Lessons Learned from DNAPL Site Remediation

RITS 2013


The End!
2
RITS 2013: Lessons Learned from DNAPL Site Remediation

Give Away the "Ending": What have we learned from DNAPL Treatments?

- Remediation success is less about *"which technology"* and more about the strategy, planning, design, and implementation
- Biggest limitations are inherent to subsurface complexities
- Characterization and conceptual site model are key – new tools can help
- Complete treatment is not achievable; we have to manage residual
- Most *in situ* technologies have similar performance, except thermal is a higher performer
- Poor treatment performance usually = poor design/implementation
- Robust remedial design and application matters!

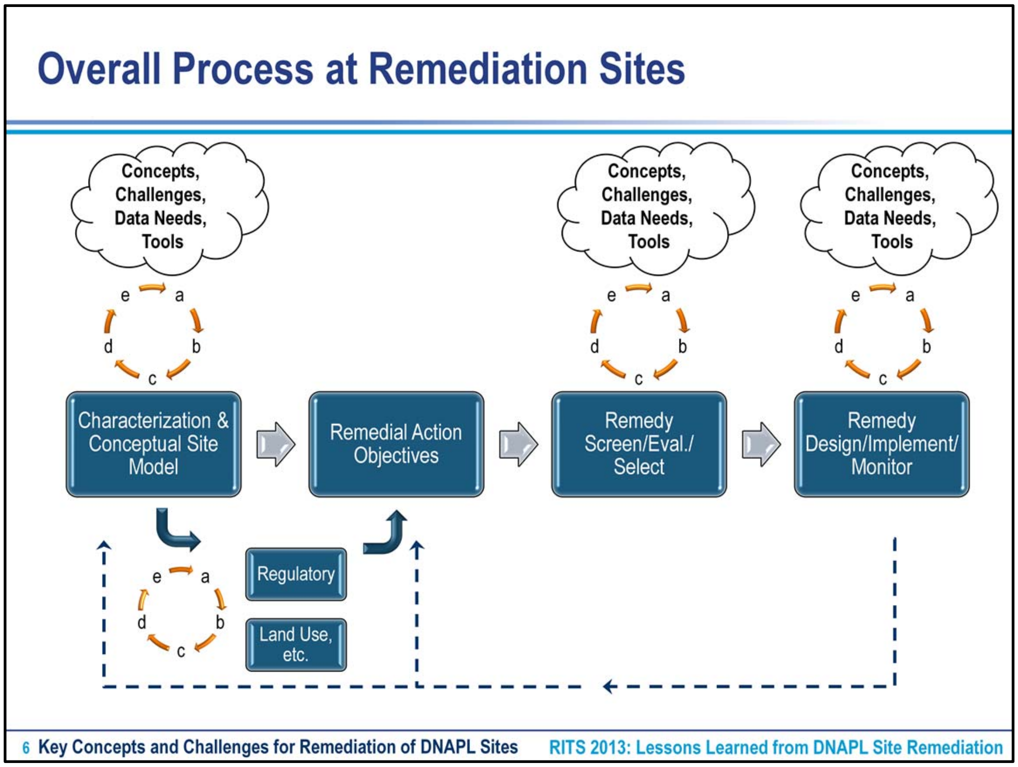
3 RITS 2013: Lessons Learned from DNAPL Site Remediation

Prior RITS Training Topics Relevant to Today's Topic

- 2012: Integrated DNAPL Site Strategy (IDSS)
- 2012: Optimization…
- 2011: Mass Flux and Mass Discharge
- 2010: *In Situ* Chemical Oxidation (ISCO)
- 2010: Alternative Endpoints and Other Approaches…
- 2010: Green and Sustainable Remediation (GSR)
- 2010: Using SiteWise™
- 2009: Getting the Most Out of Your Conceptual Site Model
- 2009: Environmental Restoration Resources
- And Others…

Presentation Overview

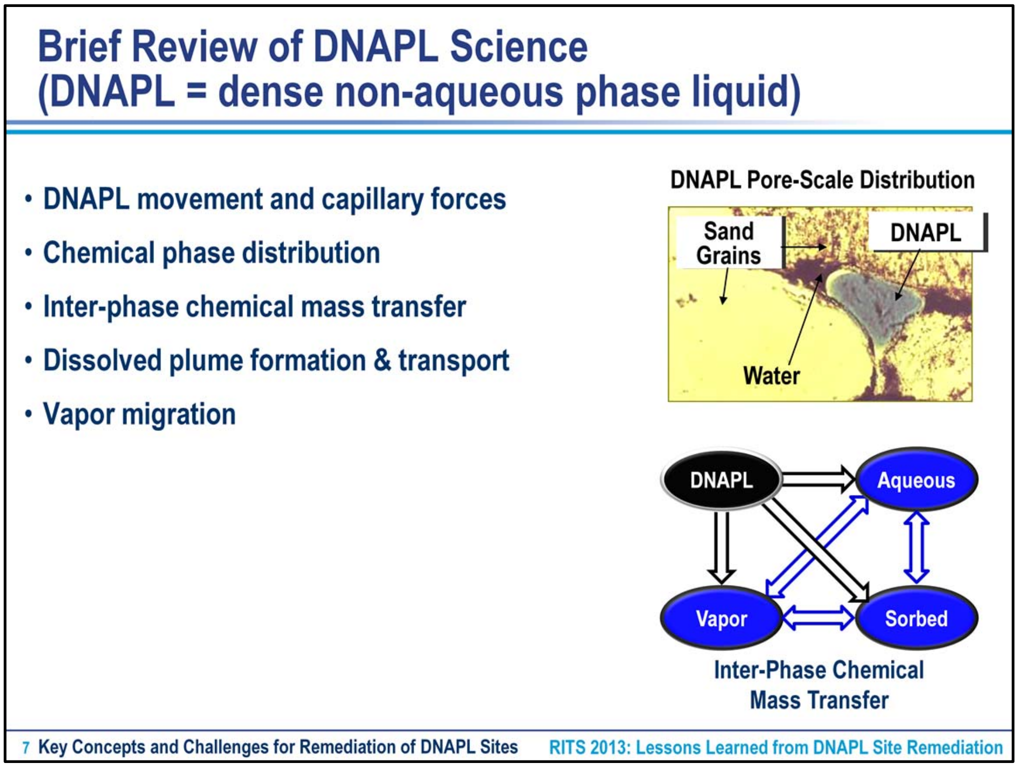
- ► **Key Concepts and Challenges for Remediation of DNAPL Sites**
- **Objectives, Data Needs, and Tools**
- **Focused NAVFAC Site Case Studies**
- **Synthesis – Best Practices and Future Directions**
- **Summary**



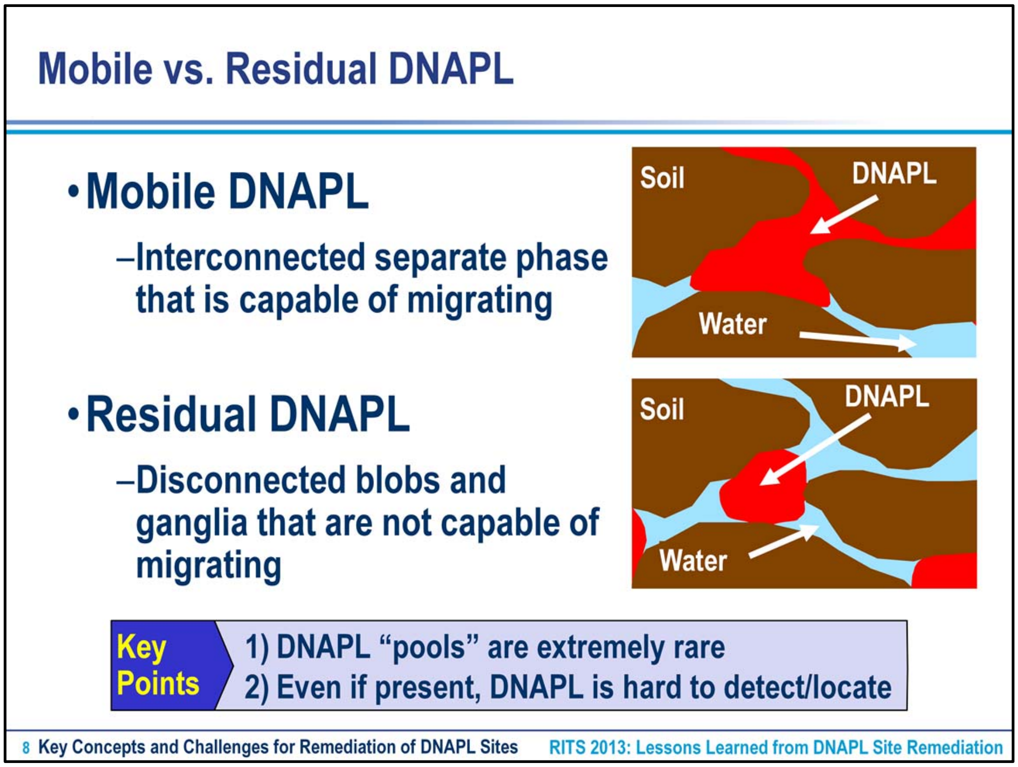
Reference: ITRC Integrated DNAPL Site Strategy (IDSS) document.

We want to focus on "lessons learned from DNAPL treatment", but to do so we have to focus on various elements throughout the process.

The CSM, objectives, screening, selection, design, implementation, and monitoring of the remedy all come into play.

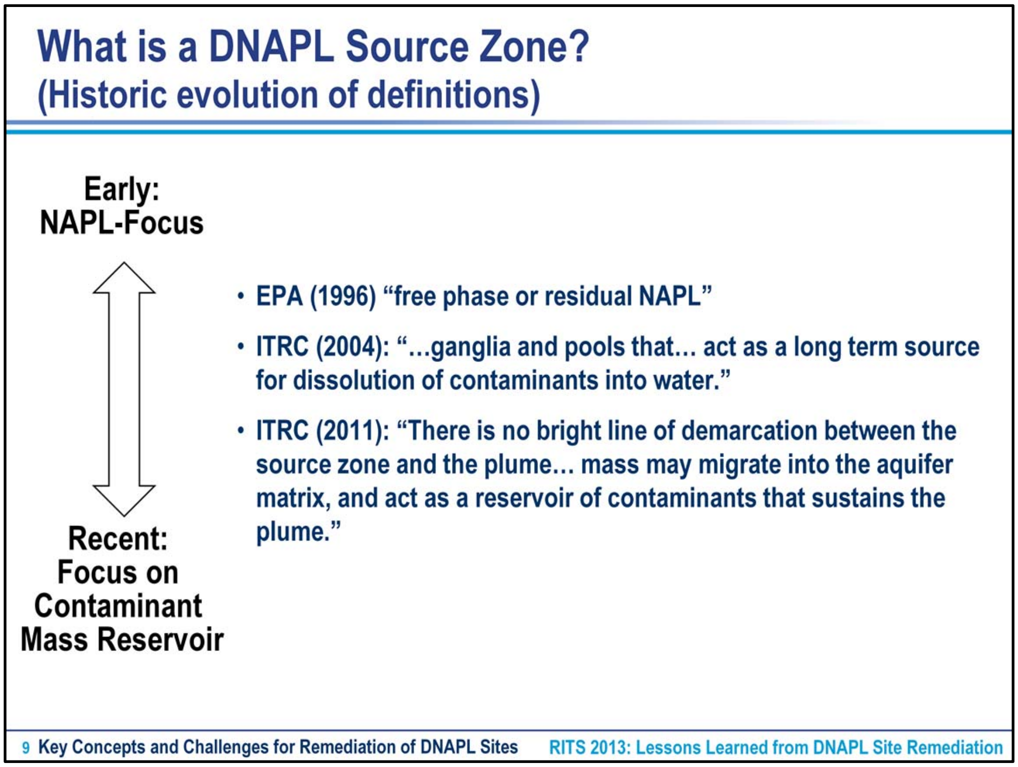


Only a very brief review of DNAPL science is provided in this presentation.

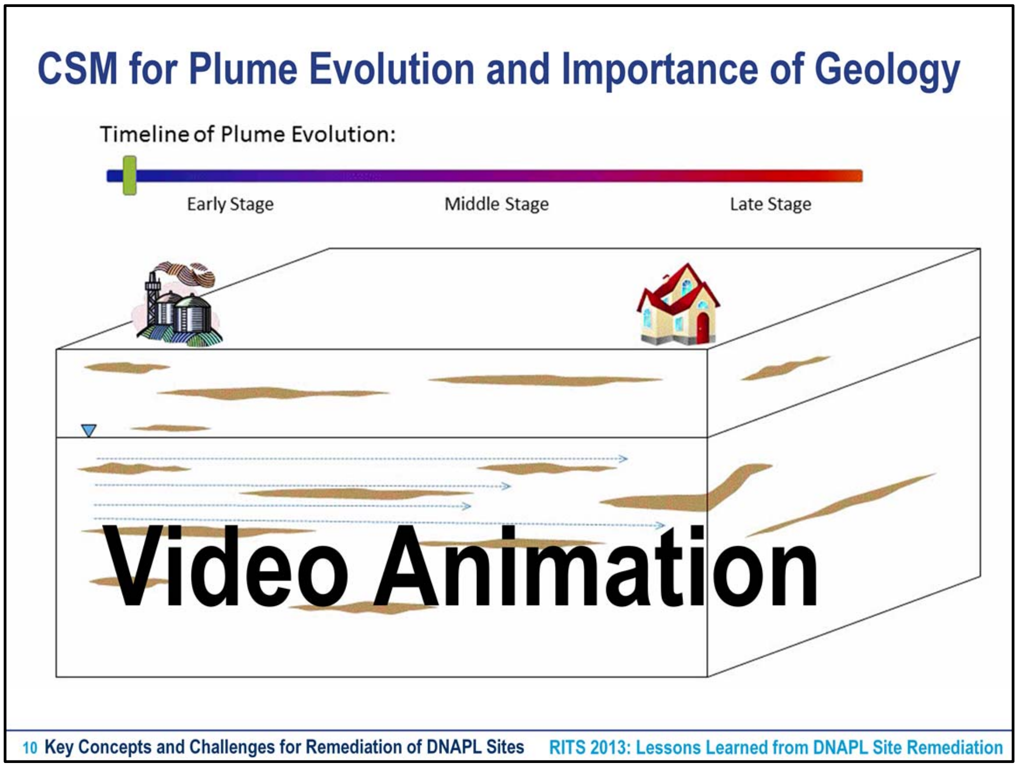


Later we will talk briefly about new tools for DNAPL characterization.

