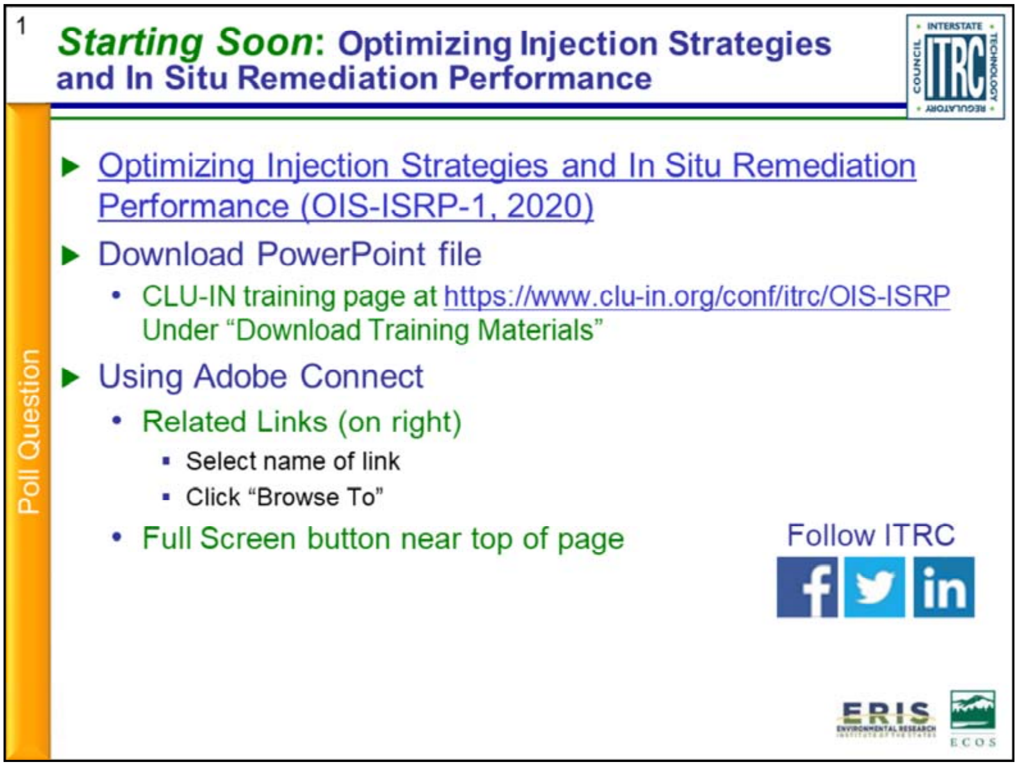


Poll Question:

Prior to participating in this training course, what level of knowledge and skills did you possess related to Optimizing Injection Strategies and In situ Remediation Performance?

1- New Topic

5 – Expert

What is your role with Optimizing Injection Strategies and In Situ Remediation Performance?

Regulator

Consultant

Responsible Party

Community Stakeholder

Other

Training Course Overview:

In situ remediation technologies using amendment injections have advanced to mainstream acceptance and offer a competitive advantage over many forms of ex situ treatment of soil and groundwater. Developing a detailed site-specific strategy is absolutely critical to the success of such in situ remedies. These strategies include conducting a thorough site characterization that will allow development of a detailed Conceptual Site Model (CSM) to guide critical analysis of subsurface features and improving remediation effectiveness. In the interest of developing expedited solutions, many past in situ remediation projects have been executed based on an incomplete understanding of the hydrogeology, geology, and contaminant distribution and mass. Some of these sites have undergone multiple rounds of in situ injections but have not advanced to closure. Better strategies and minimum design standards are required to decrease uncertainty and improve remedy effectiveness.

In an effort to overcome these challenges and improve the effectiveness of in situ remediation using injected amendments, ITRC developed the guidance: Optimizing Injection Strategies and In Situ Remediation Performance (OIS-ISRP-1). The guidance and this associated training course identify challenges that may impede or limit remedy effectiveness and discuss the potential optimization strategies, and specific actions that can be pursued, to improve the performance of in situ remediation by:

Refining and evaluating remedial design site characterization data;

Selecting the correct amendment;

Choosing delivery methods for site-specific conditions;

Creating design specifications;

Conducting performance evaluations, and

Optimizing underperforming in situ remedies.

The target audience for this guidance and training course is: environmental consultants, responsible parties, federal and state regulators, as well as community and tribal stakeholders. This training will support users in efficiently and confidently applying the guidance at their remediation sites. An optimization case study is shared to illustrate the use of the associated guidance document.

Prior to attending the training class, participants are encouraged to view the associated ITRC guidance, Optimizing Injection Strategies and In Situ Remediation Performance (OIS-ISRP-1) as well as to be familiar with the characterization process described in Integrated DNAPL Site Strategy ((ITRC 2011c).

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

3

Housekeeping

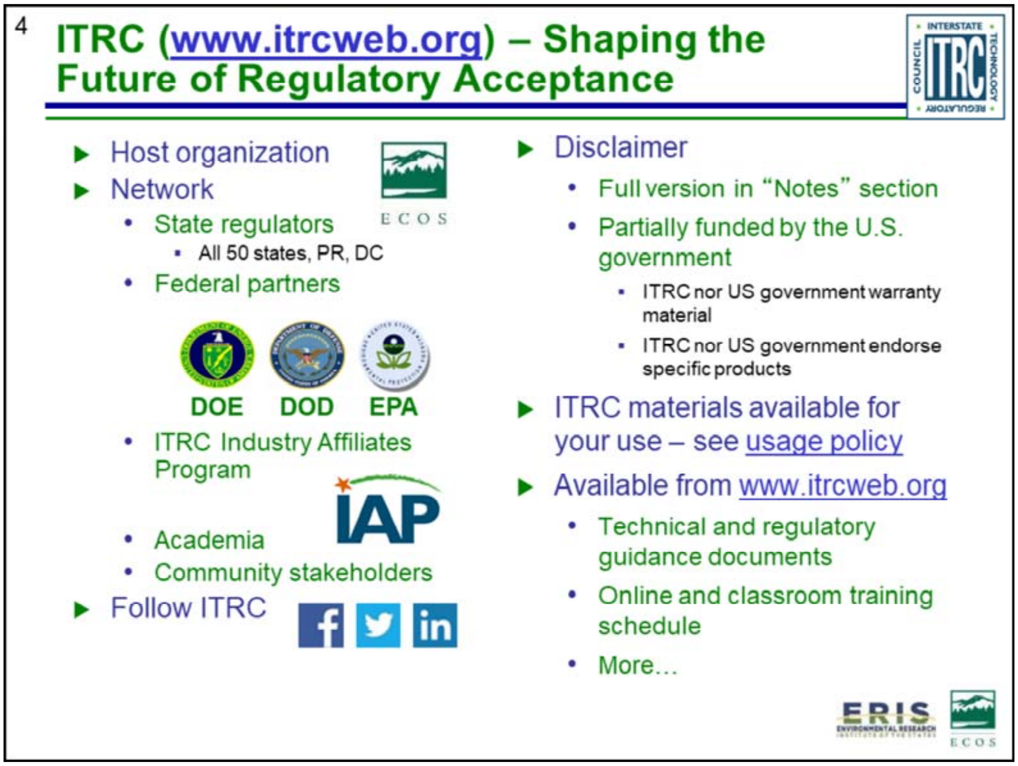
- Course time is 2¼ hours
- This event is being recorded
- Trainers control slides
  - **Want to control your own slides?** You can download presentation file on CLU-IN training page
- Questions and feedback
  - **Throughout training:** type in the "Q & A" box
  - **At Q&A breaks:** unmute your phone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

Notes:

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

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

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



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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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Kristopher (Kris) McCandless has worked for the Virginia Department of Environmental Quality (DEQ) in Woodbridge, Virginia since 2015. As an Environmental Geologist in the petroleum storage tank remediation division, he manages the characterization and remediation of numerous leaking petroleum storage tank sites, as well as assists the Land Protection Program with chlorinated solvent sites. Kris has spent most of his career as a project manager and hydrogeologist in the environmental consulting field. In the past two decades, his projects were focused on investigating and managing petroleum and chlorinated solvent sites in the Mid-Atlantic Piedmont states. Kris spearheaded investigations for Alternate Water Supplies for the DEQ Petroleum Program for State Lead sites as a contractor for DEQ, including locating new supply well locations, tracking groundwater flow through fractured media, performing packer testing to sample and isolate impacted zones within a supply well, performing pump tests in fractured rock, and assessing bedrock sites for remediation of chlorinated solvents. While reaping the benefits of many ITRC webinars during his consulting career, Kris joined the Fractured Bedrock team soon after employment with DEQ. Kris is actively engaged as a chapter lead for the ITRC Optimization of In situ Remediation team beginning in 2018. Kris earned his Bachelor of Science degree in Geology from George Mason University in 1988 in Fairfax, Virginia and is a Certified Professional Geologist (CPG) in Virginia.

Richard Desrosiers is Vice President/Hydrogeologist for GZA GeoEnvironmental, Inc. in Glastonbury, Connecticut. Beginning his environmental career in the mid-1980s, Richard has focused on large complex geologic, hydrogeologic and geochemistry fate & transport problems associated with soil and groundwater contamination. He designed and led site investigations and remediation actions at a site with chlorinated solvents and hexavalent chromium encompassing a one square mile using high resolution site characterization and designing in-situ remediation remedies using chemical oxidation for VOC and biochemical reduction to treat hexavalent chromium and volatile organic compounds. Richard has completed RCRA/CERCLA hazardous waste investigations/closures; implemented in-situ innovative recirculation well technology to capture, treat and reinject remediate groundwater within the same well; identified and developed high yielding groundwater supplies in surficial and bedrock aquifers; completed numerous hydrogeologic evaluations and groundwater models; and has provided depositions, bench and jury expert testimony regarding litigation issues. Most recently, Richard leads GZA's PFAS initiative and has participated on CT PFAS Task Force Committees. Since 2015, Richard has been an active member on the Interstate Technology & Regulatory Council (ITRC) "Characterization and Remediation in Fractured Rock", "Optimization of In-Situ Remediation and Injection Strategies" and "Per- and Polyfluoroalkyl Substances (PFAS)" teams. Richard earned a bachelor's degree in Geology from Northeastern University in Boston, Massachusetts in 1982. He is a Licensed Environmental Professional in Connecticut and a licensed Professional Geologist in New Hampshire and Tennessee.

Suzanne O'Hara is a senior contaminant hydrogeologist with Geosyntec Consultants based in Ontario Canada. She has over 20 years of field and project management experience focusing on remediation of groundwater and soil containing recalcitrant compounds using innovative and more conventional technologies. She has directed, managed, or provided technical support for multiple projects ranging from overall strategy development, site investigation, remedial design, costing and implementation, contaminant fate and transport, and conceptual site model (CSM) development. Her technical experience involves dense non-aqueous phase (DNAPL) fate and transport in fractured media and the design, implementation and interpretation of innovative in situ remediation technologies for complex contaminated sites. Suzanne's remediation technology experience includes enhanced in situ bioremediation (EISB), in situ chemical oxidization (ISCO) and reduction (ISCR), Self-sustaining Treatment for Active Remediation (STAR) thermal remediation, passive treatment using zero-valent iron barriers, and reductive dechlorination using emulsified zerovalent iron (EZVI) for DNAPLs. Suzanne has been involved in ITRC since 2017 as a team member of the Optimizing Injection Strategies and In Situ Remediation Performance team. Suzanne earned a bachelor's degree in Earth Science (geology) from the University of Waterloo, Ontario, in 1994 and a master's in Hydrogeology from the University of Waterloo, Ontario, in 1997. Suzanne is a Professional Geoscientist in Ontario and a Professional Geologist in New York.

Elizabeth Rhine is an Independent Consultant in Greenville, South Carolina. She has more than 25 years of professional experience focused on the characterization and remediation of impacted sites in the chemical, oil and gas, and transportation sectors. She is adept at developing creative and cost-effective remediation strategies for clients to meet the objectives of project stakeholders including responsible parties, regulatory agencies, potential developers, and the public. Her work has focused primarily in groundwater remediation of sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA), developing site conceptual models, evaluating site conditions for in situ groundwater remedies, indoor air quality, regulatory compliance, environmental liability valuations, transactional due diligence, and brownfield redevelopment. Elizabeth is the author or co-author of more than a dozen peer-reviewed technical papers and has presented at a number of conferences and universities. Elizabeth earned a bachelor's degree in biology from Furman University in Greenville, South Carolina in 1989 and a master's in business administration with an emphasis in data management in 1998.

Poll Question:

Have you ever had a remedy not meet design expectations? Yes/No

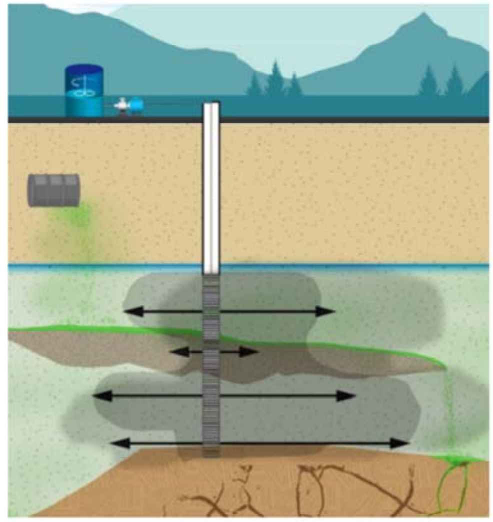
Thank you, (host name), and thank you all for attending this webinar. This slide gives you the web link to our document and its landing page

(next slide, keep poll question up)

7

In Situ Remediation

- A typical in situ remedy includes **delivery** and **dosing** of **amendments** to enhance abiotic and/or biotic **processes** to treat contaminants in subsurface
- More than thirty years of experience with in situ remedies has greatly improved the state of the science and engineering; though challenges remain



You are in the right spot for the next 1.5 hours if you said yes to the poll question! If you said no, there are a handful of us who contributed to this guidance that would like to know your secret!

As our first slide implies, this webinar is aimed for your site involving injection of amendments at the correct doses for the in situ remediation of contaminant mass and how to optimize any phase of that process.

Although this subject of In situ remediation is far from new – has been around for at least 30 years with great progress made in each advancing year – everyone, even the ones who said NO to the poll question, have encountered challenges when it comes to in situ remediation.

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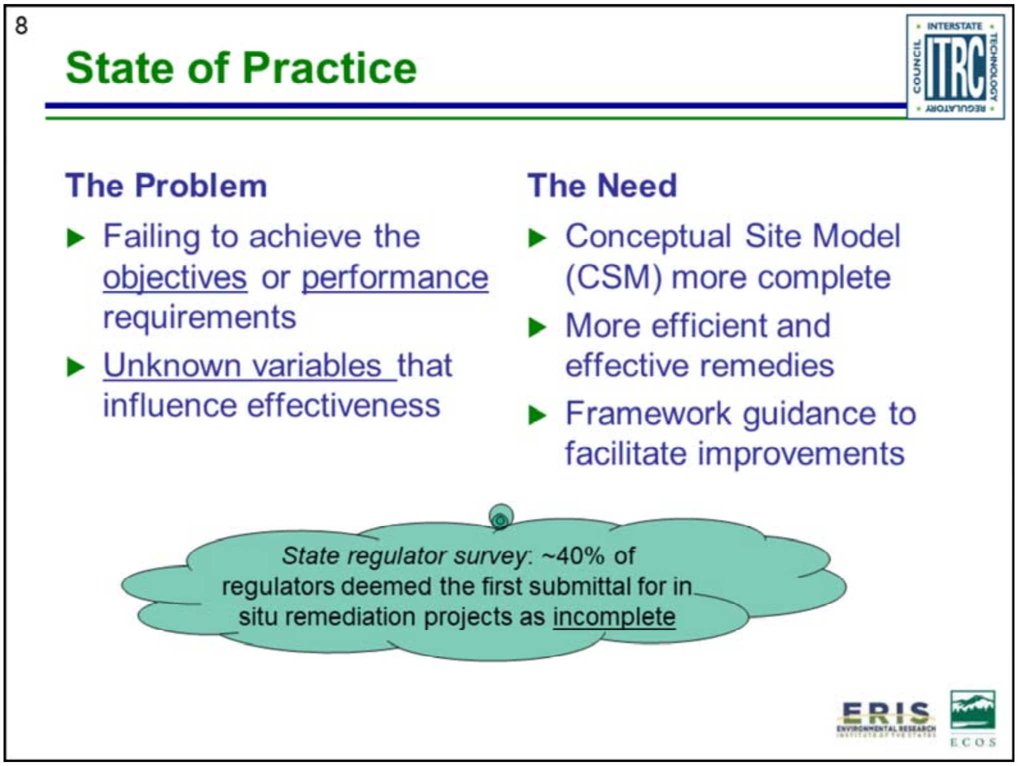

OK, the problem we are facing going into this document is failing to achieve expected performances of in SITU INJECTION REMEDIES and encountering UNKNOWN VARIABLES that impact effectiveness

Our team did a survey of state regulators across the US for remediation proposals they received…..and about 40% deemed the first submittal as incomplete. WHY?

It hinged around an incomplete conceptual site model (CSM) which in turn led, for example, to inadequate amendment placement or choosing the wrong delivery for the site geology.

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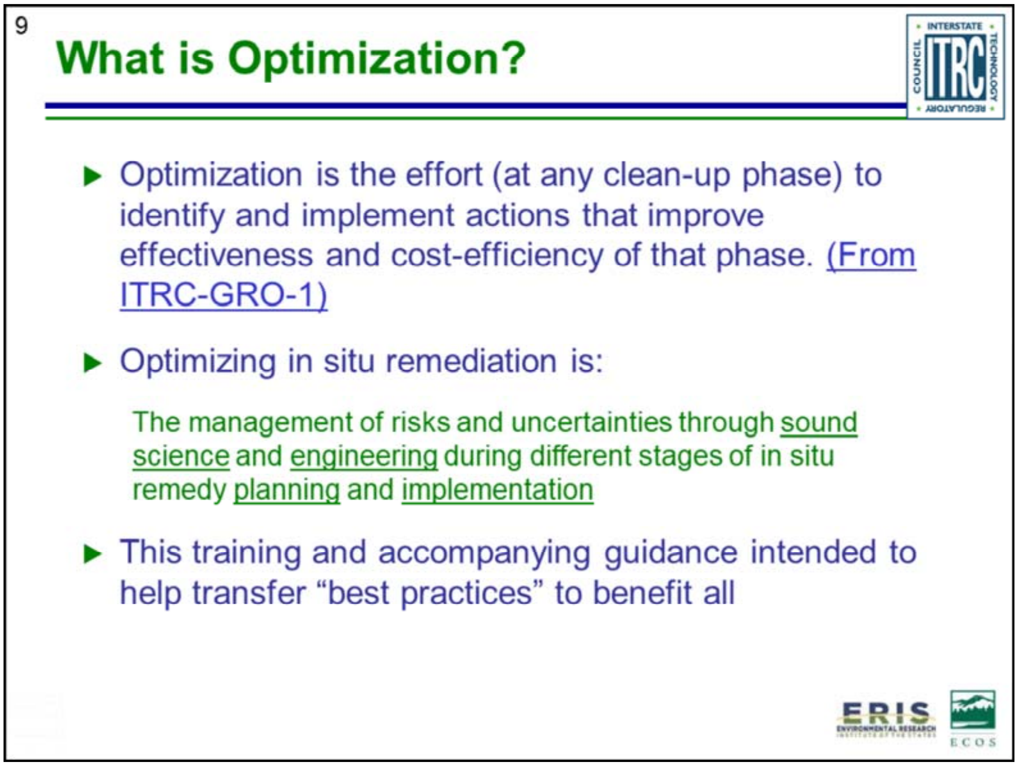

-What is Optimization --- (read definition), 2016 geospatial analysis for Optimization

-Optimizing in situ remediation is…..

I emphasize these words because they are the THEME of this course and of this document

I hope you can see this webinar and the accompanying guidance document intend to promote best practices for the benefit of ALL: the Regulatory agencies, Responsible Parties, Consultants and the public

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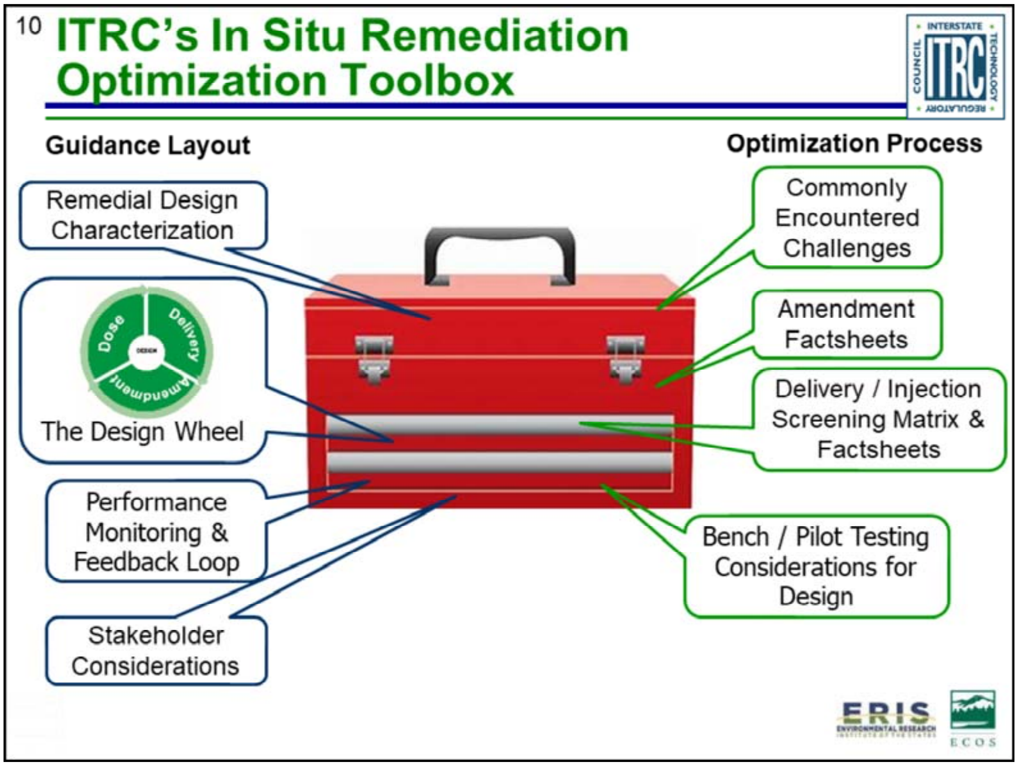

I want you all to think of this document and its tables and fact sheets as an Optimization Tool Box.

ON the LEFT is your first introduction to the layout of this guidance

ON the RIGHT are those tools we are going to use to OPTIMIZE the remedial process

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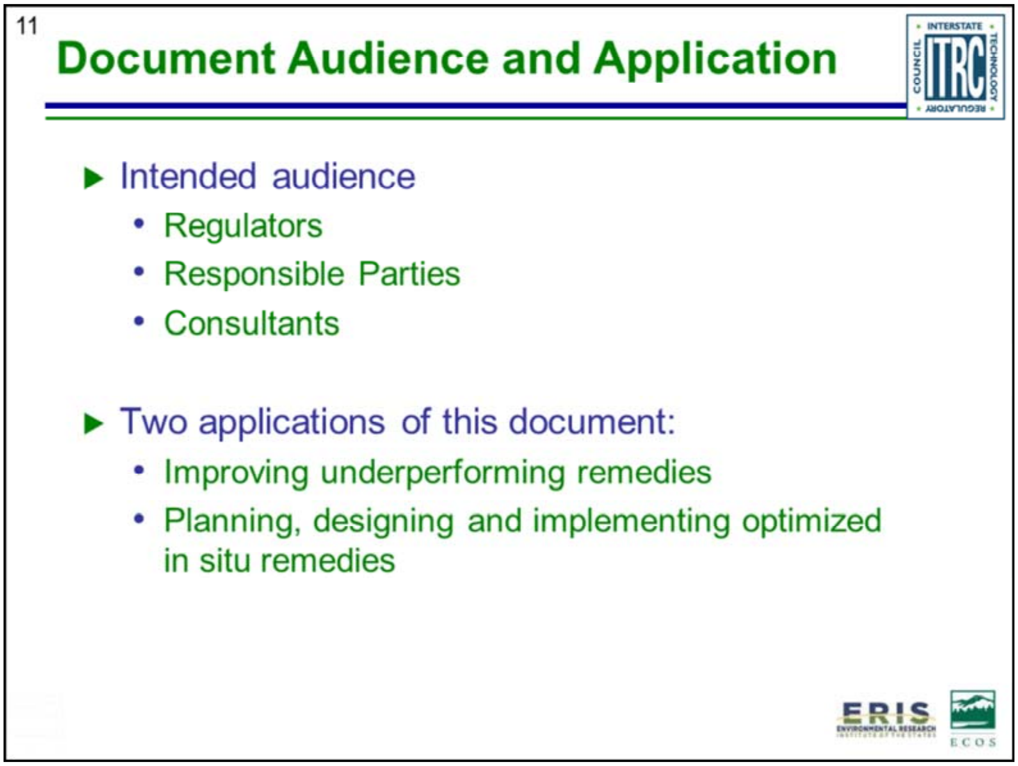


We want to make it clear that we wrote this document for remediation managers, responsible parties and regulators.

