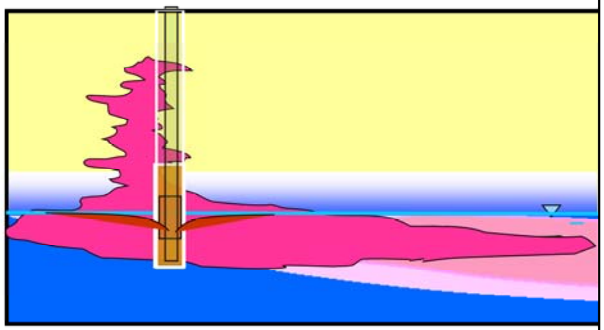


This slide illustrates how model-predictions using a numerical model may be used to develop a better understanding of the mechanisms and limitations for soil vapor extraction. The site for which the model was applied was a former petrochemical plant with extensive benzene, toluene, and xylene contamination where soil vapor extraction was proposed to remove LNAPL mass above the water table. The model output shown in the left figure shows the soil gas velocity vectors, while the graph on the right shows the predicted vapor concentrations after one year of remediation. As shown, there is a roughly triangular area near the well where LNAPL has been removed. In contrast, there is residual LNAPL that remains deeper in soil where there is less soil gas flow. The model demonstrated that the rate of soil gas pore flushing is key for remedial success. Techniques for directing soil gas flow and expanding the radius of influence, such as the addition of surface barriers, can help further improve performance.

k = 12 Darcy
Q = 30 cfm
Pw = 60 inches

40

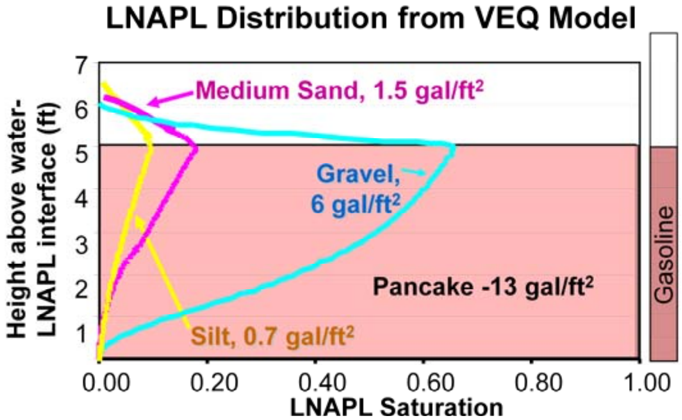
Hydraulic Recovery Methods – LNAPL Mass Recovery



- Key site conditions
  - Grain size distribution
  - Depth below grade
- Key LNAPL conditions
  - Saturation
  - Viscosity
  - Interfacial tension
- Technologies target saturation objective often to address potential LNAPL mobility
- Advantages are potential significant LNAPL recovery, but will depend on technology – efficiency of low intensity methods (skimming) may be low compared to higher intensity methods such as multi-phase extraction
- Disadvantages include residuals management and cost

Hydraulic recovery or mass recovery can involve a range of technologies from low intensity methods such as skimming, where a pump is placed at the water/LNAPL interface in the well, to higher intensity methods such as multiphase extraction where the groundwater table is drawn down and where a vacuum is applied. One key site condition is grain size, which controls permeability and the rate at which LNAPL will move to the well. LNAPL viscosity is another parameter that affects the rate at which LNAPL will move to the well. The advantages and disadvantages will depend on the technology implemented. For example, skimming is a low cost technology, but will have a reduced radius of influence compared to multiphase extraction, for which there will be greater drawdown and consequently recovery. The disadvantages of multiphase extraction are greater cost and residuals management.

41 **Review – Before Designing Hydraulic Recovery Technologies Need to Understand LNAPL Distribution (Training Part 1)**



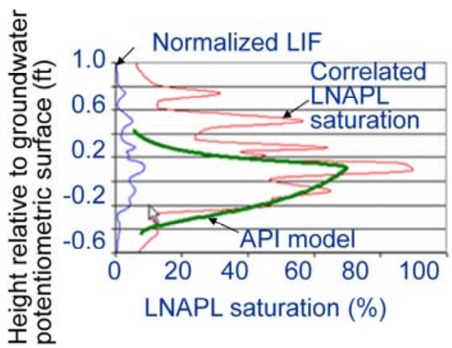
➡ Key Point: Model-predicted LNAPL specific volume depends on soil type and in-well thickness – Do you understand volume present and potentially recoverable?

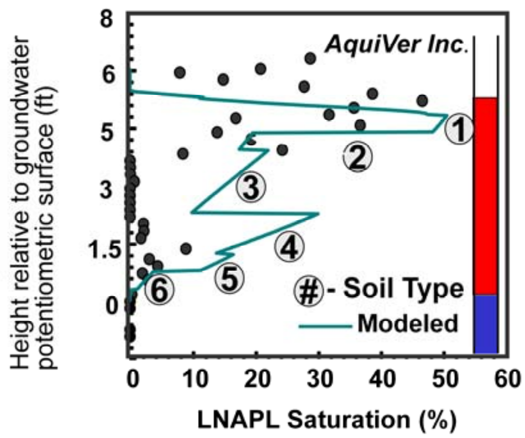
Volume estimates for different soil types for a given LNAPL thickness in the well are shown in this figure. For the outdated pancake model, the volume is the LNAPL thickness in well x porosity, or 13 gal/ft2 for this example. Using the more up-to-date Vertical equilibrium model (VEQ), the LNAPL saturation distribution (shark fins) and volumes depend on grain size, and vary from 6 gal/ft^2 for gravel to 0.7 gal/ft^2 for silt.

Do you understand the volume of LNAPL that is potentially recoverable?

42

Review – Evaluate Measurement Lines of Evidence in Addition to Model (Training Parts 1-2)

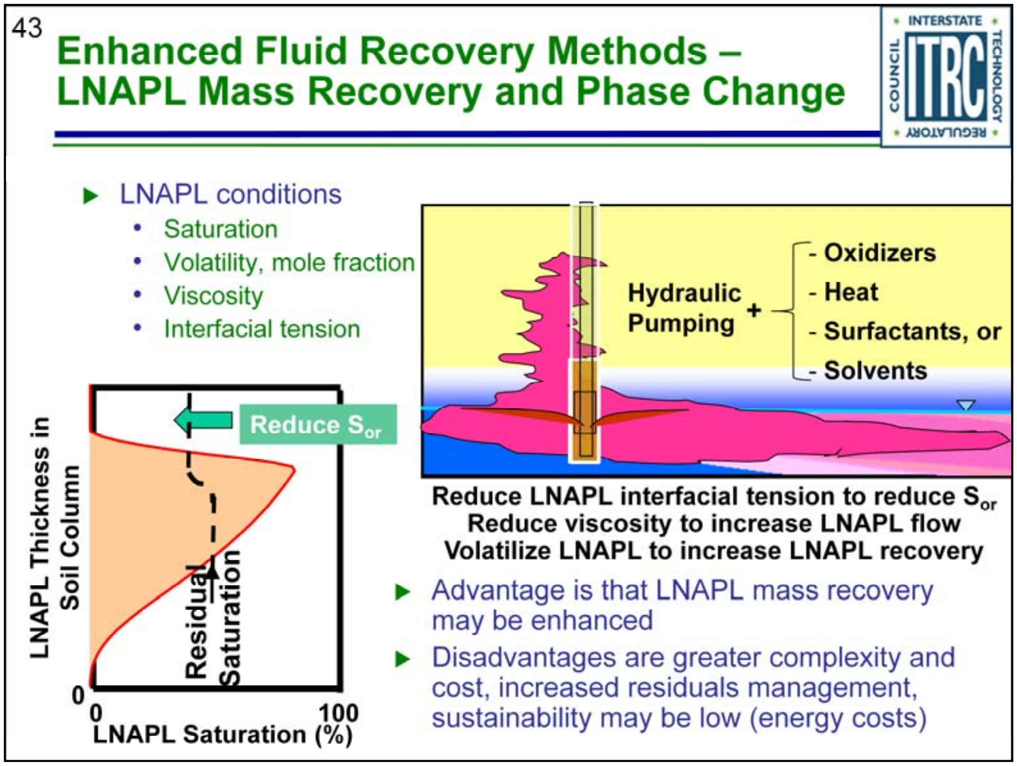




Can correlate laser induced fluorescence (LIF) data with model predictions of LNAPL saturation

Can compare measured residual saturation with model predictions of LNAPL saturation

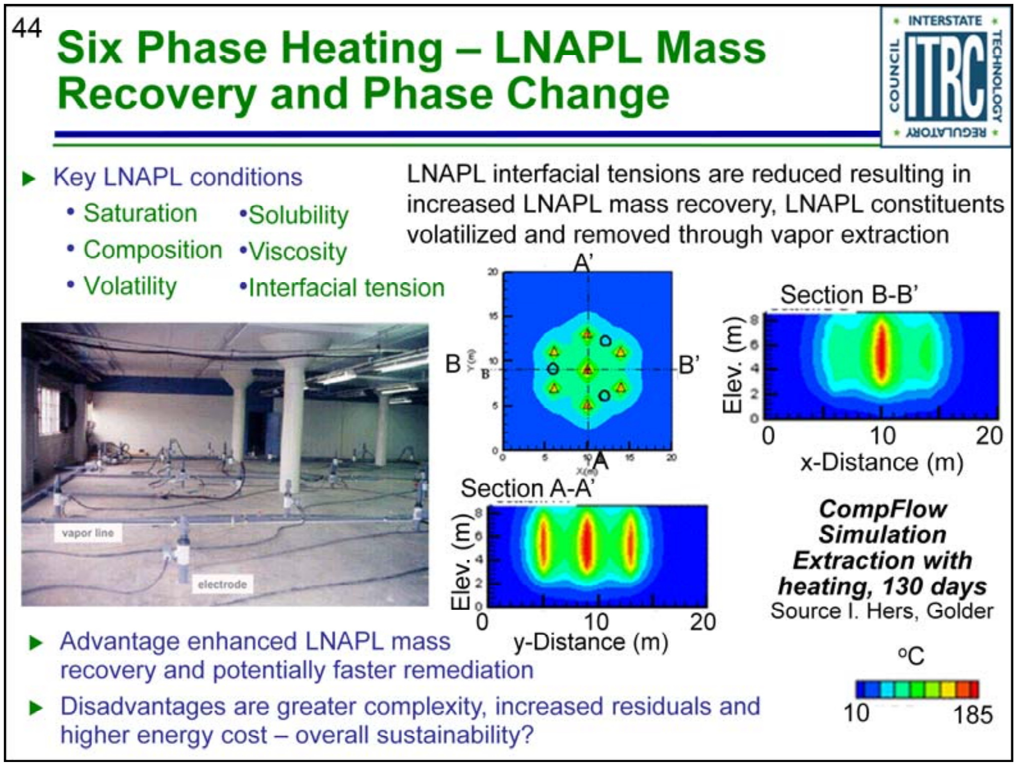
The purpose of this slide is to highlight the variability in LNAPL distribution based on measurement. While the VEQ model shown on the previous slide can provide for useful predictions, the use of technologies such as laser induced fluorecence or LIF shown on the left graph or measurements of LNAPL saturation shown on the right graph can be used to obtain a better understanding of the vertical variability in LNAPL saturation. When such measurement data exists, it is important to compare model predictions to the VEQ model predictions. Depending on the results, it may be possible to develop correlations between model predictions and measurements. This type of analysis can be important when evaluating LNAPL recovery efforts.



Enhanced fluid recovery methods involve a combination of LNAPL mass recovery and phase change. Typically these technologies involve a combination of hydraulic pumping and technologies that change the nature of the LNAPL, such as the addition of oxidizers, heat, surfactants, or solvents. One strategy may be to reduce the residual saturation through addition of a surfactant, and therefore increase the recoverable LNAPL mass. As a reminder, we have shown the figure on the left showing the shark fin and how recoverable LNAPL increases as residual saturation is reduced. Another technology for increasing mass recovery is the addition of heat, which enhances the volatilization of LNAPL constituents.