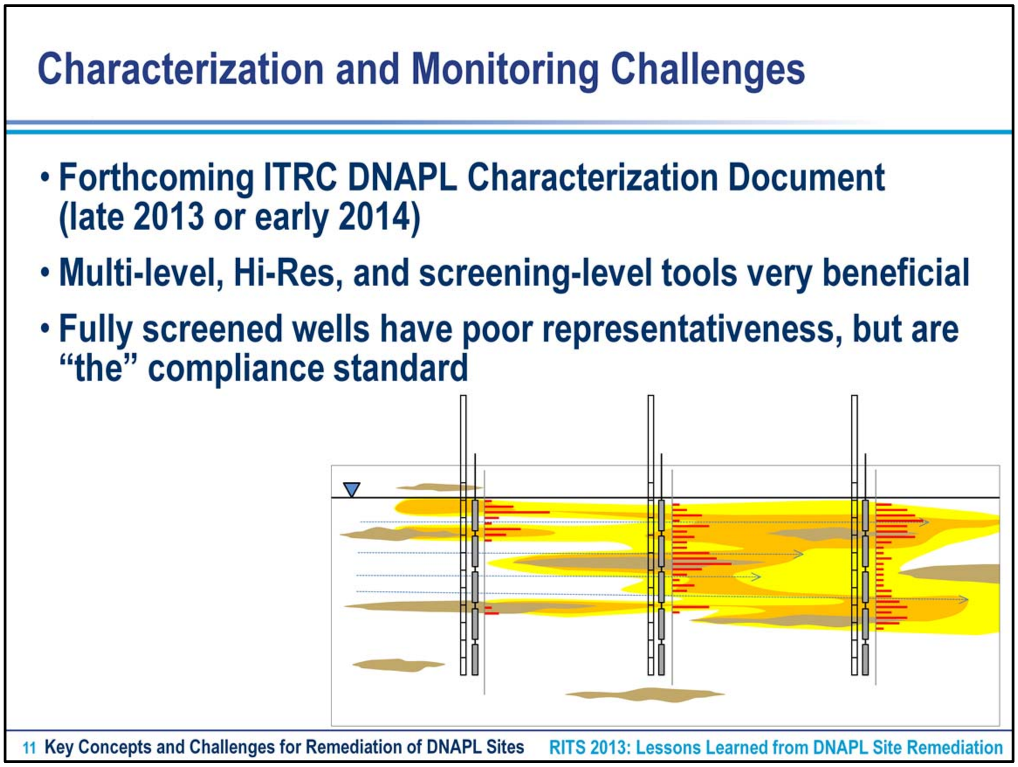
However, identifying DNAPL “itself” is perhaps less critical at many sites than we used to think.



Bottom line – a source zone is now considered to be less defined by the presence of DNAPL and more defined by other factors that lead to plume persistence. Primary in these considerations is the presence of contaminant mass reservoirs held in lower permeability media which provide a long term source of back-diffusion of contaminant mass into the plume.



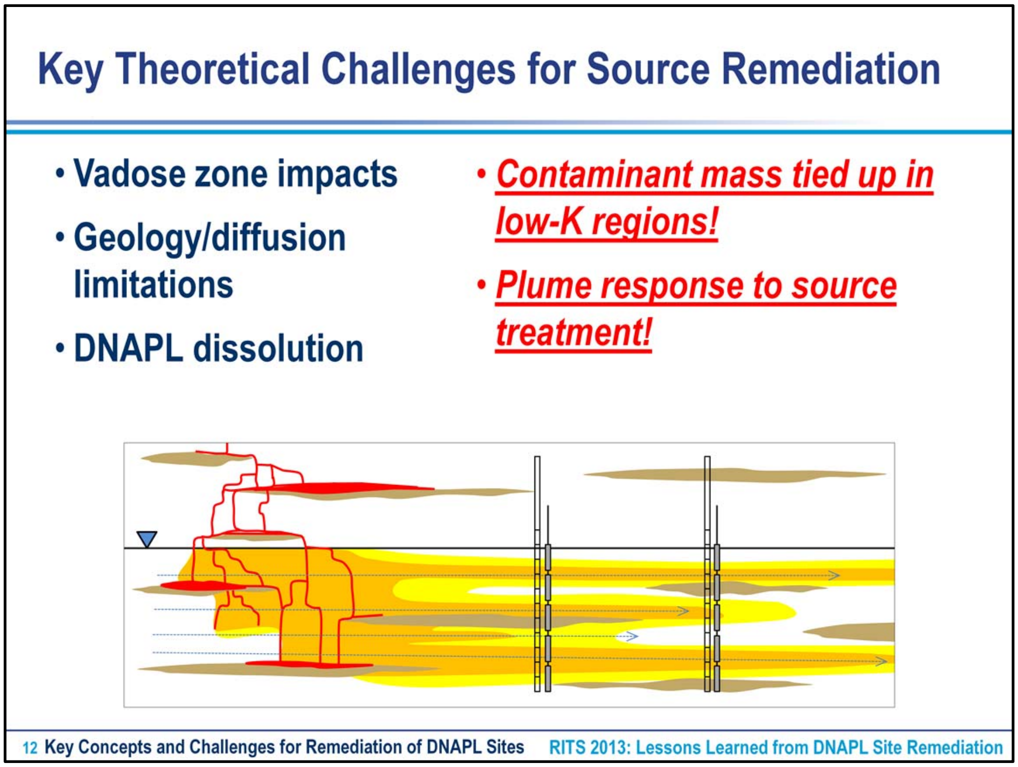
1) Importance of geology: 90% of flow in 10% of formation
2) Evolution: Early vs. middle vs. late stage
    - significant attenuation rate implied by “stable” plume represented here at middle stage
    - NAPL may or may not persist into late stage, although shown here to attenuate at middle stage
    - late stage concepts in source may result from passage of time, or from active source remediation
3) Matrix diffusion – early stage diffusion into and late stage back-diffusion out of low-K zones



Differences in information gathered through traditional fully screened monitoring wells and multi-level characterization can be visualized on this slide.

3 levels of characterization shown:

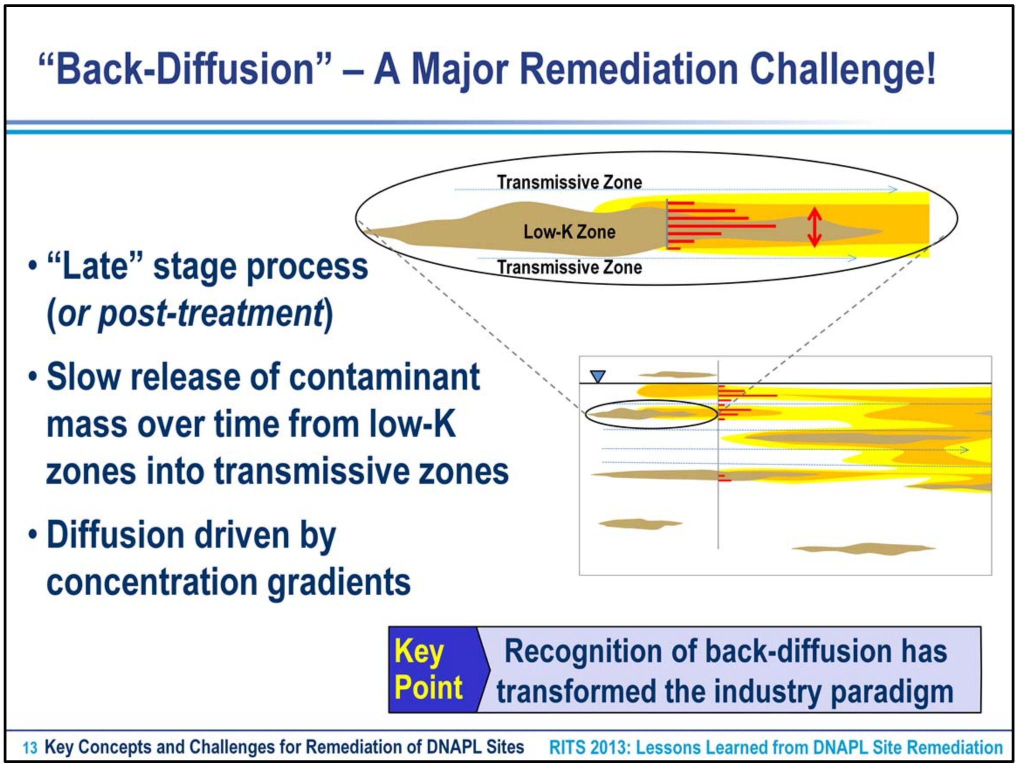
1) Traditional = fully screened MWs
2) Multi-level groundwater sampling (could be 2-3 levels, or more as shown)
3) Hi-resolution vertical profile. Could be soil sampling, groundwater sampling, or screening such as MIP



Contaminant mass is very heterogeneously distributed due to both:

1) Geology, and
2) DNAPL physics leading to discontinuous DNAPL distribution

Traditional fully screened monitoring wells don’t give us the full picture, so the importance of more highly resolved characterization data comes into play especially for remediation.

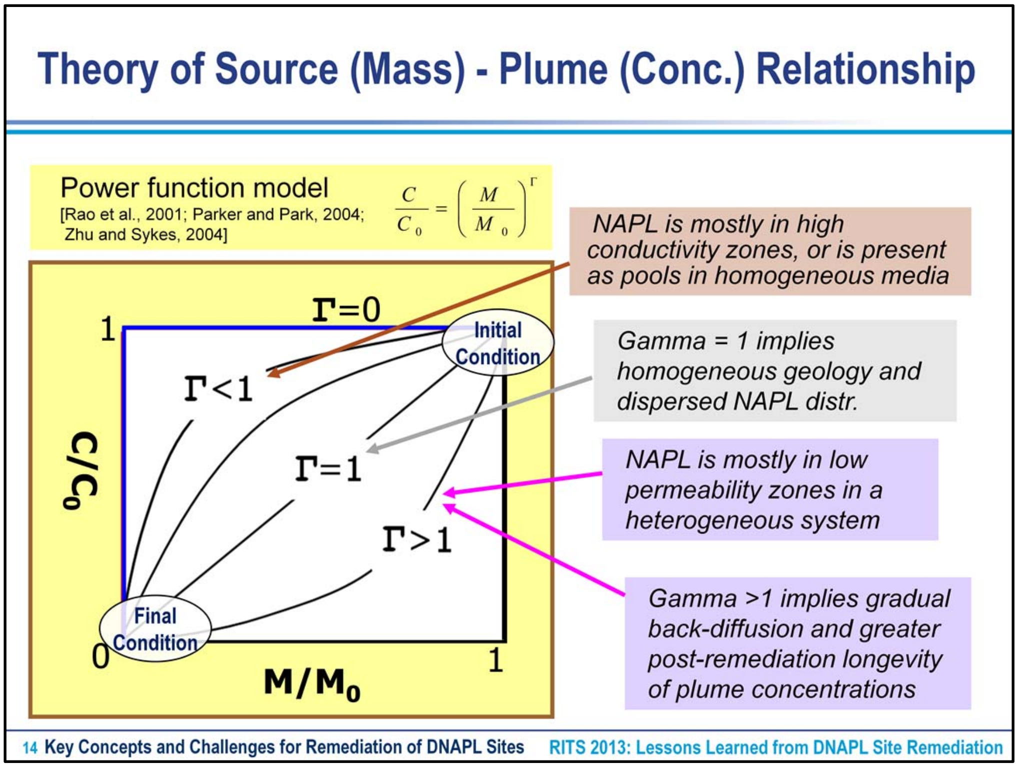


The late-stage contaminant distribution in this figure can result from long-term source attenuation, or from active source remediation that did not fully treat low-K zones.

Larger scale graphic is from video animation, and shows vertical profile of contaminant concentrations.

Zoom-in graphic shows finer-scale vertical delineation of contaminant concentration, which may not be measurable in reality depending on scale.

Transport by chemical diffusion always moves from high to low concentration.



Graphics adapted from Ron Falta presentation via EPA Clu-in.

Multiple possible paths from "initial condition" to "final condition"

Final condition is zero contaminant mass and zero concentration… may be decades or centuries away for highly impacted sites.

Movement along the path occurs over time through attenuation processes, or by active source mass remediation.

As source mass is reduced, can either have a proportional (1:1) reduction in concentration (gamma = 1), or…
Can have a greater or lesser effect of source mass reduction on concentration loading into the plume.

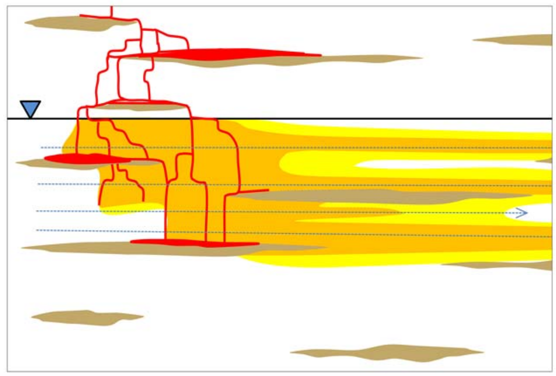
A trade-off exists for a given amount of mass reduction between:
(a) Greater concentration reduction but more long term plume longevity (gamma >1), and
(b) Lesser plume concentration reduction but shorter duration longevity (gamma <1).

Gamma >1 leads to common observation of (a) significant early-time decrease in groundwater concentration followed by (b) long-term asymptotically low levels. In that scenario, it may require substantial additional mass depletion to achieve lower groundwater concentrations.

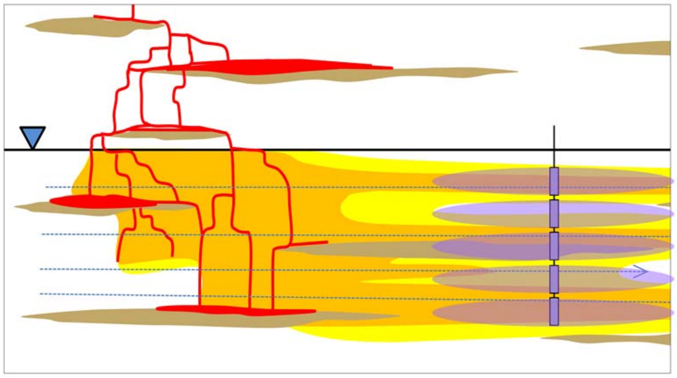
Key Practical Challenges for Source Remediation

- Subsurface delivery of amendments, *i.e.*, contacting target zone
- Permeability limitations on injection volume
- Having adequate characterization data pre- and post-treatment

Key Point Remediation design needs to target the contaminant mass distribution



Delivery Systems for *In Situ* Amendment Injection



- **Multiple variations:**
  - Permanent wells
  - Packers
  - Horizontal wells
  - Direct push points
  - Special injection tools
  - Injection only
  - Recirculation
- **Commonalities:**
  - Lithologic targeting
  - Process monitoring for amendment distribution

Key Point Innovation in delivery can be a critical success factor

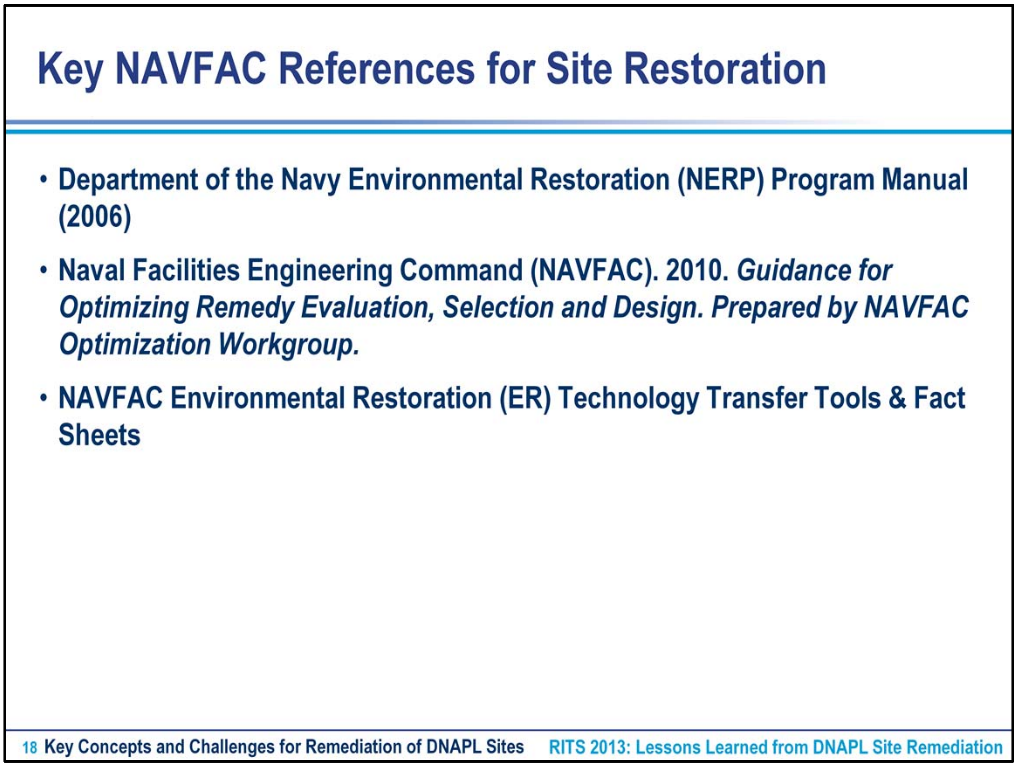
16 Key Concepts and Challenges for Remediation of DNAPL Sites RITS 2013: Lessons Learned from DNAPL Site Remediation

Delivery systems have to be selected considering site-specific conditions.