Perhaps you're having partial success but progress has stalled out

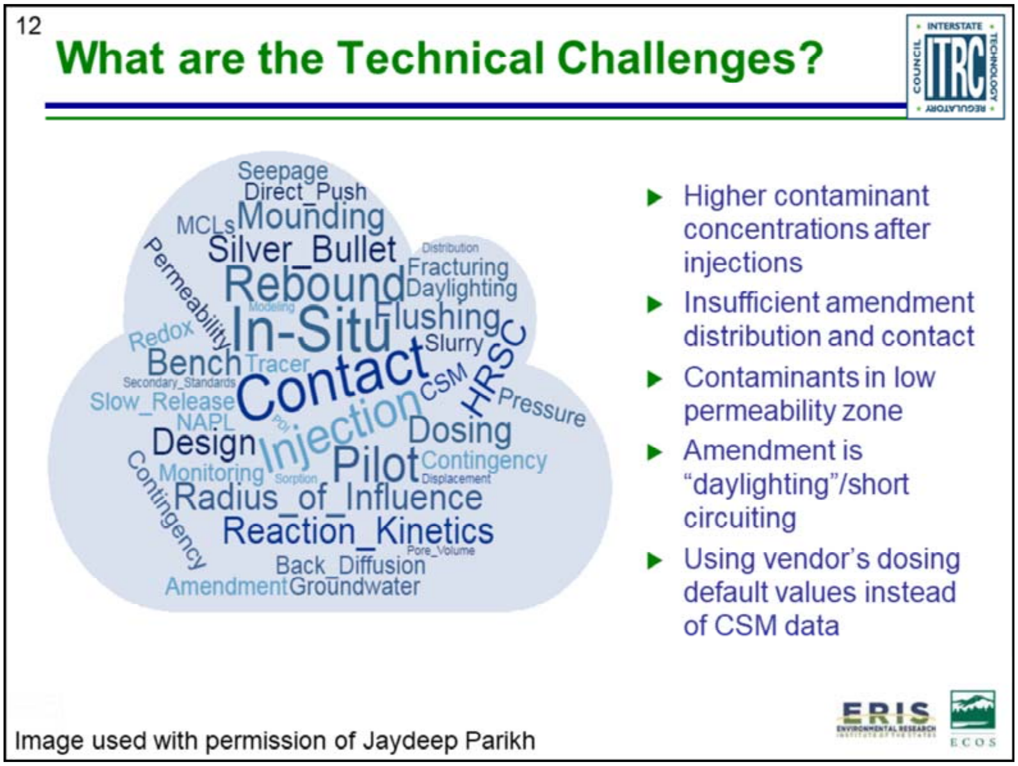
Perhaps you've pushed the contaminant mass towards a sensitive receptor – what did I do wrong?

Perhaps you've written a good CSM, feel pretty confident about your remedy selection, but want to make sure there are no data gaps or that your amendments will work with the selected delivery method.

We also wrote this for state regulators to identify potential shortcomings in remediation plans and to ask SPECIFIC questions of the consultants and responsible parties

We did NOT write this document as REMEDIATION 101. You need to be familiar with the principles of in situ remediation and preparation of a CSM.

(Next slide)



So where do we start? Well, what are the challenges YOU are encountering with an existing remedy and its implementation?

Let me throw out a few scenarios and see if this might be happening at your site….

1-Are we having higher concentrations after injections compared to baseline?

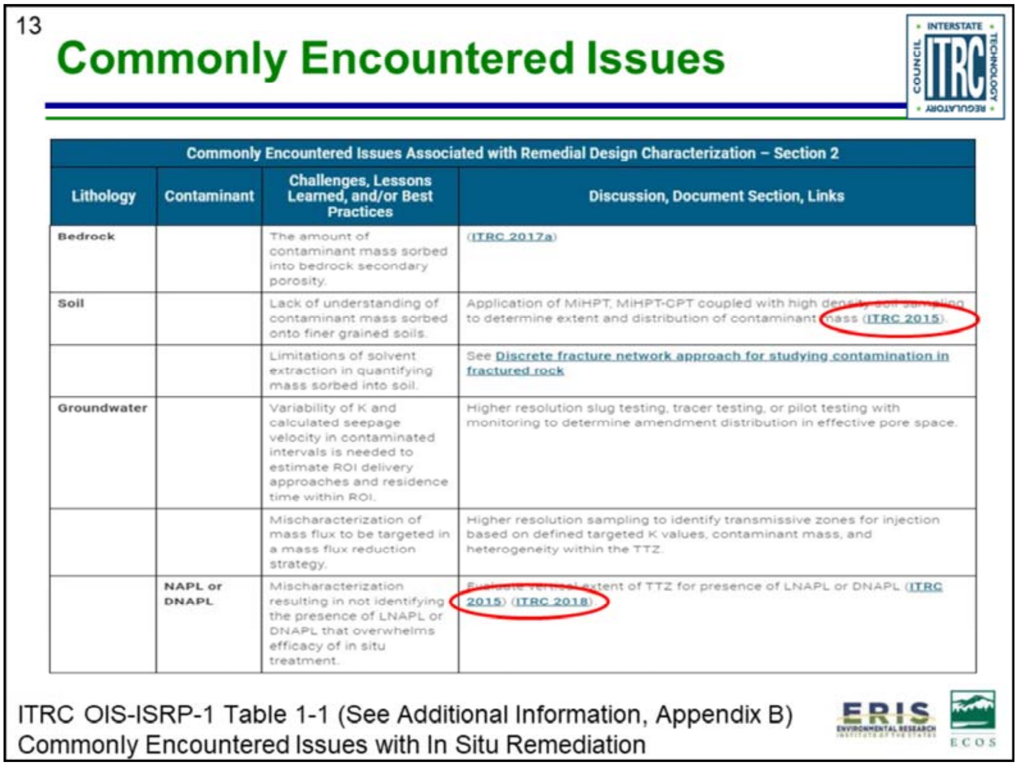
2-Or is there no indication of change after an amendment injection?

3-Do you have insufficient amendment distribution and CONTACT at your site?

4-Is your amendment daylighting?

5-OR, are you using the vendor's dosing default values instead of data from the CSM?

(Next slide)



Commonly Encountered Issues Associated with Remedial Design Characterization – Section 2			
Lithology	**Contaminant**	**Challenges, Lessons Learned, and/or Best Practices**	**Discussion, Document Section, Links**
Bedrock		The amount of contaminant mass sorbed into bedrock secondary porosity.	(ITRC 2017a)
Soil		Lack of understanding of contaminant mass sorbed onto finer grained soils.	Application of MiHPT, MiHPT-CPT coupled with high density soil sampling to determine extent and distribution of contaminant mass (ITRC 2015).
		Limitations of solvent extraction in quantifying mass sorbed into soil.	See **Discrete fracture network approach for studying contamination in fractured rock**
Groundwater		Variability of K and calculated seepage velocity in contaminated intervals is needed to estimate ROI delivery approaches and residence time within ROI.	Higher resolution slug testing, tracer testing, or pilot testing with monitoring to determine amendment distribution in effective pore space.
		Mischaracterization of mass flux to be targeted in a mass flux reduction strategy.	Higher resolution sampling to identify transmissive zones for injection based on defined targeted K values, contaminant mass, and heterogeneity within the TTZ.
	NAPL or DNAPL	Mischaracterization resulting in not identifying the presence of LNAPL or DNAPL that overwhelms efficacy of in situ treatment.	Evaluate vertical extent of TTZ for presence of LNAPL or DNAPL (ITRC 2015) (ITRC 2018).

With these challenges in mind, let's head to Table 1-1 in Appendix B of the guidance!

This slide is a snapshot of the Commonly Encountered Issues Associated with Remedial Design Characterization.

This is one of 3 sections in this table, the other two being

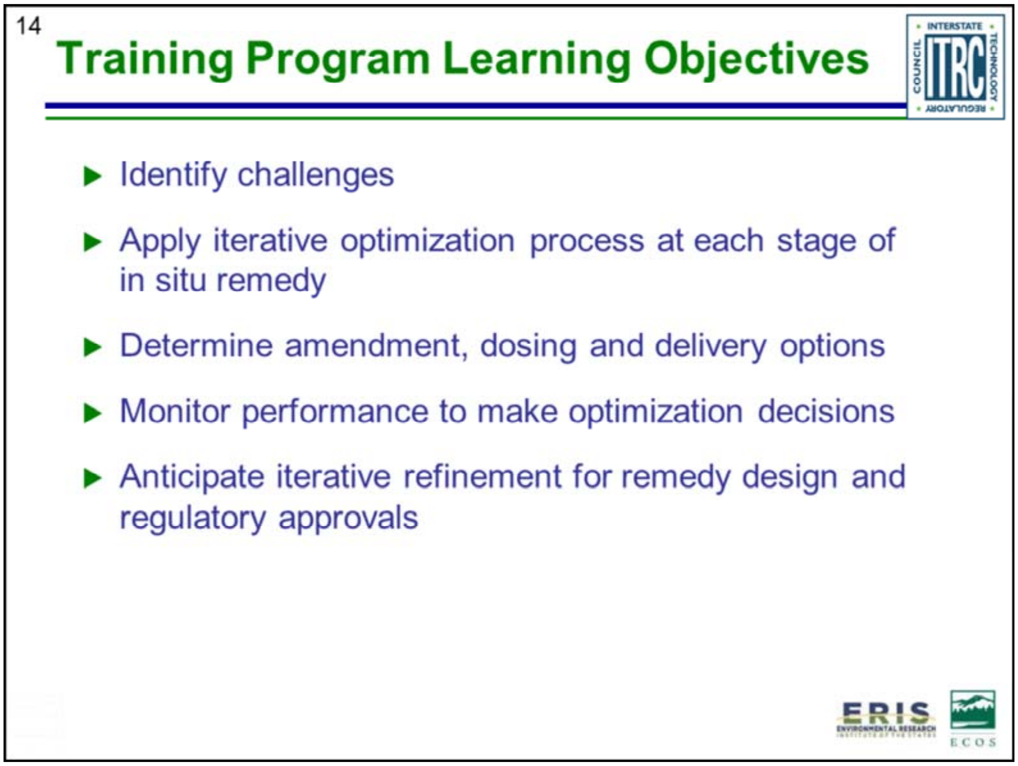
Commonly Encountered Issues with A D & D and Common Enc Issues with Field Implementation (animation click)

Please don't try to read the gray print BUT pay attention to the column headings

As you identify your lithology and contaminant (2 left columns), you can read the common challenges Lessons Learned and get answers via the 4th column, which contains links to the content within the text, links to view a particular delivery or amendment factsheet, and links to other documents ((**animation x 2**), including applicable ITRC guidance as shown here

I want you to think of this table as your Custom TOC, tailored to your particular site conditions OR the challenges you are facing.

(next slide)



Now, these are the objectives of this Internet-Based training session; take a look at these and think about them as I move through these introductory slides

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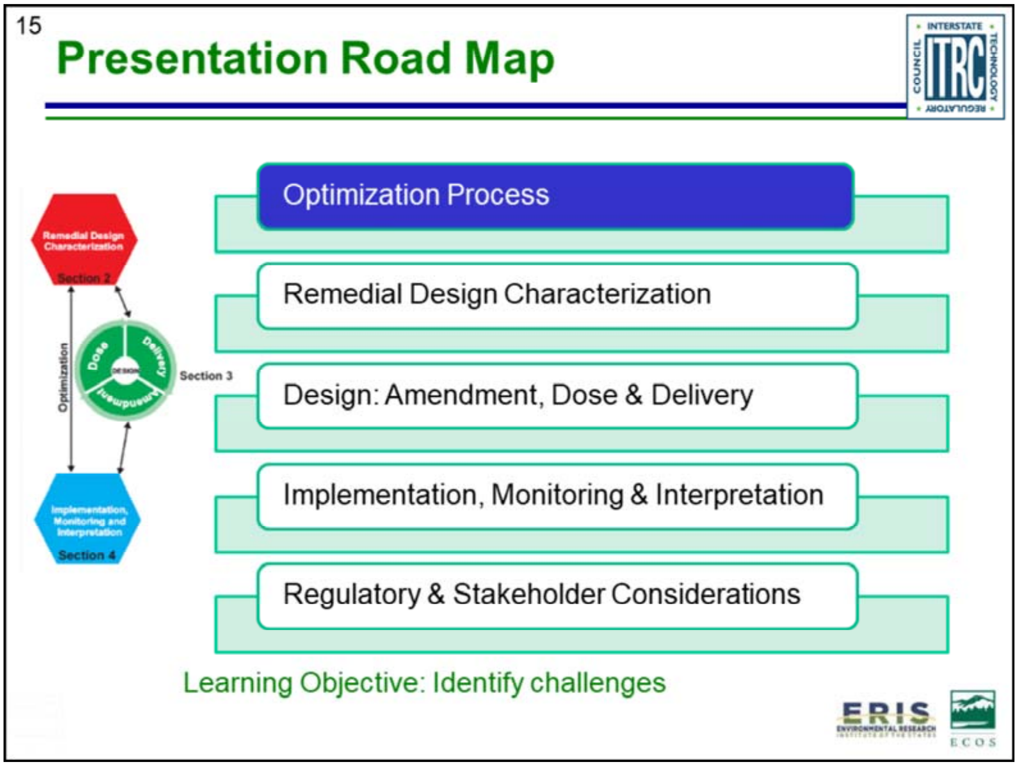

Roadmap introduces the 3 major elements of our key graphic, on the left.

If you consider the top and bottom boxes as the bread of a sandwich, the lettuce, tomato and meat of the middle three correlate to the order the document is written in.

Rich - RDC

Suzanne - AD&D

Elizabeth - Imp Mon Interp

I will circle back for Stake & Regulatory

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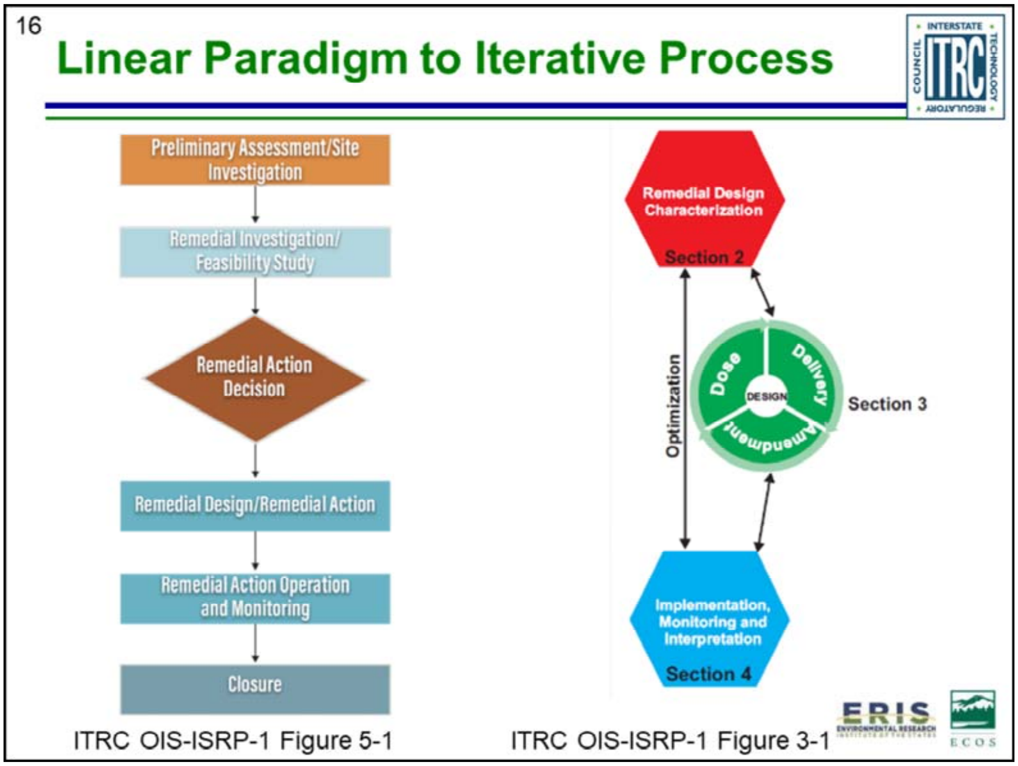


This flow chart is likely familiar to most of you because it is the CERCLA process of remediating sites and taking them to closure, which is similar to the RCRA process for petroleum impacted sites.

BUT, The common goal of both is to CLEAN UP SITES, right?

As we developed this guidance document, we realized the linear approach to the left gave us no flexibility; and so...(animation)…..our key graphic was born (point to right side)

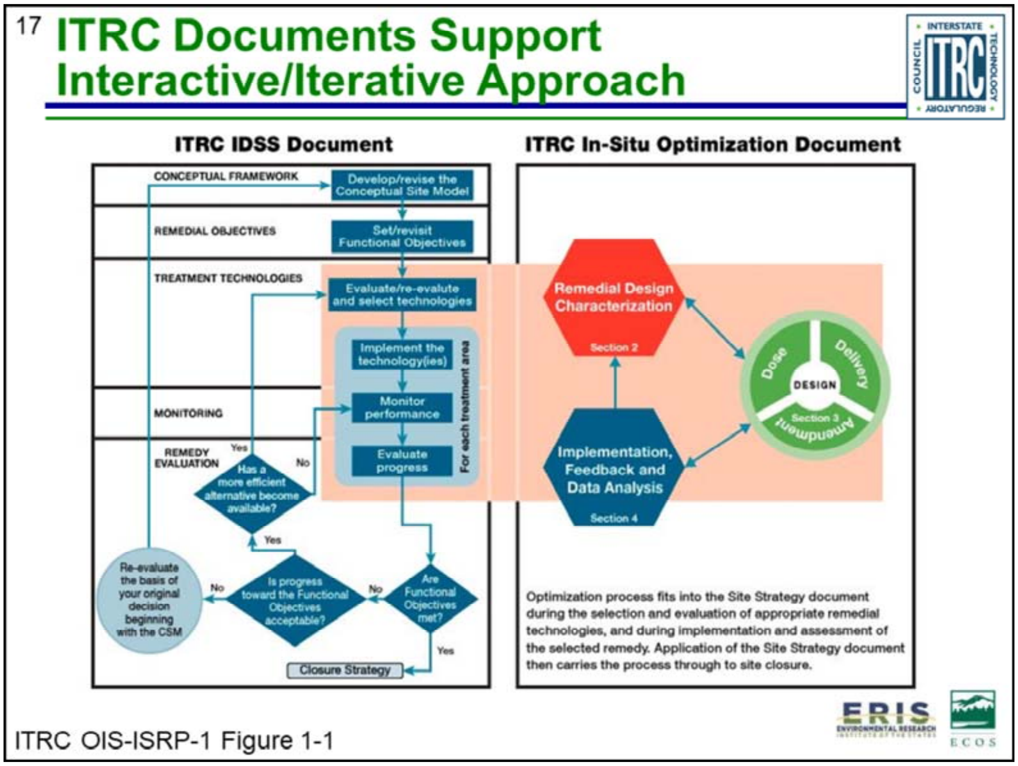
By now, you've gotten a good hint of our three main ELEMENTS of our document – RDC, Design Wheel with A D & D, and Implementation, Monitoring and Interpretation

Can you see the difference simply in the arrows connecting both diagrams, left and right?

We discovered that optimization was the outcome of better characterizing our subsurface conditions, improving the CSM, performing bench tests and pilot studies, making mistakes and then going back to an earlier step – i.e. the double headed arrows. We realized the most flexible approach had to be iterative!

We are not throwing away the graphic to the left – we are augmenting it by placing our key graphic *(and point to RD/RA light blue box)* in place of these two steps!

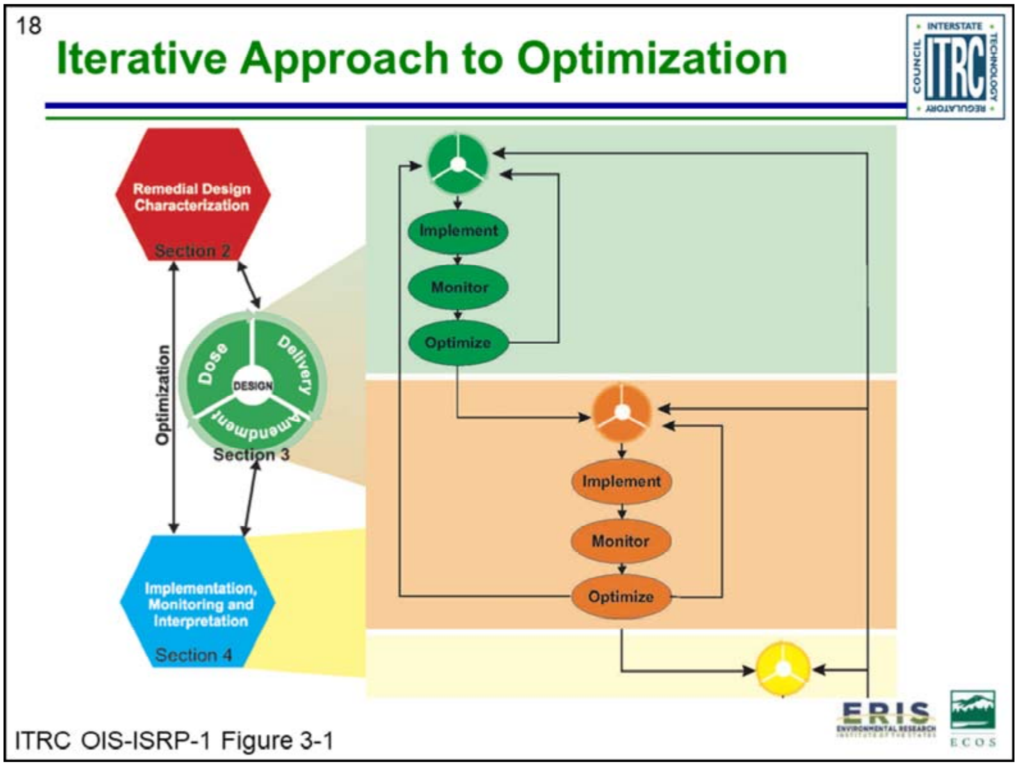
(next slide)



And guess what? The iterative approach is not new! Our key graphic is an augmentation of ITRC's 2011 Integrated DNAPL Site Strategy (IDSS) guidance document (on the left).

Do you see how it fits into "treatment technologies"?

(next slide)



The True nature of in situ remediation is iterative!

The interactive/iterative approach lets the CSM become adaptable to new technologies and new contaminants.

The team further augmented the key graphic with what we called The Optimization Staircase (to the right of the key graphic), wherein the process of implementing, monitoring and optimization takes place during the Bench Test and the Pilot Test Phases of DESIGN phase (section 3) and again during the actual full-scale implementation phase in the blue hexagon.

Do you see the opportunities for optimization (animation) where in the feedback loops of the optimization staircase take you back to the miniature design wheels…IF…monitoring and implementation didn't work?

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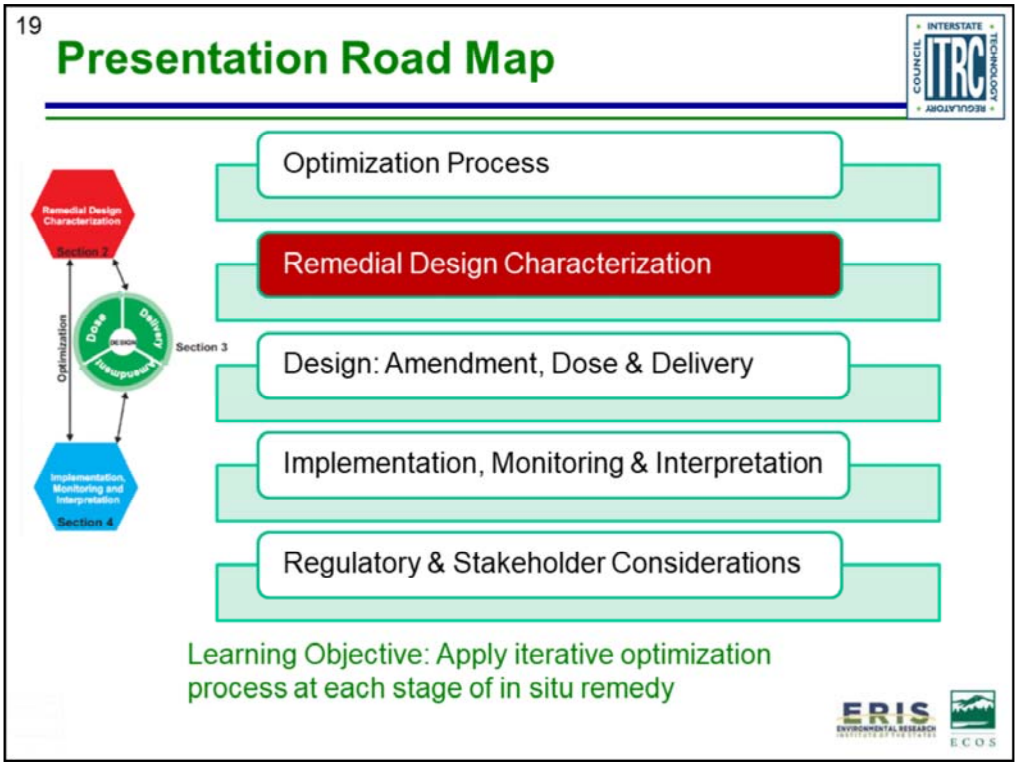

We shall now get into our first hexagon, Remedial Design Characterization with Rich Desrosiers of GZA GeoEnvironmental…..Rich?