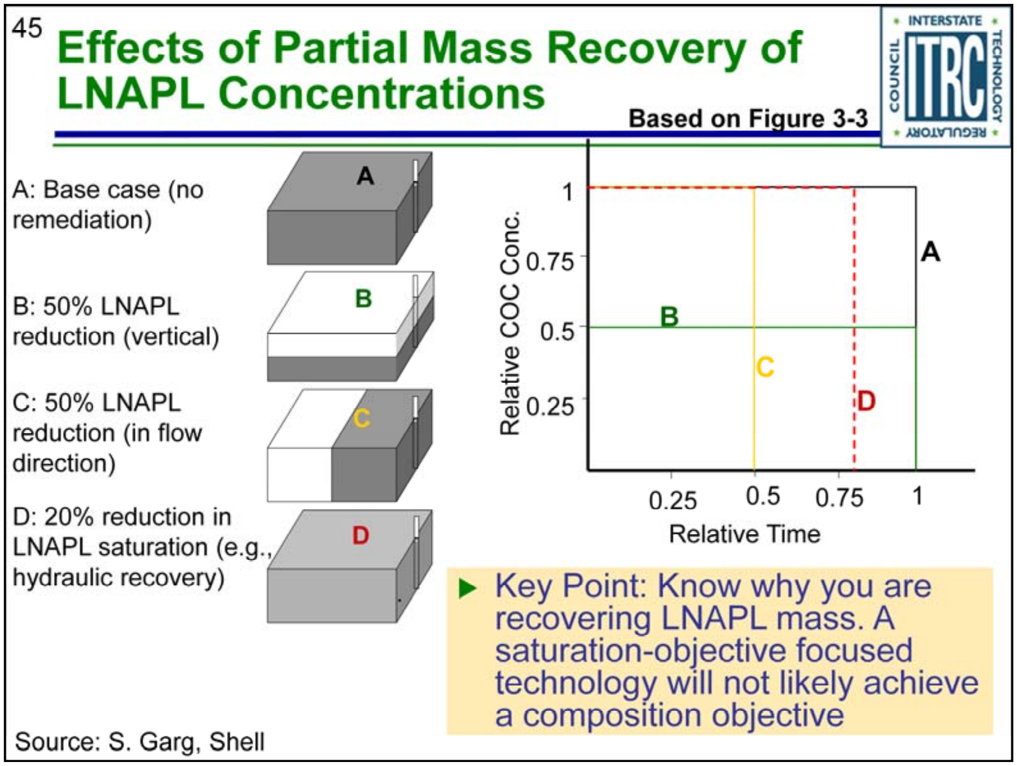
An advantage of enhanced technologies is increased mass recovery, but limitations include greater technological complexity and cost, elevated safety concerns, and also increased residuals management, for example, requirement to treat volatile emissions. For some technologies the energy inputs may be relatively high and therefore potentially less sustainable than less aggressive technologies, although the potential advantage of faster remediation timeframes would need to be considered as part of this evaluation.

ITRC has previously developed comprehensive guidance on in situ chemical oxidation that can be accessed on the ITRC website.



Six phase heating involves LNAPL mass recovery and phase change. Six phase heating is electrical resistance heating that applies electricity to the ground through electrodes, which is able to raise temperature to the boiling point of water. The middle array for six phase heating consists of a vapor extraction well, which is important for control and removal of volatilized constituents. A six phase heating array is shown in the photograph, while model predictions of heat modeling are shown on the right. Modeling may be important to help predict volatilization and optimize design. The key LNAPL conditions include saturation and composition, which could affect rate at which contaminants are being removed. If the goal is to mobilize LNAPL, properties such as viscosity and interfacial tension may be important.

An advantage of this technology is that LNAPL mass recovery may be enhanced and it is also a technology that works reasonably well in both coarse and fine-grained soils. Some disadvantages include greater complexity, increased safety concerns, higher energy cost and increased residuals management. The technology may be appropriate at sites with localized contamination areas where an aggressive technology can be used to quickly clean up the site.



The effect of partial LNAPL mass removal on the LNAPL constituent concentrations in a monitoring well positioned downgradient of the source zone and screened completely across the initial thickness of LNAPL impacts is shown. The LNAPL source zone is considered uniformly impacted. For these scenarios, it was assumed that there is no dispersion or biodegradation, and that dissolution is not mass-transfer limited (i.e., equilibrium dissolution).

Case A: This case is the base case, where no active remediation is performed. Here the constituent of concern dissolves into the groundwater until it is completely depleted from the LNAPL. The groundwater concentration and time to total depletion of the COC in the other cases are normalized to those for Case A. For example, a relative time of 0.5 indicates that the constituent will completely dissolve away in one-half the time when compared to Case A; similarly, a relative concentration of 0.5 indicates that the groundwater concentrations in the monitoring well defined above will be one-half of that in the base case.

Case B: Here the source has been partially cleaned up vertically, for example, by partial excavation to a certain depth. Here since the well is screened across the entire thickness of the original source zone, the concentration in the monitoring well is reduced by half due to dilution. However, since the source length is not changed, there is no effect on source longevity. Another example of this case could be cleanup of coarse-grained layers in an inter-bedded setting.

Case C: In this case the source has been partially removed in the direction of groundwater flow, for example, the upgradient half of the source has been excavated and other half is left, say due to lack of access. Here the groundwater concentrations in the monitoring wells are unchanged, but the longevity is reduced by half, because twice as many source pore volumes are flushed through the source in the same amount of time resulting in more rapid constituent depletion.

Case D: As is discussed earlier, the theoretical endpoint of hydraulic recovery is residual saturation. Case D represents a scenario where 20% of the LNAPL is removed via hydraulic recovery. With a 20% reduction in saturation, the concentration is unchanged, but relative time is reduced by approximately 20%.

46

Summary of LNAPL Remedial Technology Overview

- LNAPL technology description and primary mechanism for remediation (details in Table 5-1)
- Composition and saturation objectives
- Summary characteristics of remedial technologies (Table 5-2)
- Key considerations for technologies

Key physics points for each technology discussed.

47

Questions & Answers

Follow ITRC

- Background: Part 3 online training focus
- LNAPL remedial technology overview

Question and Answer Break

- Remedial objective setting
- LNAPL remedial technology selection framework – ITRC LNAPL Technical and Regulatory Guidance overview and use

No associated notes.

48

Training Overview

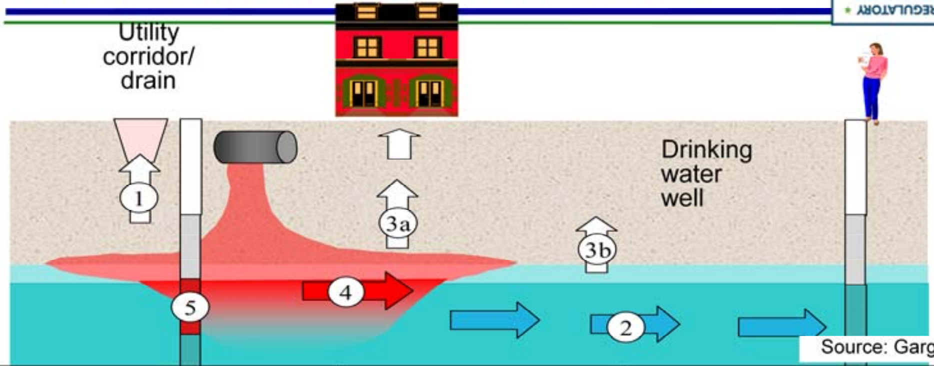
- Background: Part 3 online training focus
- LNAPL remedial technology overview
- Remedial objective setting
- LNAPL remedial technology selection framework – ITRC LNAPL Technical and Regulatory Guidance overview and use

- Establishing remedial objectives.

49

Key Training Message:

Understand the LNAPL Concerns



LNAPL emergency issues when LNAPL in the ground	LNAPL considerations when LNAPL in the ground (evaluated using standard regulations)	Additional LNAPL considerations when LNAPL in wells (not evaluated using standard regulations)
(1) Vapor accumulation in confined spaces causing explosive conditions ***Not shown*** - Direct LNAPL migration to surface water ***Not shown*** - Direct LNAPL migration to underground spaces	(2) Groundwater (dissolved phase) (3a) LNAPL to vapor (3b) Groundwater to vapor ***Not shown -*** Direct skin contact	(4) LNAPL potential mobility (offsite migration, e.g. to surface water, under houses) (5) LNAPL in well (aesthetic, reputation, regulatory)
LNAPL **Composition**		LNAPL **Saturation**

•You have seen this slide before.

•It illustrates your site-specific LNAPL concerns.

•Design your remediation system to mitigate your concerns.

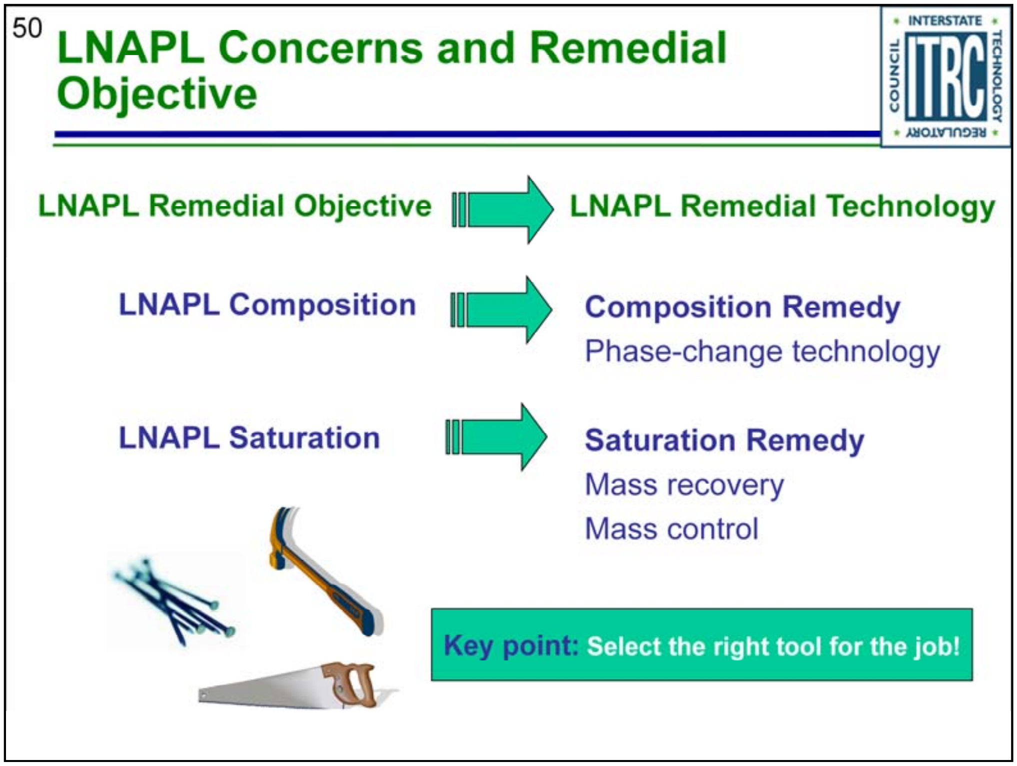
•For each LNAPL concern identified in the LCSM, there must be an remedial objective established for addressing it.

•If there are multiple concerns, then set multiple remedial objectives.

•These remedial objectives dictate what a remedial technology must achieve to mitigate an LNAPL concern.

•For example, if you are concerned about LNAPL constituents dissolved in groundwater possibly impacting a drinking water well, address that.

•You don't need to focus on LNAPL migration when selecting a remediation technology if the LNAPL is not migrating.



- First identify your LNAPL concerns as composition concerns or saturation concerns.
- Then establish remedial objectives based on your concerns.
- Then select an LNAPL remediation technology that mitigates your LNAPL composition or saturation concerns.
- Composition concerns will require a phase-change technology.
- Saturation concerns will require an LNAPL mass removal or mass control technology.