Specific Delivery Challenges

- **Stratigraphic/Lithologic Preferential Flow**
- **Density-Driven Flow**
  - Primarily relevant at percent-level amendment concentrations
  - Counteracted by: low vertical/horizontal permeability ratio and horizontal gradients
- **Reactive Transport Limitations**
  - Fast reacting amendments have limited radius of influence

Key Point
Fast-Reacting Amendments (oxidants) will not "drift"
Slow-Reacting Amendments (bio) transport more easily



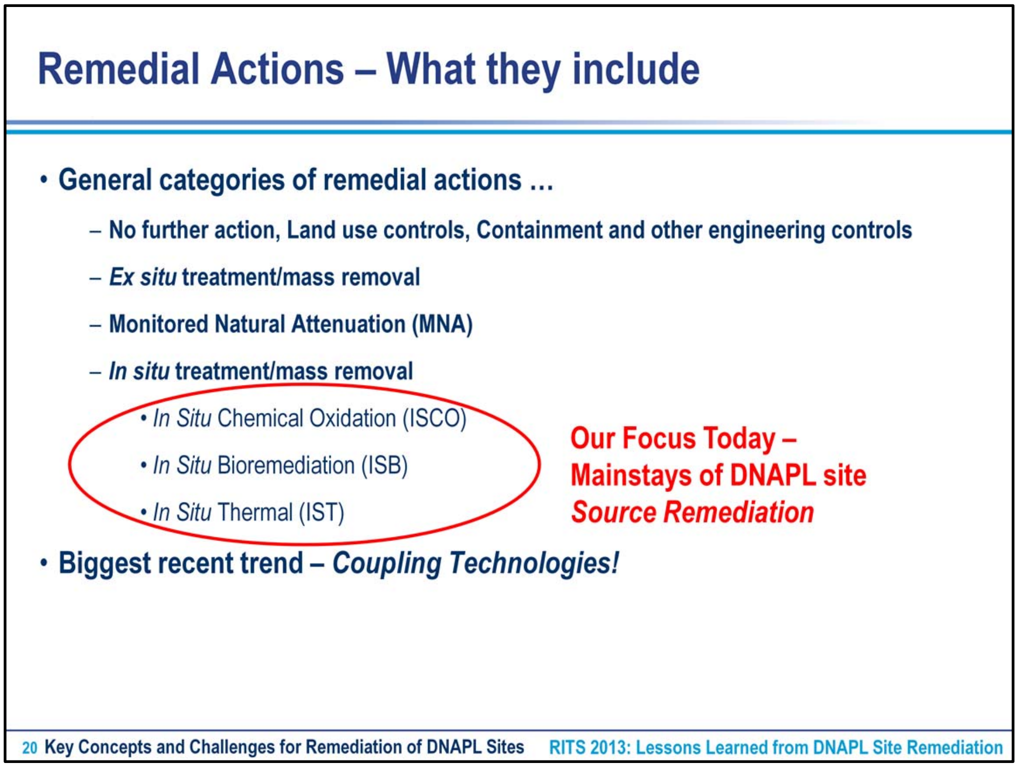
NAVFAC (2010) also discusses many of the broad issues being discussed today such as back-diffusion, and how these issues pertain to remedy selection and design.

General Strategies: DNAPL Site Source Remedies

- Source containment (physical or reactive barrier)
- Source removal (excavation)
- Source treatment
- Downgradient plume treatment
- Monitor and manage receptors/risk
- No action

19 Key Concepts and Challenges for Remediation of DNAPL Sites RITS 2013: Lessons Learned from DNAPL Site Remediation

Notwithstanding our focus today on in-situ treatment of DNAPL source areas – excavation/ex-situ or other approaches can be the most favorable alternative and have to be considered.

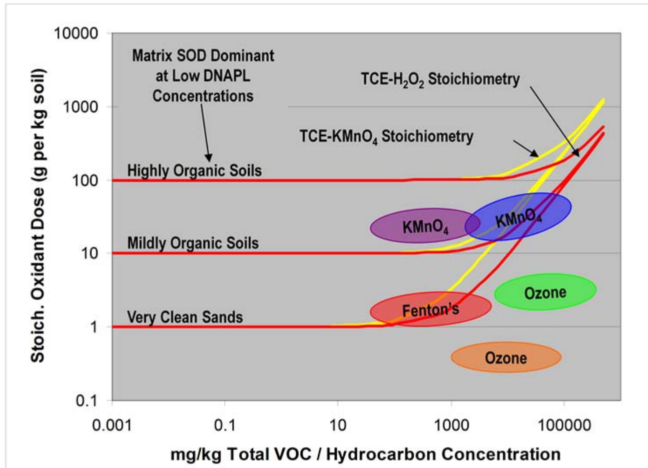


These are discussed further in Naval Facilities Engineering Command (NAVFAC) 2010. *Guidance for Optimizing Remedy Evaluation, Selection and Design. Prepared by NAVFAC Optimization Workgroup*

NAVFAC (2010) also discusses many of the broad issues being discussed today such as back-diffusion, and how these issues pertain to remedy selection and design.

Lessons Learned: Oxidant Dose for Source Treatment

- **Example of five successful DNAPL Source Treatments using ISCO**
  - **ISCO requires large oxidant dosing and multiple applications to effectively treat DNAPL sources areas**



oxidant

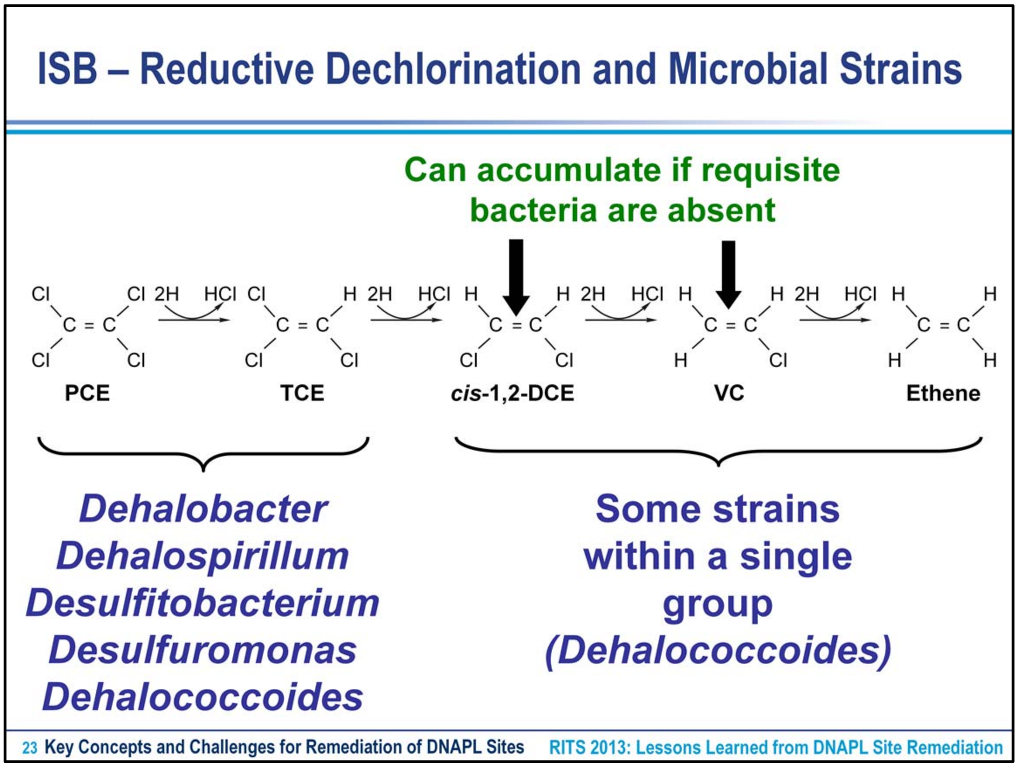
Circles represent full-scale, successful, published DNAPL treatment case studies

In Situ Bioremediation (ISB) Source Zone Treatment (ITRC, 2008)

- Gradual Process: 3-4x increase in DNAPL dissolution rate
- Variety of carbon donors available, some very long lasting
- Microbial diagnostic tools available
- Potentially limited effect for some VOC constituents *e.g.*, chloroform, 1,4-dioxane, sometimes chloro-ethanes
- Process involves <u>biostimulation</u> (carbon donors) and potentially <u>bioaugmentation</u> (microbial cultures)
- Delivery of microbial cultures can be challenging

22 Key Concepts and Challenges for Remediation of DNAPL Sites RITS 2013: Lessons Learned from DNAPL Site Remediation

ISB = in-situ bioremediation
Gradual and persistent process, multiple injections required

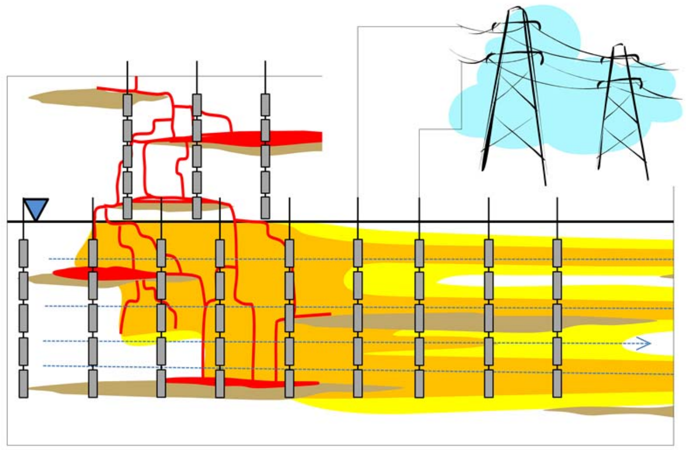


This slide shows the reductive dechlorination pathway for PCE/TCE bioremediation through carbon donor addition.

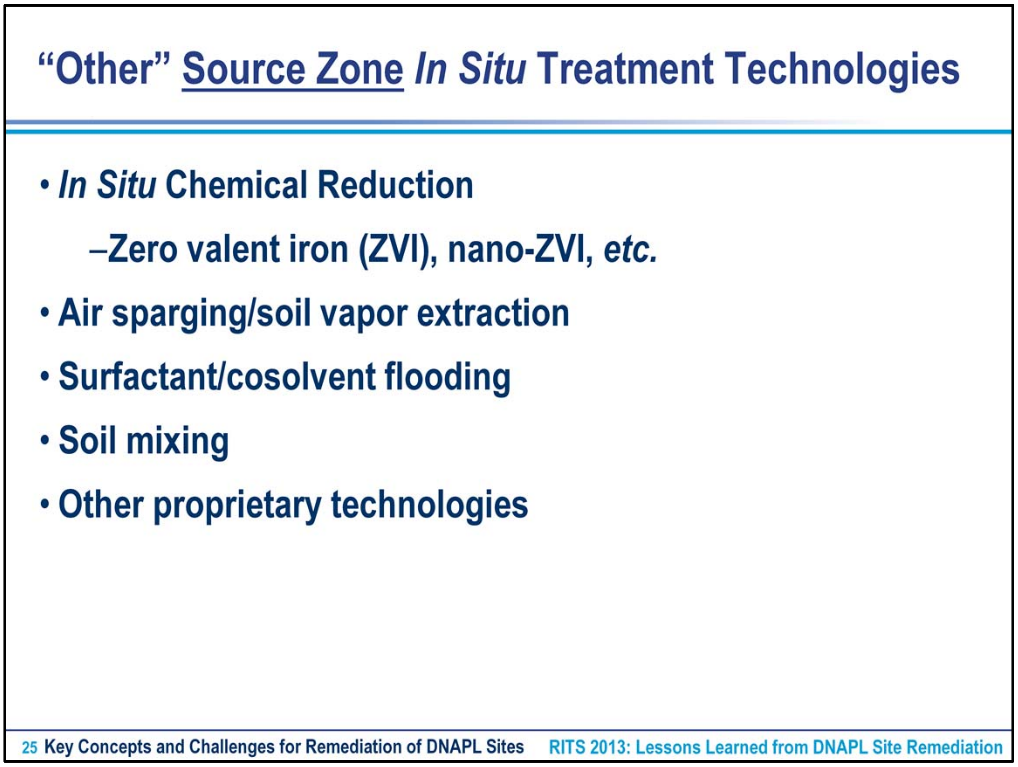
More on Thermal… ERH and TCH

- *Advantage:* **Electrical and thermal conductivities are fairly similar between different lithologies!**

- **Still some limitations exist for low-K media**
  - –Electrode spacing
  - –Time
  - –Cost



24 Key Concepts and Challenges for Remediation of DNAPL Sites   RITS 2013: Lessons Learned from DNAPL Site Remediation

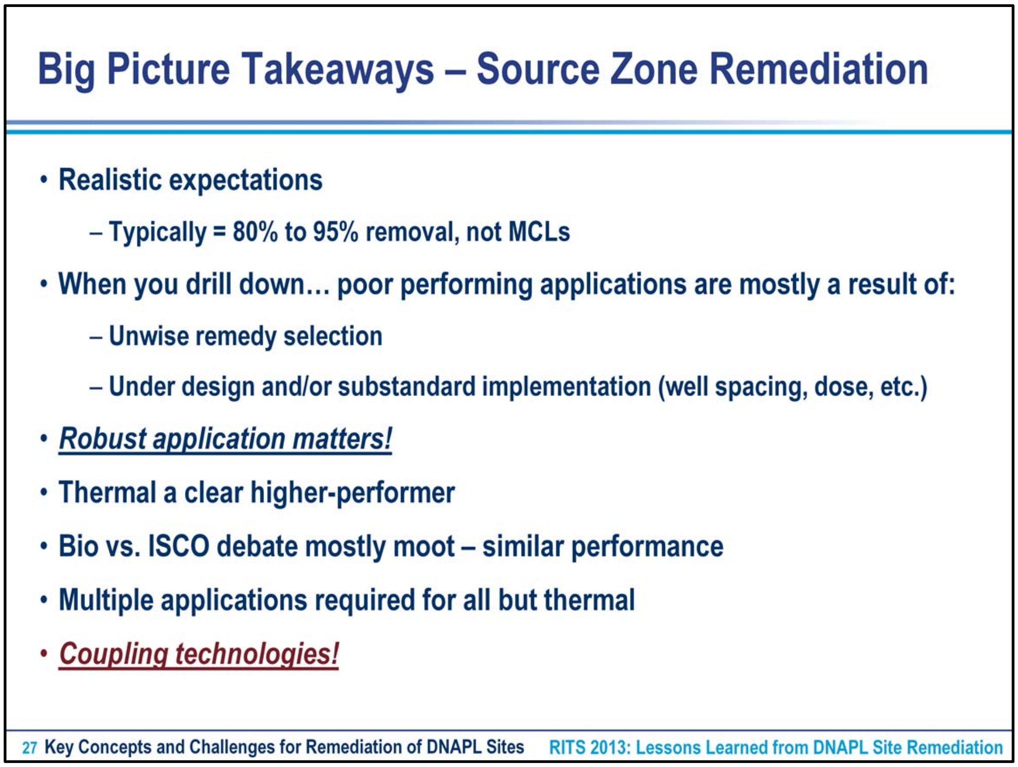


SVE, thermal and others are able to treat vadose zone sources.