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RDC – WHAT IS IT?

RDC = REMEDIAL DESIGN CHARACTERIZATION

It is the collection of additional data, above and beyond general site characterization, necessary to develop a sufficiently detailed CSM

This enables the design basis for a successful in situ remedy

No associated notes.

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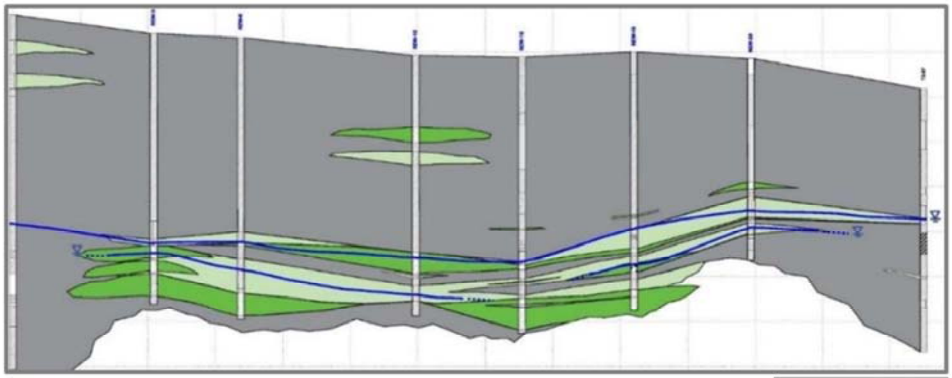
RDC – WHY DO IT?

When in situ remedies fail, or produce less than optimal outcomes, it is often due to a lack of detailed data or an insufficiently developed conceptual site model (CSM)

The success of in situ remedies is directly related to a thorough understanding of site and subsurface conditions

No associated notes.

The Impact of Data



HYDROGEOLOGIC DATA:

- Alluvial formation
- 7 borings to ~140 feet
- 3,500-foot alignment
- Soil logged every 5 feet

Figure used with permission of Amy Wilson

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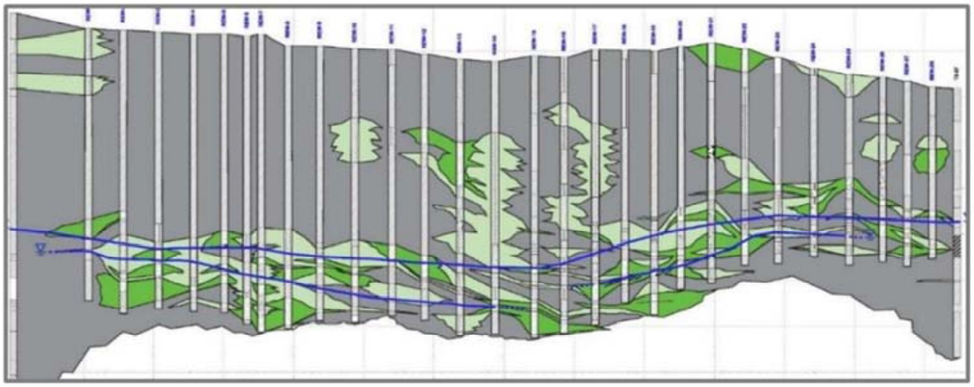
The Impact of More Data



MORE DATA

- ~40 borings over the 3,500-foot alignment
- Soil logged every 5 feet in vadose zone
- Soil logged continuously below first saturated zone
- Increasing complexity revealed

Figure used with permission of Amy Wilson

This shows the evolution of a hydrogeologic cross-section as more borings were drilled and more data were collected over the years. In the first figure, limited vadose zone data were collected and only 7 borings had been advanced along a 3,000-foot alignment. The second cross-section has more vadose zone data and approximately 30 borings or wells. The third section has significantly more vadose zone data and about 60 borings. You can see how the complexity of this alluvial formation increases as the data set grows.

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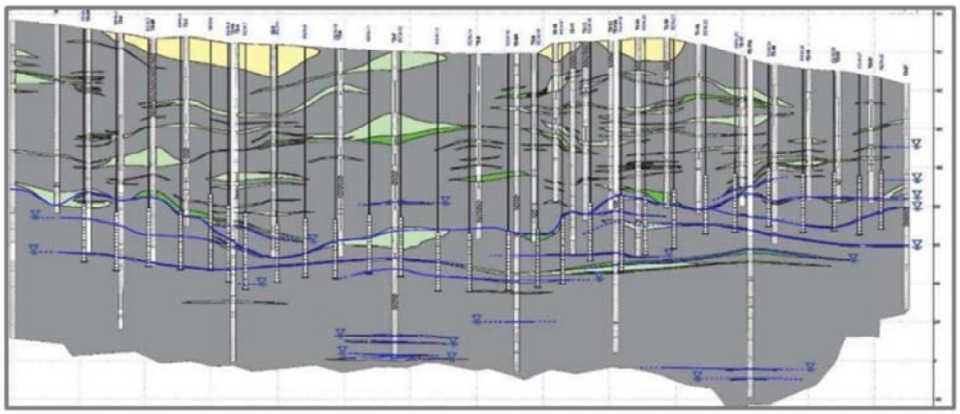
The Impact of More (and More) Data



EVEN MORE DATA

- ~60 borings over the 3,500-foot alignment
- Soil logged continuously
- Cross-section evolves – even more complex

Figure used with permission of Amy Wilson

You can see how the complexity of this alluvial formation increases as the data set grows.

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Remedial Design Characterization (RDC)

WHAT DO WE NEED TO KNOW?

Geology

properties that define flow regimes

Hydrogeology

properties that influence flow and transport

Geochemistry

electron acceptors, competitors, metal mobilization

Microbiology

degradation potential

No associated notes.

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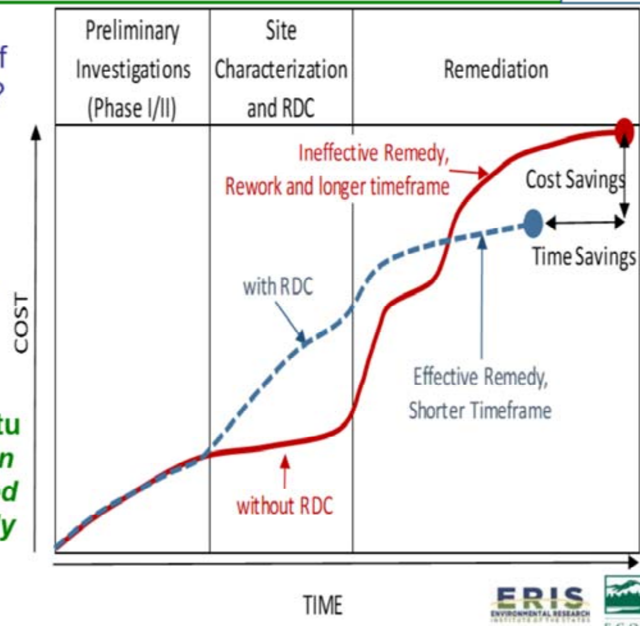
RDC - Why Do It? (Redux)

- What is the value of investigation (VOI)? Figure 2-1
- Why spend more money on characterization, when you could be spending it on cleanup?

***Remember*: when in situ remedies fail, it is often due to a lack of detailed data or an insufficiently developed CSM**



ITRC OIS-ISRP-1 Figure 2-1

Often it can be challenging to convince clients and other financial stakeholders to spend more money on investigation when they feel ready to begin remediation and demonstrate that they are making progress. We need to be able to work with stakeholders to help them understand that without this additional RDC investment, the remedy is more likely to be ineffective, costing more in the long run. This conceptual graph shows the “value of investigation.”

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Value of Investigation (VOI) Case Study

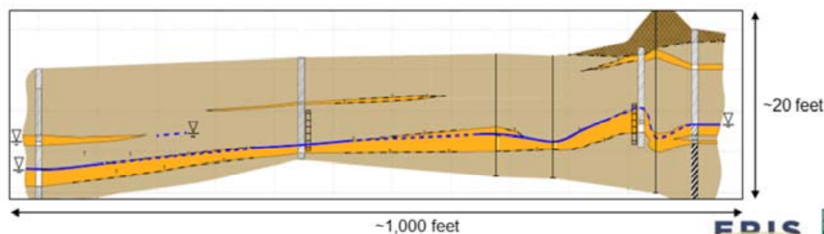
Case Study

The Setting:

- 20-acre site in California Central Valley
- VOC impacts to soils and groundwater
- Geology - floodplain deposits
- TTZ - sand lens, several feet thick approximately 15 feet below grade

Initial Remedy Attempt:

- Tight redevelopment timeframe
- Enhanced In Situ Bioremediation implemented using sodium lactate



ITRC OIS-ISRP-1 Section 2.1.2

Value of Investigation (VOI) Case Study

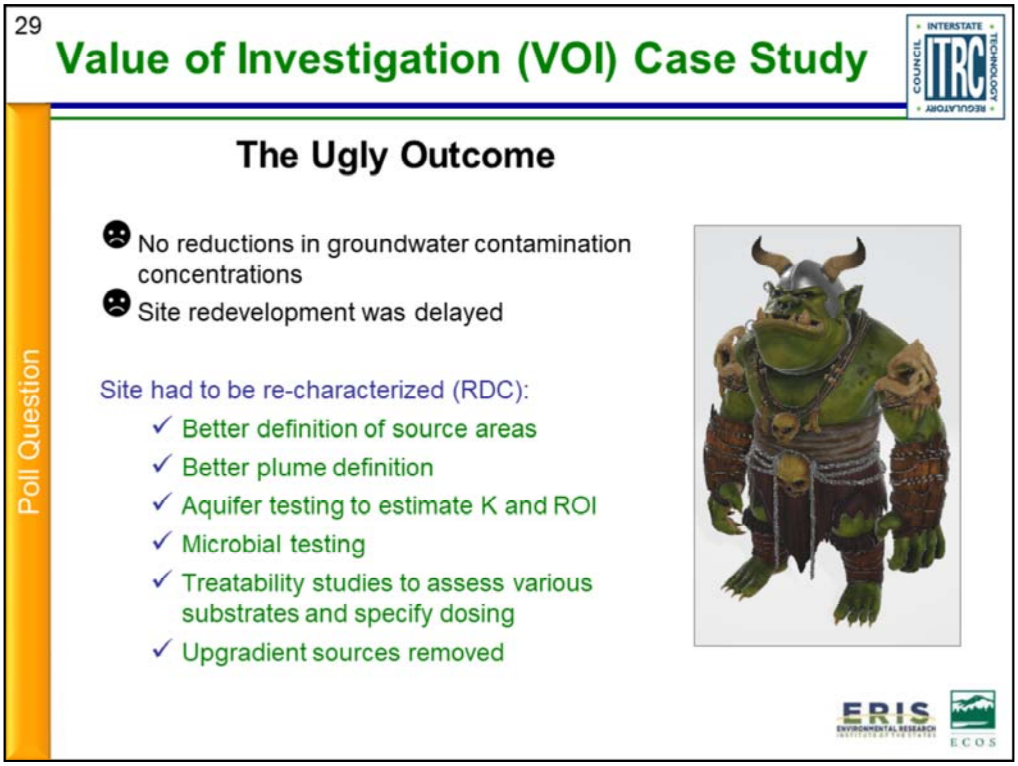
Case Study

The Good

- **Geology well characterized**
- **Injections properly performed within the sand interval**

The Bad

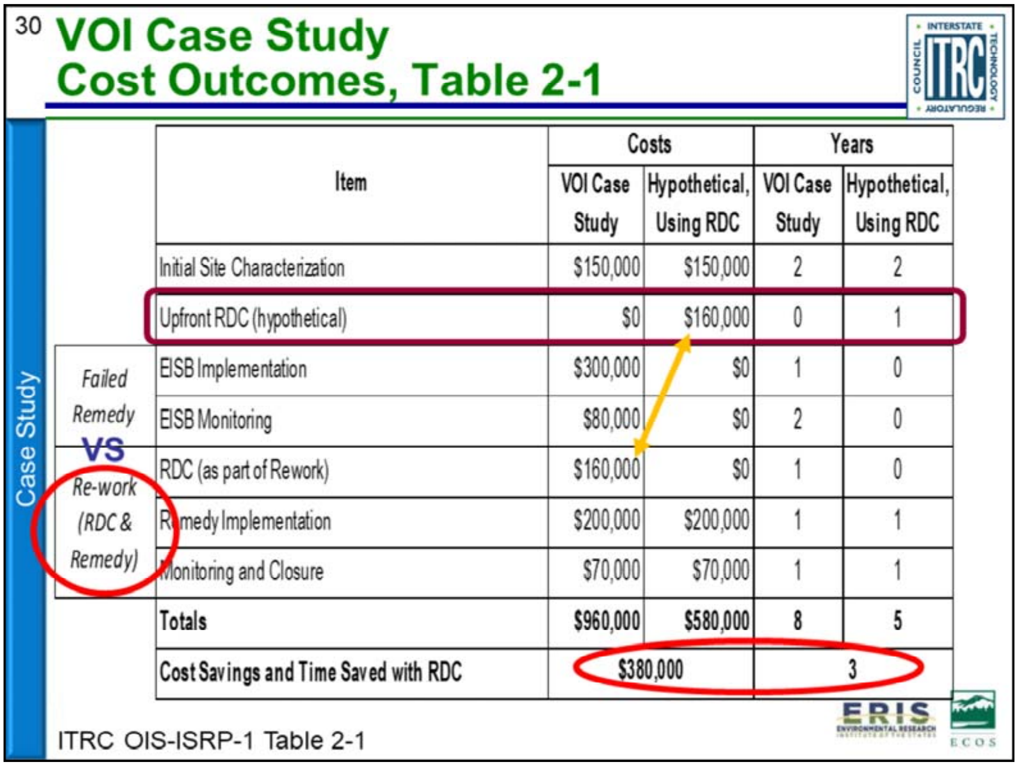
☹ Hydraulic conductivity not evaluated
☹ Injection test not performed
☹ Geochemical parameters not used to assess EISB viability
☹ No treatability testing
☹ Choice of substrate and dosing “based “similar sites”
☹ Microbial studies not performed
☹ Upgradient sources not assessed or removed



Poll Question:

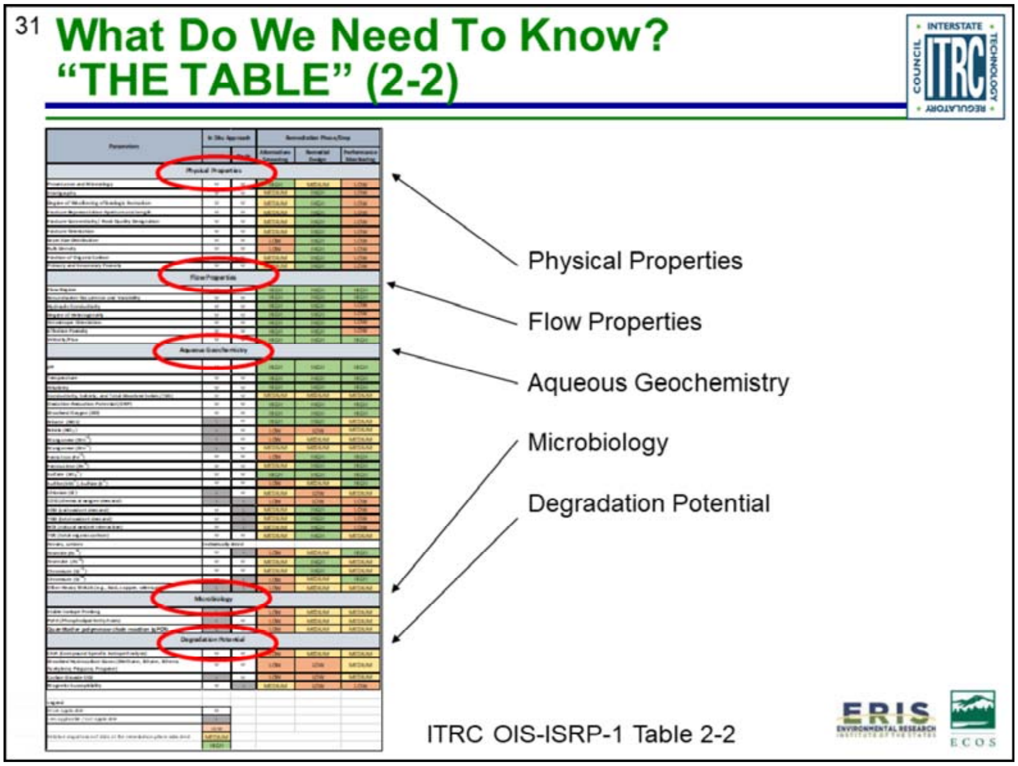
Have you ever had to perform in situ re-work because of poor initial site characterization?

YES / NO



Item	Costs		Years	
	VOI Case Study	Hypothetical, Using RDC	VOI Case Study	Hypothetical, Using RDC
Initial Site Characterization	$150,000	$150,000	2	2
Upfront RDC (hypothetical)	$0	$160,000	0	1
EISB Implementation	$300,000	$0	1	0
EISB Monitoring	$80,000	$0	2	0
RDC (as part of Rework)	$160,000	$0	1	0
Remedy Implementation	$200,000	$200,000	1	1
Monitoring and Closure	$70,000	$70,000	1	1
Totals	**$960,000**	**$580,000**	**8**	**5**
Cost Savings and Time Saved with RDC	$380,000		3	

The additional remediation cost and years lost do not include the opportunity cost of delayed redevelopment to the client/site owner.



Most of the content of the RDC section (Section 2) is contained in Table 2-1, where we have consolidated the parameters potentially needed for RDC.

32

and When? (Table 2-2)

Remediation Phase/Step		
Alternatives Screening	Remedial Design	Performance Monitoring

In Situ Approach	
Abiotic	Biotic

Legend	
More applicable	M
Less applicable / not applicable	L
	LOW
Relative importance of data at the remediation phase indicated	MEDIUM
	HIGH

ITRC OIS-ISRP-1 Table 2-2

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Physical Properties (Table 2-2)

Parameters	In Situ Approach		Remediation Phase/Step		
	Abiotic	Biotic	Alternatives Screening	Remedial Design	Performance Monitoring
Physical Properties					
Provenance and Mineralogy	M	M	HIGH	MEDIUM	LOW
Stratigraphy	M	M	MEDIUM	HIGH	LOW
Degree of Weathering of Geologic Formation	M	M	MEDIUM	HIGH	LOW
Fracture Representative Aperture and Length	M	M	MEDIUM	HIGH	LOW
Fracture Connectivity / Rock Quality Designation	M	M	MEDIUM	HIGH	LOW
Fracture Orientation	M	M	MEDIUM	HIGH	LOW
Grain Size Distribution	M	M	LOW	HIGH	LOW
Bulk Density	M	M	LOW	HIGH	LOW
Fraction of Organic Carbon	M	M	MEDIUM	HIGH	LOW
Primary and Secondary Porosity	M	M	MEDIUM	HIGH	LOW

ITRC OIS-ISRP-1 Table 2-2

We will now go through each of the 5 parameter categories and give examples of the kind of information available there.

34

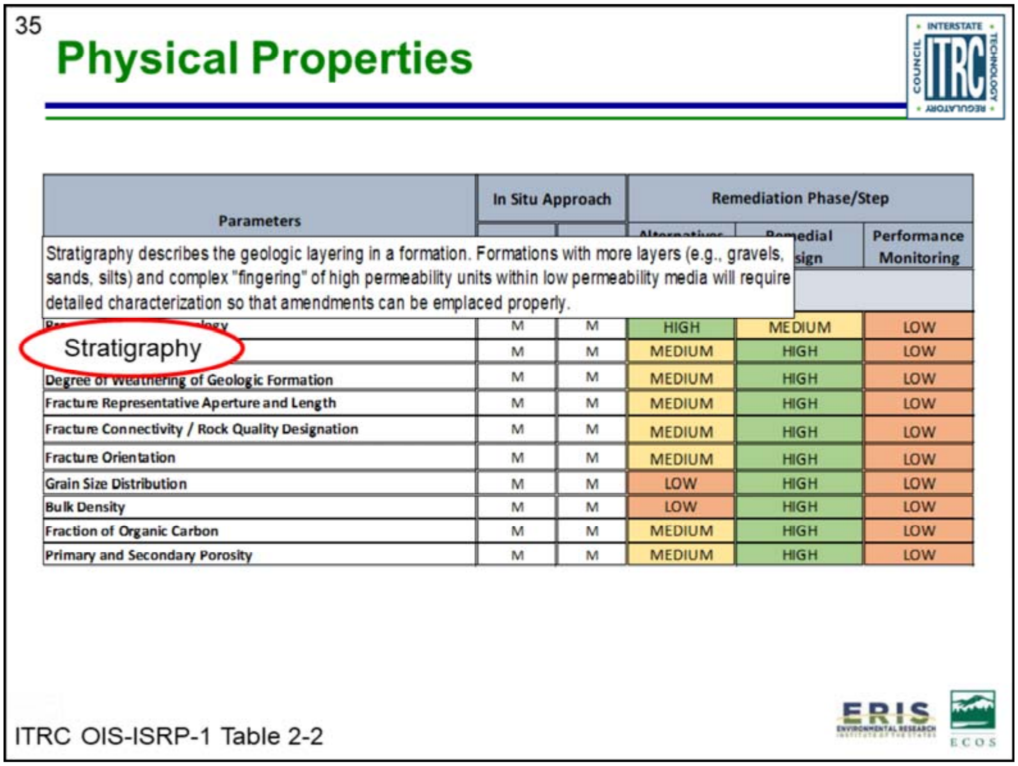
THE “HOVER” TABLE (2-3)

Provenance and mineralogy of a rock or soil matrix are the properties of its physicochemical formation - geologic structure, chemical composition, distribution, and occurrence. They are the governing factors for the physical, flow, and geochemical properties, discussed in Table 2-2, that are necessary to understand and quantify in order to design an optimal in-situ approach.

				Phase/Step	
				dial n	Performance Monitoring
	Physical Properties				
Provenance and Mineralogy	M	M	HIGH	MEDIUM	LOW
Stratigraphy	M	M	MEDIUM	HIGH	LOW
Degree of Weathering of Geologic Formation	M	M	MEDIUM	HIGH	LOW
Fracture Representative Aperture and Length	M	M	MEDIUM	HIGH	LOW
Fracture Connectivity / Rock Quality Designation	M	M	MEDIUM	HIGH	LOW
Fracture Orientation	M	M	MEDIUM	HIGH	LOW
Grain Size Distribution	M	M	LOW	HIGH	LOW
Bulk Density	M	M	LOW	HIGH	LOW
Fraction of Organic Carbon	M	M	MEDIUM	HIGH	LOW
Primary and Secondary Porosity	M	M	MEDIUM	HIGH	LOW

ITRC OIS-ISRP-1 Table 2-2

Describe the “hover” feature. The hovering properties are also included in the guidance as a stand-alone table (Table 2-2). (NOTE – NEED TO CONFIRM THIS FOLLOWING ON LINE PUBLICATION OF DOCUMENT.) In each of the following slides, discuss briefly the circled parameter and its importance to RDC.



Parameters	In Situ Approach		Remediation Phase/Step		
				sign	Performance Monitoring
	M	M	HIGH	MEDIUM	LOW
Stratigraphy	M	M	MEDIUM	HIGH	LOW
Degree of Weathering of Geologic Formation	M	M	MEDIUM	HIGH	LOW
Fracture Representative Aperture and Length	M	M	MEDIUM	HIGH	LOW
Fracture Connectivity / Rock Quality Designation	M	M	MEDIUM	HIGH	LOW
Fracture Orientation	M	M	MEDIUM	HIGH	LOW
Grain Size Distribution	M	M	LOW	HIGH	LOW
Bulk Density	M	M	LOW	HIGH	LOW
Fraction of Organic Carbon	M	M	MEDIUM	HIGH	LOW
Primary and Secondary Porosity	M	M	MEDIUM	HIGH	LOW

Describe the “hover” feature. The hovering properties are also included in the guidance as a stand-alone table (Table 2-2). (NOTE – NEED TO CONFIRM THIS FOLLOWING ON LINE PUBLICATION OF DOCUMENT.)