51

Key Terms and Concepts

- LNAPL Remedial Objectives – Established to mitigate the LNAPL concerns
- LNAPL Remediation Goals – the Remedial Objectives stated in the context of a remedial technology
- Performance Metrics – measurements that demonstrate achievement or progress to achievement of the Remediation Goal

Example LNAPL Remedial Objectives

- Risk-based objectives
  - Reduce risk-level or hazard
  - Exposure pathway/LNAPL specific
- Non-risk objectives (examples)
  - Reduce LNAPL flux
  - Reduce source longevity
  - Reduce LNAPL mass or well thickness
  - Reduce LNAPL transmissivity
  - Abate LNAPL mobility
  - Corporate policy – liability/risk tolerance
- Regulatory driver: "recover to maximum extent practicable"
  - Different states have different interpretation

- **Potentially a different remedial strategy to target LNAPL saturation versus LNAPL composition drivers**
- **Evaluate whether applicable objective(s) are best addressed by reducing LNAPL saturation or by modifying the LNAPL composition**

Key Terms and Concepts

LNAPL Remedial Objective – Examples:

- Concern: LNAPL present in a well
  - Objective: recover LNAPL mass to the extent practicable
- Concern: LNAPL sourcing a dissolved plume
  - Objective: reduce soluble LNAPL fraction to meet groundwater quality standards at a compliance point or point of exposure
- Concern: LNAPL generating explosive conditions in a utility
  - Objective: reduce volatile LNAPL fraction to eliminate vapor accumulations in the utility

Key Terms and Concepts

Example Objective: recover LNAPL mass to the extent practicable:

<u>LNAPL Remediation Goal</u> – Examples

- Goal: LNAPL removal to residual saturation
    - Technology Option 1: Dual-phase LNAPL recovery
- Goal: Complete LNAPL removal
    - Technology Option 2: Excavation of LNAPL impacted soil

55

Key Terms and Concepts

Example Goal: LNAPL recovery approaching residual saturation

Performance Metric – Examples

- Endpoint: LNAPL Transmissivity decreased to practical limit of hydraulic recovery (0.1 to 0.8 ft^2/day)
  - Metric: LNAPL Transmissivity
- Endpoint: Stabilized dissolved-plume concentrations
  - Metric: Stable dissolved-plume
- Endpoint: >250 gals:1 gal
  - Metric: water/oil recovery ratio
- Endpoint: $100/gallon
  - Metric: Dollars per gallon
- Endpoint: LNAPL center of mass moves less than X ft
  - Metric: LNAPL source zone center of mass

•This slide shows some examples of performance metrics for the remediation goal of removing LNAPL to residual saturation.

•On page 14 of the Tech/Reg, there is an explanation on the use of LNAPL transmissivity as a performance metric.

•In 2012, ASTM published a "Standard Guide for Estimation of LNAPL Transmissivity" that you can buy for $69.

•The ASTM guide describes in detail the various field tests (and appropriate site conditions) to determine transmissivity.

•The API has an LNAPL Transmissivity spreadsheet available on-line.

•According to the Tech/Reg, if your LNAPL transmissivity is less than about 1 ft2/day, you are at the end of practical hydraulic removal of LNAPL.

56

Importance

- Principles to promote a successful LNAPL cleanup
  - Adequate LNAPL site characterization and LNAPL Conceptual Site Model
  - Identify LNAPL concerns
  - Establish achievable remedial objectives and remediation goals based on the concerns
  - Establish metrics to measure progress
  - Develop a remedial strategy to achieve the objectives
- Failure to complete any one of the steps may result in a failed or perpetual remedial attempt

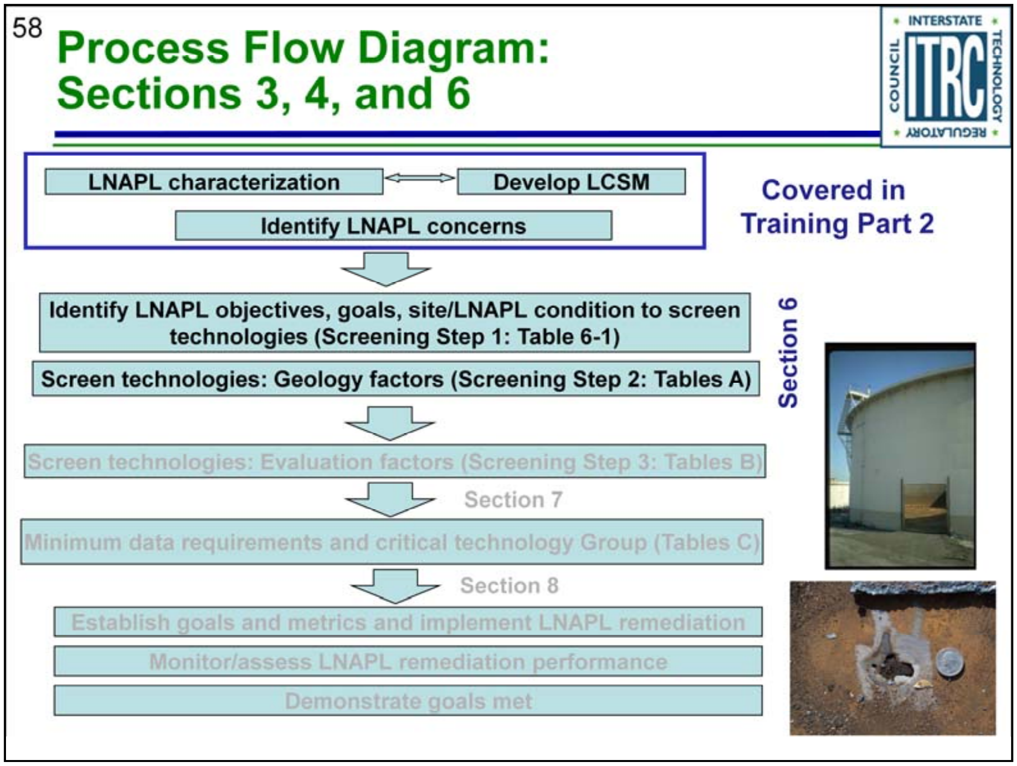
- Now we have Rick Ahlers (Arcardis) who will talk about LNAPL remediation technology selection.

57

Training Overview

- Background: Part 3 online training focus
- LNAPL remedial technology overview
- Remedial objective setting
- LNAPL remedial technology selection framework – ITRC LNAPL Technical and Regulatory Guidance overview and use

No associated notes.



This flow chart will be used throughout the presentation to remind everyone where we are in the associated ITRC Technical and Regulatory Guidance: Evaluating LNAPL Remedial Technologies for Achieving Project Goals.

Graphic: AST with hole in floor found during routine turn around.

59

Process Flow Diagram: Sections 7 and 8

LNAPL characterization ↔ Develop LCSM

Identify LNAPL concerns

Sections 3 and 4

Identify LNAPL objectives, goals, site/LNAPL condition to screen technologies (Screening Step 1: Table 6-1)

Screen technologies: Geology factors (Screening Step 2: Tables A)

Section 6

Screen technologies: Evaluation factors (Screening Step 3: Tables B) — Section 7

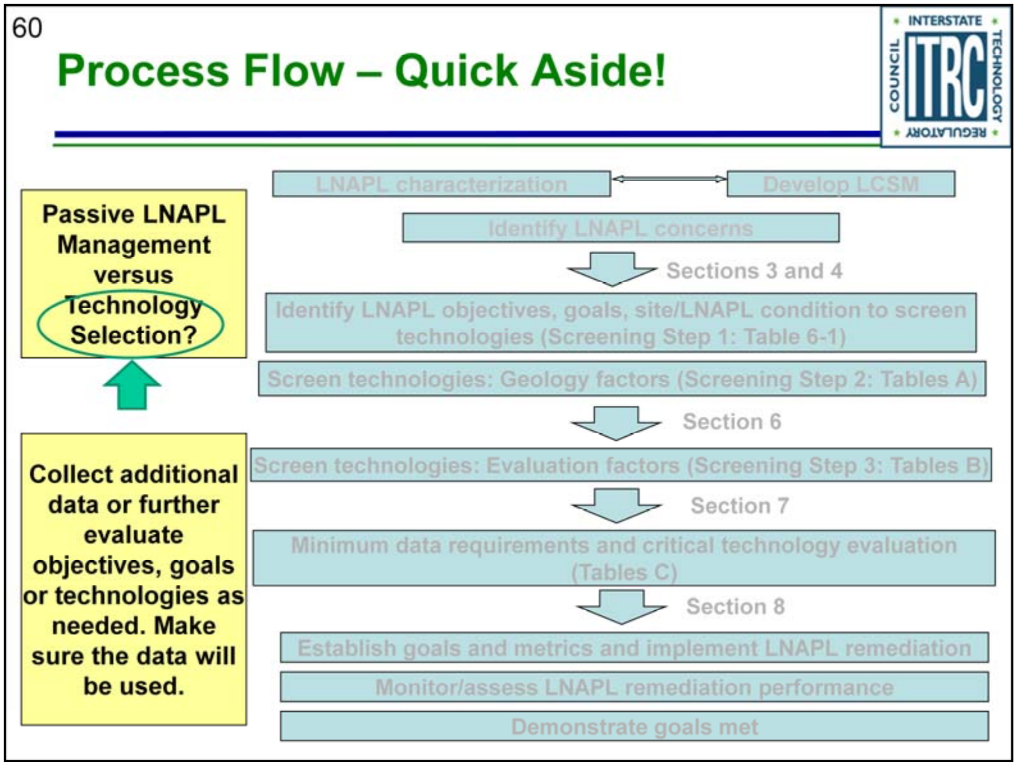
Minimum data requirements and critical technology Group (Tables C) — Section 8

Establish goals and metrics and implement LNAPL remediation

Monitor/assess LNAPL remediation performance

Demonstrate goals met

No associated notes.



Key Point: The ITRC Guidance focuses on active technology selection. There might be sites that are low risk, and are in a routine monitoring program where active remediation is not needed.

Also, at any step of technology selection, additional data might be needed to close characterization data gaps or help screen in or screen out a technology.

61

Section 6 – Preliminary LNAPL Remedial Technology Screening

- Goal: 17 technologies to 5 or less
- 2-step process
  - **Step 1** – Table 6-1. Set remedial objectives, set goals, and metrics, then screen technologies according to site conditions
  - **Step 2** – Compare screened technologies against Geologic Factors in "A-series" tables in Appendix A to further refine list

Major Goal in Section 6 is to narrow the long list of technologies down to a shorter list.

It is a two step process, and we will begin with the first step.

Step 1, Table 6.1
LNAPL Remedial Objectives

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objectives	LNAPL Remedial Goals	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic Tech limit or limited/ infrequent well thickness, decline curve analysis	-Dual Pump Liquid Extraction$^{C, S, , LS, HV, HS}$ -Multi-Phase Extraction (Dual Pump) $^{C, S, , LS, HV, HS}$ -Multi-Phase Extraction (Single Pump) $^{C, S, , LS, HV, HS}$ -Water Flooding $^{C, S, , LS, HV, HS}$ -LNAPL Skimming $^{F, C, S, , LS, HV, HS}$ -Bioslurping/EFR $^{F, C, S, , LS, HV, HS}$ -Excavation $^{F, C, U, S, , LS, HV, HS}$ -NSZD $^{F, C, U, S, HV, HS}$

- Reduce LNAPL mass and further reduce mobility
- Terminate LNAPL body expansion
- Abate generation of toxic and/or vapor accumulations from LNAPL source
- Aesthetic LNAPL concern abated
  - Saturation objective
  - Composition objective

On the next five slides, we will go through Table 6-1 in the Guidance. At a site, a practitioner would also work this table from left to write to help narrow technologies.

Important: There is a lot of information in the ITRC Guidance. The presentation slides have less information, so the text can be large enough to be seen.

LNAPL Remedial Objectives: One example is shown above in the table. The other LNAPL Remedial Objectives from Table 6-1 are shown below at the left.

The graphic shows a LNAPL skimmer system, which could be used as a technology to address two LNAPL Remediation Objectives as indicated by the arrows.

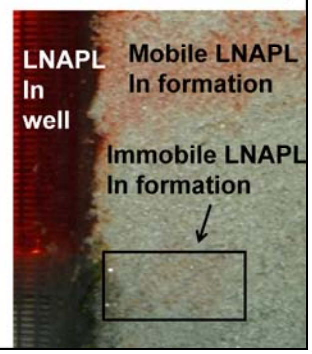
63

Step 1, Table 6.1
LNAPL Remedial Goals

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic performance of the recovery system	-Dual Pump Liquid Extraction [C, S, , LS, HV, HS] -Multi-Phase Extraction (Dual Pump) [C, S, , LS, HV, HS] -Multi-Phase Extraction (Single Pump) [C, S, , LS, HV, HS] -Water Flooding [C, S, , LS, HV, HS] -LNAPL Skimming [F, C, S, , LS, HV, HS]

- Recover LNAPL to the maximum extent practicable
- Abate LNAPL body expansion
- Arrest LNAPL spreading by a physical barrier
- Abate toxic vapors
- Remove sufficient soluble mass fraction to reduce down gradient mass flux



LNAPL remedial goal is what the objective is supposed to accomplish. The table shows one example, the other examples from Table 6-1 are shown at the bottom left.