Pump and treat is not listed as a source zone technology because it is not effective for source mass reduction.

Current Thinking re: DNAPL Treatment Efficacy

- Now that we have several decades of experience to draw from, recognition that some level of contaminant concentration and mass will remain after treatment is now considered a reality at most sites.

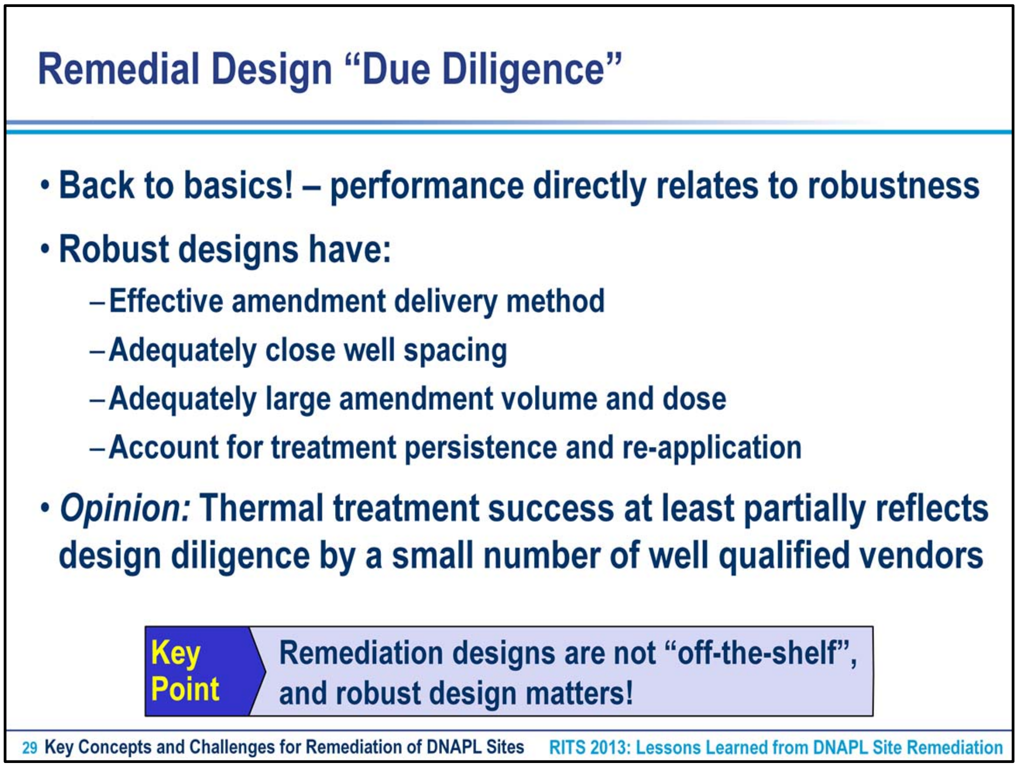


ISCO has shown more rebound, but bio has potential for rebound later in time

Bio has more bang for buck in flux reduction, but likely less mass reduction

Impact of Back-Diffusion on Remedy Selection

- Remedy evaluation/selection and Feasibility Studies (FS) should account for:
  - Potential post-remedy groundwater concentration rebound with any technology
    - ISCO and Thermal (sooner)
    - ISB (later, after reducing conditions no longer present)
  - Long time frame (decades) for back diffusion of contaminant mass into groundwater

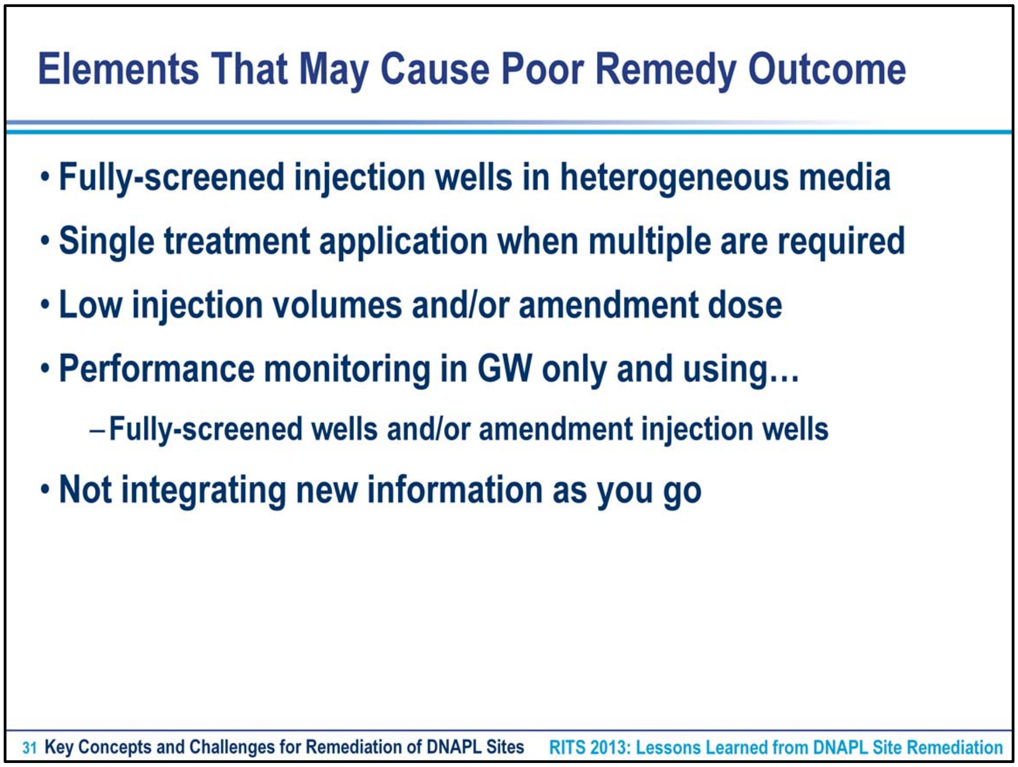


Note that implementation of a highly robust design will result in increased costs relative to a less robust design.

Role of Pilot Testing

- May or not be required to establish treatability
- Often focused on delivery and design parameters
- Can be scaled approach – "first phase of treatment":
  - pilot scale > intermediate scale > full scale
- Technology-specific needs
  - ISCO = oxidant delivery and consumption rates
  - ISB = delivery and geochemical/microbial response
  - Thermal = heating rates and soil vapor extraction removal

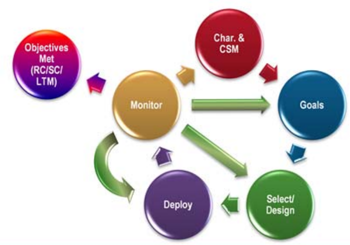
Key Point Pilot testing determines actual delivery and distribution/radius of influence!



These are a few things that have been shown through experience to sometimes result in less than optimal results.

The Observational Approach – Adaptive Remediation

- Avoids designing to worst case scenario
  - Assess conditions to reasonable extent
  - Develop design around most probable condition
  - Develop alternatives for possible conditions
  - Measure conditions while implementing
  - Modify design to actual conditions
  - Must select modifications in advance



32 Key Concepts and Challenges for Remediation of DNAPL Sites RITS 2013: Lessons Learned from DNAPL Site Remediation

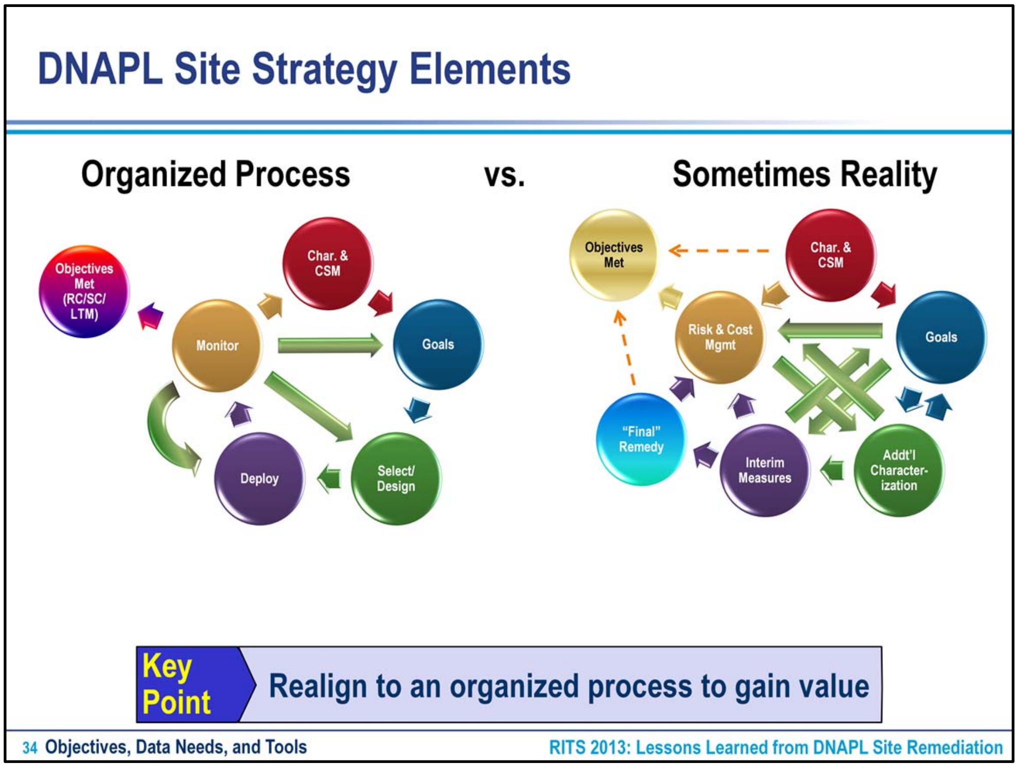
The observational approach was developed to address geologic uncertainty in geotechnical engineering, and has strong applicability to remediation design and implementation.

Presentation Overview

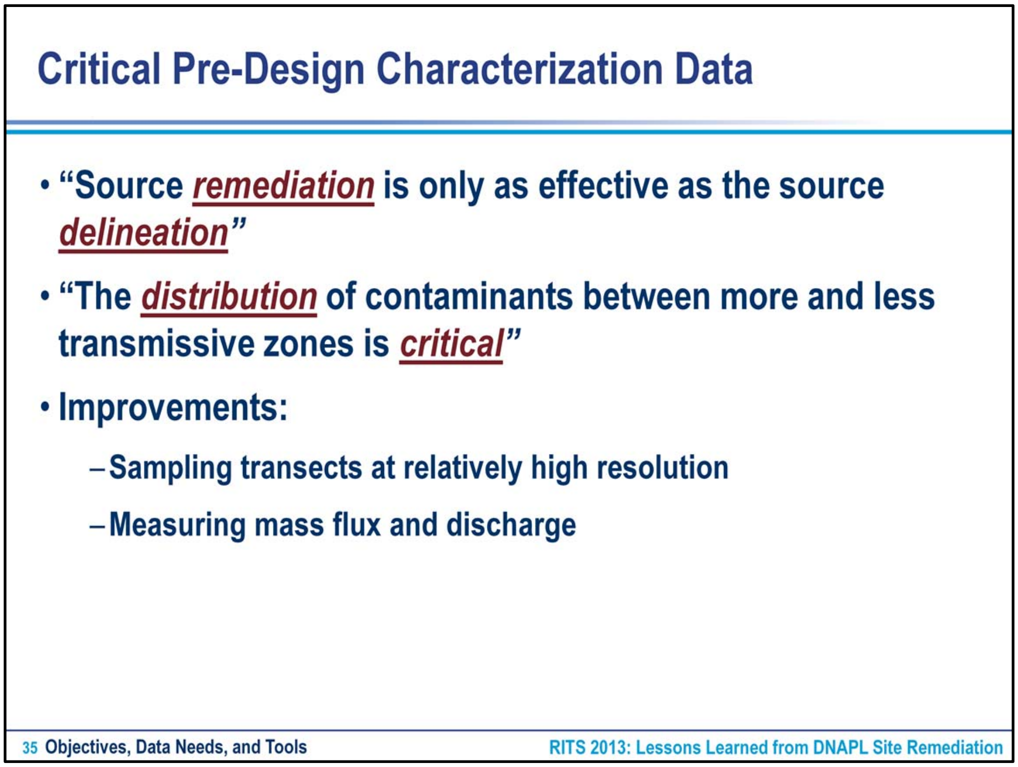
- Key Concepts and Challenges for Remediation of DNAPL Sites

► Objectives, Data Needs, and Tools

- Focused NAVFAC Site Case Studies
- Synthesis – Best Practices and Future Directions
- Summary



As described in the ITRC Integrated DNAPL Site Strategy (IDSS) document, following a structured process beings great value to remediation projects.



Note – prior RITS topic on mass flux and discharge was presented in 2011 and can be found on the NAVFAC Environmental Restoration and BRAC website under Past RITS

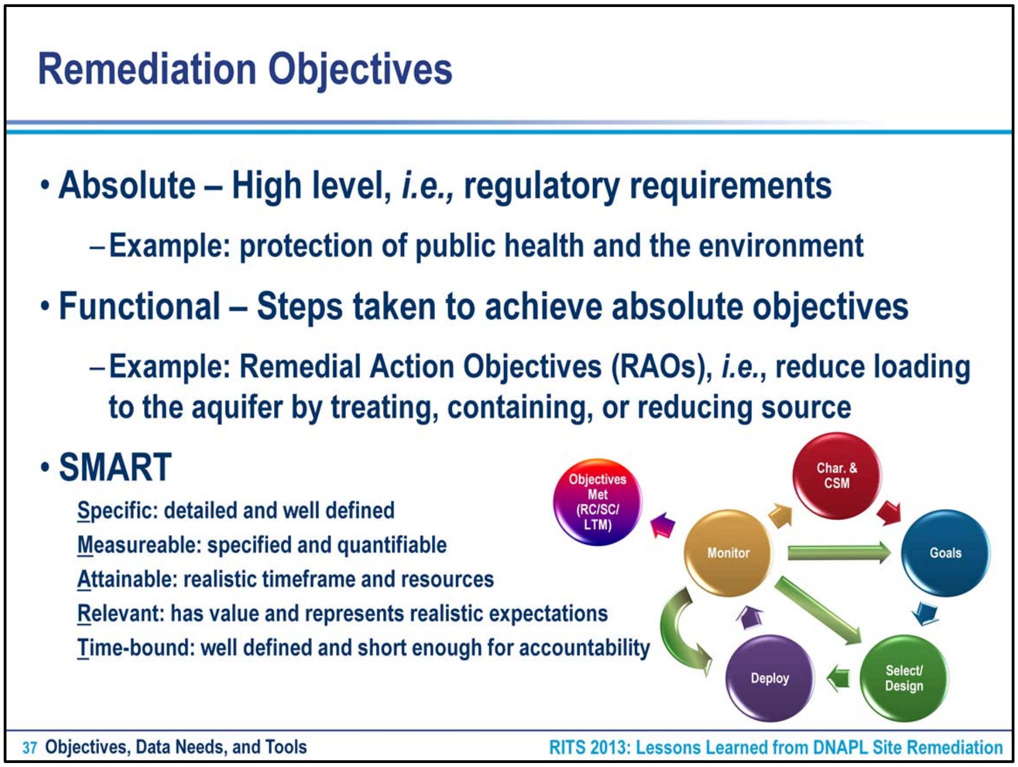
Site Data that, *if Absent*, are Commonly Associated with Remedy Failure

- "Hot-spot" source delineation or undetermined sources
- Vertical delineation of contaminant distribution
- Hydraulic conductivity values in target treatment zone
- Presence, extent, & magnitude of contaminants in low permeability media
- Mass distribution (likely approximate) of contaminants between chemical phases and low- vs. high-K zones