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Flow Properties

Parameters	In Situ Approach		Remediation Phase/Step		
			...ves ...ng	Remedial Design	Performance Monitoring
				HIGH	HIGH
				HIGH	HIGH
				HIGH	LOW
Deg...	M	M	HIGH	HIGH	LOW
Anisotrop...	M	M	HIGH	HIGH	LOW
Effective Porosity	M	M	HIGH	HIGH	LOW
Velocity/Flux	M	M	HIGH	HIGH	HIGH

Heterogeneity refers to the variability in soil types within an aquifer (gravels, sands, silts, clays, bedrock/fractures). Heterogeneity is related to a unit's provenance and conditions of formation, for example, alluvial units are more heterogeneous than fluvial units. Understanding and mapping the more permeable zones is a critical step in characterization, because these zones are more likely to be saturated with groundwater and contain contaminants. The less permeable units are more likely to have sorbed contaminants that will be slowly released over time via back-diffusion.

Heterogeneity

ITRC OIS-ISRP-1 Table 2-2

No associated notes.

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Flow Properties

Anisotropy refers to the directionality of physical aquifer properties. Layered units are generally anisotropic, with continuity of properties and flow in the lateral direction, limited in the vertical direction by low permeability layers.

Anisotropy

Parameters	In Situ Approach		Remediation Phase/Step		
	Abiotic	Biotic	Alternatives Screening	Remedial Design	Performance Monitoring
Flow Properties					
				HIGH	HIGH
				HIGH	HIGH
				HIGH	LOW
De[illegible]	M	M	HIGH	HIGH	LOW
	M	M	HIGH	HIGH	LOW
Effective [illegible]	M	M	HIGH	HIGH	LOW
Velocity/Flux	M	M	HIGH	HIGH	HIGH

ITRC OIS-ISRP-1 Table 2-2

No associated notes.

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Aqueous Geochemistry

ITRC OIS-ISRP-1 Table 2-2

Parameters	In Situ Approach		Remediation Phase/Step		
	Abiotic	Biotic	Alternatives Screening	Remedial Design	Performance Monitoring
Aqueous Geochemistry					
					HIGH
					HIGH
					HIGH
					MEDIUM
					HIGH
					HIGH
					MEDIUM
					MEDIUM
					MEDIUM
					MEDIUM
					HIGH
	M	M	MEDIUM	HIGH	HIGH
Sulfate (SO_4^{2-})	M	M	HIGH	HIGH	HIGH
	M	M	LOW	MEDIUM	HIGH
Chloride (Cl^-)	L	M	MEDIUM	LOW	MEDIUM
COD (chemical oxygen demand)	L	L	LOW	LOW	LOW
SOD (soil oxidant demand)	M	L	MEDIUM	HIGH	LOW
TOD (total oxidant demand)	M	L	MEDIUM	HIGH	LOW
NOI (natural oxidant interaction)	M	L	MEDIUM	HIGH	LOW
TOC (total organic carbon)	M	M	MEDIUM	HIGH	MEDIUM
Anions, cations	*Individually listed*				
Arsenite (As^{+3})	M	L	LOW	MEDIUM	HIGH
Arsenate (As^{+5})	M	M	MEDIUM	HIGH	MEDIUM
Chromium (Cr^{+3})	M	M	MEDIUM	HIGH	MEDIUM
Chromium (Cr^{+6})	M	L	LOW	MEDIUM	HIGH
Other Heavy Metals (e.g., lead, copper, selenium)	L	L	LOW	MEDIUM	MEDIUM

Sulfate is naturally present in many ground waters as a product of geologic formations and their naturally occurring minerals and is often elevated in saline waters. It can also be a manufacturing or agricultural contaminant and a byproduct of persulfate used in some ISCO treatments. Sulfate needs to be carefully considered when selecting a remedial approach, as it can be beneficial and impeding, depending on the technology selected. Natural or pre-remediation sulfate at elevated concentrations can inhibit reductive processes such as reductive dechlorination, because sulfate, at elevated concentrations, is a powerful competitor for electrons. Typically, approximately 400 mg/L or greater sulfate at pre-remediation conditions can be a potential cause for concern (for reductive dechlorination) and special consideration for dosing. On the other hand, sulfate can react in situ with iron to form iron sulfides, which can provide long-term anaerobic chemical reduction. Sulfate reduction is yet another process, where sulfate is used as the primary electron acceptor, that can degrade specific contaminants (i.e., petroleum hydrocarbons).

No associated notes.

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The Redox Ladder

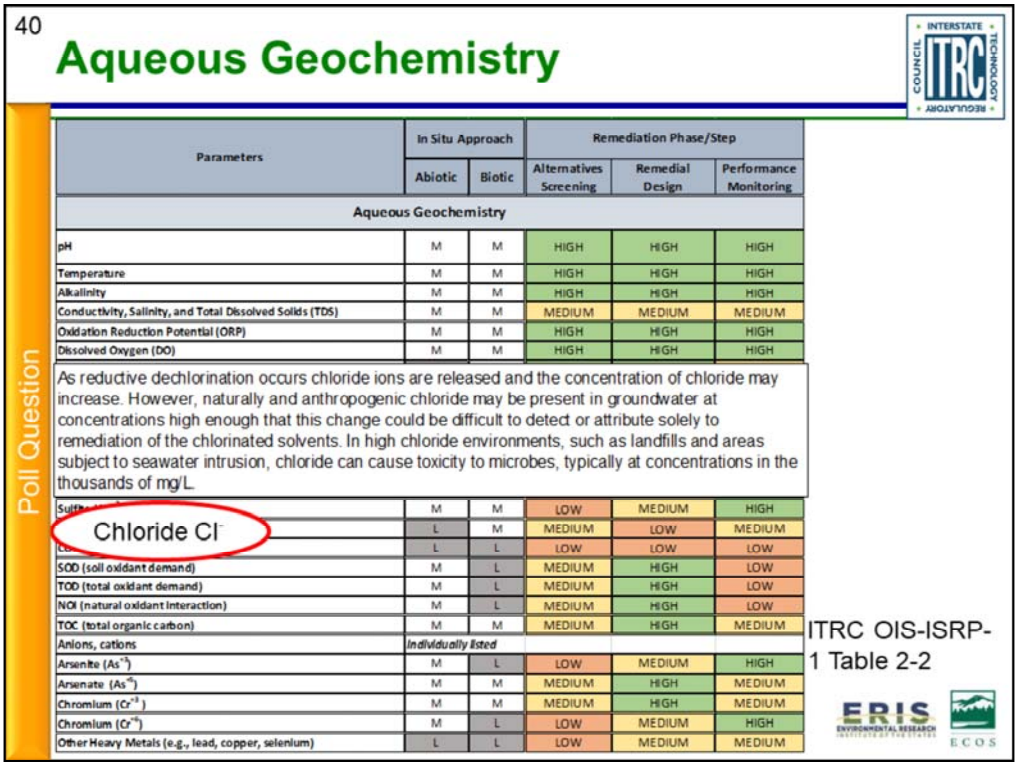
Poll Question

Terminal Electron Acceptors	→	Associated Metabolic Byproducts
Oxygen (O_2)	Oxidizing	Water (H_2O)
Nitrate (NO_3^-)		Nitrite (NO_2), Nitrogen (N_2)
Tetrachloroethene (PCE)		Trichloroethene (TCE), Chloride (Cl^-)
Manganic Manganese (Mn^{4+})	Reducing	Manganous Manganese (Mn^{2+})
Ferric Iron (Fe^{3+})		Ferrous Iron (Fe^{2+})
Trichloroethene (TCE)		Cis- and Trans- Dichloroethene (Cis-, Trans- DCE)
Vinyl Chloride (VC)		Ethene (C_2H_4), Chloride (Cl^-)
Cis- and Trans- Dichloroethene (Cis-, Trans- DCE)		VC, Chloride (Cl^-)
Sulfate (SO_4^{3-})		Sulfite (SO_3^{2-}) and Sulfide (S^{2-})
Carbon Dioxide (CO_2)		Methane (CH_4)

ITRC OIS-ISRP-1 Figure 2-2. Electron acceptors and products in order of reaction preference in progressively reducing groundwater conditions. Select contaminants are included for reference.

Poll Question:

In your experience, has sulfate been beneficial or inhibitory to in situ implementation? BENEFIT/INHIBITOR



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Aqueous Geochemistry

Poll Question

Parameters	In Situ Approach		Remediation Phase/Step		
	Abiotic	Biotic	Alternatives Screening	Remedial Design	Performance Monitoring
Aqueous Geochemistry					
pH	M	M	HIGH	HIGH	HIGH
Temperature	M	M	HIGH	HIGH	HIGH
Alkalinity	M	M	HIGH	HIGH	HIGH
Conductivity, Salinity, and Total Dissolved Solids (TDS)	M	M	MEDIUM	MEDIUM	MEDIUM
Oxidation Reduction Potential (ORP)	M	M	HIGH	HIGH	HIGH
Dissolved Oxygen (DO)	M	M	HIGH	HIGH	HIGH
Sulf[illegible]	M	M	LOW	MEDIUM	HIGH
Chloride Cl^-	L	M	MEDIUM	LOW	MEDIUM
[illegible]	L	L	LOW	LOW	LOW
SOD (soil oxidant demand)	M	L	MEDIUM	HIGH	LOW
TOD (total oxidant demand)	M	L	MEDIUM	HIGH	LOW
NOI (natural oxidant interaction)	M	L	MEDIUM	HIGH	LOW
TOC (total organic carbon)	M	M	MEDIUM	HIGH	MEDIUM
Anions, cations	*Individually listed*				
Arsenite (As^{+3})	M	L	LOW	MEDIUM	HIGH
Arsenate (As^{+5})	M	M	MEDIUM	HIGH	MEDIUM
Chromium (Cr^{+3})	M	M	MEDIUM	HIGH	MEDIUM
Chromium (Cr^{+6})	M	L	LOW	MEDIUM	HIGH
Other Heavy Metals (e.g., lead, copper, selenium)	L	L	LOW	MEDIUM	MEDIUM

As reductive dechlorination occurs chloride ions are released and the concentration of chloride may increase. However, naturally and anthropogenic chloride may be present in groundwater at concentrations high enough that this change could be difficult to detect or attribute solely to remediation of the chlorinated solvents. In high chloride environments, such as landfills and areas subject to seawater intrusion, chloride can cause toxicity to microbes, typically at concentrations in the thousands of mg/L.

ITRC OIS-ISRP-1 Table 2-2

Poll Question:

In your experience, can chloride concentrations be effectively used as a line of evidence of reductive dechlorination?

YES/NO

Microbiology and Degradation Potential

	In Situ Approach		Remediation Phase/Step		
					Performance Monitoring
					MEDIUM
					MEDIUM
					MEDIUM
CSIA (Compound	M	M	LOW	MEDIUM	MEDIUM
Dissolved hydrocarbon gases		M	LOW	LOW	MEDIUM
Carbon Dioxide CO2	L	M	LOW	LOW	MEDIUM
Magnetic Susceptibility	M	L	MEDIUM	LOW	LOW

Dissolved hydrocarbon gases are typical degradation products of reductive dechlorination of chlorinated ethenes (e.g., PCE), methanes (e.g., carbon tetrachloride), and propanes (e.g., 1,2-dichloropropane). Acetylene is thought to be primarily a byproduct of the abiotic reduction of chlorinated ethenes by reaction with ZVI or ferrous sulfide. The presence of these dissolved gases generally indicates that some complete reductive dechlorination is occurring. Methane can be produced from the contaminant(s), electron donor, other organics, or carbon dioxide. Methane is also the product of methanogenesis, that is, the reduction of carbon dioxide, and in that case is indicative of a significantly reducing environment. Natural gas contains many of these dissolved gases.

ITRC OIS-ISRP-1 Table 2-2

No associated notes.

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Q&A Break

Follow ITRC:

No associated notes.

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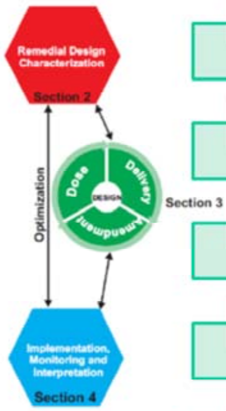
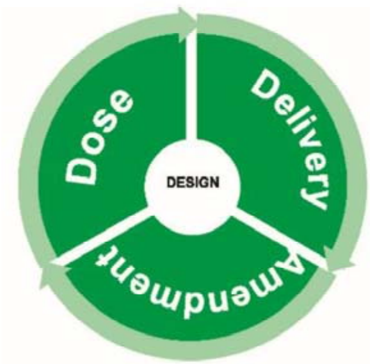
Presentation Road Map



- Optimizing Process
- Remedial Design Characterization
- **Design: Amendment, Dose & Delivery**
- Implementation, Monitoring & Interpretation
- Regulatory & Stakeholder Considerations

Learning Objective: Determine amendment, dosing and delivery options

Amendment Delivery and Dose Design – The Design Wheel



Section 3

- Involves consideration of the proposed amendment, delivery method and dose applied simultaneously throughout the in situ RDC design and implementation and monitoring process
- Any step in the sequence can be repeated as new information becomes available

ITRC OIS-ISRP-1 Modified from Figure 3-1

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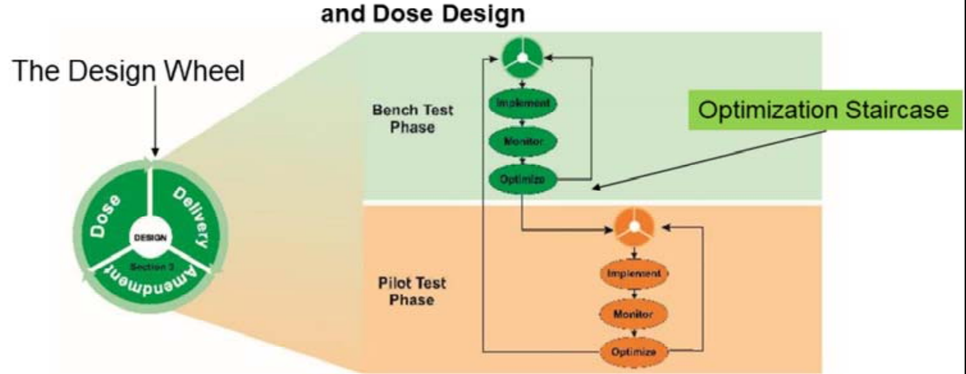
Iterative Nature of Design

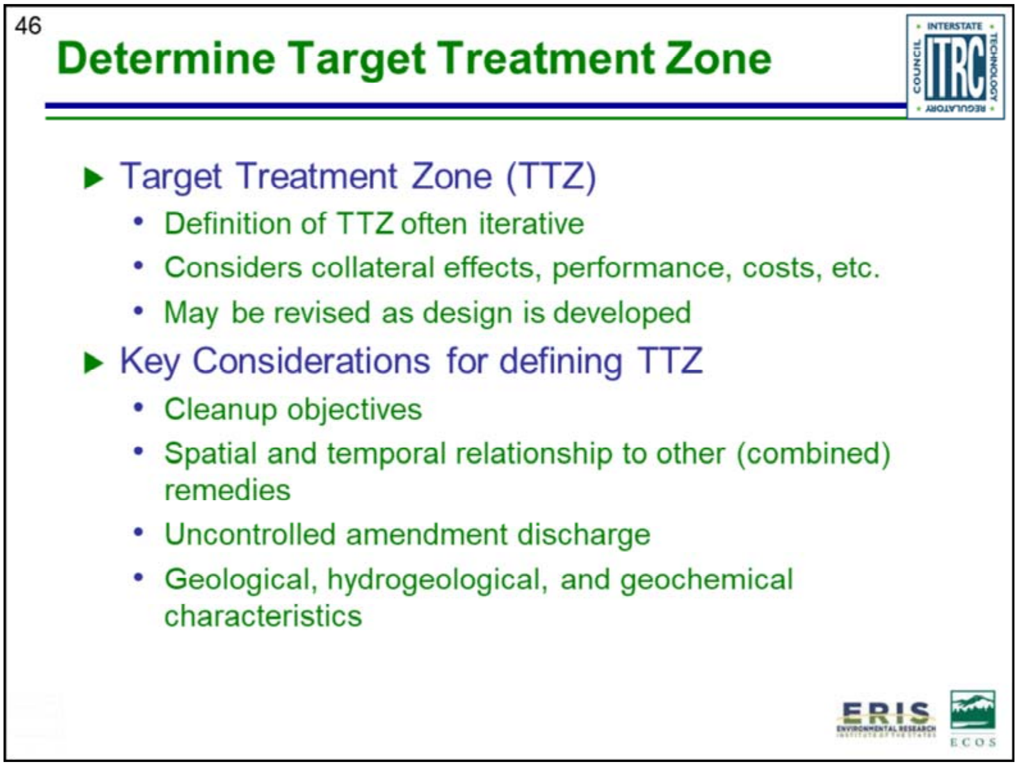
Section 3: Amendment, Delivery and Dose Design



- Refinement of design following selection of amendment and delivery strategy may involve various tests, all applying the dose, delivery and amendment design feedback;
  - Results of each test feeding refinements into a subsequent test

ITRC OIS-ISRP-1 Modified from Figure 3-1

The cyclical nature of the Design Wheel is extended into the implementation phase of testing and monitoring.



1. The objective may be reduction of source area mass, protection of a particular receptor, meeting an interim remedial goal, achieving closure, or other site specific objective.

2. If more than one remedy is planned for a site, the TTZ for each remedy must consider how the remedies may interact with each other. For example, if ISCO is selected for a DNAPL source area and ISCR is selected for a plume area, then the TTZ for each remedy should consider downgradient transport of the ISCO amendment to the ISCR TTZ.

3. The TTZ must consider the potential for unintended discharge of injected amendments. For example, if the potential exists for discharge of groundwater to surface water, then the TTZ should consider the potential for transport of remedial amendments to the discharge area.

4. Definition of the TTZ should consider the selected remedial design with the geologic, hydrogeologic and geochemical characteristics of the site. For example, if the selected remedial design is injection of a liquid amendment, and a portion of the TTZ is characterized as very low permeability clay, then perhaps either the TTZ or the remedial approach should be reconsidered because the planned design may be ineffective in the low permeability clay zone.

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Design Support Elements

- Design elements to support remedial design are an extension of the CSM and RDC data
  - Number one source of failure for amendment injection is lack of adequately detailed characterization of TTZ and reliance on overly simplified CSM
- Design elements used to support design include:
  - Modeling and analytical tools
  - Laboratory bench testing, and
  - Field pilot tests

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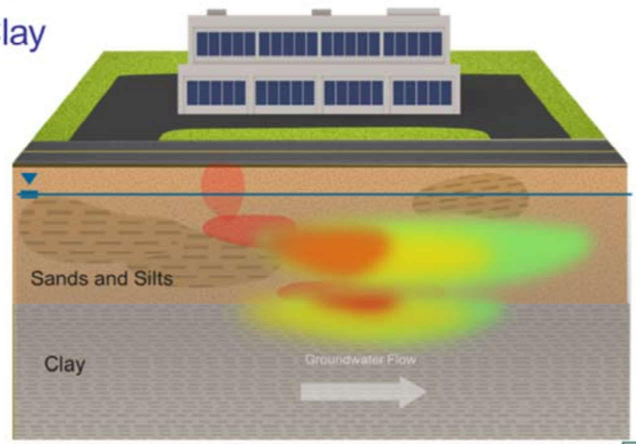
CSM – Contaminated Industrial Site

- Solvent release
- Sand and Silt
- Underlying Clay



Example Case Study – image prepared using Health Canada CSM Builder Tool 2015

Case Study

Done characterization, identified where the mass is, what the geology, hydrogeology is

Now on to site remediation planning and design

Used some of the modeling and analytical tools to help come up with remedial options analysis and feasibility studies

Have a few technologies that we are going to consider applying – ISCO and Bio

Modeling and Analytical Tools

- Modeling and Analytical Tools
  - Parameter estimation,
  - Groundwater flow and transport
  - Geochemical reactions
- Can range from simple spreadsheet calculations to complex 3D models
- Some of the software is public domain and others are commercially available and require a license

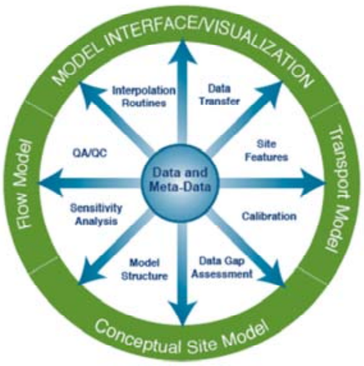
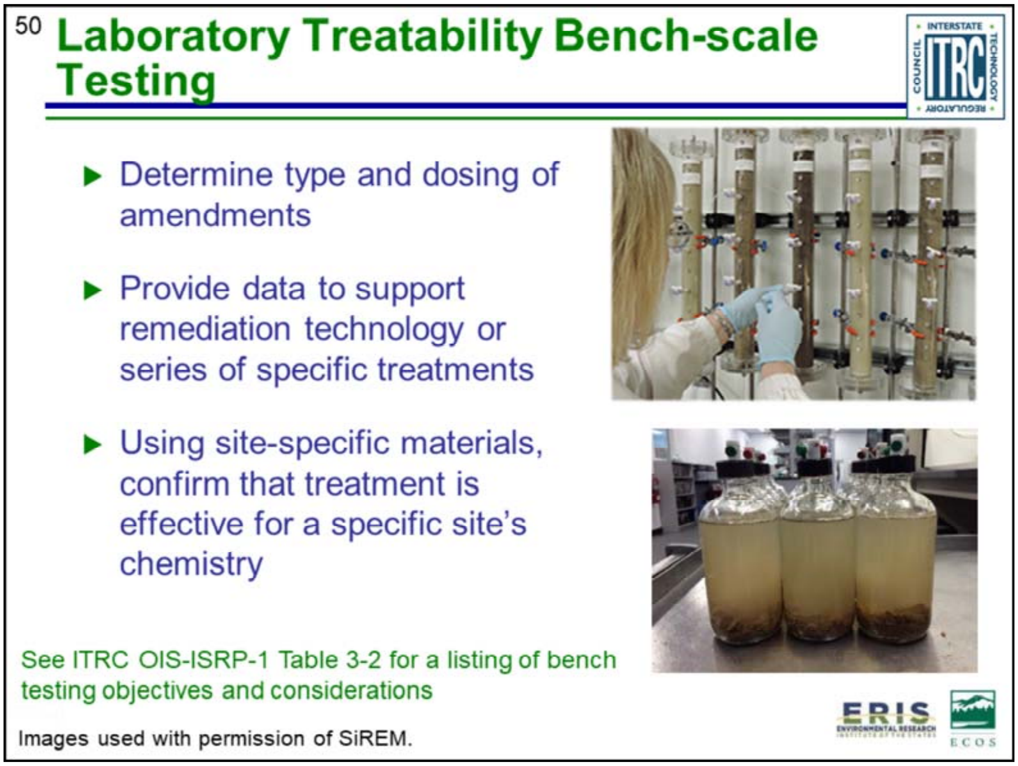


Image used with permission of Geosyntec Consultants.



#1 in situations where chemistry is complex, or multiple treatment steps may be necessary

#2 are effective and timely in the degradation or transformation of a contaminant or suite of contaminants

Initial, screening-lev

Bench tests are often conducted under ideal mixing conditions, which can increase or decrease the resulting amendment requirement estimates relative to field conditions.

Field heterogeneity and its influence on amendment transport, reaction kinetics, and other characteristics cannot be accurately duplicated in the laboratory.

Bench tests are generally not accurate models of field conditions due to issues of scale.

el evaluation of potential outcomes and effects of treatment and can be utilized to inform and initially optimize field remedial design and monitoring strategies.

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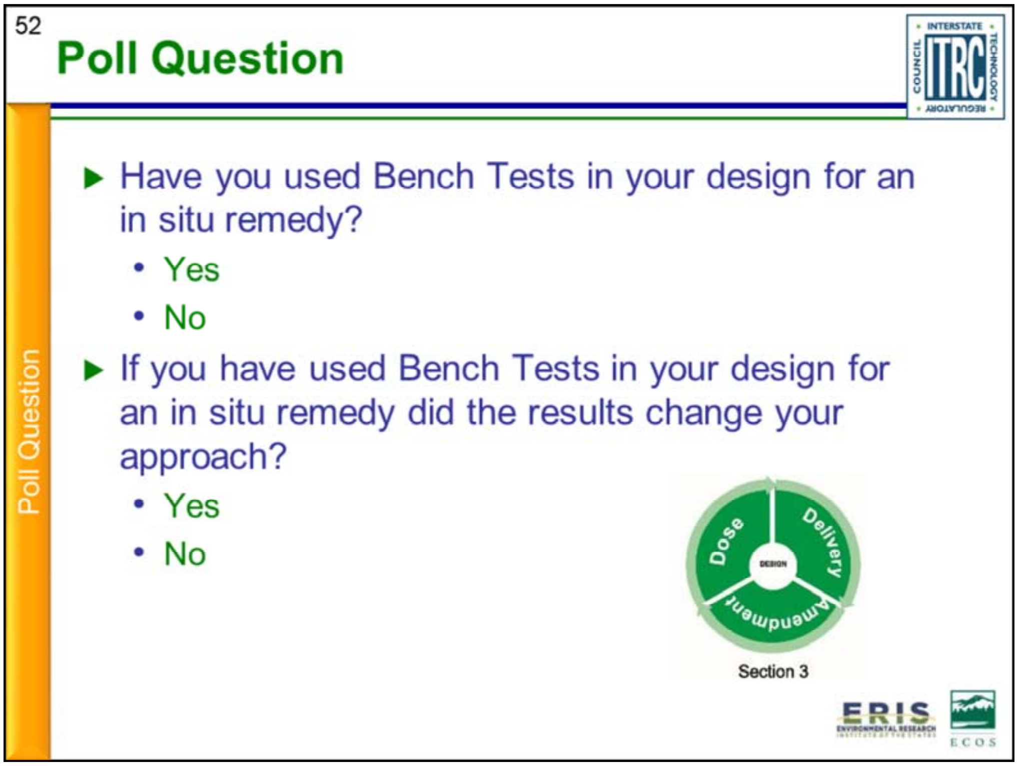
Consider Secondary Effects

- Secondary effects can occur over a wide range of time:
  - Transient shifts lasting hours or days
  - Long-term changes that may last years
- Consider potential secondary effects of the remedy design:
  - Evaluate and potentially mitigate secondary effects
  - Beginning with bench and field pilot tests

Example: The addition of sodium persulfate can affect the natural or anthropogenic chromium present in the soil or aquifer matrix, which may be oxidized to hexavalent chromium



Poll Question:

Have you used Bench Tests in your design for an in situ remedy?