Graphic, Important!: This shows LNAPL in a sand tank at Colorado State University. LNAPL is shown (red liquid) in a stainless steel tank cut in half on the left. The LNAPL saturation profile can be seen in the upper right, and shows the fraction of LNAPL that might be recovered. On the bottom right, residual LNAPL is shown in the formation. When LNAPL is recovered, this residual LNAPL will still be in the formation contributing to a dissolved phase groundwater plume. So a mass recovery goal might not address a LNAPL concern based on a groundwater concentration, like an MCL.

64

Step 1, Table 6.1
Technology Group

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic performance of the recovery system	-Dual Pump Liquid Extraction C, S, , LS, HV, HS -Multi-Phase Extraction (Dual Pump) C, S, , LS, HV, HS -Multi-Phase Extraction (Single Pump) C, S, , LS, HV, HS

- What is a technology group? A high level grouping that the technology achieves:
  - LNAPL mass recovery →
  - LNAPL mass control (containment) →
  - LNAPL compositional change

Technology group: Does a technology work by removing LNAPL, containing LNAPL or by compositionally changing it.

Graphic: Shows two technology groups. An LNAPL skimmer system is housed in the plastic structures for mass recovery, and a sheet pile wall is present for LNAPL containment.

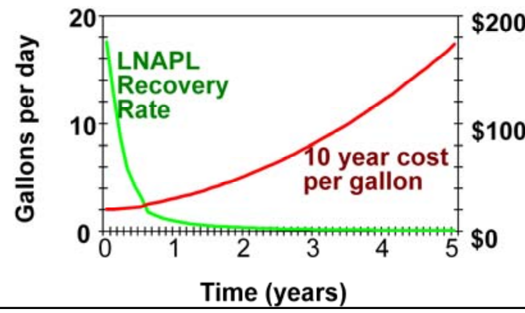
65

Step 1, Table 6.1
Performance Metrics

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic performance of the recovery system	-Dual Pump Liquid Extraction C, S, , LS, HV, HS -Multi-Phase Extraction (Dual Pump) C, S, , LS, HV, HS -Multi-Phase Extraction (Single Pump) C, S, , LS, HV, HS

- Asymptotic recovery
- Water/oil ratio
- Dollars per gallon of LNAPL removed →
- Pounds of CO_2 generated per gallon of removed LNAPL



Example metrics are all about when a system has met its technological endpoint.

Examples from Table 6-1 are shown on the bottom left.

Graphic: Shows a $/gallon or LNAPL removed metric. As systems approach their endpoint, less LNAPL is recovered, while O&M costs may remain at a constant level, increasing the cost of LNAPL removing as measured as $/gallon.

66

Step 1, Table 6.1 LNAPL Technology and LNAPL/Site Conditions

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Example Performance Metrics	**LNAPL Technology and LNAPL/Site Conditions**
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic performance of the recovery system	-Dual Pump Liquid Extraction$^{C, S, LV, LS, HV, HS}$ -Multi-Phase Extraction (Dual Pump) $^{C, S, LV, LS, HV, HS}$ -Multi-Phase Extraction (Single Pump) $^{C, S, LV, LS, HV, HS}$

- A grouping of technologies can be further reduced based on
  - LNAPL type
    - LV- low Volatility, HV-High Volatility, HS-High Solubility, LS-Low Solubility
  - Geologic indicators
    - F-Fine grained soils, C-Coarse grained soils, V-vadose zone, S-Saturated zone

LNAPL Halos in Clay

The last column gives a little more site specific LNAPL and soil texture criteria to help screen the technologies.

Subscripts are shown on the bottom left.

Graphic: Clay from a soil core. LNAPL in halos. This soil is an “F,” fine grained soil.

67

Starting with Section 6: Step 2

LNAPL characterization ↔ Develop LCSM

Identify LNAPL concerns

Sections 3 and 4

Identify LNAPL objectives, goals, site/LNAPL condition to screen technologies (Screening Step 1: Table 6-1)

Screen technologies: Geology factors (Screening Step 2: Tables A)

Section 6

Screen technologies: Evaluation factors (Screening Step 3: Tables B)

Section 7

Minimum data requirements and critical technology Group (Tables C)

Section 8

Establish goals and metrics and implement LNAPL remediation

Monitor/assess LNAPL remediation performance

Demonstrate goals met

Now we are in the second step of Section 6.0, looking at the A-Series tables to get more information on technologies based on site specific geologic information.

Example: Skimming Table A-6.A

Section 6: Step 2

Geologic factors	Saturated zone	Permeability	Soil permeability is proportional to recovery rate—higher LNAPL recovery and saturation reduction in higher permeabilities

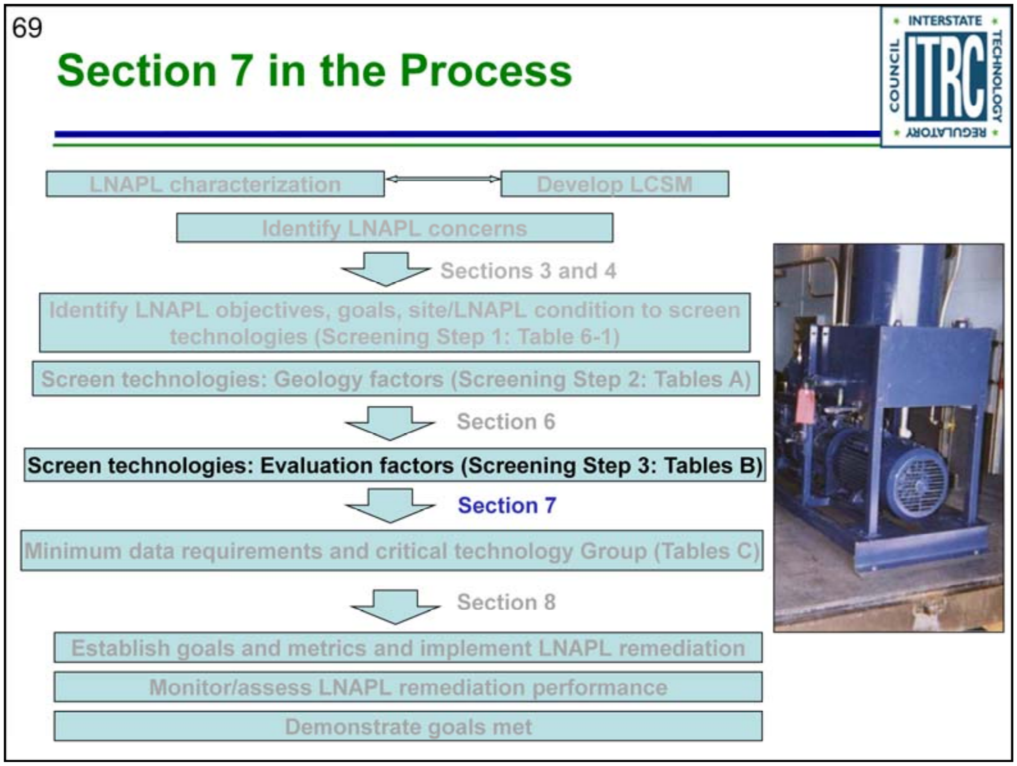
Table A-6.A. Skimming

Technology	Active LNAPL skimming	Uses a single pump or hydrophobic belt (e.g., bladder pump, pneumatic pump, or belt skimmer) to extract LNAPL from a well at air/LNAPL interface under natural gradients. The available drawdown is limited based on the LNAPL thickness, the density difference between LNAPL and water, and the heterogeneity of the adjacent soil. LNAPL skimming typically induces a limited ROI of <25 feet in unconfined conditions. LNAPL skimming is effective for confined, unconfined, and perched LNAPL.	
Remediation process	Physical mass recovery	Yes	Removes LNAPL at the groundwater surface; does not affect residual LNAPL mass.
	Phase change	No	LNAPL remains in liquid phase.
	In situ destruction	No	N/A
	Stabilization/binding	No	N/A
Objective applicability	LNAPL saturation	Yes	Active skimming drives LNAPL saturation towards residual saturation, decreasing LNAPL transmissivity and mobile LNAPL extent.
		Example performance metrics	Direct analysis of soil to indicate changes in formation LNAPL saturations; LNAPL transmissivity reduction/ LNAPL conductivity reduction, LNAPL/water ratio, asymptotic recovery of LNAPL from a well.
	LNAPL composition	No	N/A—Skimming recovers LNAPL as a fluid and does not exploit volatilization or dissolution, so it does not lead to a compositional change.
		Example performance metrics	N/A
Applicable LNAPL type	All LNAPL types; however, lower-viscosity LNAPL (0.5–1.5 cP) is much more recoverable than high-viscosity LNAPL (>5 cP).		
Geologic factors	Unsaturated zone	Permeability	Technology not applicable to LNAPL in the unsaturated zone.
		Grain size	
		Heterogeneity	
		Consolidation	
	Saturated zone	Permeability	Soil permeability is proportional to recovery rate—higher LNAPL recovery and saturation reduction in higher permeabilities. Permeability has significant effect on ROI of a skimming well. LNAPL permeability greater at lower water table levels when saturations are higher (smear zone opened).
		Grain size	[illegible] can achieve lower residual saturation in coarser materials where capillary pressures are less.
		Heterogeneity	Moderately sensitive to heterogeneity, affecting ROI; well screen location and pump depth can help overcome heterogeneities.
		Consolidation	Not typically a factor.
Cost	Per well, the capital costs of skimming wells are low compared to other technologies; however, to achieve a remedial time frame similar to that of dual pump or total fluids extraction, a denser well spacing is required due to the small ROC and lower per-well rate of LNAPL removal. Skimming wells typically need to be operated longer than DPLE because they can have lower recovery rates achieved compared to other mass recovery technologies.		

Bottom Left: An example table (SKIMMING) from Appendix A.

Top: A zone in of information highlighted in red box.

Graphic: LNAPL skimmer



Now we will move into Section 7, to look at site specific evaluation factors.

Graphic: We will talk about community concerns. Pictured is a blower. Noise from the blower could be a community concern

Section 7 – LNAPL Technology Evaluation for the Short List

- Further evaluate technologies from Section 6 if more than one technology – or – **reevaluate goals**
- Review Table 7-1 to understand evaluation factors
- Select and rank top 5 factors in importance for site considerations
- Review "B-series" tables in Appendix A

No associated notes.

71

Section 7 – Example Evaluation Factors – Table 7-1

Table 7-1. Evaluation Factors

Remedial Time Frame	**Defined**	The time frame by which the LNAPL remedial goal is to be met. The time frame may be a regulatory or non-regulatory evaluation factor.
	Impact	Holding all other variables the same, the shorter the time frame, the more aggressive the effort required, which increases costs.

An example from Table 7-1.

72

Section 7 – Example Evaluation Factors – Table 7-1

- Remedial time frame
- Safety
- Waste stream generation and management
- Community concerns
- Carbon footprint/energy requirements
- Site restrictions
- LNAPL body size
- Cost
- Other

Each factor is **Defined** and its **Impact** is listed

The rest of the evaluation factors from Table 7-1.