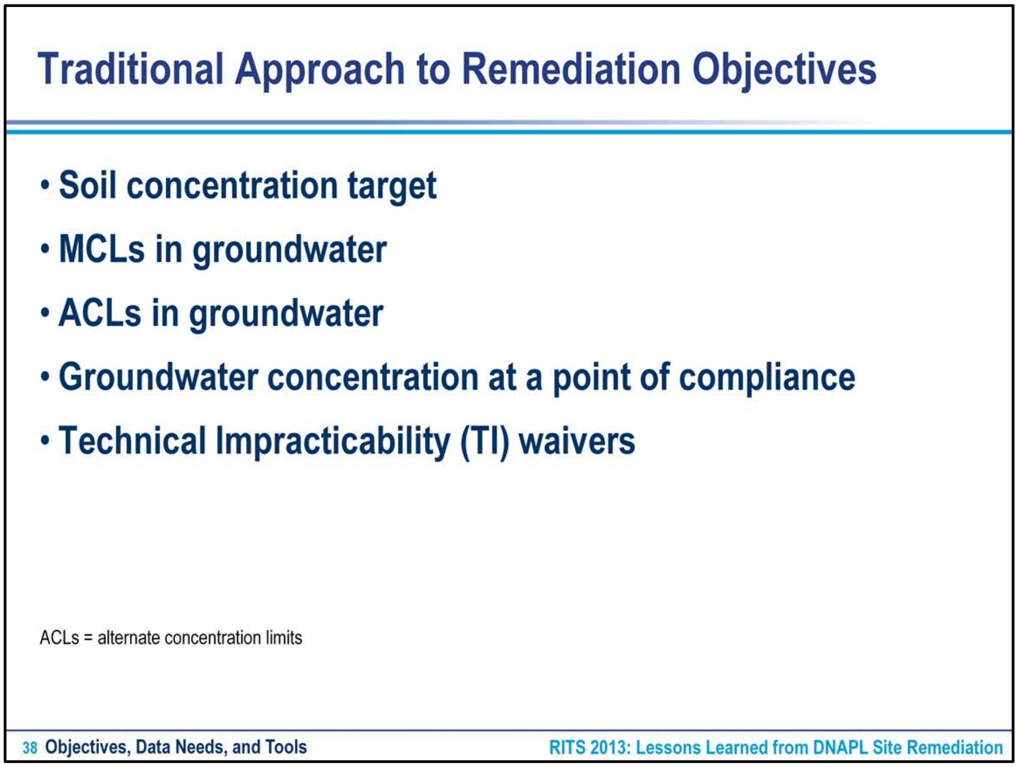
Key Point If we don't understand the problem, we probably cannot solve the problem

36 Objectives, Data Needs, and Tools   RITS 2013: Lessons Learned from DNAPL Site Remediation

These are a few items that, based on experience, have been found to potentially result in remedy failures.



See ITRC IDSS document for additional information on absolute and functional objectives applicable to remediation projects.



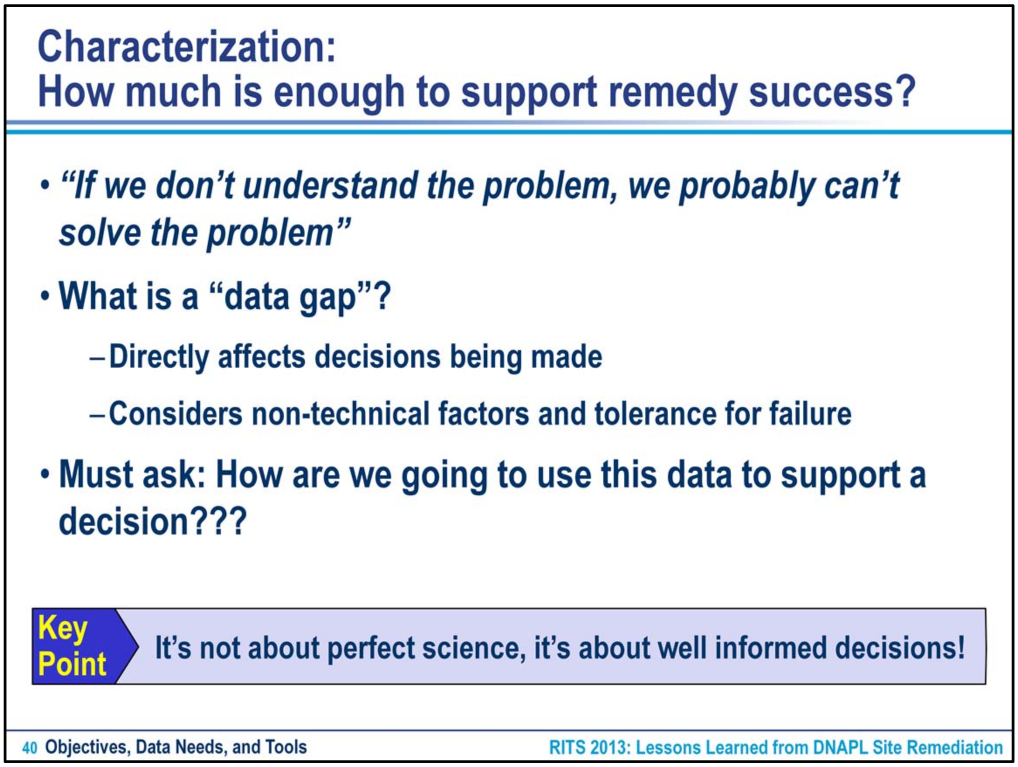
Traditional approaches to remediation objectives are driven largely by statutory requirements at the federal or state level, and by the guidelines and policies within the associated regulatory environments.

New Approaches to Remediation Objectives

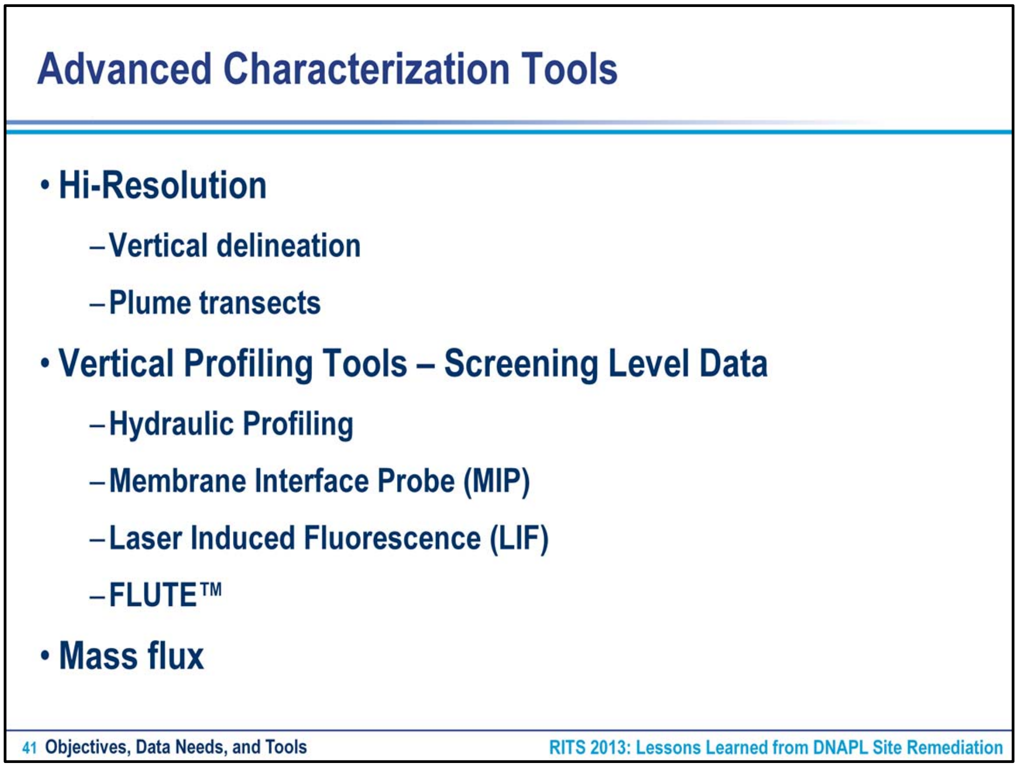
- **Mass flux/mass discharge**
  - EPA approved PRG for Hamilton Road Interim Actions (OU1) *"Reduce mass discharge of PCE contamination by 90%"*
- **GSR analysis using SiteWise™ tool or AFCEE SRT™ tool**
- **Objectives that define "treatment train" transition points**
- **Recognition that Long Term Management (LTMgt) will often be required following *in situ* remedies – because MCLs are not achievable in DNAPL source zones**

39 Objectives, Data Needs, and Tools RITS 2013: Lessons Learned from DNAPL Site Remediation

New approaches to remediation objectives acknowledge that complexity in DNAPL site conditions leads to multiple parameters considered in setting goals, as well as providing alternative ways to measure remediation end points other than numeric concentration goals.



For RPMs, it may be a good idea to ask this question and document the answer.

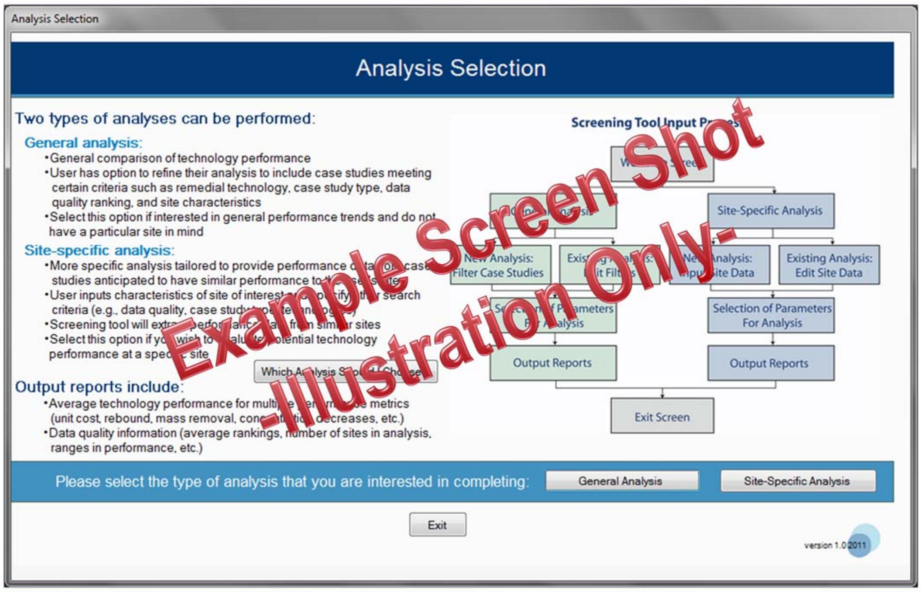


Advanced characterization tools serve to generate more detailed data on both subsurface lithology and contaminant distribution.

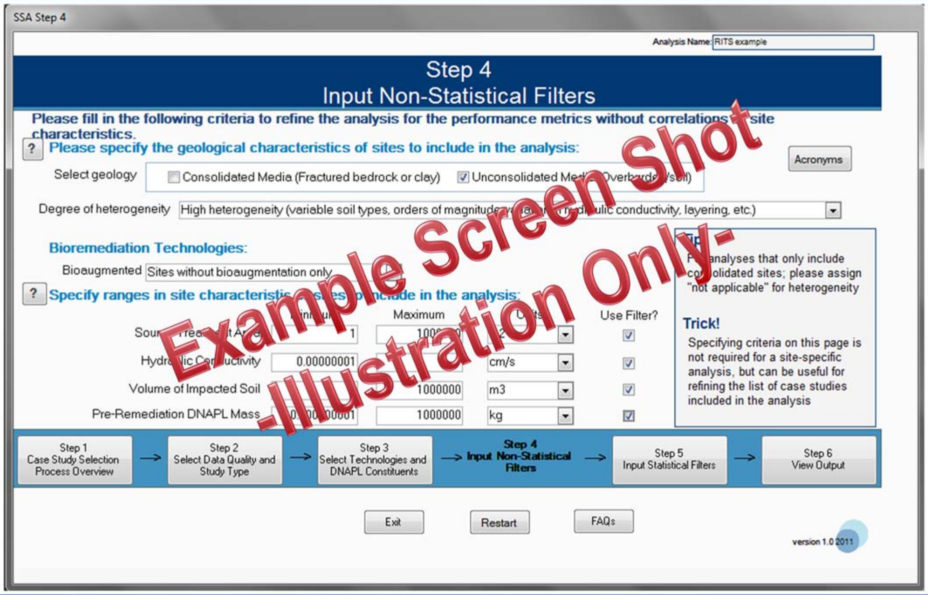
NAVFAC ER Technology Transfer Web Site

- Wide variety of ER tools and information

New Tool: DNAPL Test Tool (ESTCP Project)



DNAPL Test Tool – Database Filters



44 **Objectives, Data Needs, and Tools** **RITS 2013: Lessons Learned from DNAPL Site Remediation**

DNAPL Test Tool – Example Outputs

Performance Metric Summary

Performance Metric	Statistic	Chem. Ox. Fenton's Reagent or H2O2	Chem. Ox. Permanganate	Chem. Ox. Ozone
DNAPL Mass Decrease	Minimum	96 %	77 %	NA
	Maximum	96 %	77 %	NA
	Average	96 %	77 %	NA
	Median	96 %	77 %	NA
	Studies Achieving Decrease	1	2	NA
	Studies Reporting Data	1	2	NA
	Total Studies	1	2	NA
Groundwater Concentration Decrease	Minimum	NA	63 %	NA
	Maximum	NA	77 %	NA
	Average	NA	70 %	NA
	Median	NA	70 %	NA
	Studies Achieving Decrease	NA	2	NA
	Studies Reporting Data	NA	2	NA
	Total Studies	NA	2	NA
Soil Concentration Decrease	Minimum	96 %	80 %	NA
	Maximum	96 %	80 %	NA
	Average	96 %	80 %	NA
	Median	96 %	80 %	NA
	Studies Achieving Decrease	1	1	NA
	Studies Reporting Data	1	1	NA
	Total Studies	1	2	[illegible]
Achieve MCLs	Probability	1/1 (100 %)	[illegible]	[illegible]
	Standard Deviation	NA	[illegible]	[illegible]
	Studies Achieving MCLs	1	[illegible]	[illegible]
	Studies Reporting Data	1	2	[illegible]
	Total Studies	[illegible]	[illegible]	NA
Probability of Rebound	Probability	[illegible]	[illegible]	NA
	Standard Deviation	[illegible]	35 %	NA
	Studies Observing Rebound	[illegible]	1	NA
	Studies Reporting Data	[illegible]	2	NA
	Total Studies	1	2	NA
Treatment Duration	Minimum (weeks)	21	[illegible]	[illegible]
	Maximum (weeks)	21	[illegible]	[illegible]
	Average (weeks)	21	8	[illegible]
	Median (weeks)	21	[illegible]	[illegible]
	Studies Reporting Data	1	[illegible]	[illegible]
	Total Studies	1	2	NA
Unit Cost of Source Zone Treatment	Minimum ($/m³)	NA	170	NA
	Maximum ($/m³)	NA	240	NA
	Average ($/m³)	NA	210	NA
	Median ($/m³)	NA	210	NA
	Studies Reporting Data	NA	2	NA
	Total Studies	NA	2	NA

RITS example
Wednesday, December 19, 2012
Page 1 of 4
GenerateStudyStatistics.mdb
version 1.0 2011

[illegible]	[illegible]	Studies Reporting Concentration Data	Percent Reporting Concentration Decrease *	Average Percent Decrease	Median Percent Decrease	Minimum Percent Decrease	Maximum Percent Decrease
[illegible]	0	1	0.0 %	17 %	17 %	17 %	17 %
ISCO-MnO4	2	2	100 %	70 %	70 %	63 %	77 %
SEAR	2	2	100 %	94 %	94 %	92 %	96 %
Th-ERH	4	4	100 %	74 %	83 %	31 %	99 %
Th-Steam	2	2	100 %	90 %	90 %	80 %	99 %

Notes:
If a percent concentration reduction was not specified in the case study report, the reduction was calculated as the difference in pre- and post-treatment maximum total molar concentrations of all chlorinated volatile organic compounds. Concentration reductions of less than 20%, which is within the typical range of analytical uncertainty, were not considered to be significant and were excluded from the analysis.