Yes

No

If you have used Bench Tests in your design for an in situ remedy did the results change your approach?

Yes

No

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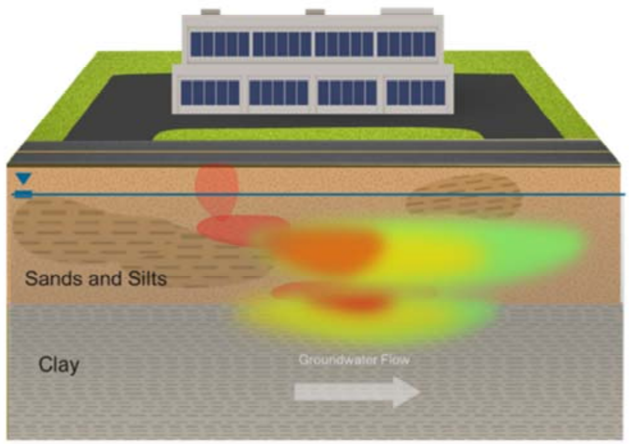
Bench Tests Results

Case Study

- ISCO
  - Faster
  - More secondary effects
  - Higher oxidant demand than ideal
- Bio
  - Slower
  - Fewer secondary effects
  - Cheaper long term
  - Emulsified vegetable oil (EVO) as donor
  - Chosen option



Example Case Study – image prepared using Health Canada CSM Builder Tool 2015

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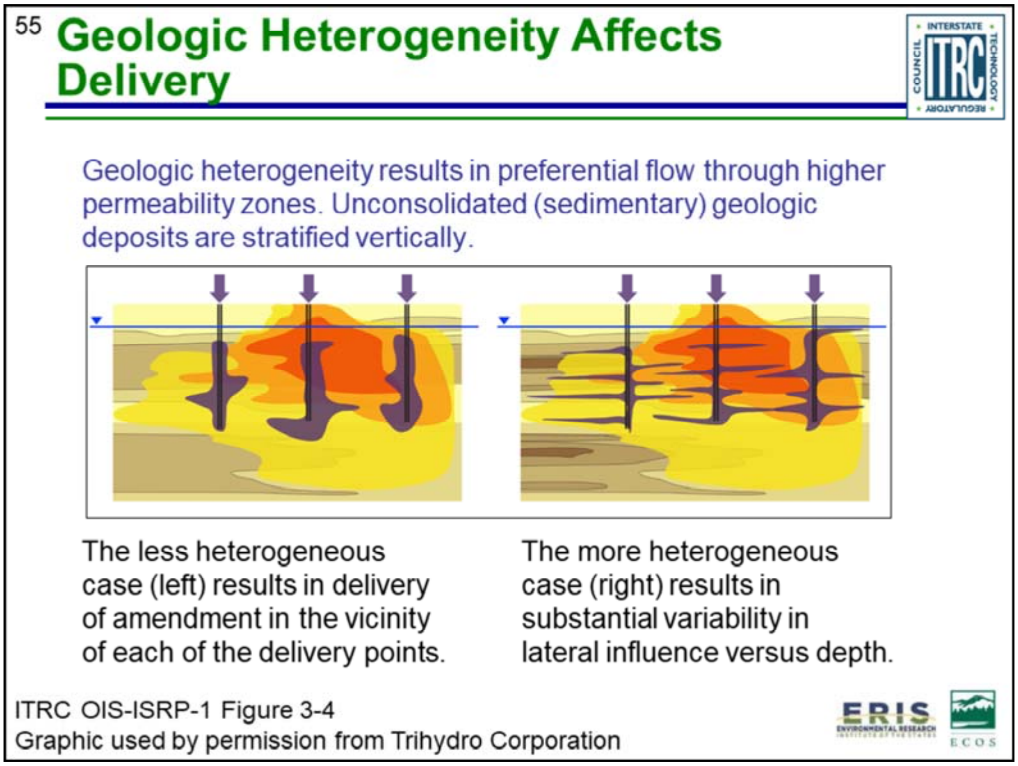
Field Pilot Tests Objectives

- Evaluate the impacts of heterogeneities on the performance of the remedial technology
- Evaluate remedy timeframe under real world conditions, combined effects of dilution, advective flow, diffusion, adverse chemical interactions, etc.
- Determine amendment distribution, ROI, injections rates and pressure, volume
- Evaluate secondary effects – metals mobilization, acid production
- Identify locations for sampling/performance evaluation

Used to test the assumptions incorporated into full-scale remedy design

Small-scale, preliminary field events, performed at the site under site-specific *in situ* conditions. Used to test the assumptions incorporated into the design of the full-scale remedy.



In this depiction the earth tone colors represent the various geologic layers with the darker browns are lower permeability zones. Warmer colors represent the area of contamination, with the highest concentration identified by orange. The purple color represents the amendment injected in the subsurface at each of the locations identified by the arrows.

In the less heterogeneous case, the amendment is distributed somewhat more uniform whereas in the more heterogeneous case (right) results in substantial variability in lateral influence versus depth.

Delivery Strategies - Distribution

Amendment distribution through a porous aquifer media is controlled by:

- The nature of the amendment
  - Soluble,
  - Semi-soluble, or
  - Insoluble
- Permeability of the formation
  - High permeability zones often receive the most fluids, allow broadest radial delivery
  - Back diffusion of contaminant mass storage in low permeability materials can be a significant source that contributes to plume longevity

High pressure emplacement methods are necessary when the particle size solid phase amendments e.g. oxygen releasing materials, ZVI (zero-valent iron), activated, carbon, etc. is larger than most pore throats and prevents delivery through well screens.

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Delivery Strategies - Pressure

- The pressure at which the fluid is applied to the formation
  - High-pressure emplacement technologies using hydraulic or pneumatic methods are required to deform the aquifer matrix and propagate seams (fractures) within the aquifer matrix
  - Soluble amendments like organic carbon substrates and chemical oxidants can be delivered under gravity flow-low pressure and via high pressure fracturing methods

High pressure emplacement methods are necessary when the particle size solid phase amendments e.g. oxygen releasing materials, ZVI (zero-valent iron), activated, carbon, etc. is larger than most pore throats and prevents delivery through well screens.

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Delivery Strategies

"Widely used = •", "Site-specific = ▣", and "Not applicable = NA"

Hydrogeologic Characteristics / Unified Soil Classification System
Gravels
Cobbles
Sandy Soils (Sm, Sc, Sp, Sw)
Silty Soils (Ml, Mh)
Clayey Soils (Cl, Ch, Oh)
Weathered Bedrock
Competent/Fractured Bedrock
K ≤ 10^{-3} to 10^{-4} (Low Perm Soils)
K ≥ 10^{-3} (High Perm Soils)
Depth > Direct Push Capabilities

Direct Push Injection (DPI) [D1]	Injection Through Wells & Boreholes [D2]	Electrokinetics This is injection through wells. [D3]	Solid Injection [D4]: Hydraulic Delivery Through Wells & Boreholes [D5]	Solid Injection [D4]: Pneumatic Delivery Through Open Boreholes [D6]	Permeable Reactive Barriers (PRBs) [D7]
•	▣	•	•	•	•
•	▣	•	•	•	•
•	•	▣	•	•	▣
NA	•	NA	▣	▣	▣
•	▣	•	•	•	•
•	•	▣	▣	▣	•
NA	•	▣	▣	▣	▣

ITRC OIS-ISRP-1 Table 3-4

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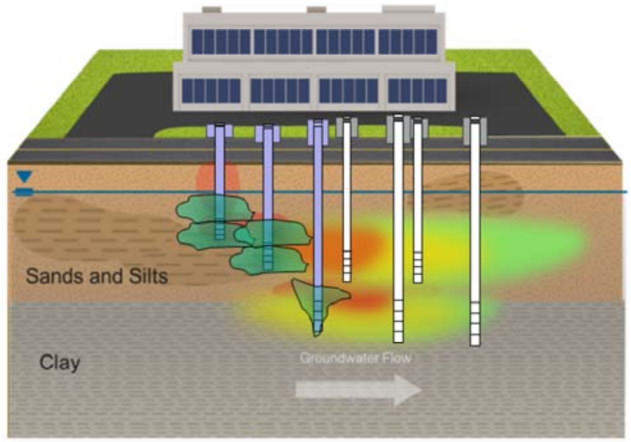
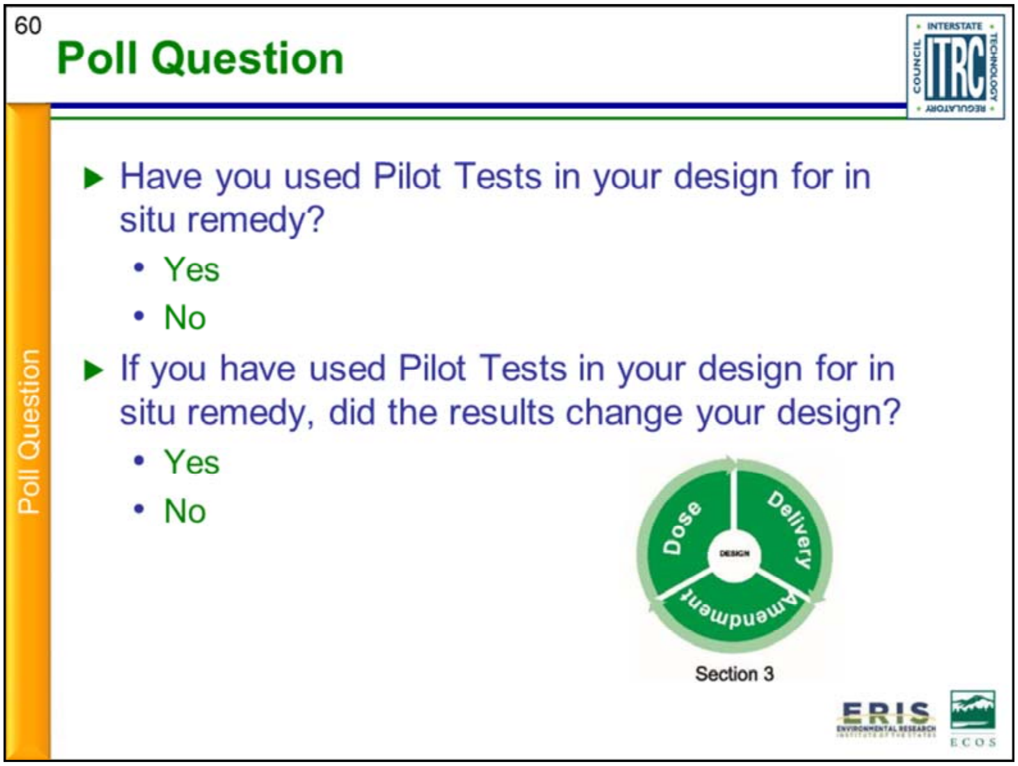
Pilot Test – Injection of Emulsified Vegetable Oil

Case Study

- Sand Layer
  - Good ROI at low injection pressures
  - Good distribution
- Clay Layer
  - High injection pressure
  - Evidence of short circuiting up into sand layer
  - Poor distribution
  - Uneven and very small ROI



Example Case Study – image prepared using Health Canada CSM Builder Tool 2015



Poll:

Have you used Pilot Tests in your design for in situ remedy?

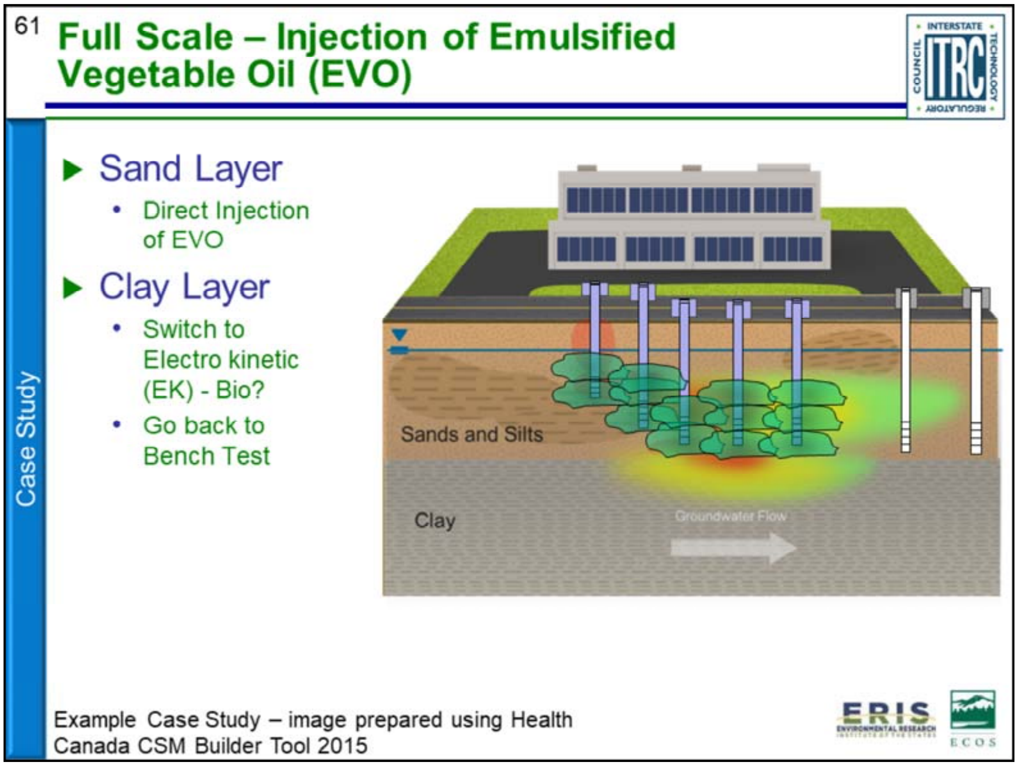
Yes

No

If you have used Pilot Tests in your design for in situ remedy did the results change your design?

Yes

No



ELECTROKINETIC remediation approaches use low level DC power to distribute amendments in low permeability matrix

Distribution of electron donors (lactate) or acceptors (oxygen, nitrate) and/or microorganisms (*Dehalococcoides, Dehalobacter*) to promote biodegradation

Return to Bench Testing

Case Study

- Clay Layer
  - Go back to Bench Test to make sure EK-Bio is an option

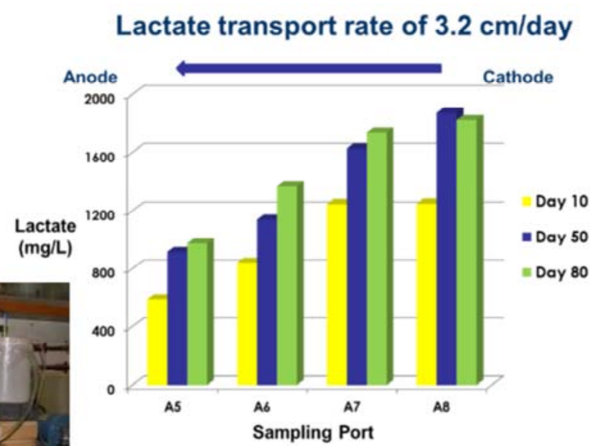


Photo and graphics used with permission from Geosyntec Consultants

Return to Pilot Testing

Case Study

- Clay Layer
  - Do pilot test to confirm design parameters and applicability
  - Dipole Test
  - Small Scale Test

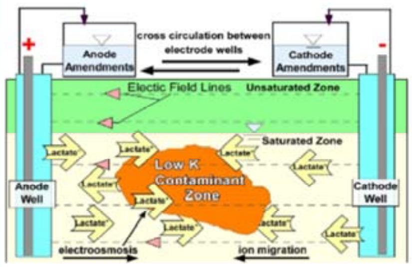
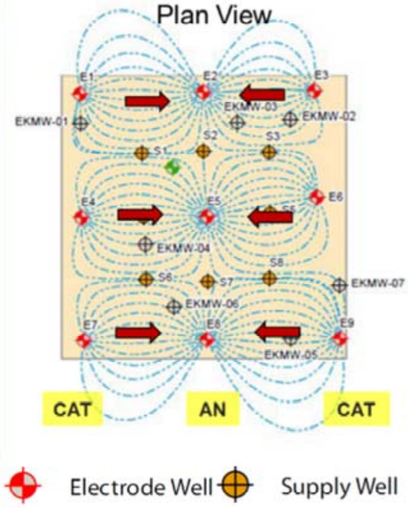


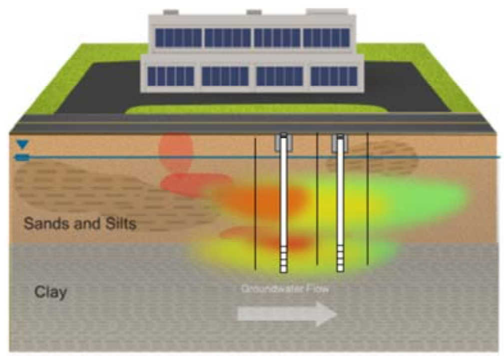
Photo and graphics used with permission from Geosyntec Consultants

Full Scale Clay Layer– EK-Bio

Case Study

- Clay Layer
  - EK-Bio Implementation





Example Case Study – image prepared using Health Canada CSM Builder Tool 2015; Graphics used with permission of Geosyntec Consultants.

Electro kinetics: OIS-ISRP Appendix D3

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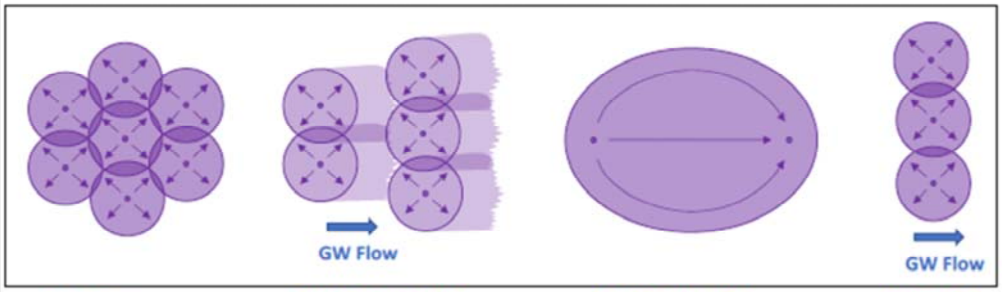
Amendment Delivery Optimization

The refinement of number and spacing of injection points, injection transects, and recirculation wells for minimization of cost or time using one of the delivery strategies:



ITRC OIS-ISRP-1 Figure 3-3
Graphic used with permission from Trihydro Corporation

- Grid Pattern: space delivery locations uniformly over the treatment zone, assumes uniform delivery

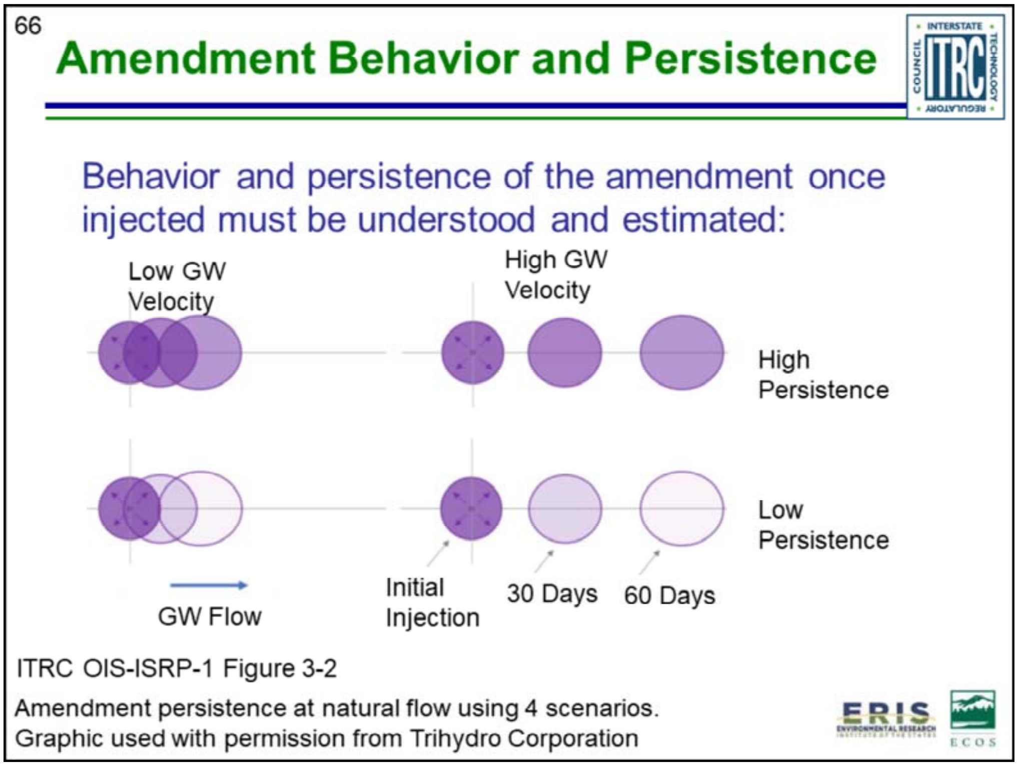
Grid Pattern: broadly applicable, i.e., there are very few site-specific constraints that would challenge this method. Some find it advantages to start with the injections on the perimeter of the TTZ before moving to the interior portion of the TTZ to limit plume spreading at the time of injection.

- Inject and Drift: leverages distribution of amendment with natural groundwater flow
  - applicable in situations in which the amendment is soluble in water, groundwater velocities are relatively high and/or the amendment is relatively persistent in the subsurface.

- Recirculation: simultaneous injection and extraction of groundwater
  - This strategy can increase the lateral extent of amendment influence and reduce the risk of daylighting of amendment. Typically limited to sites with relatively high transmissivity.

- Barrier: linear transect, contaminated groundwater flows into the treatment zone

a barrier to contaminant migration, but not to groundwater flow.



Number and spacing of injection locations to achieve distribution of amendment throughout the target treatment zone.

Processes affecting amendment distribution:

Advection as the result of pressurized delivery

Advection due to natural groundwater flow

Diffusion as the result of concentration gradients

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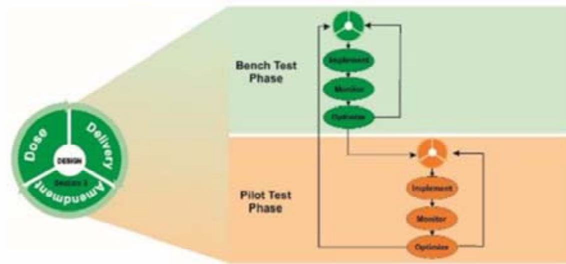
Remedial Design is Iterative

- Need to constantly evaluate the data you have
- Refinement of design following selection of amendment and delivery strategy may involve bench and pilot tests
  - Results of each test needs to feed back refinements into a subsequent test or next version of design
- Iterative approach and constant evaluation of new data will provide a strong design and more successful remedial effort



ITRC OIS-ISRP-1 Modified from Figure 3-1

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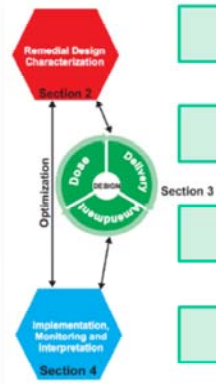
Presentation Road Map



- Optimization Process
- Remedial Design Characterization
- Design: Amendment, Dose & Delivery
- **Implementation, Monitoring & Interpretation**
- Regulatory & Stakeholder Considerations

Learning Objective: Using performance monitoring to make optimization decisions.

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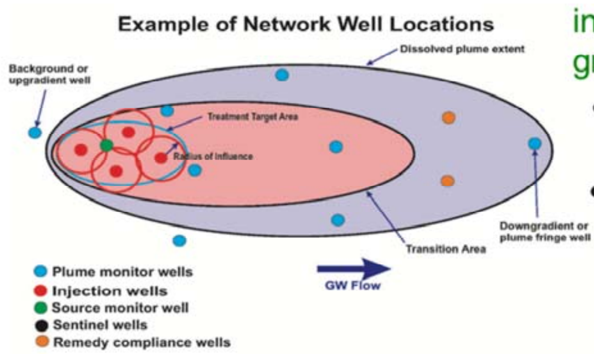
Implementation and Feedback Monitoring Optimization

- Baseline monitoring
- Compliance monitoring
- Process monitoring
  - Frequency and parameters vary with amendment
  - Field parameters are inexpensive and have great value



Key Points:

Monitoring is remedy specific. See tables in Section 4 for recommended parameters.