73

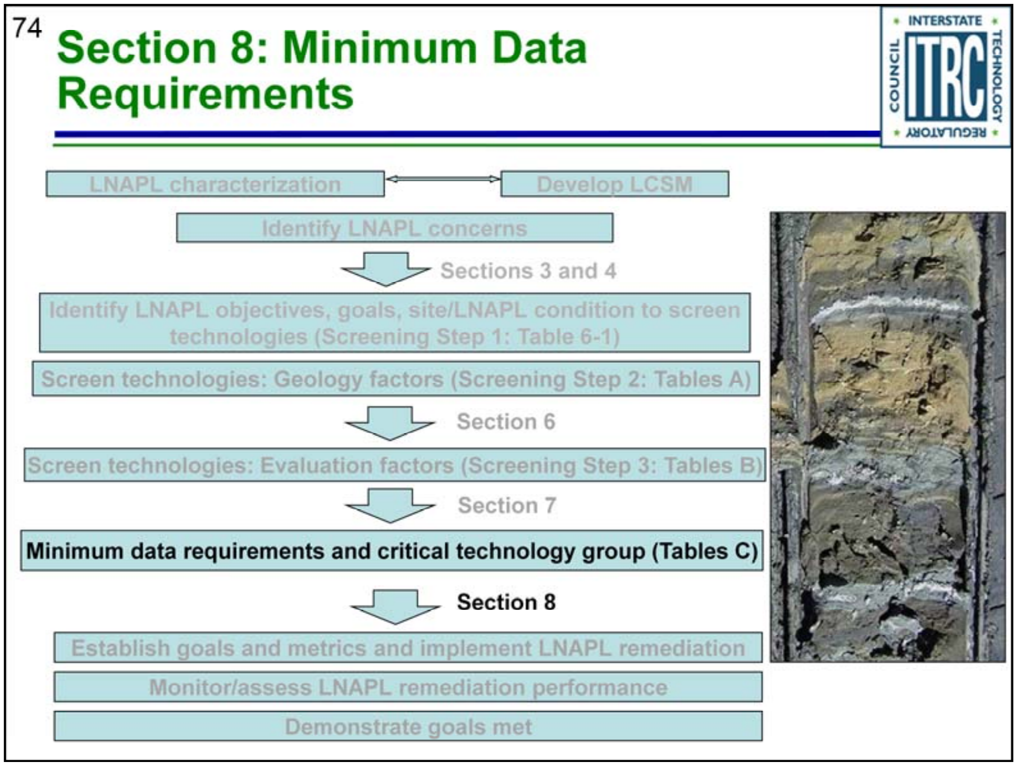
Example: Multi-Phase Extraction (Dual Pump) Table A-10.B

Technology:	Multi-Phase Extraction (Dual Pump)	
Remedial Time Frame	Concern	Moderate
	Discussion	Medium. Higher viscosity LNAPL will take longer to remove.
Community Concerns	Concern	Moderate
	Discussion	Although equipment is usually out of sight, there is a potential for concerns with noise, potential odors, volatile emissions, aesthetic, and access issues.

From Table 7-1, with several (or up to five) evaluation factors selected, more information to screen technologies against evaluation factors can be found in the B-series tables in Appendix A.

An example is shown above.

Graphic: MPE pilot test well head. PVC is the conduit to apply a vacuum. The narrow red line is a pump for LNAPL recovery. The thicker red line is attached to a pump for watertable depression.



Now we will move into Section 8.

Graphic: Clay from boring log—this has to be known by Section 8, and a complex site with fine grained soils will need to be closely evaluated in Section 8.

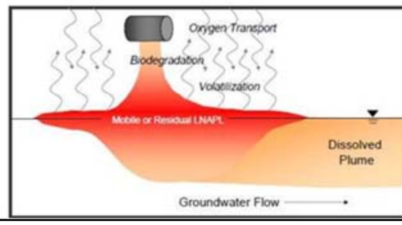
Section 8 – Minimum Data Requirements and Critical Considerations for Technology Evaluation

- Table 8-1 is a summary table of the critical information
- Further evaluate considering bench or pilot test or field deployment information
- Use the "C-series" tables in Appendix A for the technologies remaining from Section 7
- If no technology can be determined, reevaluate the objectives or goals

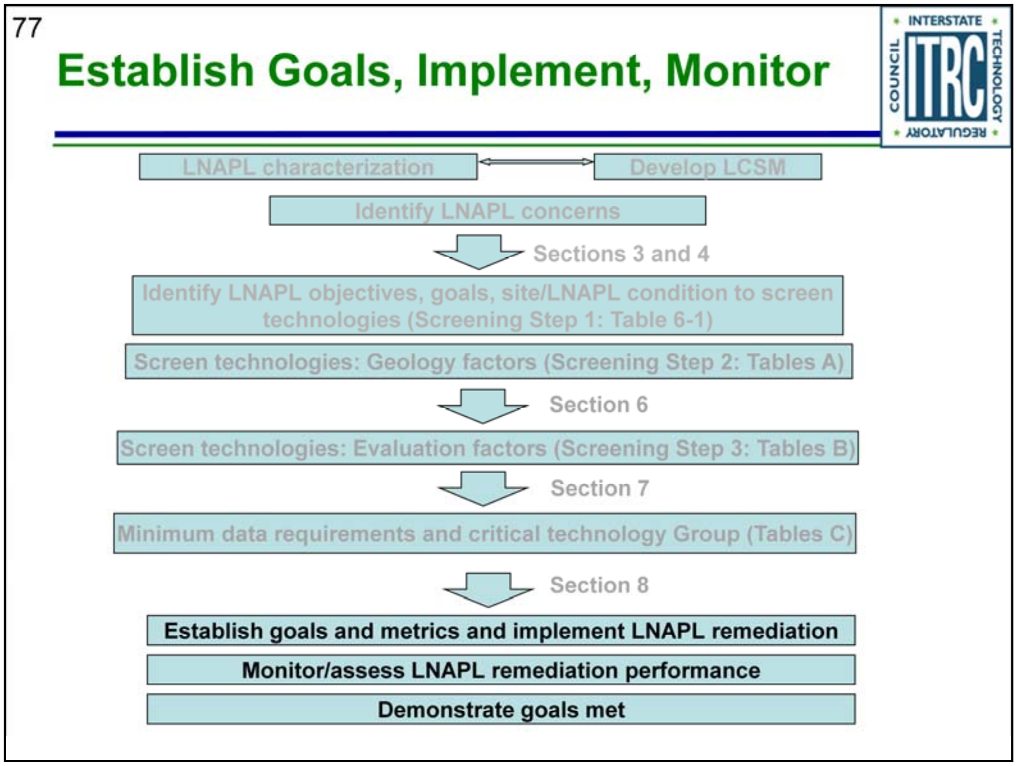
No associated notes.

Section 8 – Critical Criteria Table 8-1

	Minimum data requirements			
LNAPL Technology (Appendix A Table with further details)	**Site Specific Data for Technology Evaluation**	**Bench Scale Testing**	**Pilot Testing**	**Full-Scale Design**
Natural Source Zone Depletion (NSZD) (A-4.C)	Qualitative and quantitative site evaluation data (ITRC 2009; Johnson et al. (2006)	Leaching and accelerated weathering tests (ITRC 2009 ; Johnson et al. 2006)	Quantitative evaluation data (ITRC 2009; Johnson et al., 2006)	Quantitative evaluation data and predictive modeling (ITRC 2009; Johnson et al., 2006)



An example from Table 8-1 and the type of information shown.



So now we picked a technology. Time to establish goals (before system deployment) then monitor, and demonstrate that goals are met.

Next, we will go through a case example starting at LCSM building through technology selection.

78

Case Study: Former Midwestern Refinery

- Site history
- LNAPL Conceptual Site Model (LCSM) development
  - Characterize physical and chemical state of the LNAPL body
  - WHY? Facilitates understanding of the LNAPL conditions, site risks, and how best to remediate
- ITRC LNAPL Technical and Regulatory Guidance application (starting from Section 6)
- Focus on LNAPL mass recovery
  - Other work done to show LNAPL stable using tracers, to quantify effects effective solubility and mass flux to groundwater, etc.

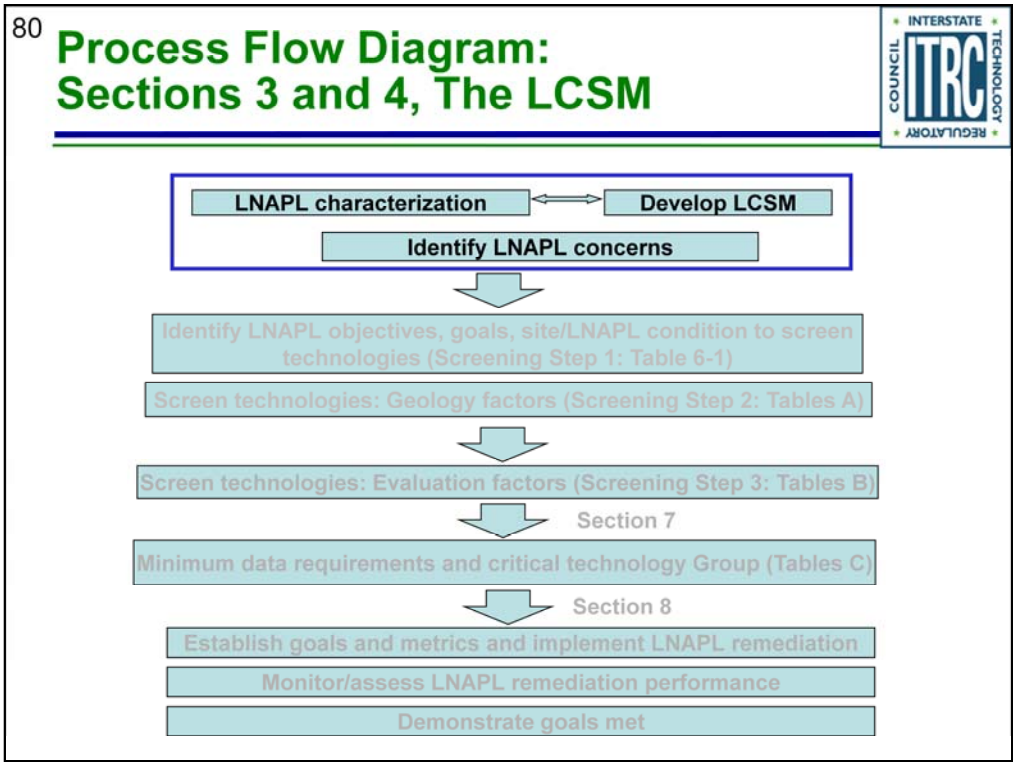
This is the outline for the case study.

79

Former Midwestern Refinery Site History

- Began refining in early 1900's
- Maximum capacity was 50,000 BBL/day (mid 1970s)
- Refinery was closed mid 1980s and has been decommissioned
- Approximately 1200 acres
- On-site waste water treatment (WWT)

This is a big site (~1200 acres), I also want to highlight what might be different at smaller sites. Throughout the case study, there will be a light green box with, "What about a service station?" I will describe how a smaller site or a more financially constrained site might go through the process as well.

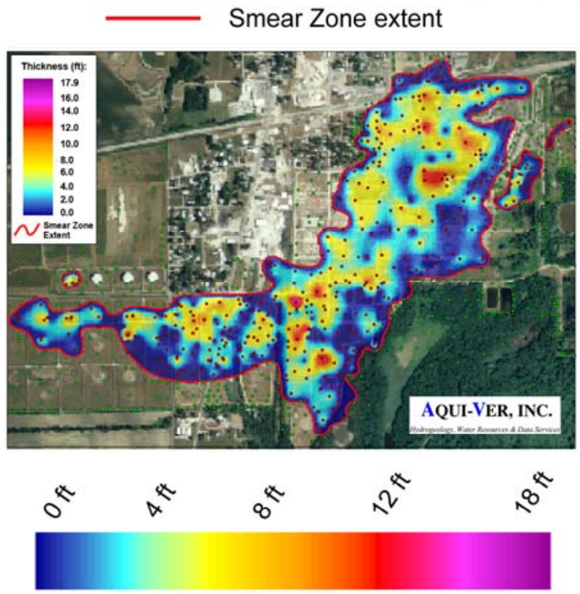


Quick pass through slide, first step is LCSM building.

81

Former Midwestern Refinery LCSM Development

- Smear zone delineation (X, Y, Z)
- Review of historic conventional data
  - Wells with LNAPL
  - Dissolved phase indicators
  - Soil sample and PID indicators from soil borings
- Approximately 200 acre footprint smear zone of varying thickness and impact

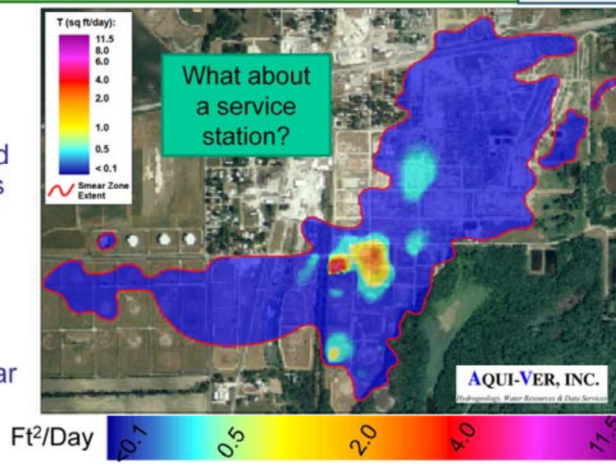


Forensic data analysis led to a high resolution snapshot of the smear zone.