* Percentage is based on the number of case studies reporting concentration data

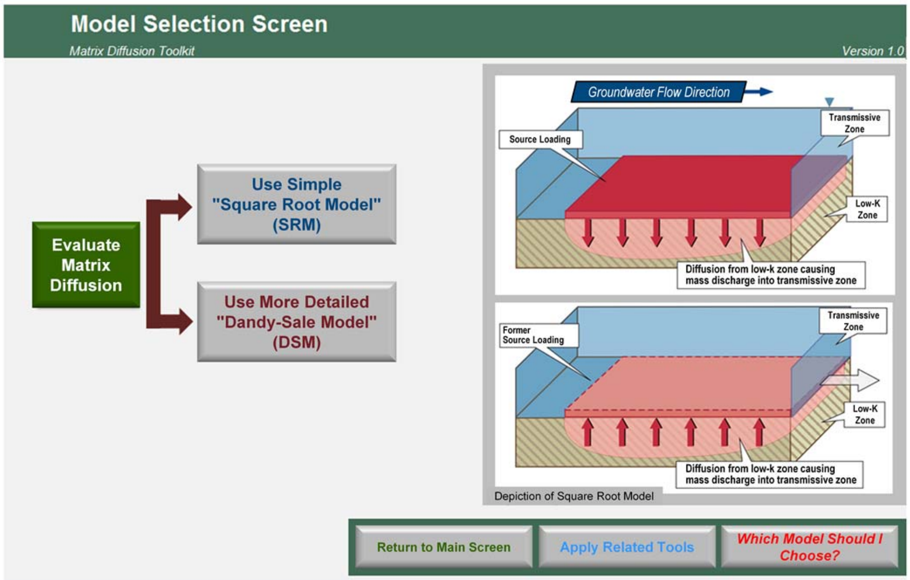
Acronyms:

RITS example
Thursday, December 20, 2012
Page 1 of 2
GenerateStudyStatistics.mdb
version 1.0 2011

45 Objectives, Data Needs, and Tools

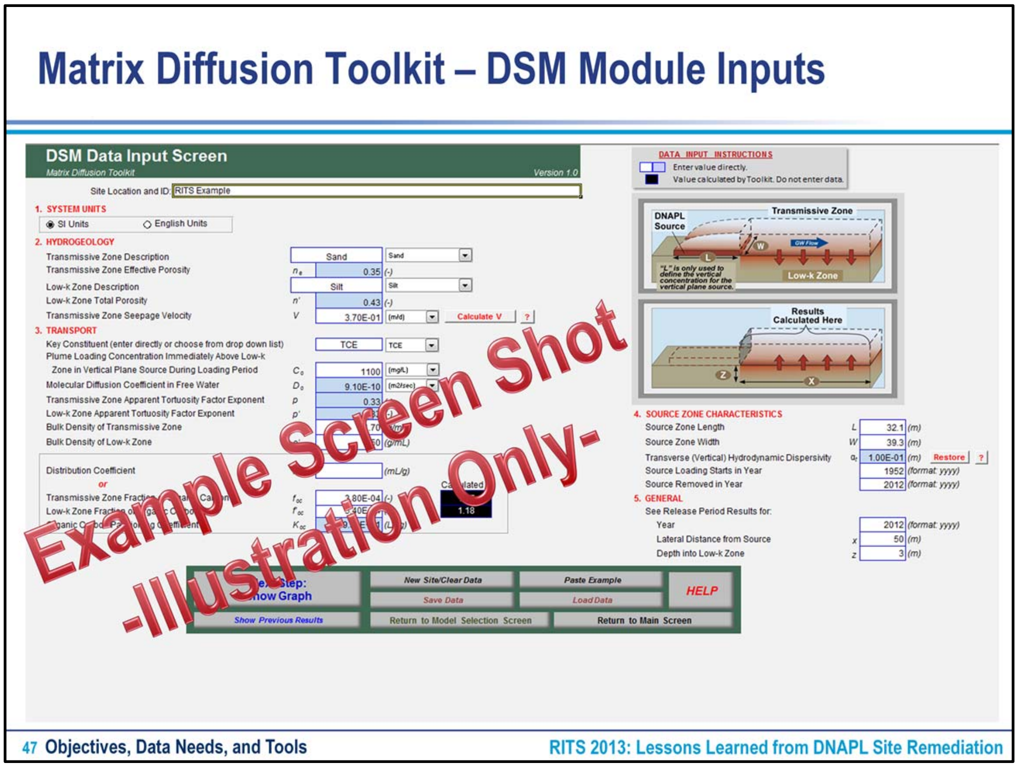
RITS 2013: Lessons Learned from DNAPL Site Remediation

New Tool: Matrix Diffusion Toolkit (ESTCP Project)



46 Objectives, Data Needs, and Tools RITS 2013: Lessons Learned from DNAPL Site Remediation

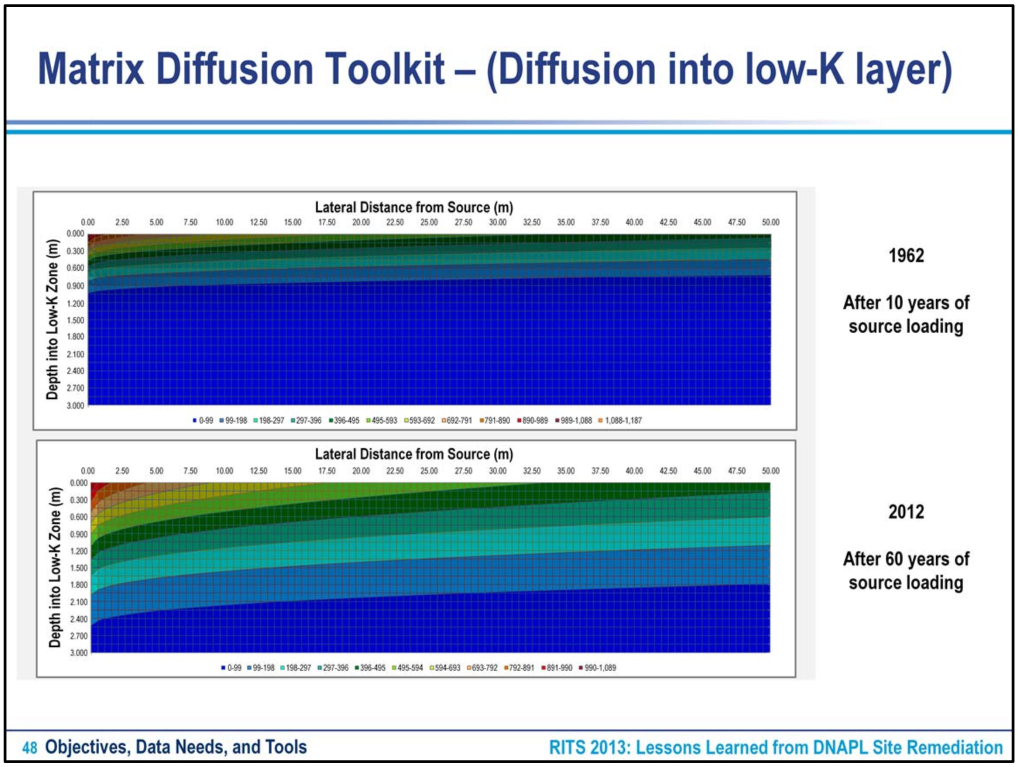
Recently released tool that will be introduced herein.



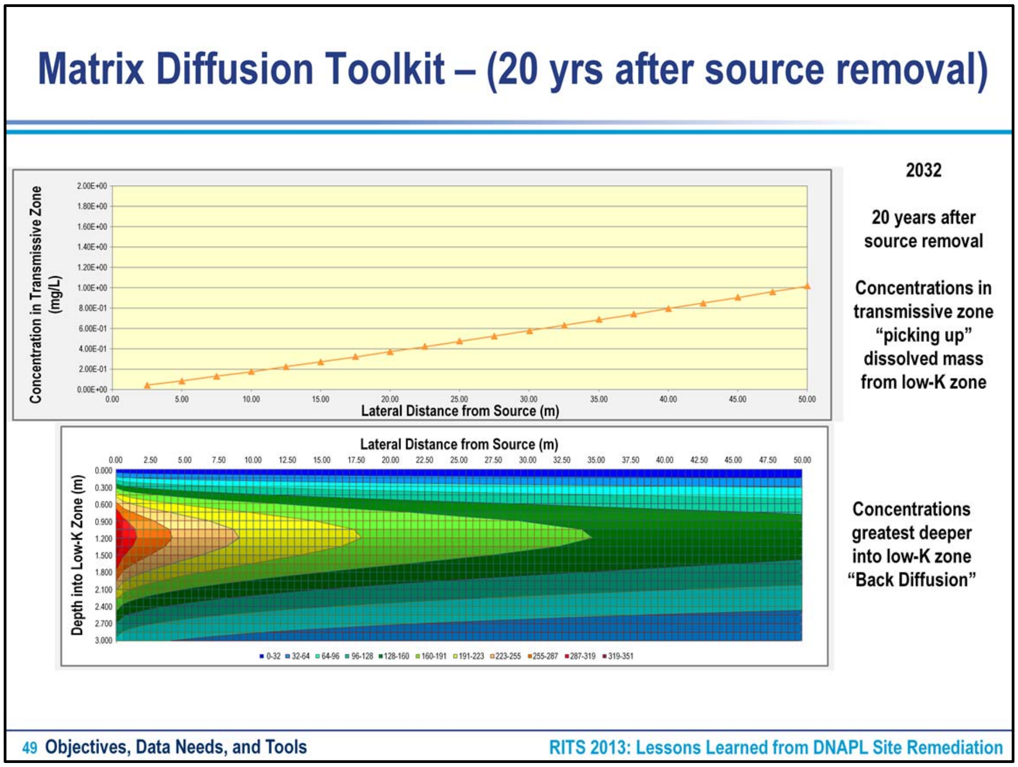
Input screen for DSM module.

An example will be used herein – 50 years of source loading from 1952 through 2012.

We will then look at source removal in 2012 followed by back-diffusion out of the low-K zone.

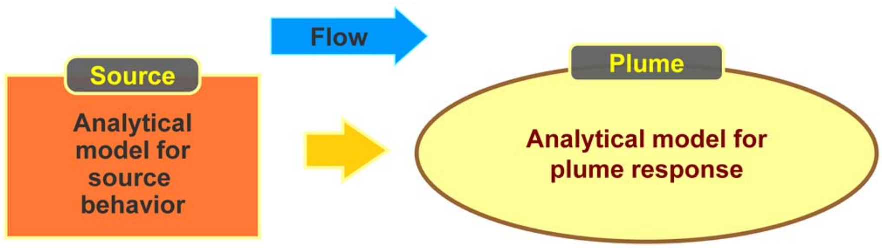


Note increase in concentrations diffused into the clay layer over both time and with closer distance to the source.



20 years after source removal, still see significant increase in concentration along flow path in transmissive zone due to back diffusion out of clay layer.

New Tool: REMChlor Model (SERDP/ESTCP Project)



- **Newer variations:**
  - Probabilistic outcomes (PREMChlor)
  - Fuel hydrocarbon sources (REMFuel)

REMChlor model links source behavior and plume behavior.

Applying Advanced Tools to Remedial Design

- No SOPs… currently as much art as engineering
  - What-if? scenarios
  - Addressing one specific aspect of remedy design at a time
- Advanced design tools require advanced data – more than has been the historical norm!
- Accurate estimates of treatment rate and extent likely requires a very detailed pilot study

Presentation Overview

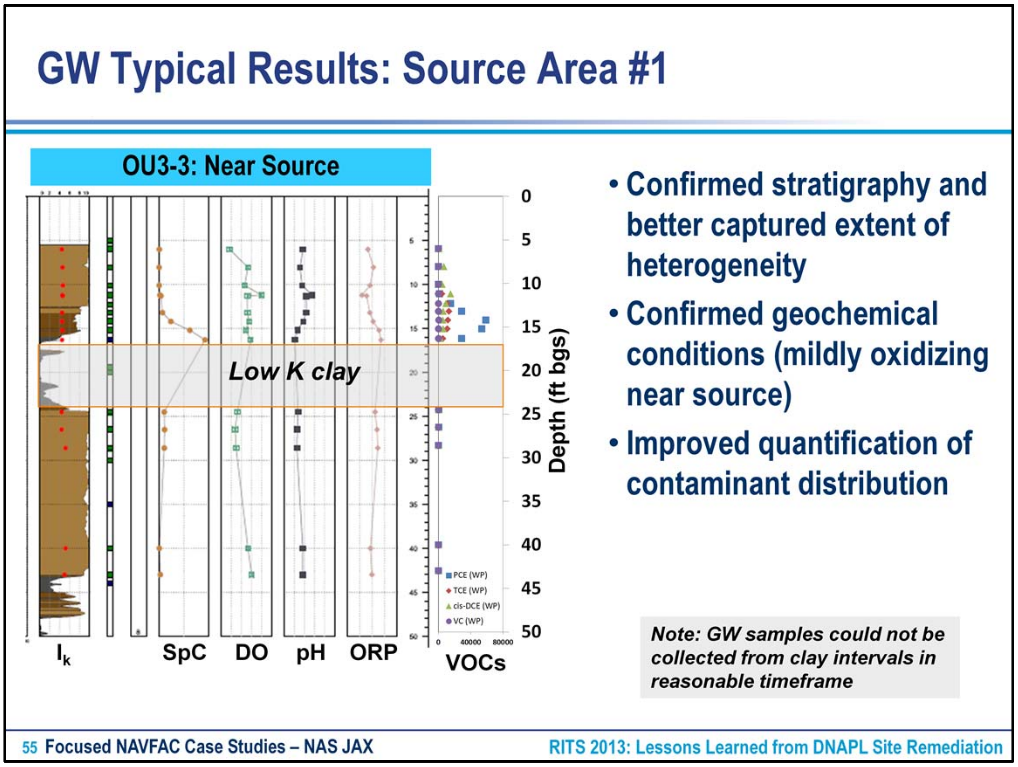
- Key Concepts and Challenges for Remediation of DNAPL Sites
- Objectives, Data Needs, and Tools
- ► **Focused NAVFAC Site Case Studies**
- Synthesis – Best Practices and Future Directions
- Summary