While monitoring the plume for regulatory purposes (COCs, secondary water quality parameters), there are other data you should gather for optimization strategies (baseline ferric/ferrous iron, sulfate)

Certain wells monitor remedial progress (including within the site-specific travel time).

Other wells monitor downgradient effects and point of compliance.

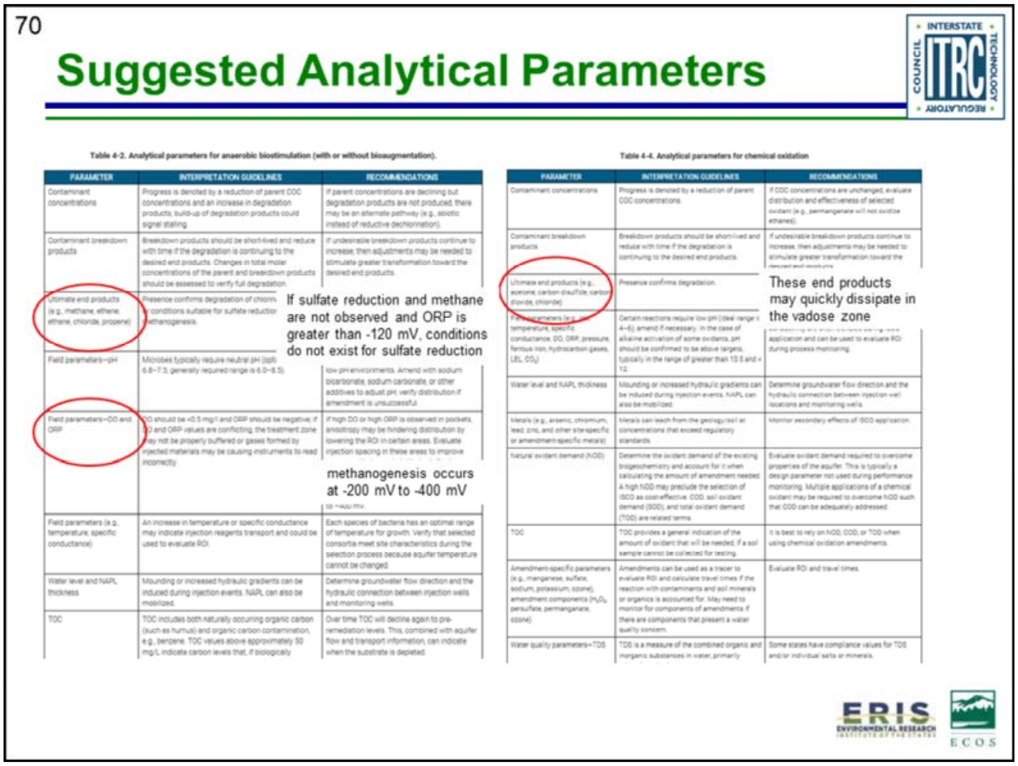


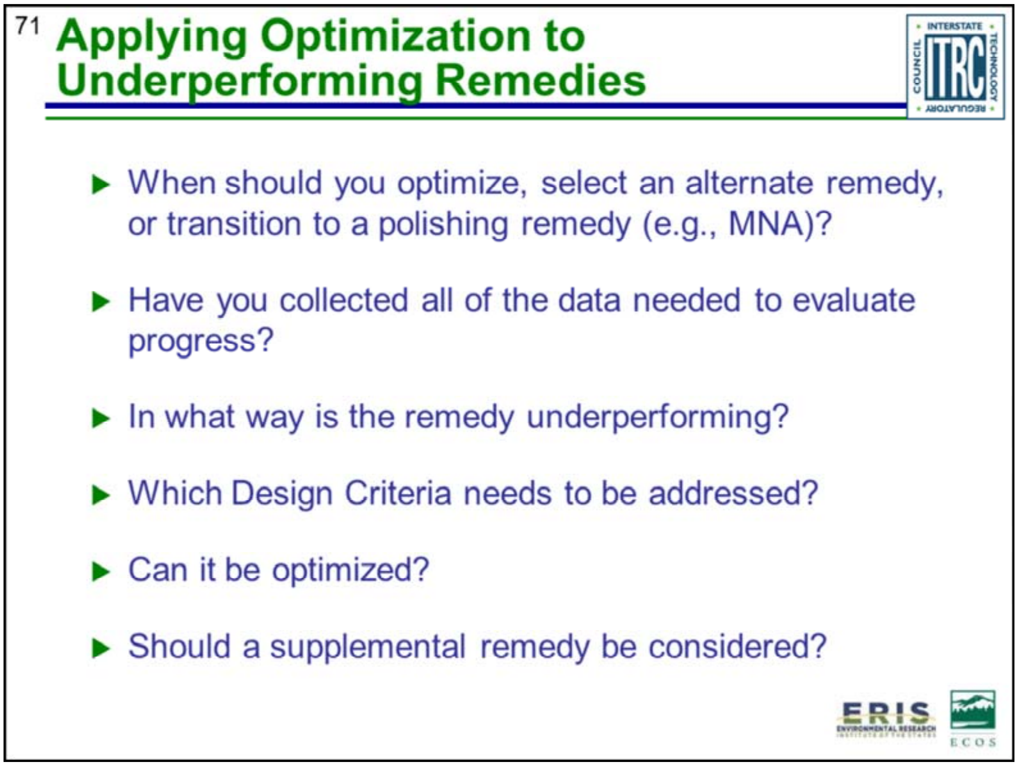
Table 4-2 Anaerobic biostimulation

Table 4-3 Aerobic biostimulation

Table 4-4 Chemical oxidation

Table 4-5 Chemical Reduction

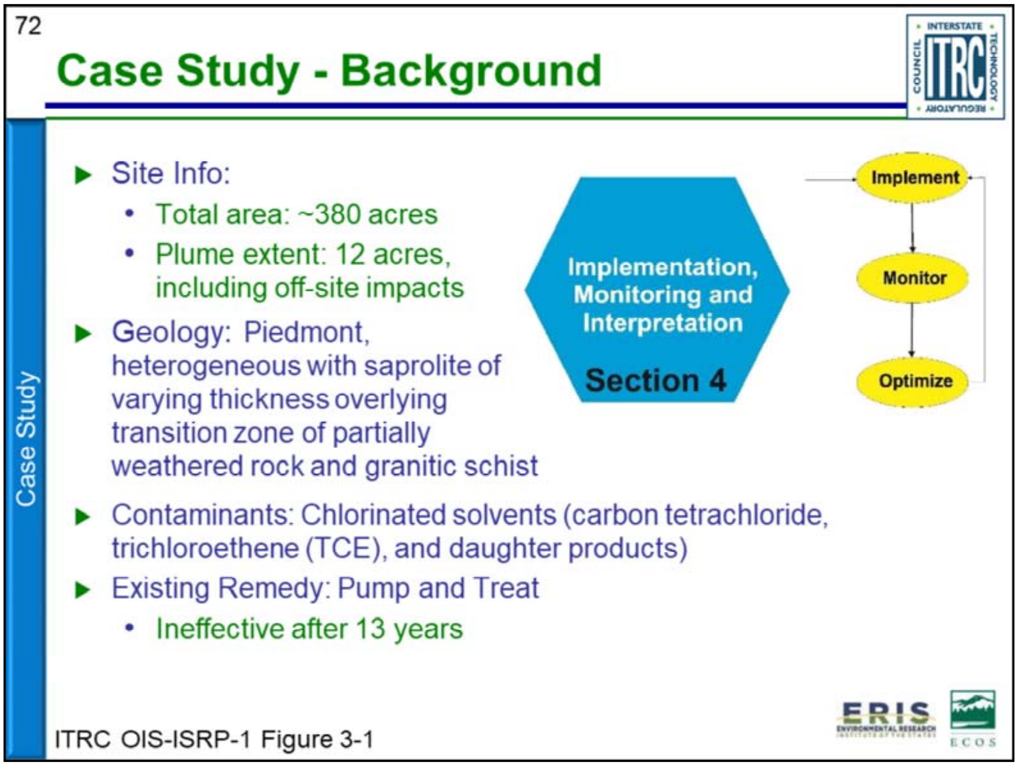
Table 4-6 Surfactant and co-solvent flushing



Intro:

What are the questions we should be asking ourselves as we begin to consider optimizing a remedy?

To demonstrate, we are going to use a case study.



COCs included carbon tetrachloride, chloroform, methylene chloride, PCE, TCE, cis-1,2-DCE.

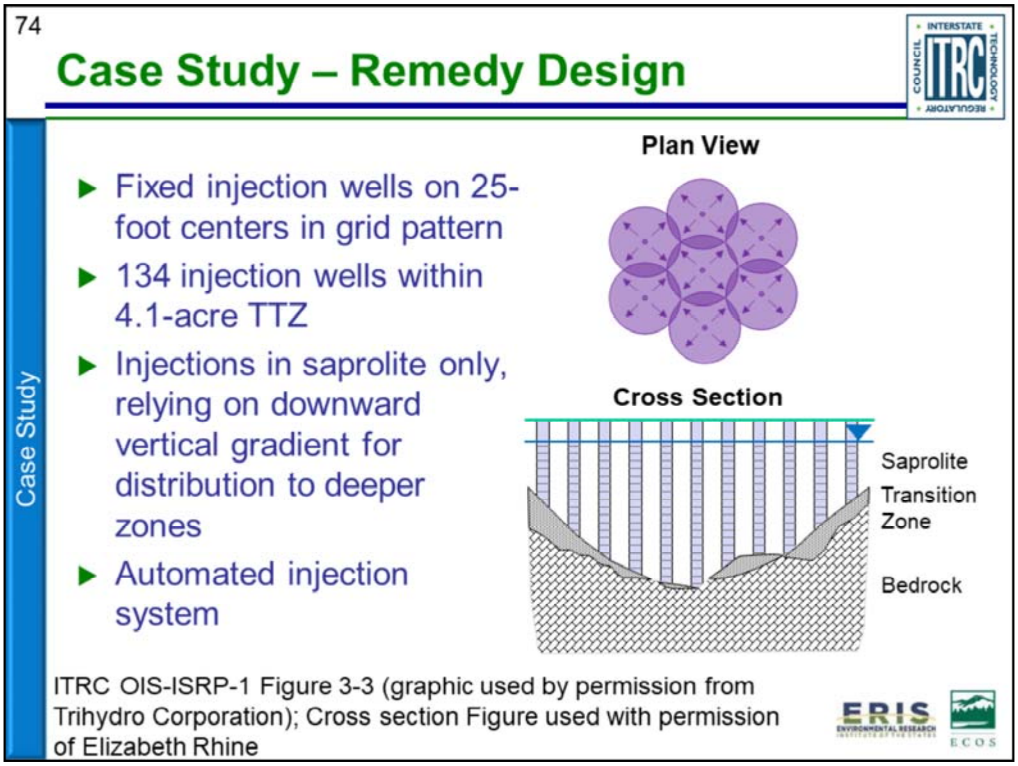
4 ppm total CVOCs in source area.

Source area was a contractor laydown area, which included laboratory waste.

Case Study – Multiple Optimizations

Case Study

- Implemented anaerobic in situ bioremediation
- Optimized bioremediation remedy
  - Evaluate monitoring data monthly – don't wait for the annual report
  - Know when to anticipate changes in groundwater chemistry and respond early
- Incorporated hydraulic fracturing to improve distribution
- Relied on natural downward vertical gradient to distribute amendments to the bedrock
  - Also anticipated MNA once shallow groundwater impacts were addressed
  - But had a contingency plan to address bedrock



Key Points:

Grid pattern selected over inject and drift or barrier strategies.

RDC continued during well installation activities.

2” wells were screened to the top of bedrock and spanned the saprolite and transition zone (PWR).

Because the hydraulic conductivity at the site is relatively low, we decided to set up a grid pattern over the inject and drift or barrier injection strategies.

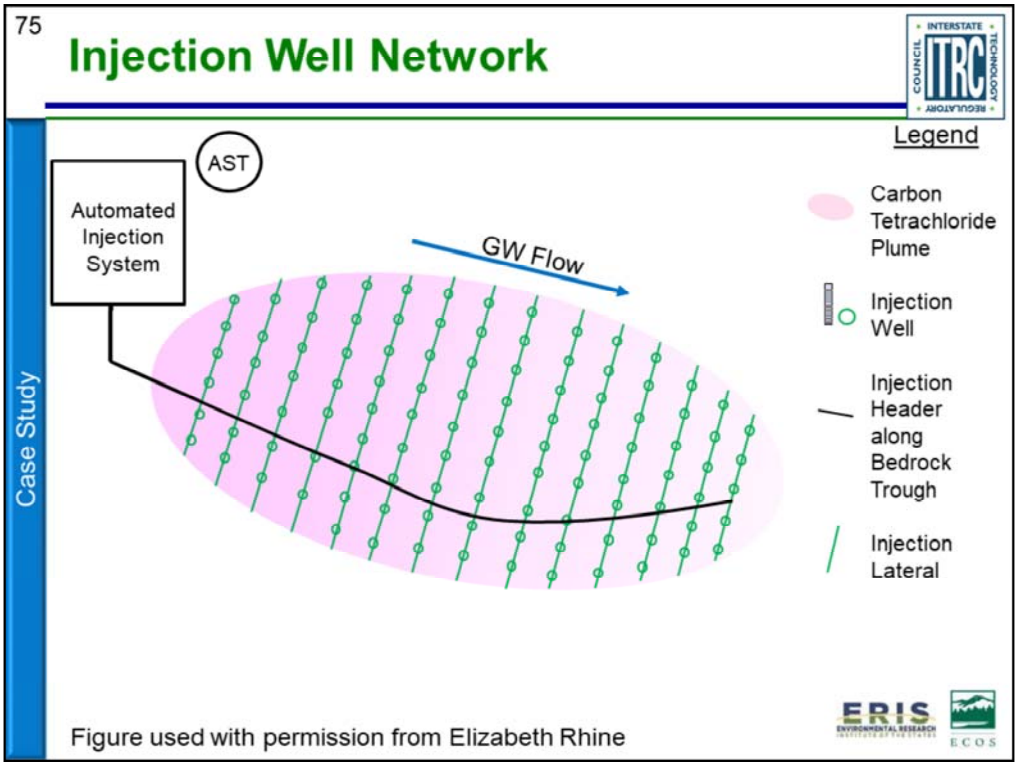
We installed the 2-inch injection wells using hollow stem augers to top of rock.

The wells were screened to intercept both the saprolite and transition zone (partially weathered rock).

We incorporated the top of rock information into the design, understanding the flow would generally follow the bedrock trough.

From Figure 3-3 (graphic used by permission from Trihydro Corporation)

Cross section Figure with permission of Elizabeth Rhine



The system piping was installed above ground because we only had two years to achieve groundwater cleanup goals (MCLs) before redevelopment activities began.

So we didn't forget where the bedrock trough ran, we placed the injection header directly above the trough and branched out with the laterals to groups of 4 to 6 wells.

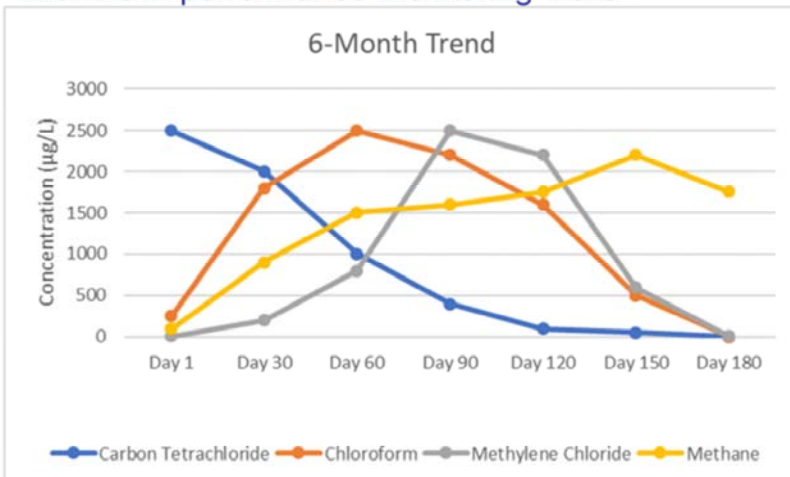
Each of these laterals of 3 to 4 wells was controlled by solenoids, and the system could be programmed to inject a specific volume to each group; ball valves at the well head could be adjusted in the event one or more of the wells needed to be turned off.

Furthermore, the automated injection system could be programmed to mix up any percent carbohydrate desired and any injection schedule. Initially, we started with a 10% carbohydrate solution at 10 gallons per foot of screen and the system operated continuously, meaning after injection of Well #134 the system immediately started over with Well #1. It took approximately 30 hours to run through an entire cycle. The header is approximately 400 feet long – 2" line holds about 70 gallons.

Figure with permission from Elizabeth Rhine

Good News…

- In the Source Area, MCLs were met within 6 months in performance monitoring wells

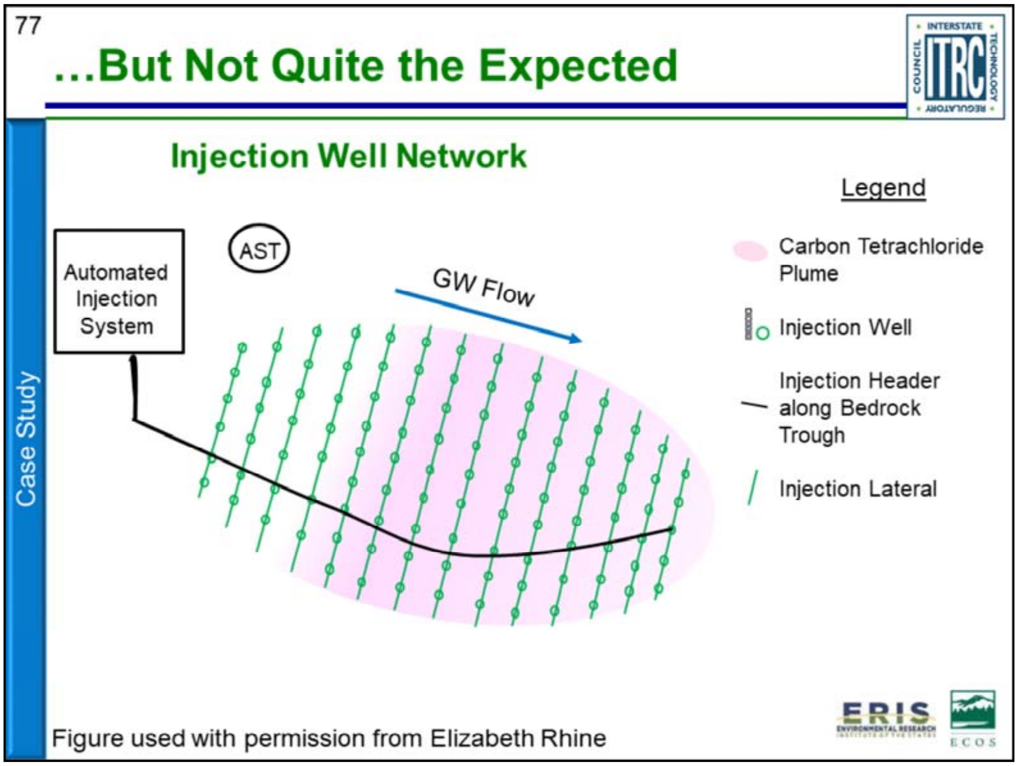


Graph used with permission of Elizabeth Rhine

With a grid system, you might expect the downgradient dissolved plume to remediate more quickly than the source area.

Here, we experienced very quick remediation of higher concentrations and stable trends at lower concentrations.

Graph with permission of Elizabeth Rhine

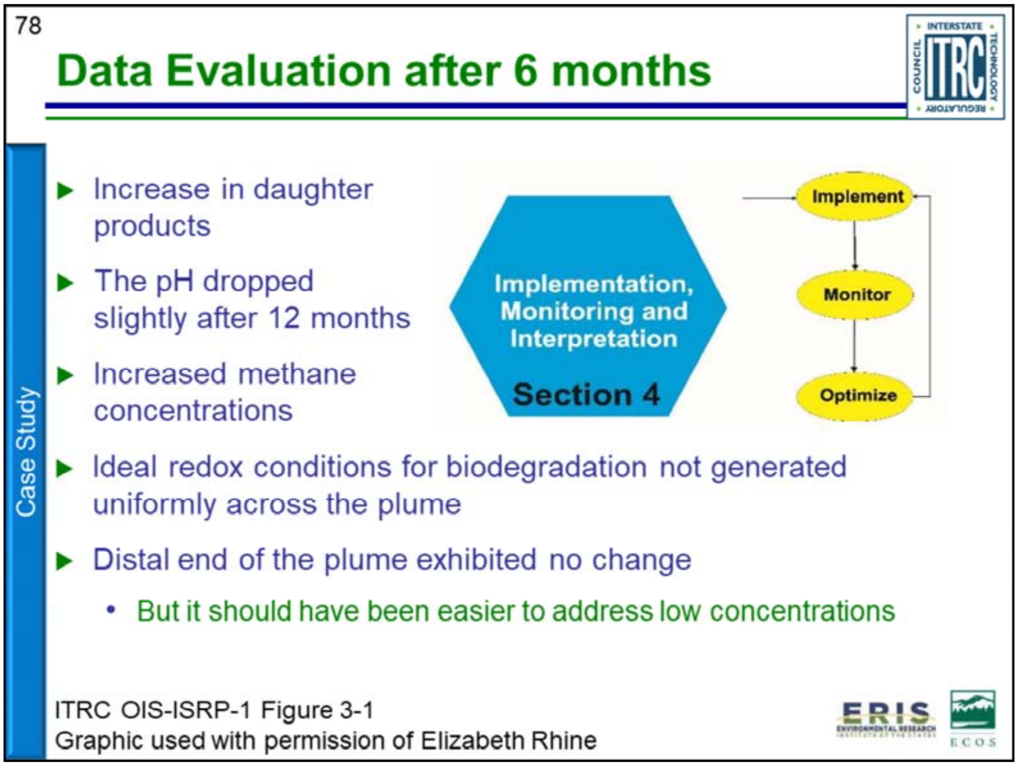


With a grid system, you might expect the downgradient dissolved plume to remediate more quickly than the source area.

Here, we experienced very quick remediation of higher concentrations and stable trends at lower concentrations.

Step through what the data shows (prior slide), how the plume now looks, dive more into the geochemistry and then look at the revised CSM prior to the next optimization step.

The header is approximately 400 feet long – 2” line holds about 70 gallons.