82

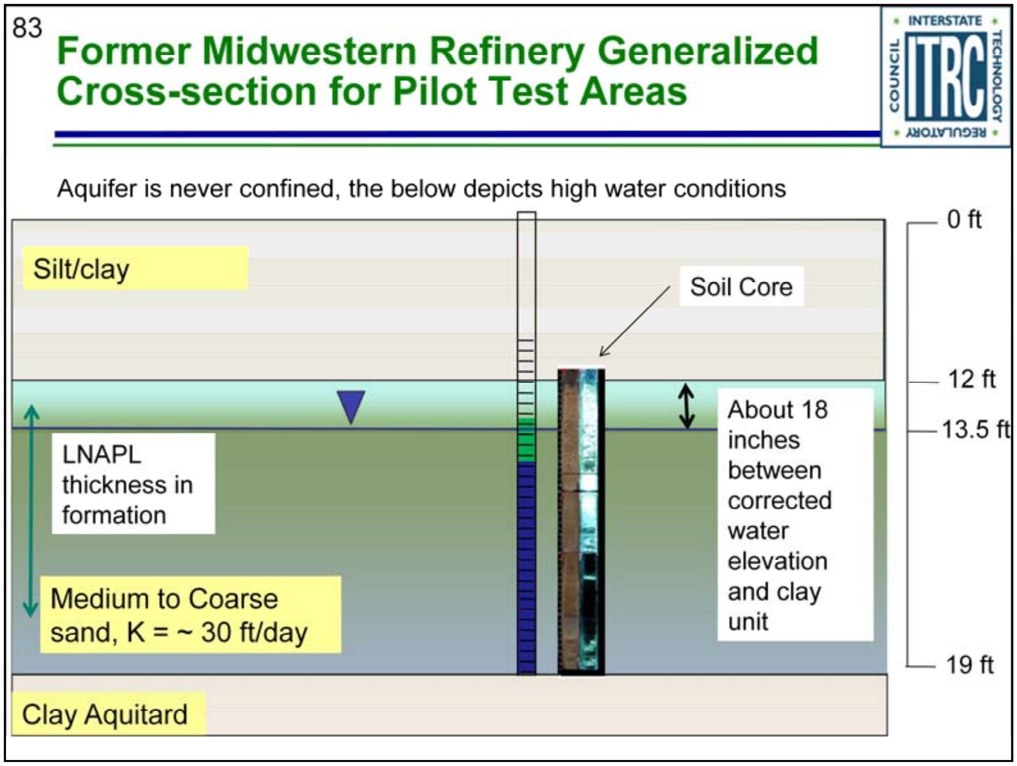
Smear Zone Transmissivity (Property of Fluid, Aquifer Material, and LNAPL Formation Thickness)

- LNAPL baildown tests conducted in all wells with LNAPL
- Transmissivity was used to focus remedial efforts where LNAPL mass recovery had a high likelihood of success
- Area of transmissivity over **1 ft²/day** is 20 acres (of 200 acre smear zone)



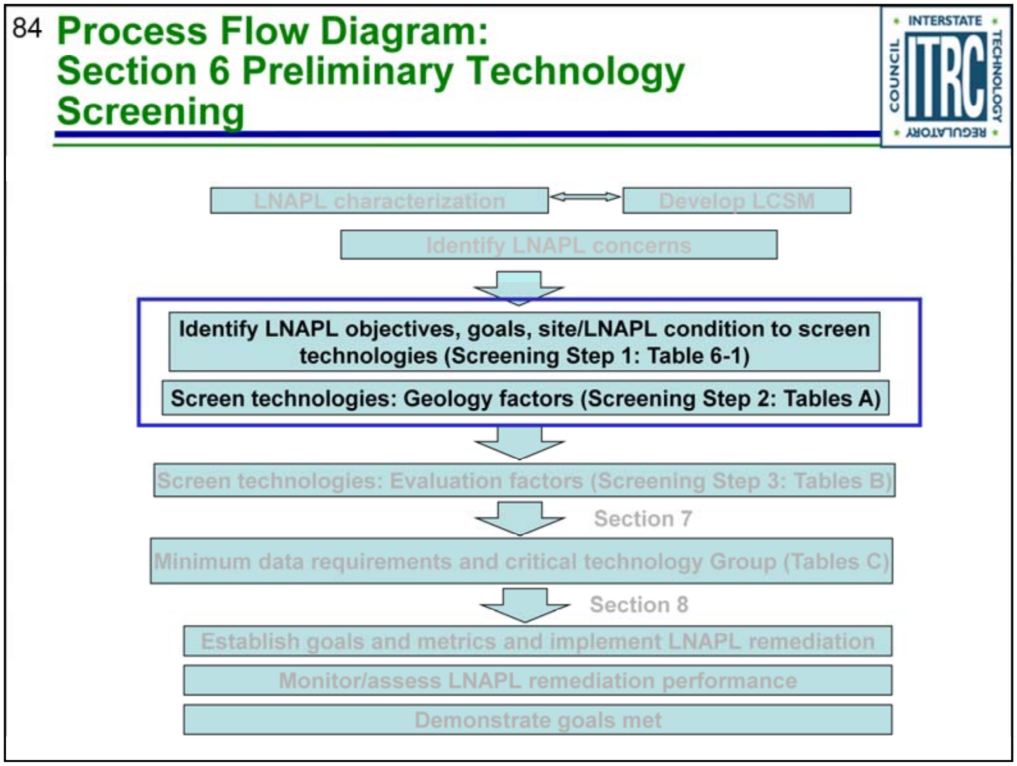
ASTM Standard Guide for Estimation of LNAPL Transmissivity (ASTM E2856 - 13)
http://www.astm.org/Standards/E2856.htm
API LNAPL Transmissivity Workbook - http://www.api.org/environment-health-and-safety/clean-water/ground-water/lnapl/lnpl-trans.aspx

No associated notes.



Important: There is about 18 inches of unsaturated above the water table, but below the overlying surficial clay unit.

Soil core: from a petrophysical lab. The left side of the graphic shows the core photographed under natural light. The graphic on the right shows the core photographed under UV light. LNAPLs will fluoresce under UV light, the LNAPL saturation is related to the UV light. The higher the fluorescence the greater amount of LNAPL in the pore spaces. The “white” in the core is the area of highest LNAPL saturation.



Quick slide, moving to Section 6.

85

Using Table 6.1 to Determine Technologies for Pilot Testing

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic Tech limit or limited/ infrequent well thickness, decline curve analysis	-Dual Pump Liquid Extraction[C, S, , LS, HV, HS] -Multi-Phase Extraction (Dual Pump) [C, S, , LS, HV, HS] -Multi-Phase Extraction (Single Pump) [C, S, , LS, HV, HS]

- So now, with basic LNAPL knowledge (Training Part 1), the LNAPL concern is based on science, and a LNAPL Conceptual Site Model (LCSM) was created (Training Part 2)
- Now the ITRC LNAPL Technical and Regulatory Guidance will be used as a framework for LNAPL remedial technology

This site will focus on the above LNAPL Remedial Objective.

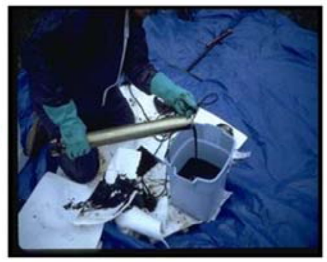
86

Goals for Pilot Testing

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objectives	LNAPL Remedial Goals	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic Tech limit or limited/ infrequent well thickness, decline curve analysis	-Dual Pump Liquid Extraction[C, S, , LS, HV, HS] -Multi-Phase Extraction (Dual Pump) [C, S, , LS, HV, HS] -Multi-Phase Extraction (Single Pump) [C, S, , LS, HV, HS]

- Pilot testing will occur in 2 areas with similar in-well LNAPL thicknesses but different viscosities to:
  - Verify and refine parameters collected during the LCSM (transmissivity and hydraulic (water) conductivity)
  - Predict LNAPL recovery using LNAPL Distribution and Recovery Model (LDRM) (American Petroleum Institute, www.api.org)
  - Determine most efficient technology to meet goals



At the site, we decided to conduct a pilot test between Guidance Sections 6 and 7. We did this because any system deployed would be expensive enough such that time spent on a short term pilot test would greatly reduce uncertainty about remediation selection.

The pilot test will occur in 2 different areas, with similar in-well LNAPL thickness, but very different viscosities, and transmissivities.

Graphic: Baildown testing as part of characterization stage.

LNAPL Distribution and Recovery Model (LDRM) from American Petroleum Institute, www.api.org
http://www.api.org/ehs/groundwater/lnapl/lnapl-reg.cfm?dl=ok&CFID=27565067&CFTOKEN=70898339&jsessionid=9630500d251277433a55

87

Technologies Chosen from Table 6.1 and A Series Tables

Table 6-1. Preliminary Screening Matrix

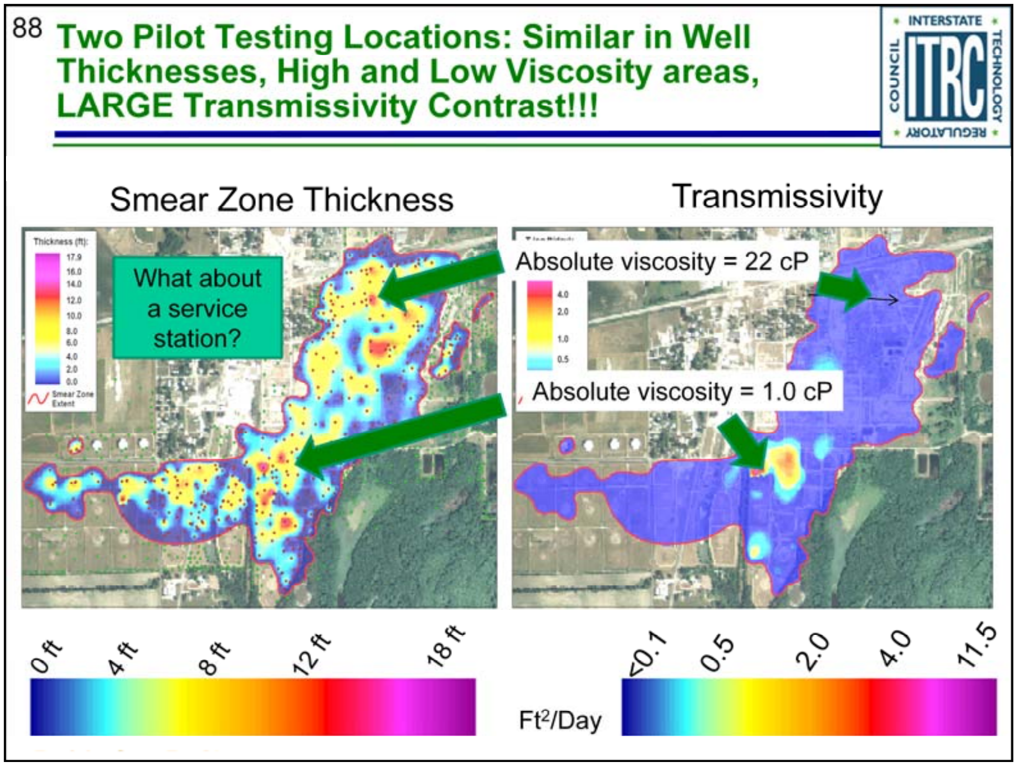
LNAPL Remedial Objectives	LNAPL Remedial Goals	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic Tech limit or limited/ infrequent well thickness, decline curve analysis	-Dual Pump Liquid Extraction[C, S, LV, LS, HV, HS] -Multi-Phase Extraction (Dual Pump) [C, S, LV, LS, HV, HS] -Multi-Phase Extraction (Single Pump) [C, S, , LS, HV, HS]

- Four technologies chosen and conducted in tandem:
  - LNAPL skimming
  - Enhanced fluid recovery (EFR)
  - Dual pump liquid extraction (DPLE)
  - Multi-phase extraction (dual pump)

What about a service station?