Case Study 1: Advanced Characterization at NAS JAX

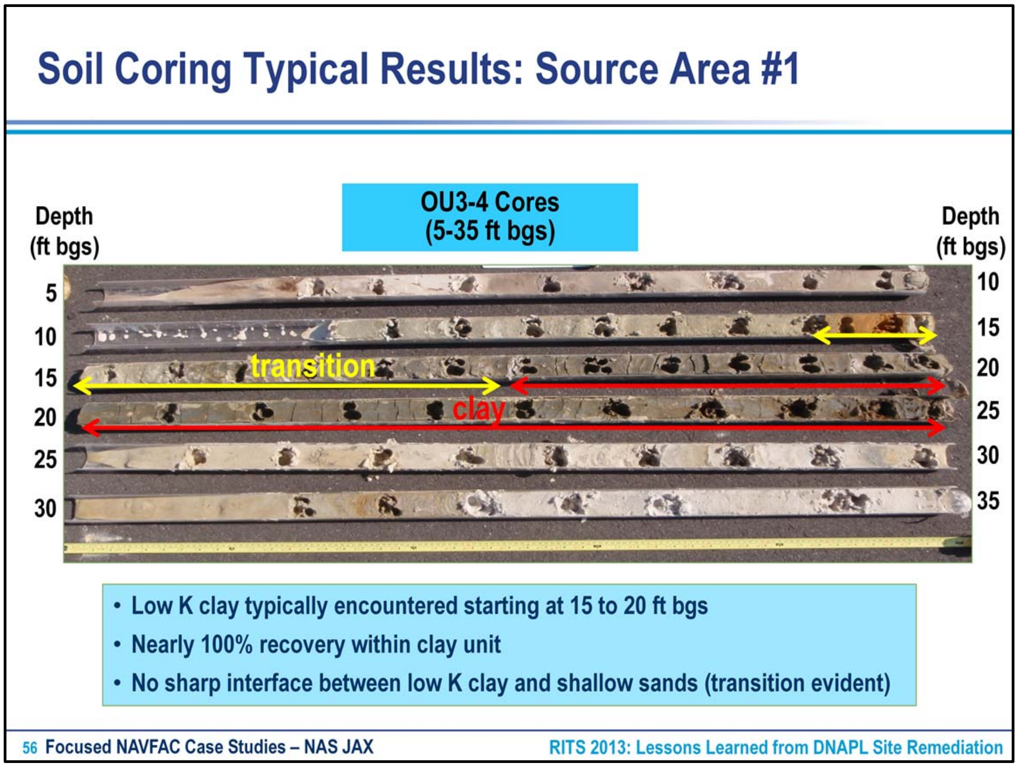
- Data from ESTCP Project 201032
- Broader purpose of ESTCP project is to assess “source history” through advanced characterization and application of modeling tools
- Data collected illustrate remediation-related concepts
  - Evaluation of new hi-res characterization tools
  - Mass distribution between low-K and transmissive zones
  - Rich data set that would support advanced design approaches

Test Design Step 1B: Multi Port Sampler

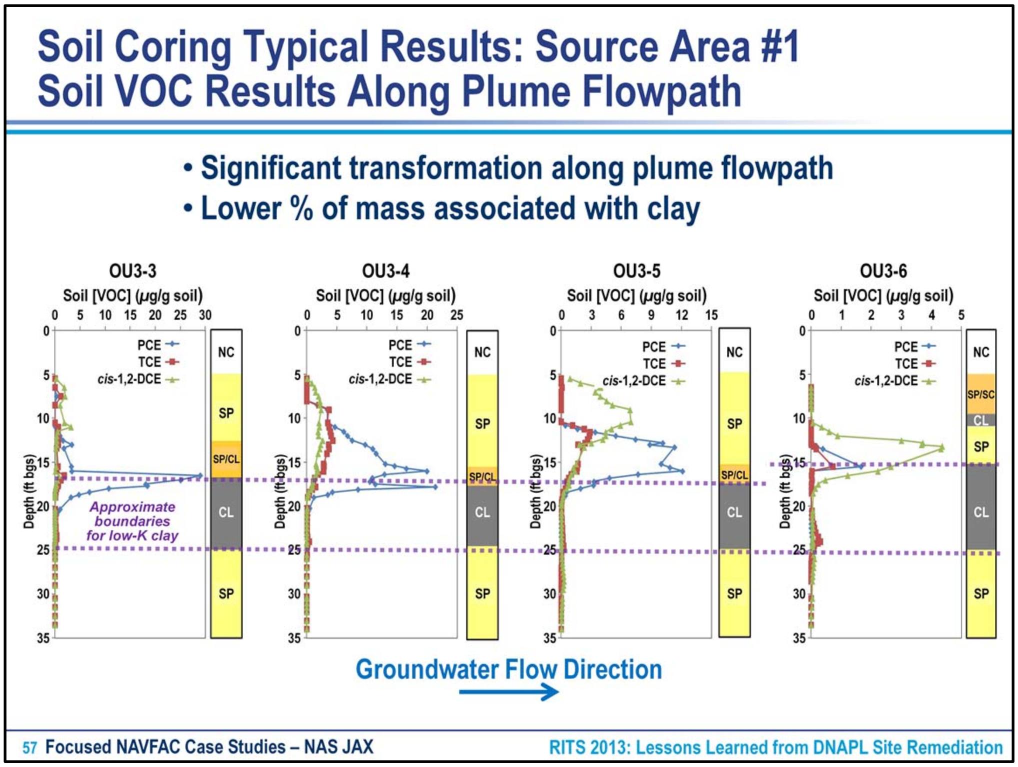
- Objective: Obtain detailed vertical permeability profile (index of hydraulic conductivity or "I_k")
- Collect depth-discrete GW samples for quantifying CVOC concentrations and geochemical parameters



I_k data (left column) identifies clay layer.



Hi-resolution characterization using closely spaced soil samples submitted for laboratory analysis.

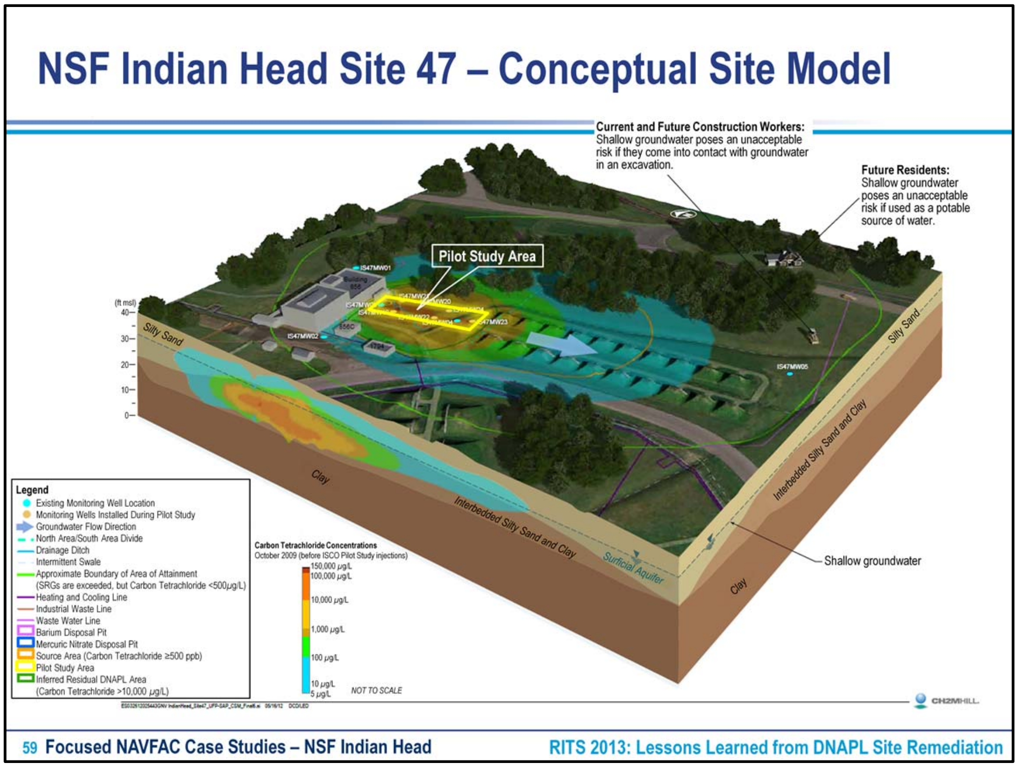


Closely vertically-spaced soil analytical data evaluated in cross section provides a rich understanding of the conceptual site model, showing "early stage" plume. No back diffusion observed, as concentrations are greatest at or above clay interface. Active diffusion into clay near source, limited diffusion into clay at distance. Slow groundwater flow and transformation to cis-1,2-DCE are consistent with active natural attenuation.

Case Study 2 – NSF Indian Head, MD
Site 47 ISCO Pilot

- "Deep Dive" into selected data – focused on deriving key lessons learned
- Not a comprehensive review of all pilot study aspects
- Primary COCs and approximate baseline concentration ranges:
  - Carbon Tetrachloride (CT)
  - Chloroform (CF)
  - PCE, TCE

	Soil (ppb)	Groundwater (ppb)	Solubility (ppb)
CT	10,000-260,000	100-150,000	793,000
CF	1,000-8,000	50-44,000	7,920,000
PCE	10-1,000	10-2,200	200,000
TCE	5-50	3-250	1,100,000



Very nice macro-scale CSM figure. Newest thinking about DNAPL site conceptual site models would suggest that a smaller-scale perspective on geologic heterogeneity and contaminant distribution across different permeability zones would also be valuable.

NSF Indian Head Site 47 – Full Scale Remedy Objectives

- **Absolute Objectives (from ROD)**
  - Prevent unacceptable risks to human receptors from exposure to contaminants in shallow groundwater
  - Prevent migration of shallow groundwater above Site Remediation Goals (SRGs) from Site 47 to uncontaminated media
  - Return the shallow groundwater to its beneficial use designation to the extent practicable
- **Functional Objectives (from 100% basis of design)**
  - SRGs: Carbon Tetrachloride 5 ppb, PCE 5 ppb (plus others)
  - Implement ISCO in the source area where the CT and PCE concentrations are greater or equal to 500 μg/L
  - Use MNA processes for the remaining dissolved plume and the source area following ISCO
  - Enforce ICs in the form of land and groundwater use restrictions
  - Incorporate sustainable remediation strategies

60 Focused NAVFAC Case Studies – NSF Indian Head   RITS 2013: Lessons Learned from DNAPL Site Remediation

Both absolute and functional objectives expressed in project documents.

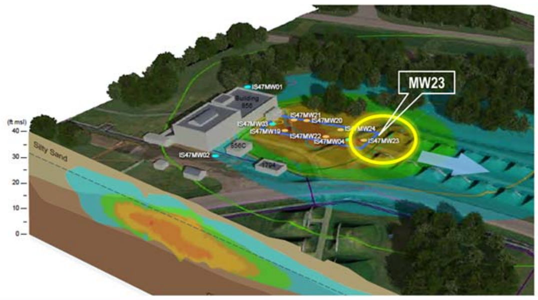
ISCO Pilot Study Design at NSF Indian Head Site 47

- **Alkaline activated persulfate**
- **Two 5-ft injection intervals (7-12 ft. bgs and 13-18 ft. bgs)**
- **Initially planned as 2 injection events; 46,200 lbs. oxidant followed by 35,200 lbs. oxidant. Second event not performed due to site logistics.**
- **Actual = 46,692 lbs. persulfate in 91,622 gallons solution**
  - **Oxidant Dose 8 g/kg (grams oxidant per kg soil)**
  - **Volume = ~ 75% of pore volume (PV)**
- **Electrical Conductivity profiling done to confirm persulfate extent, and overall good distribution obtained**
- **Baseline and Post-treatment sampling in soil and groundwater**

A well-planned and highly robust ISCO pilot test was pursued. The second planned injection event was not able to be applied, and results need to be viewed in that context, as some partial/incomplete treatment was observed.

Post-ISCO Reductive Dechlorination??

- **6 Months post-ISCO @ MW23 – downgradient end of treatment zone**
  - **ORP = -331 mv**
  - ***cis*-1,2-DCE @480 ppb and increasing (max. at site pre- or post-ISCO)**

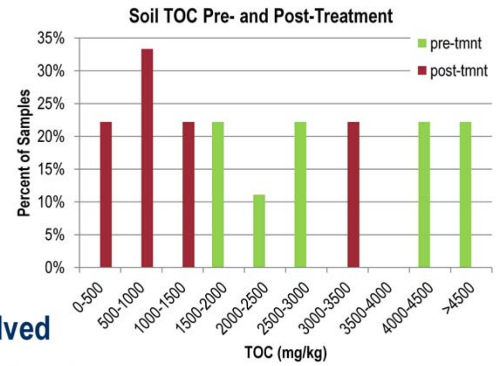


62 Focused NAVFAC Case Studies – NSF Indian Head RITS 2013: Lessons Learned from DNAPL Site Remediation

Partial oxidation of soil total organic carbon as well as organic contaminants can result in post-ISCO reductive dechlorniation, as apparently occurred at this site.

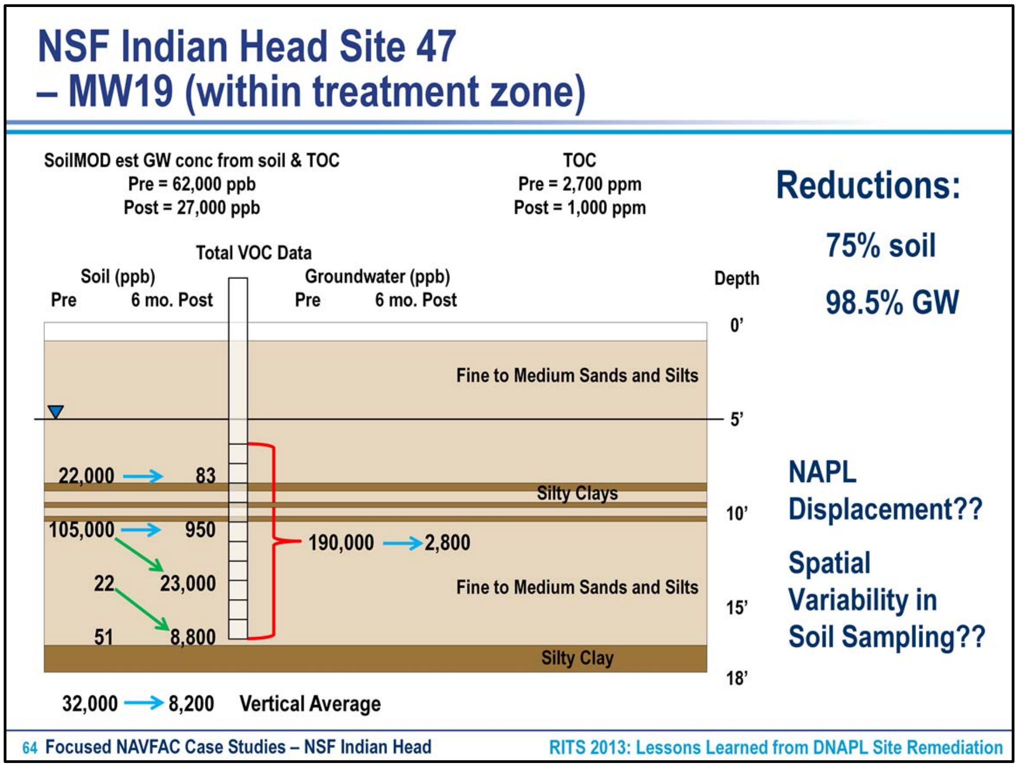
Geochemical Results of ISCO Pilot – TOC Oxidation

- Soil TOC oxidation by persulfate shifts sorption equilibria and releases sorbed VOCs to groundwater
- Avg. TOC in soil
  - Pre-Tmnt: 7,100 mg/kg
  - Post-Tmnt: 1,300 mg/kg
- 10 ppm soil equivalent
  - Pre-Tmnt: 10,000 ppb dissolved
  - Post-Tmnt: 29,000 ppb dissolved