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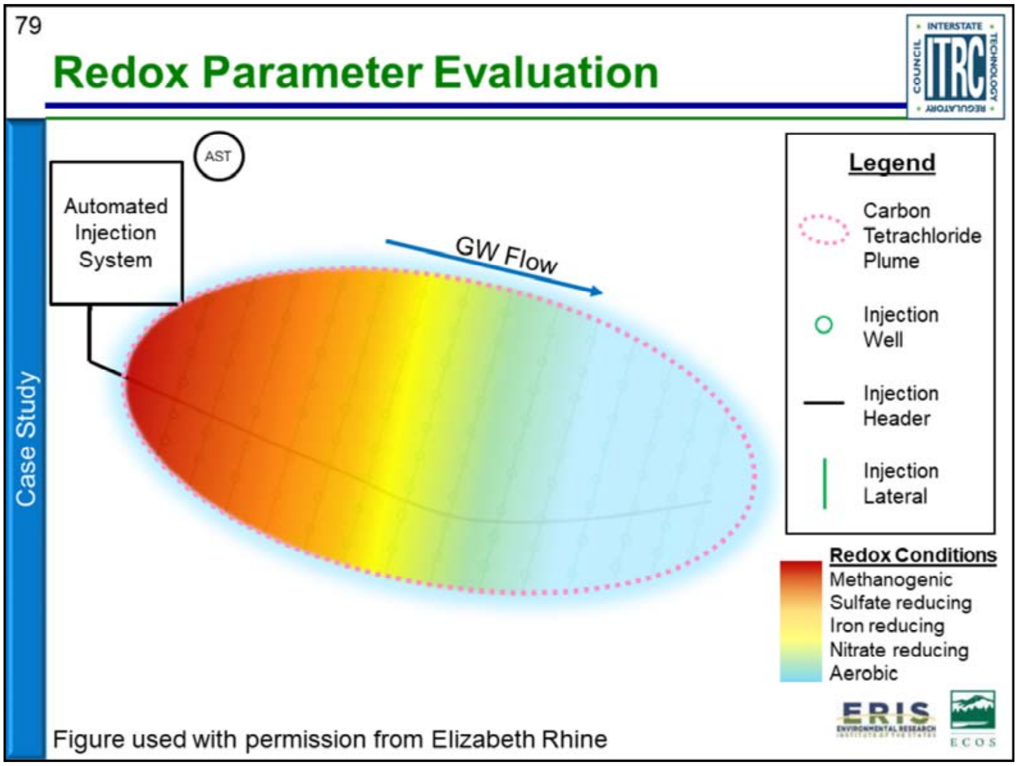
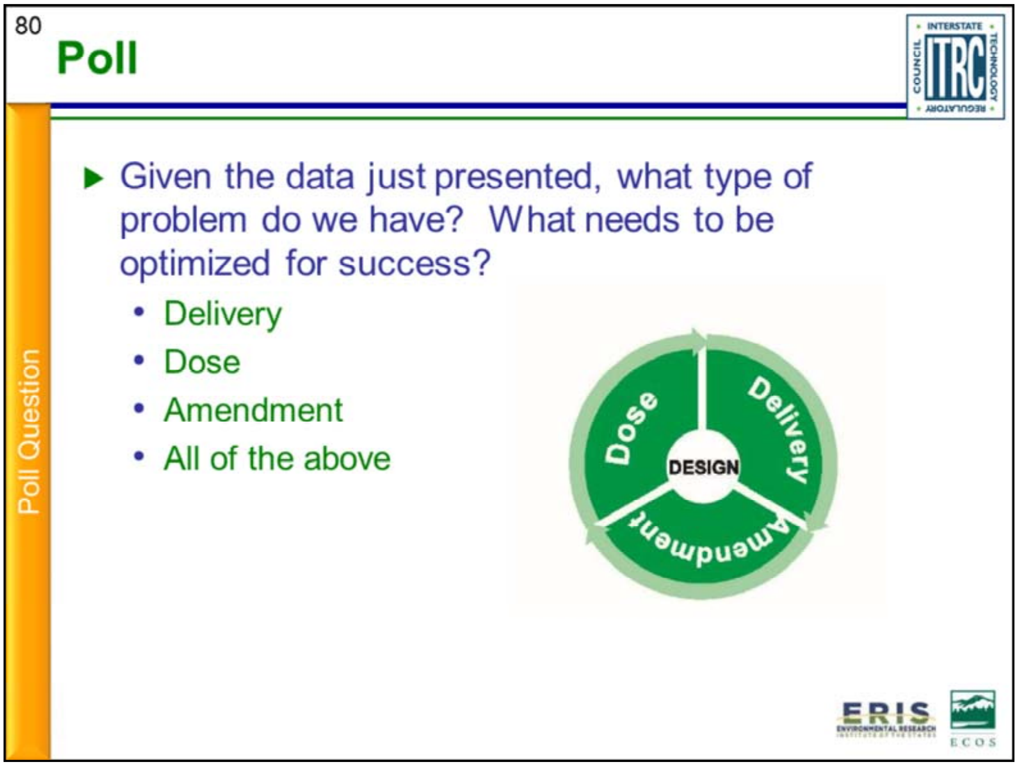
Graph with permission of Elizabeth Rhine



Explain that this color scheme shows redox conditions – red being methanogenic in the area with highest concentrations. This means that reductive dechlorination is occurring, and the plume is not being displaced. The header is approximately 400 feet long – 2” line holds about 70 gallons.



Poll Question:

Given the data just presented, what type of problem do we have? What needs to be optimized for success?

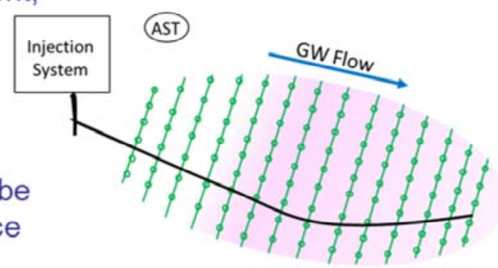
- Delivery
- Dose
- Amendment
- All of the above

All three are correct

Optimization 1

Case Study

- Downgradient, anaerobic conditions not established
  - COC concentrations and pH stable in this area
- Degradation by-products not observed in the downgradient, low-concentration plume
- Low TOC compared to upgradient
- ROIs in downgradient monitoring wells appear to be less than observed in source area monitoring wells
- What should we do?
  - Revisit RDC
  - Revisit the Design Wheel
  - Increase the radius of influence (ROI) in the downgradient wells



With a grid system, you might expect the downgradient dissolved plume to remediate more quickly than the source area.

Here, we experienced very quick remediation of higher concentrations and stable trends at lower concentrations.

We considered that amendments closest to the injection trailer were under pressure, whereas the downgradient wells were gravity-fed, and thus a lower ROI.

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Optimization 1 – Operational Changes

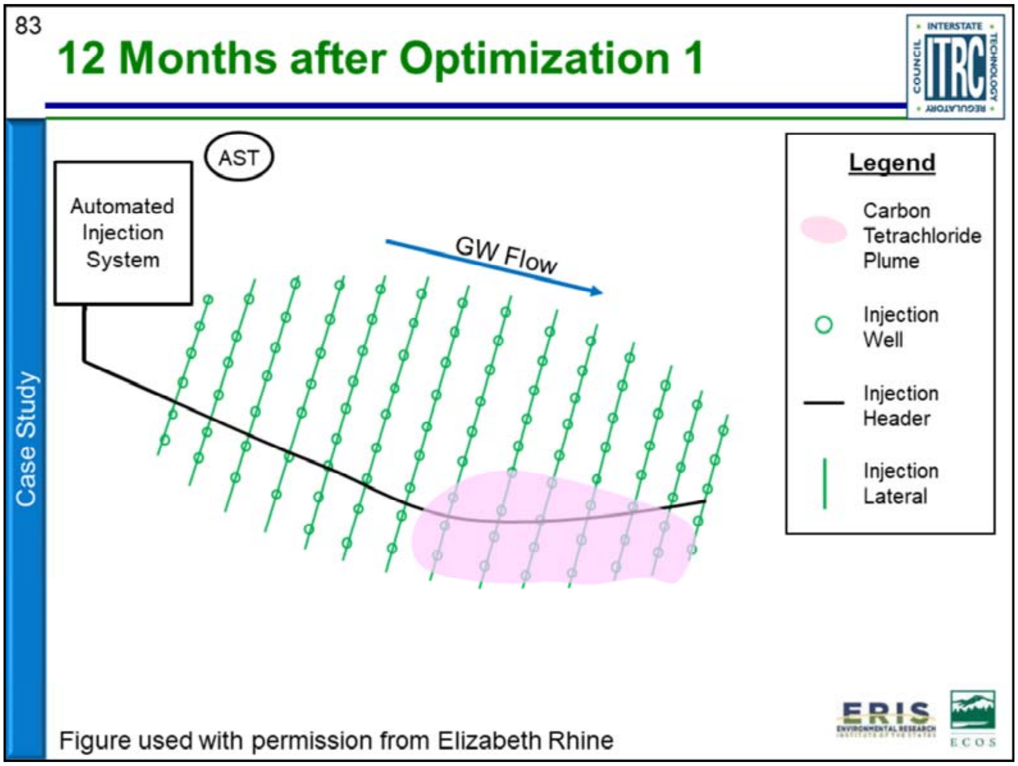
Case Study

	Problem	Resulting Optimization
Amendment	▶ Address the pH drop	▶ Lower carbon load from 10% to 5%
Dose	▶ Increase the radius of influence (ROI) of downgradient wells	▶ Decrease the frequency of injection ▶ Increased the volume from 10 to 25 gal/ft
Delivery	▶ Solve the fermentation issue in the holding tank	▶ Add a clean water flush ▶ Stir the holding tank

Key Points:

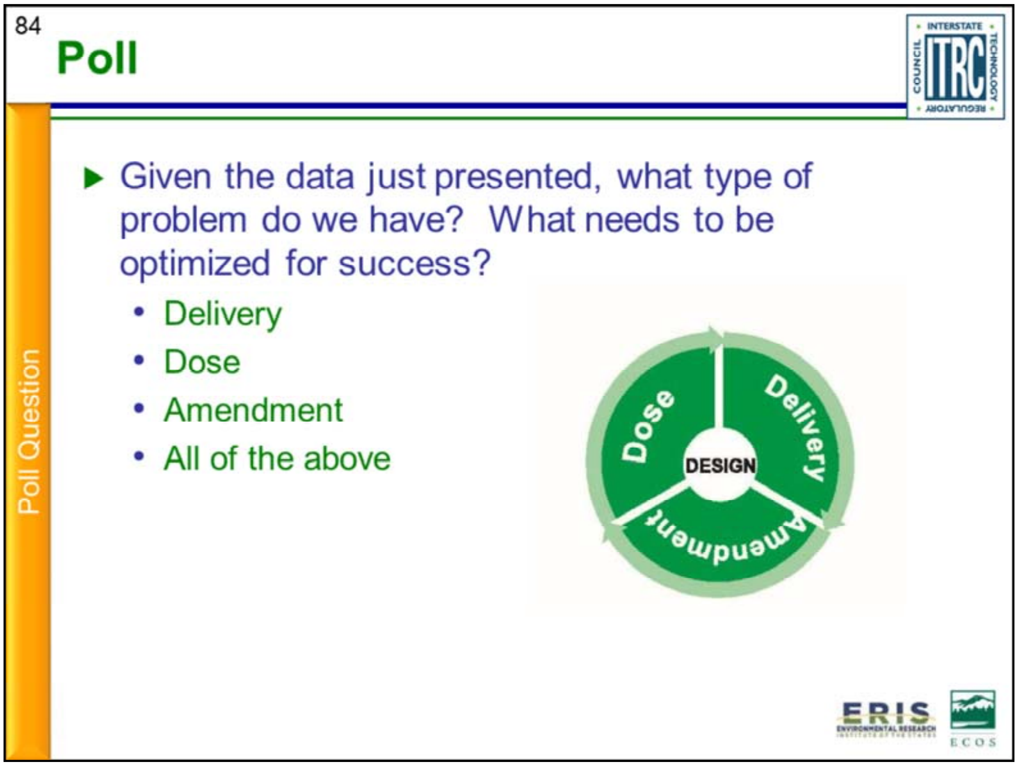
The pH drop was slight, but we wanted to get on top of it before it got out of hand. Adding sodium bicarbonate or sodium hydroxide to the system would be a major add-on that we really didn't have time for, so we evaluated other avenues for controlling pH. Often, too much carbon loading can cause the pH to drop. Since the system was so effective in the source area during the first 6 months, we decided we could back off on the carbohydrates. This was particularly important since we needed to also increase the ROI. Calculating the amount of carbohydrate solution in the lateral, it was determined that the wells closest to the injection system received solution under pressure, while the downgradient wells relied solely on gravity flow. Hence, if the aquifer did not readily drink the solution, it was backed up in the lateral until the next injection cycle. We also added a clean water flush just to make sure all of the reagent got into the aquifer and prevent biofouling in the lateral. We now injected every 14 days.

As a result of decreasing the injection frequency, the system no longer ran continuously. On hot days, the reagent would ferment and the foam would overtop the tank, cascading down the outside of the tank and onto the floor. We added a setting to stir the tank every 15 minutes to disrupt the process since it was not simple to program it to stop with the tank empty.



Changes made during Optimization #1 returned significant improvements to the site. However, we still have a recalcitrant problem.

Carbon tetrachloride and TCE ranged from 300 to 500 µg/L in the area shown.

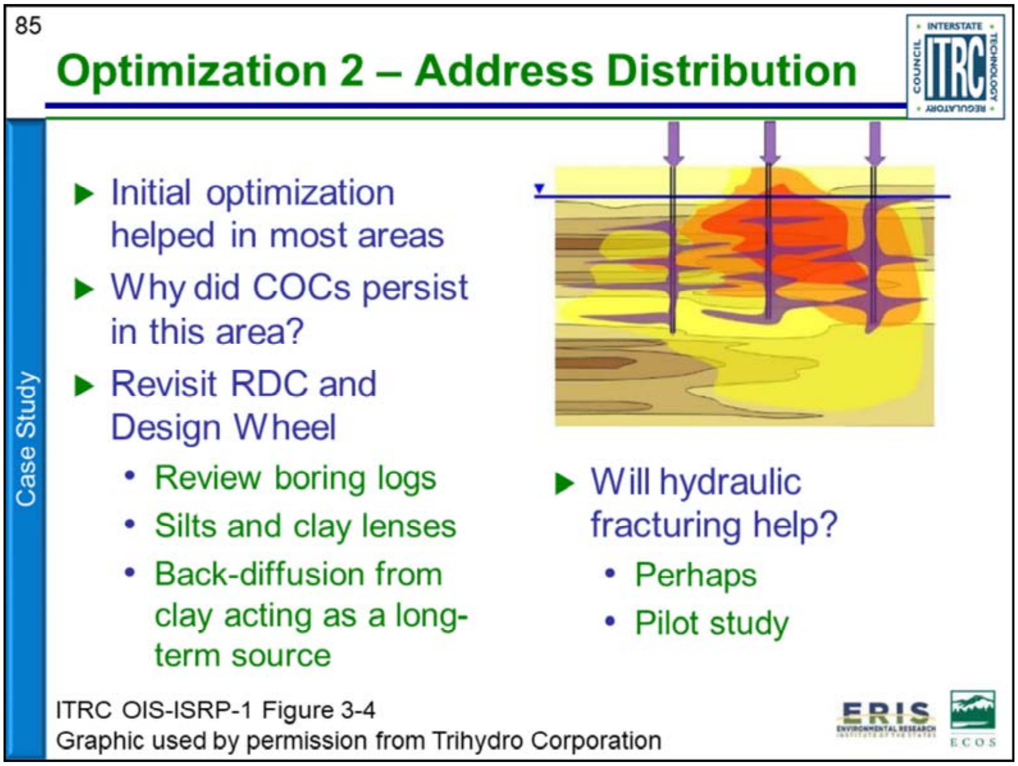


Poll Question:

Given the data just presented, what type of problem do we have? What needs to be optimized for success?

- Delivery
- Dose
- Amendment
- All of the above

The best answer is Delivery



Advise: always take detailed boring logs. They are a tremendous asset when the expected results are not achieved.

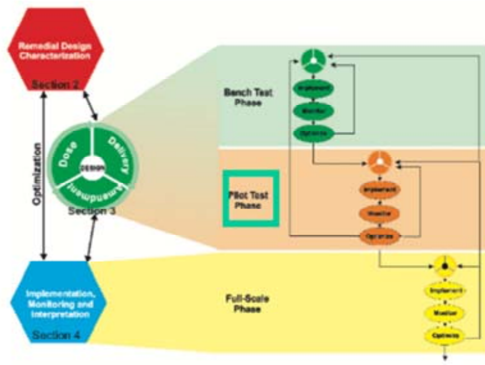
In this case, clay lenses were observed in the injection wells that did not respond well to the remedial design, whereas thin stringers of clay were observed in the remainder of the plume area. How do we get at the clay layers?

Figure 3-4 Cross section view of heterogeneous oxidant transport (graphic used by permission from Trihydro Corporation, modified from (Clayton 2008) presentation "In Situ Chemical Oxidation (Basics, Theory, Design and Application)" presentation to California DTSC Remediation Technology Symposium, May 14-16.

Optimization 2 – Fracturing Pilot Test

Case Study

- Reagent takes path of least resistance, which in this case was the silty sands
- Hydraulic fracturing pilot test to evaluate potential to enhance distribution by creating additional sand layers



ITRC OIS-ISRP-1 Figure 3-1

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Hydraulic Fracture - Prelim Pilot Test

Case Study

- Installed a single hydraulic fracture using sand suspended in food-grade guar gel using DPT tooling
- Installed piezometers at various depths and equipped with data loggers
- Injected water into fracture
- Influence was observed 3 to 4 feet above and below fracture

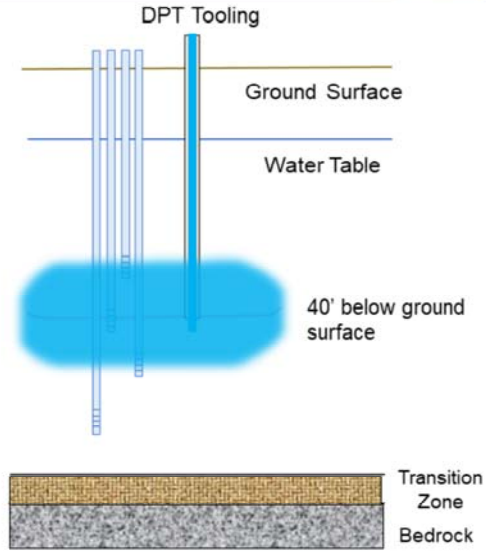
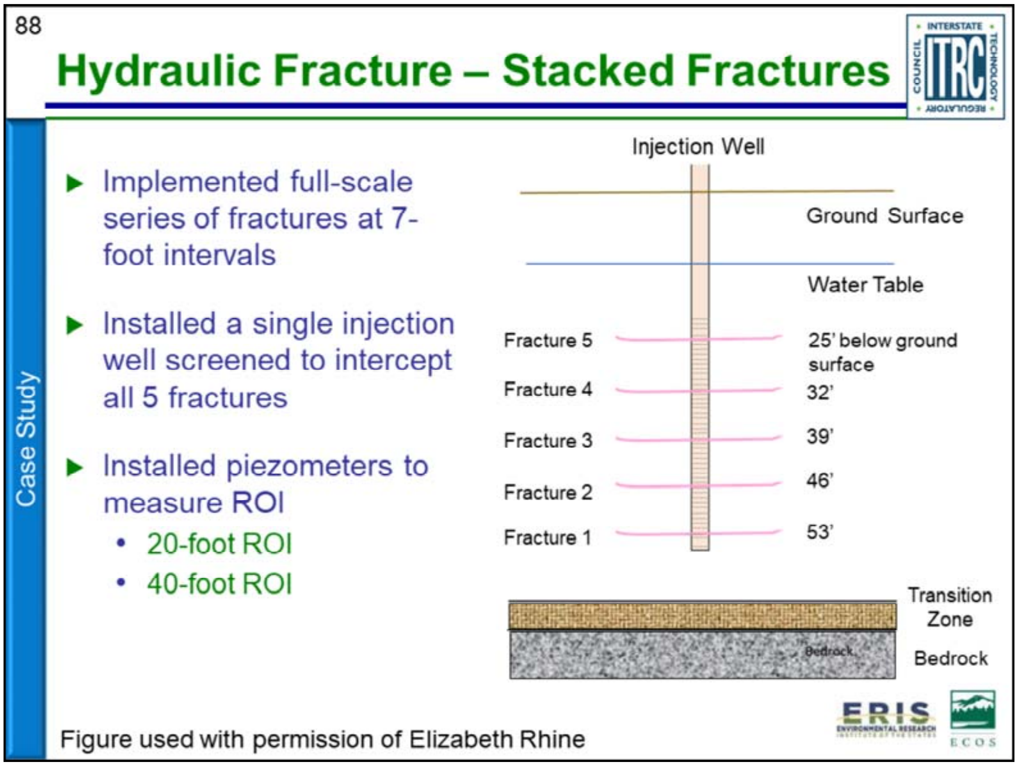


Figure used with permission of Elizabeth Rhine

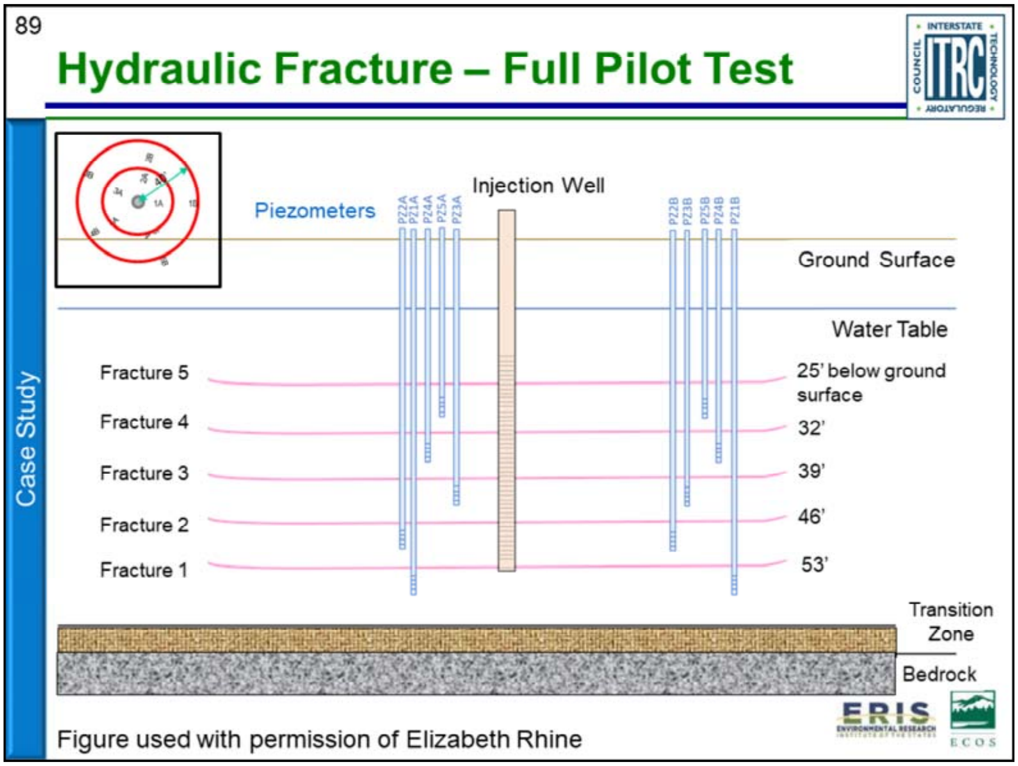
Animated - click

Figure with permission of Elizabeth Rhine



The number of fractures depended on the depth to the transition zone.

Figure with permission of Elizabeth Rhine



- Don't get bogged down in the details on this slide, because most sites won't use hydraulic fracturing.
- It's simply an example of something in our toolbox, and we weren't afraid to go back to the pilot study phase to see if it would help with the delivery problem.
- For your site, it might be evaluating the addition of ZVI or carbon amendments or adding a PBR.
- Just remember, some combinations of remediation amendments and delivery techniques work better than others.