The four technologies chosen and the rest of Table 6-1 are shown.

Service Station: A pilot might not be conducted, or only one technology might be tested.



So pilot test were conducted is in 2 areas, similar in-well thicknesses, but much different transmissivities. With only knowledge of the graphic on the right, resolution of LNAPL transmissivity is lost.

Service Station: Only one type of LNAPL, and only one area for pilot testing.

89

Why Were Some Technologies Screened Out?

Table 6-1. Preliminary Screening Matrix

LNAPL Remedial Objectives	LNAPL Remedial Goals	Technology Group	Example Performance Metrics	LNAPL Technology and LNAPL/Site Conditions
Reduce LNAPL saturation when LNAPL is above the residual range	Reduce recoverable LNAPL to extent practicable	LNAPL mass recovery	Asymptotic Tech limit or limited/ infrequent well thickness, decline curve analysis	-Dual Pump Liquid Extraction[C, S, , LS, HV, HS] -Multi-Phase Extraction (Dual Pump) [C, S, LS, HV, HS] -Multi-Phase Extraction (Single Pump) [C, S, LS, HV, HS] -Water Flooding [C, S, , LS, HV, HS] -LNAPL Skimming [F, C, S, , LS, HV, HS] -Bioslurping/EFR [F, C, S, , LS, HV, HS] -Excavation [F, C, U, S, , LS, HV, HS] -NSZD [F, C, U, S, HV, HS]

- **MPE Single Pump**: On-site waste water treatment (WWT) incompatible with NAPL/water stream
- **Water flooding**: Regulatory issues with injecting untreated groundwater
- **Bioslurping**: This site not focused on aerobic biodegradation
- **Other?**

No associated notes.

90

Pilot Test Instrumentation and Additional Data Collection

- In each location a 6” stainless steel well is installed
  - Why: To avoid well screen inefficiencies due to small diameters and/or PVC swelling in contact with LNAPL
- Continuous soil cores are collected during
  - Why: To collect soil capillary parameters (van Genuchten and Brooks-Corey) for as inputs to models to predict total recovery
- 2” PVC monitoring wells at 5, 15, and 25 feet
  - Why: To calculate radius of influence (ROI) and radius of vacuum influence (ROVI) during pilot testing and refine hydraulic conductivity estimates

No associated notes.

91

Pilot Test Set-up

Picture of Pilot Test Set-up.

92

Pilot Test Results in Gallons
(test time: 72 hours of pseudo-steady state conditions)

No Additional Benefit

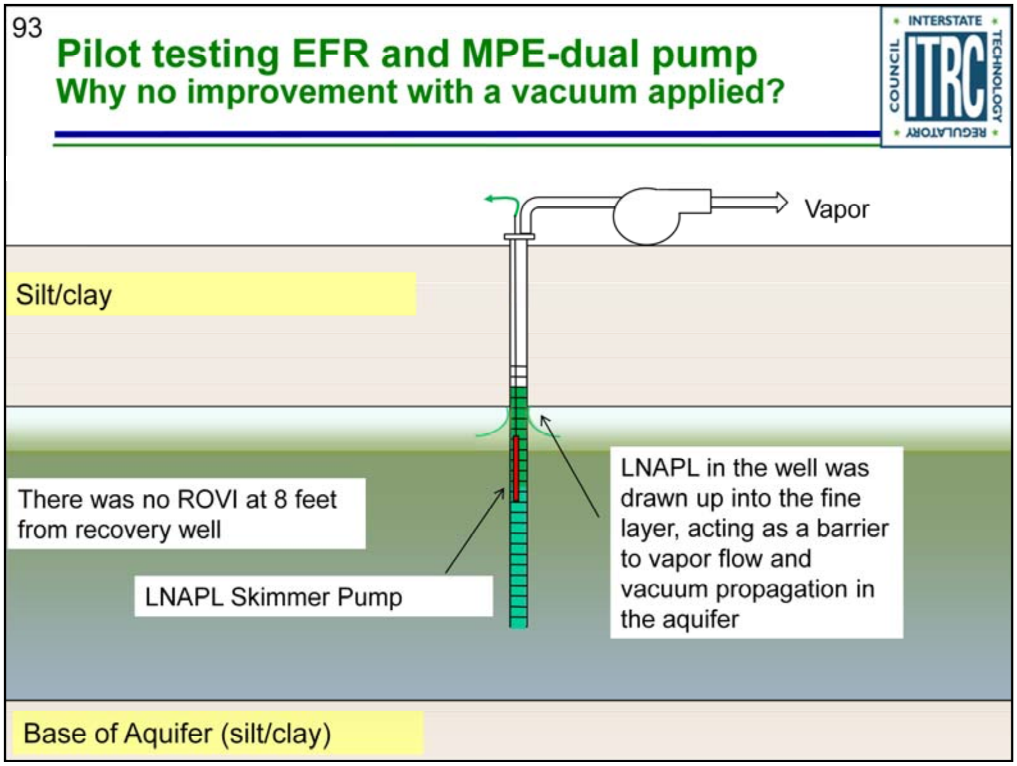
	LNAPL Skimming	Enhanced Fluid Recovery	Dual Pump Liquid Extraction	Multiphase Extraction (dual pump)
Low Viscosity Area (1 cP)	40	**40**	600	**600**
High Viscosity Area (22 cP)	0	0	0	0

- Enhanced Fluid Recovery (EFR) and Multi-phase extraction (MPE) did not increase LNAPL recovery
- High viscosity area had NO LNAPL recovery despite > 5 feet of LNAPL in well at static conditions
- Pilot test demonstrated high viscosity (low transmissivity) areas not hydraulically recoverable.
- Hydraulic recovery focus shifted to areas with a transmissivity greater than 1 ft^2/day (20 acre area)

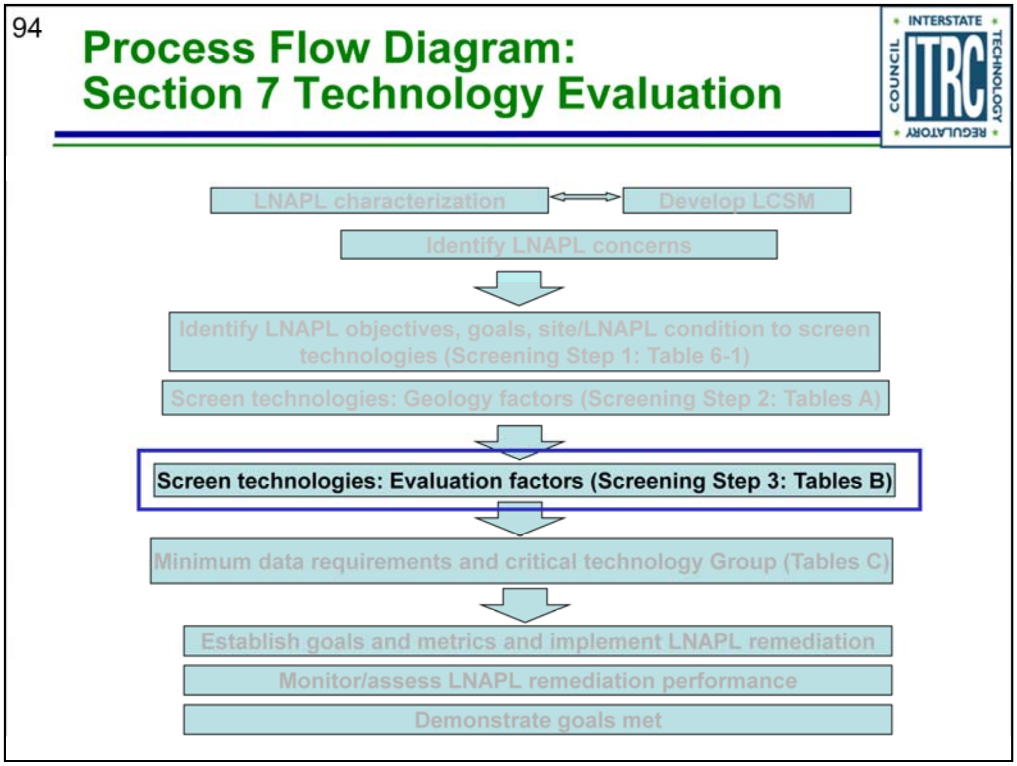
The vacuum enhanced technologies did not provide additional benefit.

The high viscosity area had NO LNAPL recovery. This shows it is infeasible to recover LNAPL here even though there is a large in-well thickness. This also verifies the baildown test result indicating a low transmissivity.

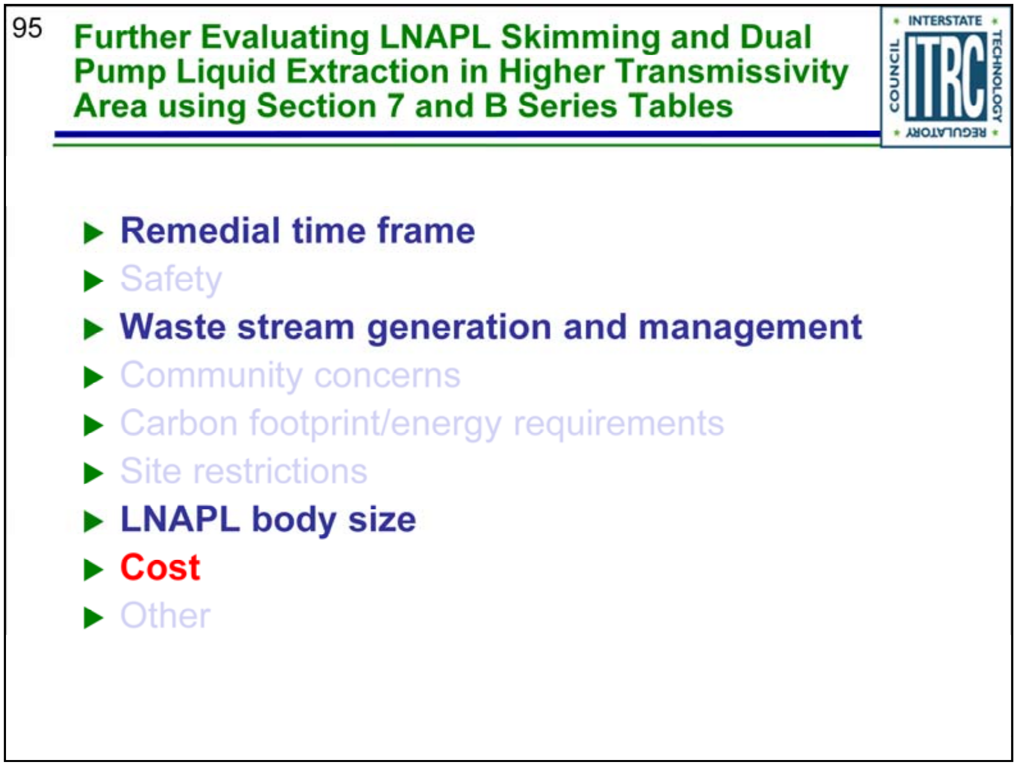
So, the focus is on skimming and DPLE in the low viscosity (high transmissivity area).



Why the vacuum failed: Vacuum drew water above the sand/clay contact cutting of vacuum propagation.



Moving into Section 7 with 2 technologies.



Moving on to Section 7, the important evaluation factors are shown bolded above.
Cost factors into the above three.