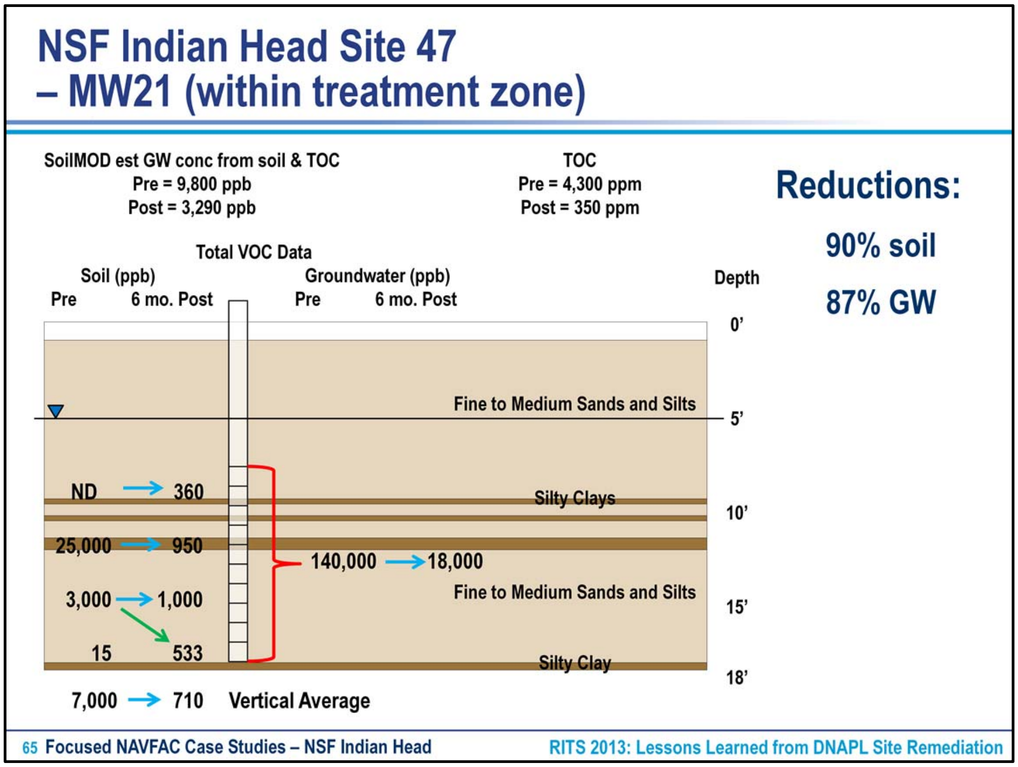


63 Focused NAVFAC Case Studies – NSF Indian Head RITS 2013: Lessons Learned from DNAPL Site Remediation

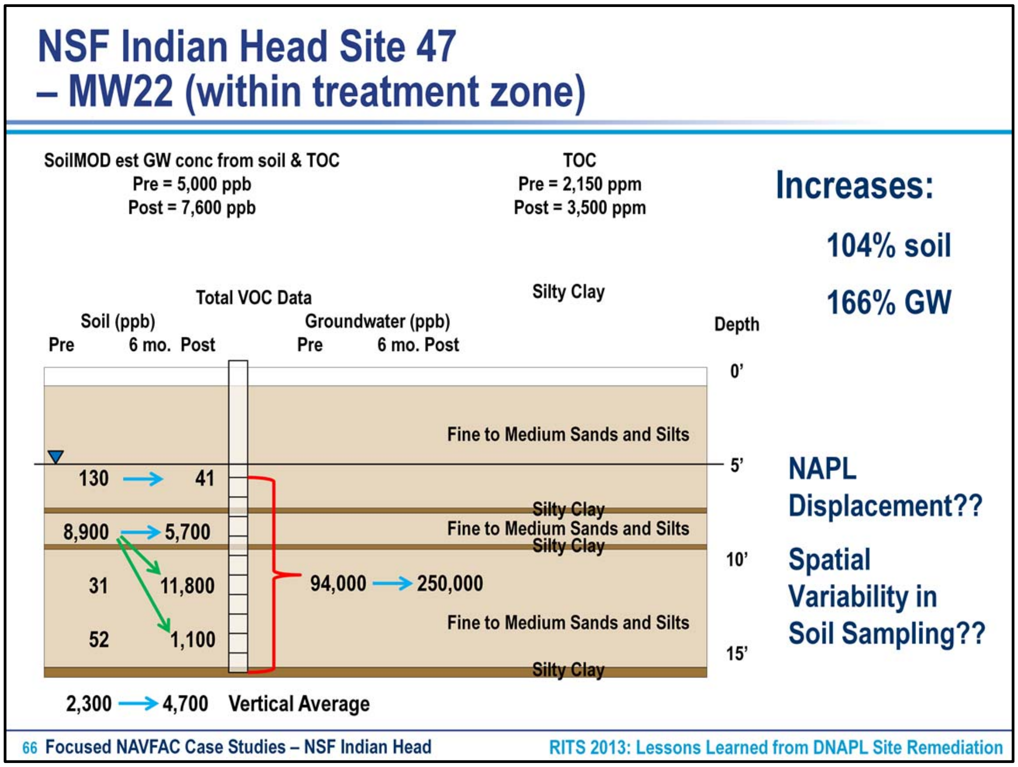
Soil TOC oxidation results in significant desorption of contaminant mass – and release into the dissolved phase. This makes it accessible to treatment, but can also result in anomalously high dissolved concentrations if not taken into account.



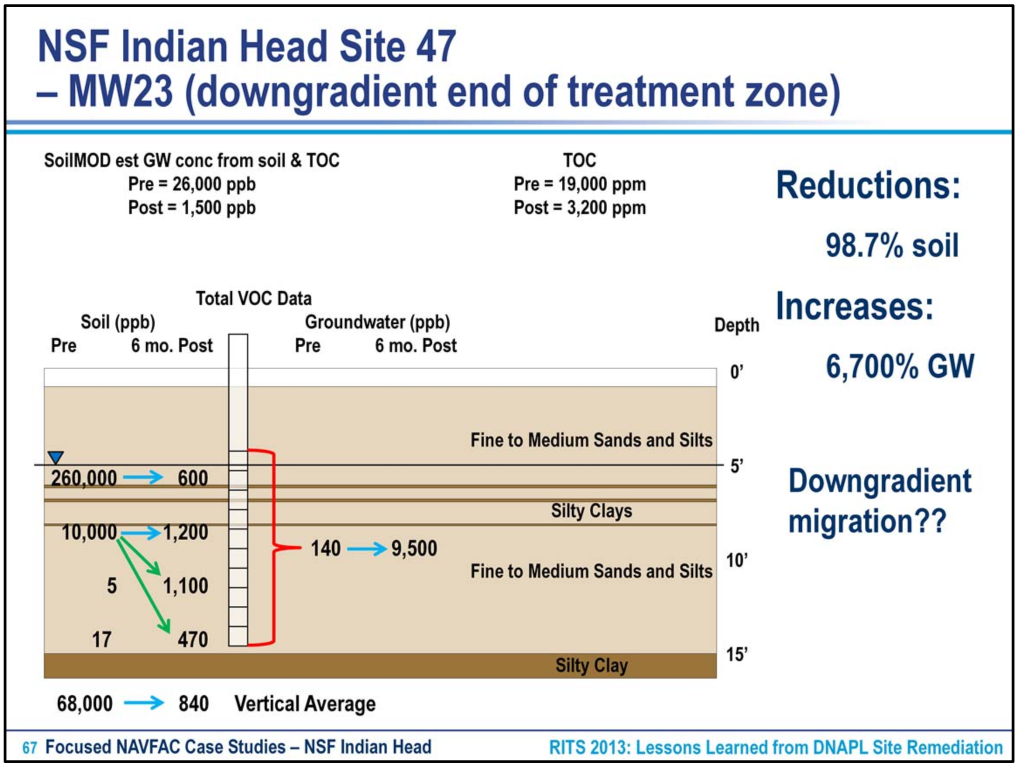
Note that vertically-spaced soil data provides a richer understanding of post treatment changes than does the fully screened monitoring well data.



Note that vertically-spaced soil data provides a richer understanding of post treatment changes than does the fully screened monitoring well data.



Note that vertically-spaced soil data provides a richer understanding of post treatment changes than does the fully screened monitoring well data.



Note that vertically-spaced soil data provides a richer understanding of post treatment changes than does the fully screened monitoring well data.

NSF Indian Head Site 47 ISCO Pilot – Treatment Summary

- Significant VOC mass reduction (estimated ~ 80%)
- Dissolved VOC concentration reduction ~ 47% on average
- Some VOC concentrations declined while others increased
- Shallow soil VOC decreases accompanied by deeper soil increases (net 83% avg. decrease)
- ISCO appeared to promote additional reductive bio-treatment

NSF Indian Head Site 47 ISCO Pilot – Lessons Learned

- Fully screened MWs did not reflect subsurface complexity
- Potential vertical movement of COCs observed
- Vertically spaced multi-level soil sampling very valuable
- A single ISCO application resulted in partial treatment, significant residual contamination remained
- Multiple applications needed for >90% reductions
- Combined technologies – ISCO can promote subsequent biodegradation and further attenuation downgradient

Presentation Overview

- Key Concepts and Challenges for Remediation of DNAPL Sites
- Objectives, Data Needs, and Tools
- Focused NAVFAC Site Case Studies

► **Synthesis – Best Practices and Future Directions**

- Summary

Best Practices from the NAS JAX Case Study

- Hi-resolution site characterization can provide data that elucidates a valid Conceptual Site Model
  - New field tools can be valuable, *BUT*…
  - Doesn't always have to be "high-tech" new tools, because hi-density vertical interval soil sampling (*e.g.*, NAS JAX) can provide valuable data
- Dense vertically-delineated data
  - Elucidates differences in mass distribution both across lithologies and with distance from the source
  - Allows targeting treatment to the zones that matter

Best Practices from the Indian Head Site 47 Case Study

- **ISCO Application was fairly robust, above average**
- **Soil sampling pre- and post-treatment was helpful to assess treatment results on a mass basis – but variability and uncertainty remains**
- **Results after partial treatment (first injection event) will often be confounding due to displacement, desorption, etc.**
- **Even with a thorough and robust approach, multiple treatment applications will likely be required for ISCO at this site (same for bio, *i.e.*, all but thermal)**

72 Synthesis – Best Practices and Future Directions   RITS 2013: Lessons Learned from DNAPL Site Remediation

ISCO application:

Oxidant Dose 8 g/kg (grams oxidant per kg soil)

Volume = ~ 75% of pore volume (PV)

Alignment (or Lack Thereof) with Standard Practice

- Relative to the "Gold Standard" at most sites…
  - We don't really understand the contaminant distribution
  - Common characterization/monitoring approaches pre- and post-treatment are not adequate to understand the complexities of treatment results and what remains
- Mediocre DNAPL source remediation performance likely results from:
  - Mediocre characterization
  - Mediocre robustness of design and implementation

Future Directions for DNAPL Source Remediation

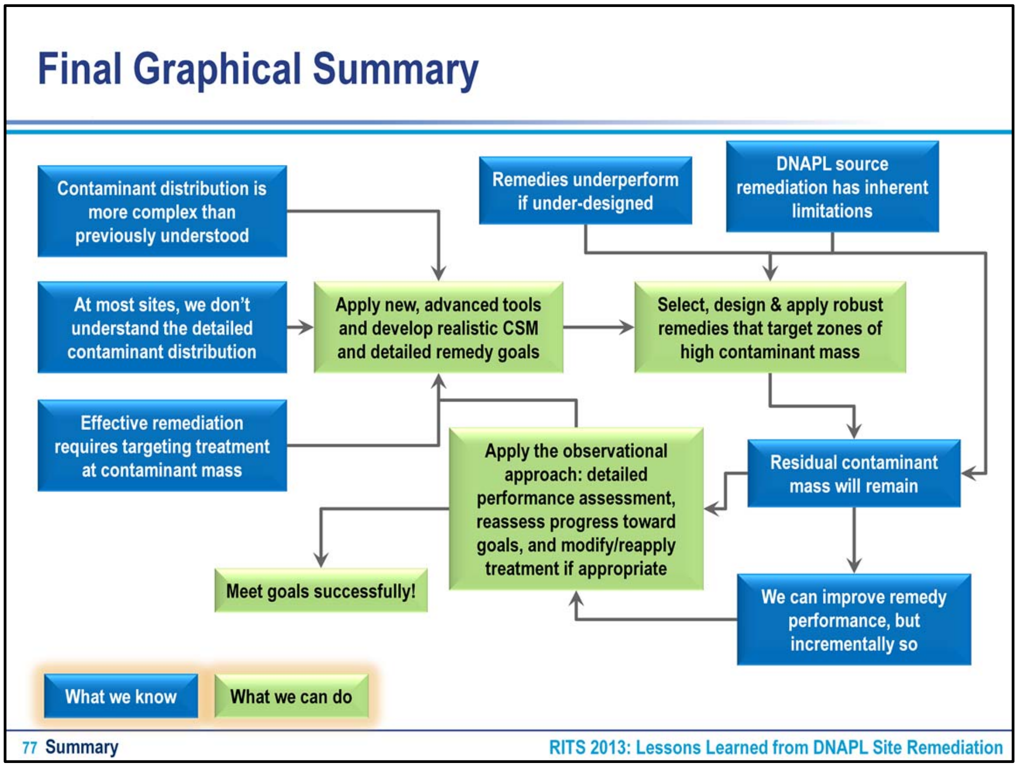
- Can probably move from 80% to 95% removals to 95% to 99% removals, ***IF*** ***WE…***
  - Use hi-resolution characterization tools to understand contaminant distribution
  - Very robustly target remedies at high-mass zones, including low-K media
  - Implement the Observational Approach, use hi-res performance monitoring, measure results then apply additional treatment
- But, residual mass will still remain and we have to understand the site specific benefit gained by the additional incremental treatment

Presentation Overview

- Key Concepts and Challenges for Remediation of DNAPL Sites
- Objectives, Data Needs, and Tools
- Focused NAVFAC Site Case Studies
- Synthesis – Best Practices and Future Directions
- ► **Summary**

Key Take-Home Points

- **To succeed we need to:**
  - Accept LTMgt as inevitable at many sites to manage the residual
  - Determine what is an acceptable and achievable residual level
  - Be realistically robust in our short-term source treatment remedy to reach the acceptable and achievable level of residual
  - Focus more on strategy/application and less on *"which technology"*



Final Graphical Summary
Contaminant distribution is more complex than previously understood
Remedies underperform if under-designed
DNAPL source remediation has inherent limitations
At most sites, we don't understand the detailed contaminant distribution
Apply new, advanced tools and develop realistic CSM and detailed remedy goals
Select, design & apply robust remedies that target zones of high contaminant mass
Effective remediation requires targeting treatment at contaminant mass
Apply the observational approach: detailed performance assessment, reassess progress toward goals, and modify/reapply treatment if appropriate
Residual contaminant mass will remain
Meet goals successfully!
We can improve remedy performance, but incrementally so
What we know
What we can do
77 Summary
RITS 2013: Lessons Learned from DNAPL Site Remediation

References

- ITRC, Technical and Regulatory Guidance for Integrated DNAPL Site Strategies (IDSS), Interstate Technology and Regulatory Council, 2011.
- ITRC, Technical and Regulatory Guidance for *In Situ* Bioremediation of Chlorinated Ethene DNAPL Source Zones, Interstate Technology and Regulatory Council, June 2008.
- ITRC, Technical/Regulatory Guidelines – Strategies for Monitoring the Performance of DNAPL Source Zone Remedies, Interstate Technology and Regulatory Council, August 2004.
- NAVFAC 2010 – Naval Facilities Engineering Command (NAVFAC). 2010. Guidance for Optimizing Remedy Evaluation, Selection and Design.
- EPA 540/R-96/023 October 1996. Presumptive Response Strategy and *Ex-Situ* Treatment Technologies for Contaminated Groundwater at CERCLA Sites.
- Strategic Environmental Research and Development (SERDP) project ER-201126, Decision Support System for Matrix Diffusion Modeling.

78 Summary RITS 2013: Lessons Learned from DNAPL Site Remediation