Optimization 2 – Startup

Case Study

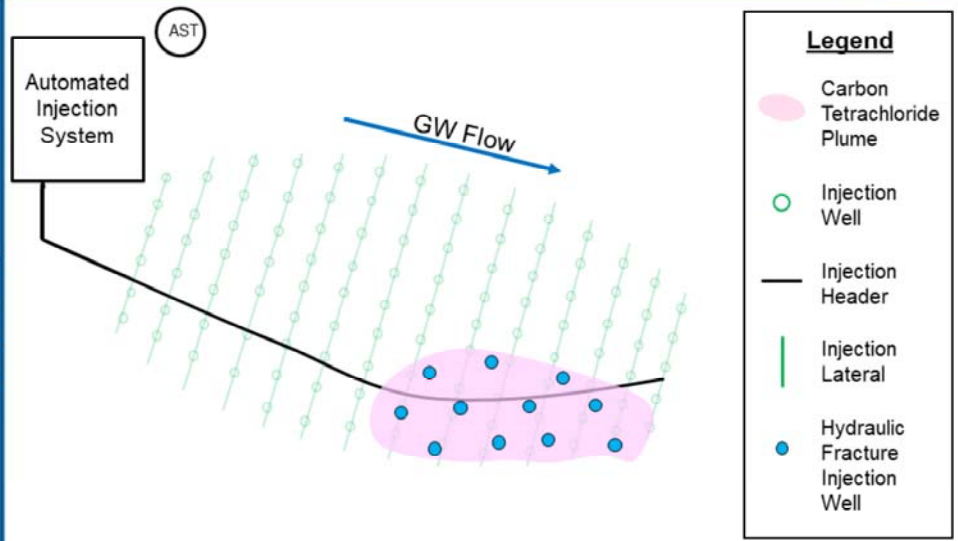
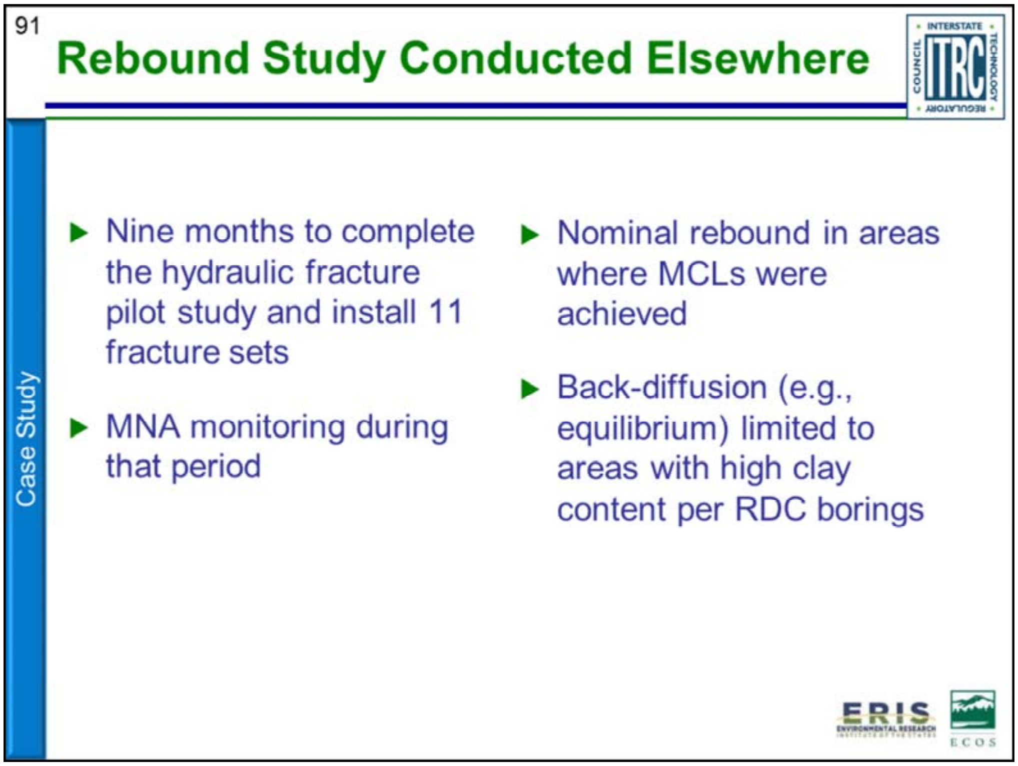
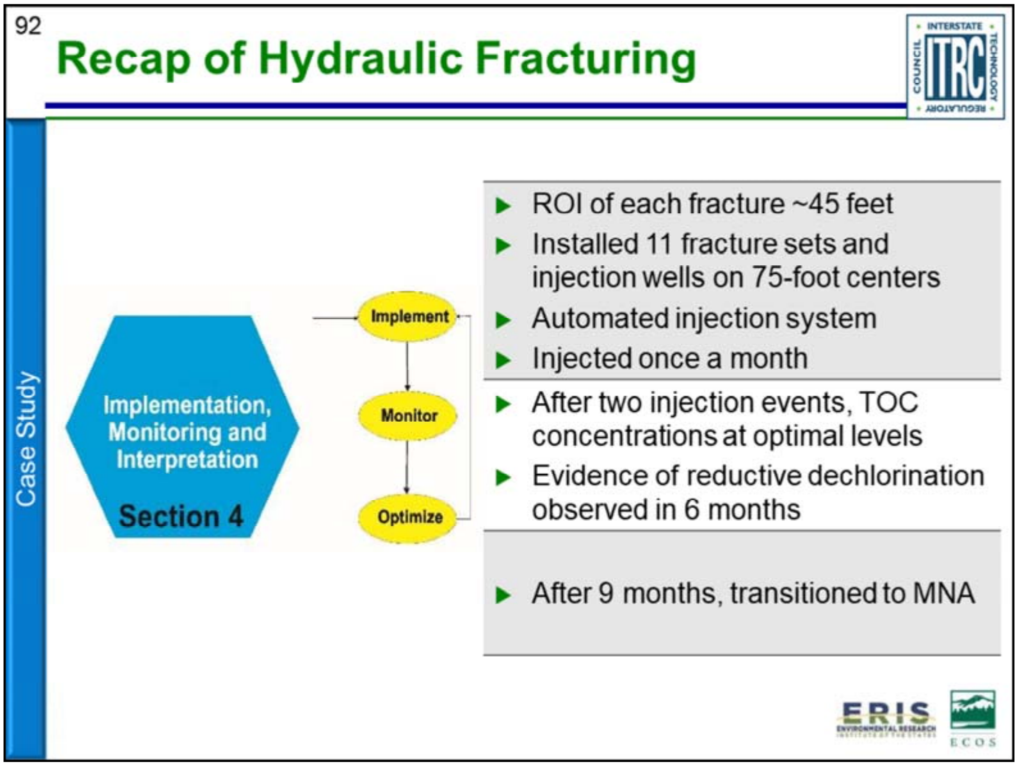


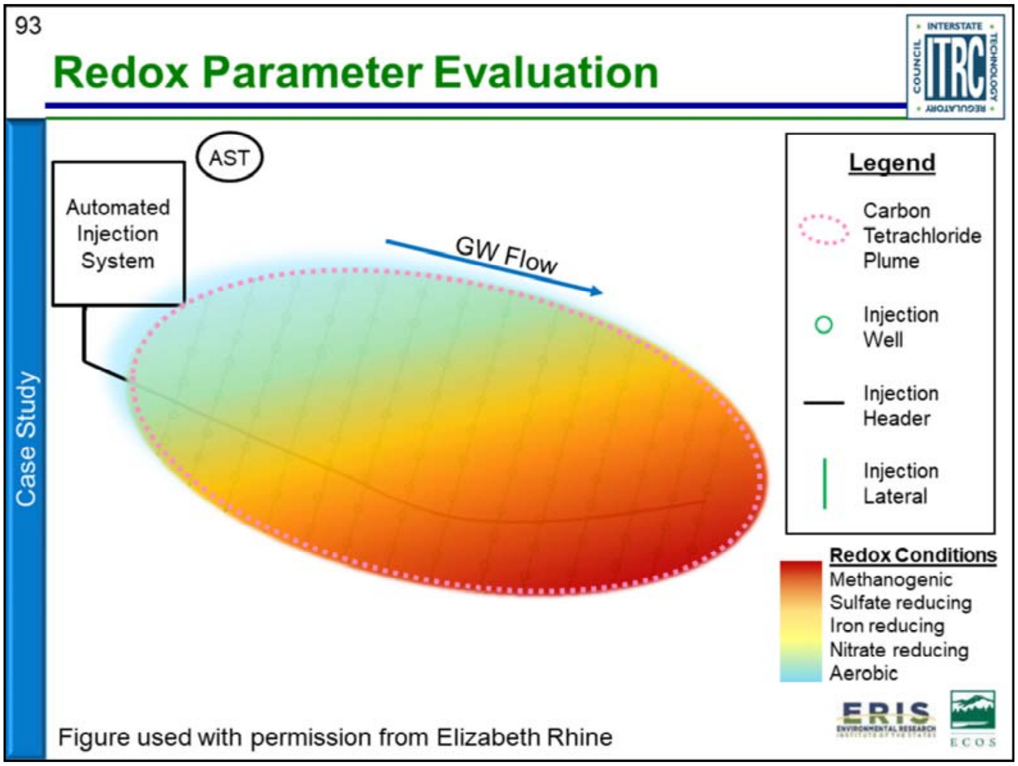
Figure with permission of Elizabeth Rhine



It took about 9 months to complete the two phases of the pilot study and install the full scale hydraulic fracturing system. During that time, we evaluated the portions of the plume that achieved MCLs for rebound. Nominal rebound was observed, and what was observed was indicative of back-diffusion of chlorinated solvents adsorbed to clay. Eventually, these transient excursions above MCLs went away, indicating the source was addressed and MNA would be appropriate for any low-level concentrations that might remain in the hydraulic fracture area.



Recap: Injected for 6 months; Optimization #1 (1 day); injected during Months 6-15, paused for Months 15-24 to conduct hydraulic fracture pilot study and install full-scale Optimization #2 while evaluating rebound; injected during Months 25-36. Transitioned to MNA in 3 years when concentrations were less than 5X MCLs.



After 12-15 months with no injections in the source area, we observed aerobic conditions returning to the source area. Once we started injecting into the wells that intersected the hydraulic fractures, our monitoring wells began to exhibit methanogenic conditions.

Progress can be determined through frequent collection if field parameters - inexpensive! – supplemented by COC and MNA parameters on a less frequent basis. Even though this is an ERD remedy, we never performed microbial analysis or amended because all other indicators confirmed complete degradation of carbon tetrachloride and TCE.

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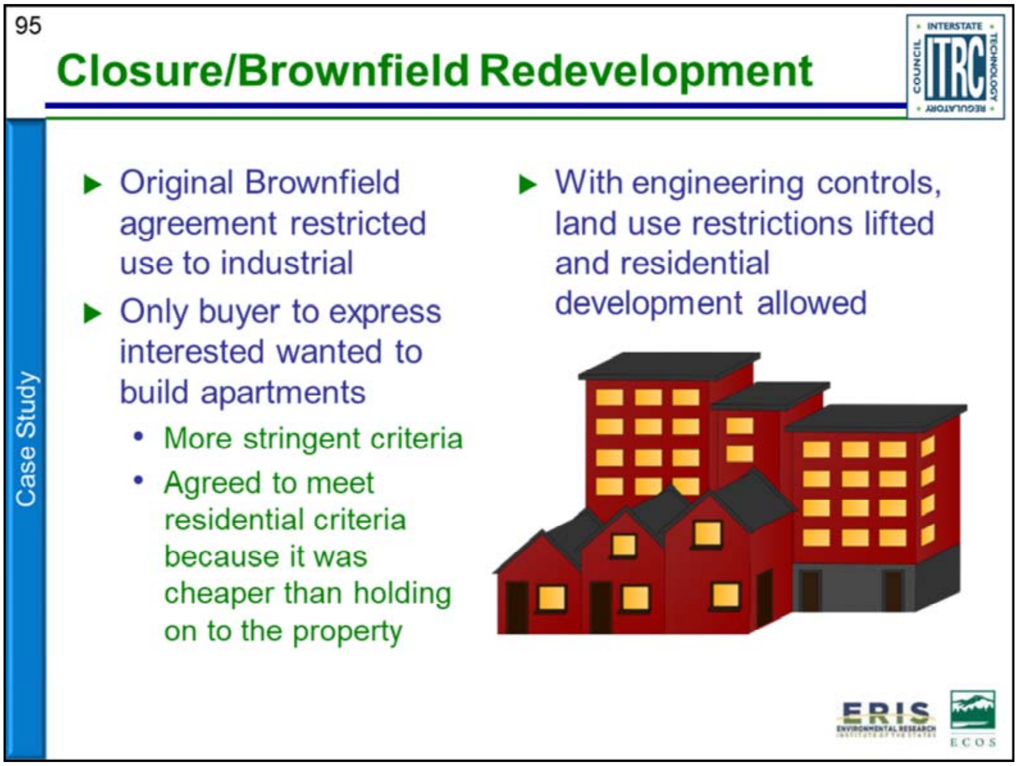
Optimization 3 – Transition to MNA

Case Study

- Know when to stop
- Know when to transition to another technology or MNA
- Consider:
  - Cost/benefit of additional remediation
  - Point of diminishing returns
  - Regulatory framework
  - Final site use

Microbial populations start to die back when chlorinated solvents are reduced below 50 µg/L.
May need to add microbes to achieve MCLs.

Highest concentrations of TCE were around 20 µg/L and carbon tetrachloride was <5 µg/L.
Back diffusion at low levels was anticipated to occur for some time, regardless of active remediation or MNA.



Interesting note: the State Regulatory Agency did not require vapor barriers. Those were demanded by the Responsible Party, our Client, because this particular client has been involved in a couple of emerging contaminant issues at their other sites. They are very risk-adverse. Even though they were confident the known COCs were remediated to MCLs by the time the apartments were occupied, they were not confident with respect to unknown, yet-to-be-identified emerging contaminants.

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Case Study Recap

Case Study

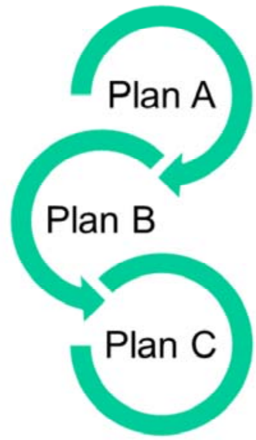
- Treating the 4.1-acre TTZ achieved MCLs or close to MCLs throughout
- Natural attenuation in the remaining 8 acres downgradient
- Bedrock aquifer also naturally attenuated
- What's the future use of the property?
- For this site, transitioned to MNA when concentrations were below 5 times the MCL
- Different states may allow MNA at higher concentrations

For this particular site, closure requirements changed because the owner wanted to sell it to a developer for residential, which was a more stringent requirement.

Key Concepts from Case Study

Case Study

- Including the original P&T remedy, there were 4 cycles of optimization to reach MNA
- Monthly evaluation was critical to maintain schedule for redevelopment
- Evaluate contingency plans up front, and be ready to implement if the data suggest it is needed



Graphic developed by and used with permission from Elizabeth Rhine

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Section 4: Five General Strategies

- Anaerobic biostimulation
- Aerobic biostimulation
- Chemical oxidation (ISCO)
- Chemical reduction (ISCR)
- Surfactant/co-flushing

Tables are organized by the following remediation technology groups: (1) Anaerobic Biostimulation, (2) Aerobic Biostimulation, (3) Chemical Oxidation, (4) Chemical Reduction, and (5) Surfactant/Co-Flushing.

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Strategy-Specific Monitoring

- Tables and Links to Fact Sheets
  - Monitor parameters appropriate for the remedy
  - Data interpretation guidelines
  - Optimization recommendations
- Sample Frequency
  - Dependent on site-specific conditions
  - Varies by reaction time of amendment
  - ISCO monitoring is very different from EISB
- Contingency Planning
  - Have one

Tables are organized by the following remediation technology groups: (1) Anaerobic Biostimulation, (2) Aerobic Biostimulation, (3) Chemical Oxidation, (4) Chemical Reduction, and (5) Surfactant/Co-Flushing.

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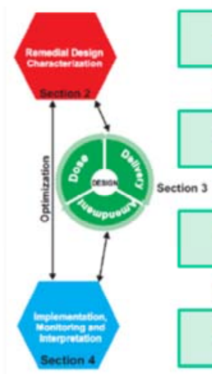
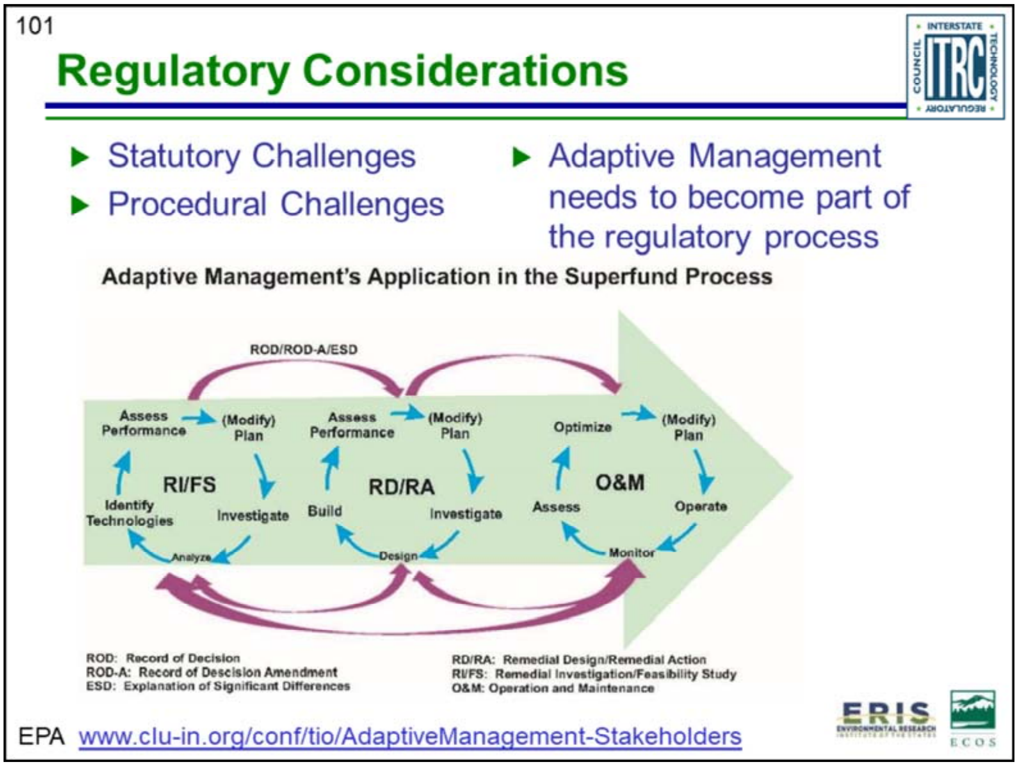
Presentation Road Map



- Optimization Process
- Remedial Design Characterization
- Design: Amendment, Dose & Delivery
- Implementation, Monitoring & Interpretation
- **Regulatory & Stakeholder Considerations**

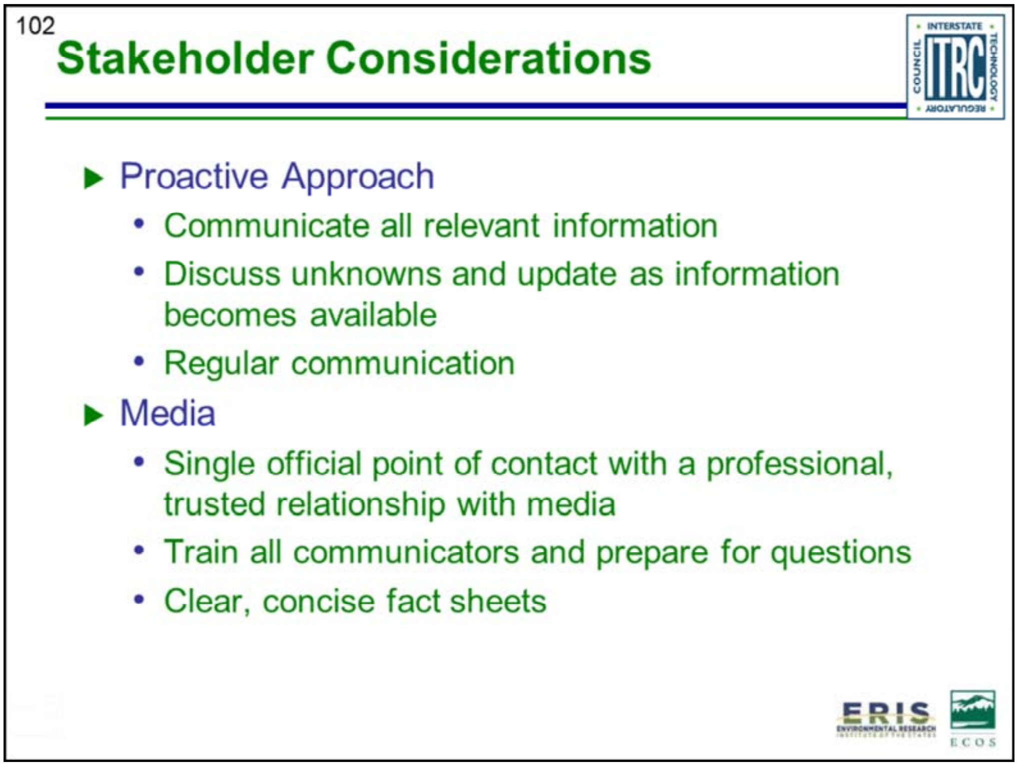
Learning Objective: Anticipate iterative refinement for remedy design and regulatory approvals



We as regulators need this document, too, so we don't fall into the old ways of the linear thinking; and that's another benefit of presenting an Optimization document via the web and ITRC, to expose the states to this iterative/interactive way of thinking and design.

As you see from this graphic, EPA recognized the need for an adaptive management style for their superfund projects. This figure, modified from that memo, clearly shows an **iterative** process similar to the key graphic of this document

(next slide)



Even though remedial activities may occur in situ (underground) or on private property, the activities are noticed by people living and working in the surrounding communities.

They want to know how the activity may affect their lives.

Honest and upfront communication can go a long way to alleviate fear of the unknown.

It may also reveal potential consequences that were not previously thought of.

It is important to develop a media communication plan identifying a single point of contact.

Anticipate questions in advance and develop fact sheet and a list of FAQs (frequently asked questions). All answers should be clear and concise.

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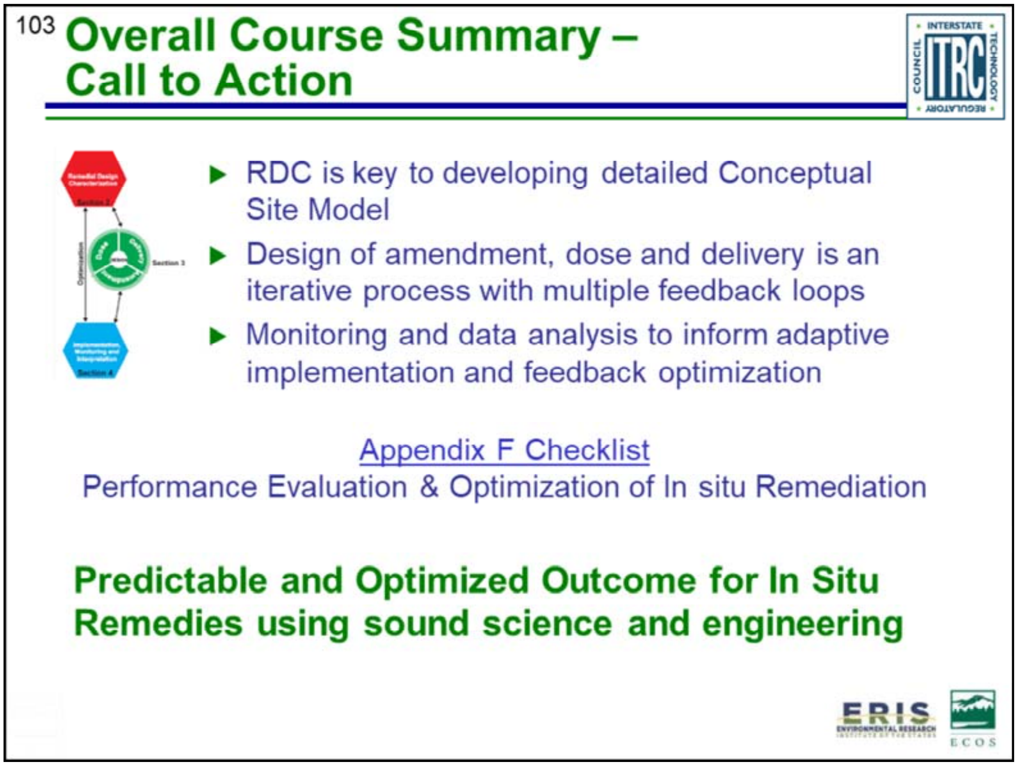

We want you to use this document – use it like your toolbox – it provides the framework for optimization, and includes a number of tools for your reference:

- use the Table in Appendix B like your table of contents, to place you in the right portion of this document,
- make sure your CSM is complete by referring to Table 2-2, dive into the fact sheets, click on the hot links.

We are excited to have produced such a useful tool that is web-based, accessible, and adaptive to new technologies and new contaminants

As I stated in my introduction: Use this document for making predictable and optimized outcomes for in situ remedies using sound science and engineering.

As soon as we end this webinar, go to the guidance document on the web and upload the Appendix F checklist to begin using everything you've learned here for your site!

It is now time for our last Q&A session….(Host)?

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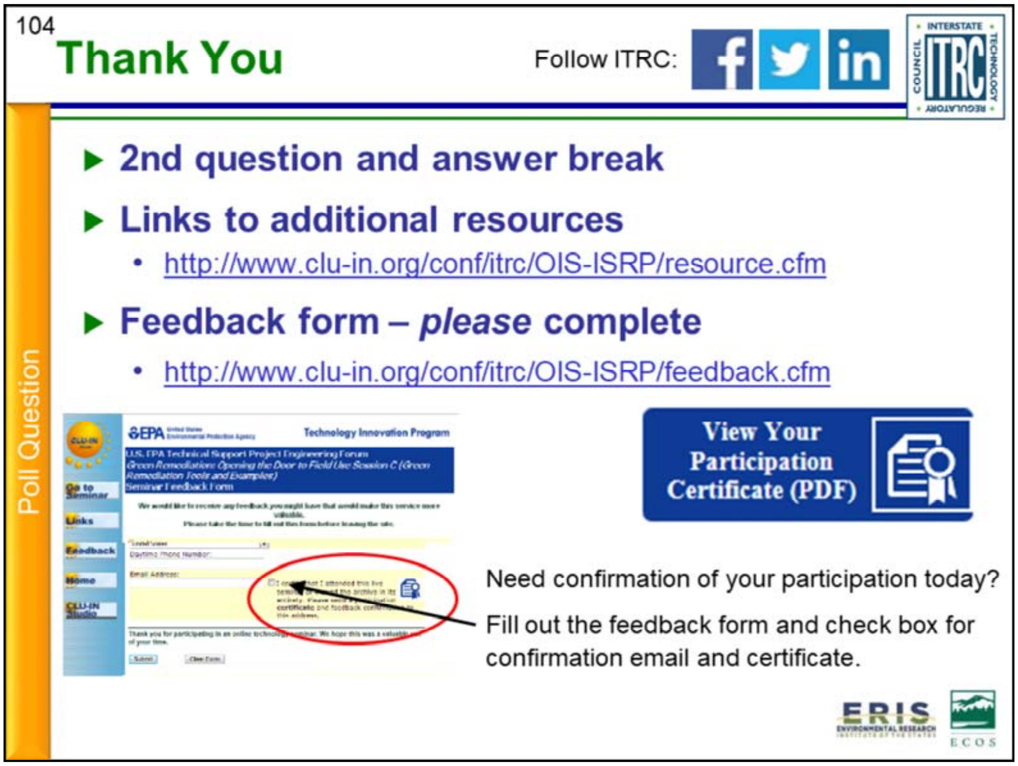

Links to additional resources:
http://www.clu-in.org/conf/itrc/OIS-ISRP/resource.cfm

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

Learn more about ITRC at: www.itrcweb.org