96

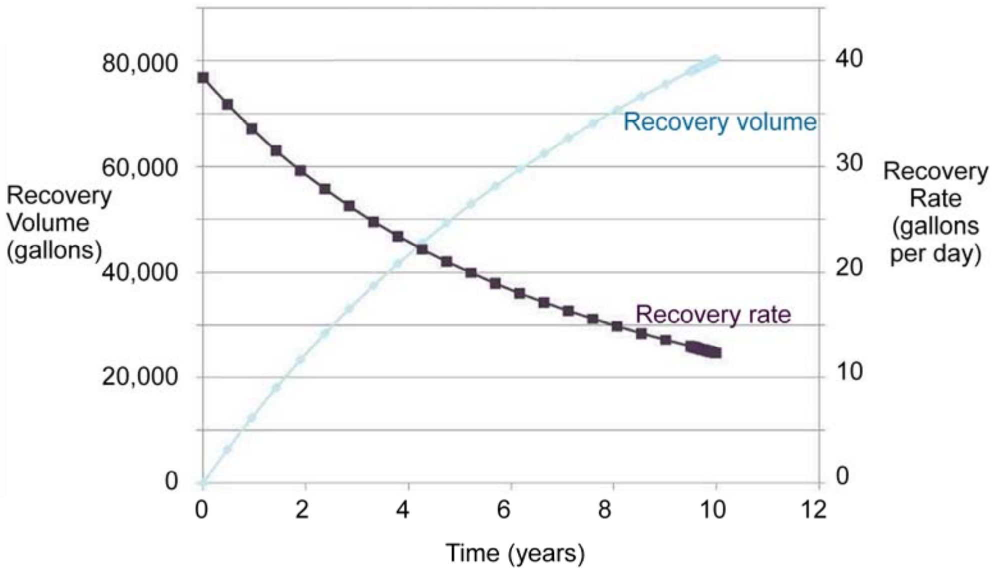
Evaluating LNAPL Skimming and Dual Pump Liquid Extraction in Higher Transmissivity Area using Section 7 and B Series Tables

		LNAPL Skimming	Dual Pump Liquid Extraction	Important Characteristics
Remedial Time Frame	Concern	High	Moderate	Ties in directly to capital versus longer term O&M Costs.
	Discussion	Long to very long. Depends on soil type, LNAPL type, release size, footprint, and end point.	Medium. Depends on soil type, LNAPL type, release size, footprint, and end point.	
Waste Management	Concern	Low to moderate	Moderate	There is an existing Waste water treatment system, only costs is for only electricity
	Discussion	Recovered LNAPL requires treatment, disposal, and/or recycling.	Recovered LNAPL and groundwater water need to be properly disposed. Need wastewater treatment.	
LNAPL Body Size	Concern	Moderate to High	Low	There will be fewer but more expensive to operate DPE wells.
	Discussion	The size of the LNAPL body directly affects the cost. Skimming radius of influence effects the number of wells required to address the LNAPL Body.	Capable of remediating larger LNAPL bodies. Lithology and permeability determine the spacing between recovery wells..	

The next slides will be a side-by-side comparison of the three evaluation factors for the two technologies.

Remedial Time frame: DPLE will reach technical endpoint much faster.

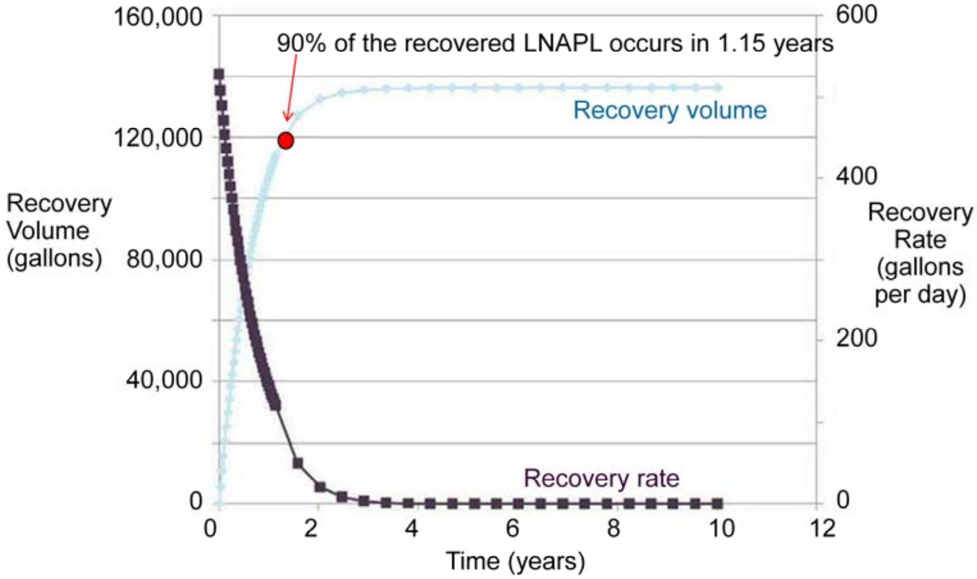
Extrapolated Results Using API's LDRM: LNAPL Skimming: Not Yet Asymptotic After 10 years!



Skimming will occur for longer than ten years (LDRM model prediction)

98

LDRM Dual Pump Liquid Extraction: Asymptotic After 1.15 years



DPLE will reach asymptotic recovery in less than 2 years (LDRM model).

99

Waste Management Between Skimming and Dual Pump Liquid Extraction

		LNAPL Skimming	Dual Pump Liquid Extraction	Important Characteristics
Remedial Time Frame	Concern	High	Moderate	Ties in directly to capital versus longer term O&M Costs.
	Discussion	Long to very long. Depends on soil type, LNAPL type, release size, footprint, and end point.	Medium. Depends on soil type, LNAPL type, release size, footprint, and end point.	
Waste Management	Concern	Low to moderate	Moderate	There is an existing Waste water treatment system, only costs is for only electricity
	Discussion	Recovered LNAPL requires treatment, disposal, and/or recycling.	Recovered LNAPL and groundwater water need to be properly disposed. Need wastewater treatment.	
LNAPL Body Size	Concern	Moderate to High	Low	There will be fewer but more expensive to operate DPE wells.
	Discussion	The size of the LNAPL body directly affects the cost. Skimming radius of influence effects the number of wells required to address the LNAPL Body.	Capable of remediating larger LNAPL bodies. Lithology and permeability determine the spacing between recovery wells..	

Key point: On site WWTP. The extra water production (waste stream) can be easily and cheaply treated.

100

LNAPL Body Size Between Skimming and Dual Pump Liquid Extraction

		LNAPL Skimming	Dual Pump Liquid Extraction	Important Characteristics
Remedial Time Frame	Concern	High	Moderate	Ties in directly to capital versus longer term O&M Costs.
	Discussion	Long to very long. Depends on soil type, LNAPL type, release size, footprint, and end point.	Medium. Depends on soil type, LNAPL type, release size, footprint, and end point.	
Waste Management	Concern	Low to moderate	Moderate	There is an existing Waste water treatment system, only costs is for only electricity
	Discussion	Recovered LNAPL requires treatment, disposal, and/or recycling.	Recovered LNAPL and groundwater water need to be properly disposed. Need wastewater treatment.	
LNAPL Body Size	Concern	Moderate to High	Low	There will be fewer but more expensive to operate DPE wells.
	Discussion	The size of the LNAPL body directly affects the cost. Skimming radius of influence effects the number of wells required to address the LNAPL Body.	Capable of remediating larger LNAPL bodies. Lithology and permeability determine the spacing between recovery wells..	

Key point: This is a big site, cost tradeoff between a lot of skimmer wells versus fewer DPLE wells

101 **Further Evaluating LNAPL Skimming and DPLE in Higher Transmissivity Area using Section 7 and B Series Tables**

	LNAPL Skimming	Dual Pump Liquid Extraction
Remedial Time Frame		X
Waste Management		X
LNAPL Body Size	X	X

- For the refinery, DPLE looks to be superior to skimming.
- Let's double check this using Section 8 and the C-Series tables

DPLE wins:

Shorter time frame
Not a huge problem from water treatment
Large LNAPL body size

102

What about a SERVICE STATION???

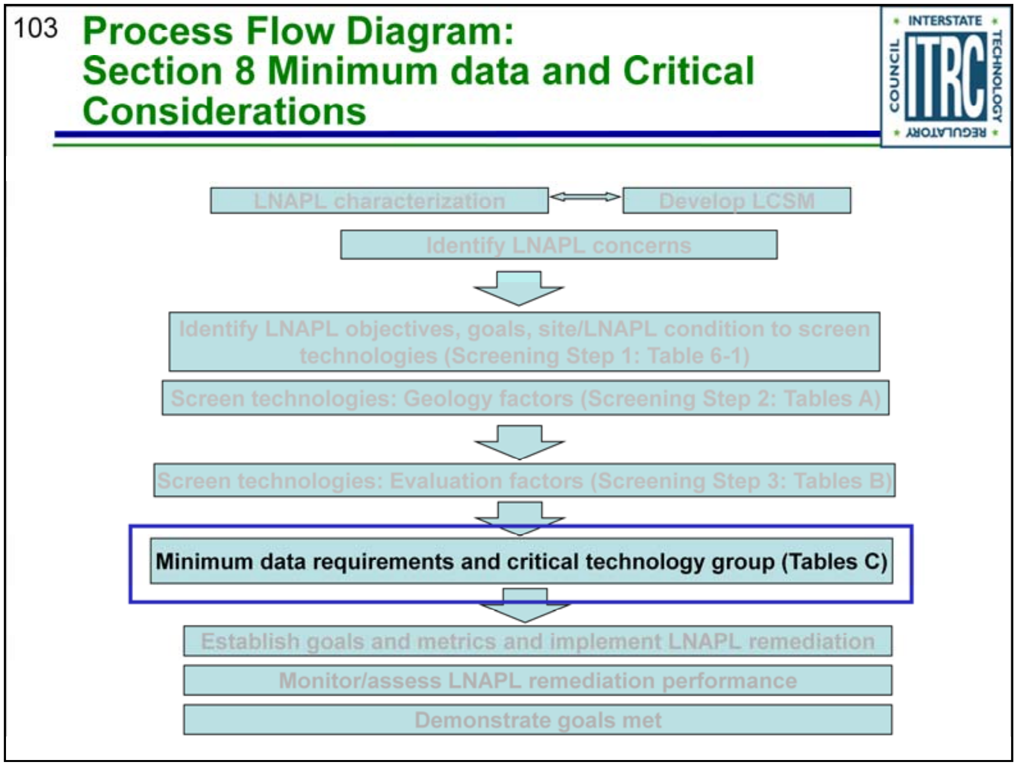
	LNAPL Skimming	Dual Pump Liquid Extraction
Remedial Time Frame		X
Waste Management	X	
LNAPL Body Size	X	

- A service station would likely have a smaller LNAPL body and greater difficulty in treating produced water (no convenient waste water treatment (WWT))

DPLE still has a more attractive time frame

Water might be difficult to treat due to size of service station, and discharge will have to be permitted.

Smaller LNAPL body might mean only 1 or 2 skimmer wells (compared to 1 DPLE well)



Moving through to Section 8, what else do we need to look out for.

Section 8 – Critical Criteria For Dual Pump Liquid Extraction

Table A-8.C. Technical implementation considerations for dual-pump liquid extraction

Data requirements	Full-scale design	Number of extraction wells	Determine number of required DPLE wells necessary to achieve adequate zone of LNAPL recovery consistent with LNAPL site objective(s).
		Groundwater ROC	Establish groundwater capture for different groundwater pumping rates. For continuous pumping systems, determine acceptable pumping rate that may be sustained without creating unacceptable drawdown.
		LNAPL ROC	Establish LNAPL capture for different LNAPL pumping rates. For continuous pumping systems, determine acceptable pumping rate that may be sustained without creating unacceptable drawdown.

- What else is in the C-Series Tables:
  - Site specific data for evaluation
  - Bench and Pilot Scale testing

This is the type of information found in the C-series tables. Highlighted is an example of ROC.

Technology Selection Framework and Case Study Summary

- LNAPL Remediation is an iterative process
  - From identifying LNAPL concerns
  - To demonstration of meeting LNAPL goals
- Communication is key!
- ITRC LNAPL Technical and Regulatory Guidance provides technology selection framework
- Case study shows how technology selection framework applies

No associated notes.

Overall Training Summary

- Background information available
  - Training Part 1: An Improved Understanding of LNAPL Behavior in the Subsurface
  - Training Part 2: LNAPL Characterization and Recoverability
- Today's Training Part 3
  - LNAPL remedial technology overview
  - Remedial objective setting
  - LNAPL remedial technology selection framework
    - ITRC LNAPL Technical and Regulatory Guidance: *Evaluating LNAPL Remedial Technologies for Achieving Project Goals* (LNAPL-2, 2009)
- LNAPLs Classroom Training
- ***Current ITRC team***: LNAPL Update (more information at www.itrcweb.org)

No associated notes.

107

Thank You

Follow ITRC

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

Your feedback is important – please fill out the form at:

http://www.cluin.org/conf/itrc/LNAPLrt/feedback.cfm

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

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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

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