INTERSTATE TECHNOLOGY REGULATORY COUNCIL
ITRC

ITRC DRAFT Document: Optimizing Injection Strategies & *In Situ* Remediation Performance

FRTR: SYNTHESIZING EVOLVING CSMs WITH APPLICABLE REMEDIATION TECHNOLOGIES

Team Leads: Dave Scheer, Minnesota PCA & Janet Waldron, Massachusetts DEP

Presented by: Kristopher McCandless, Virginia DEQ

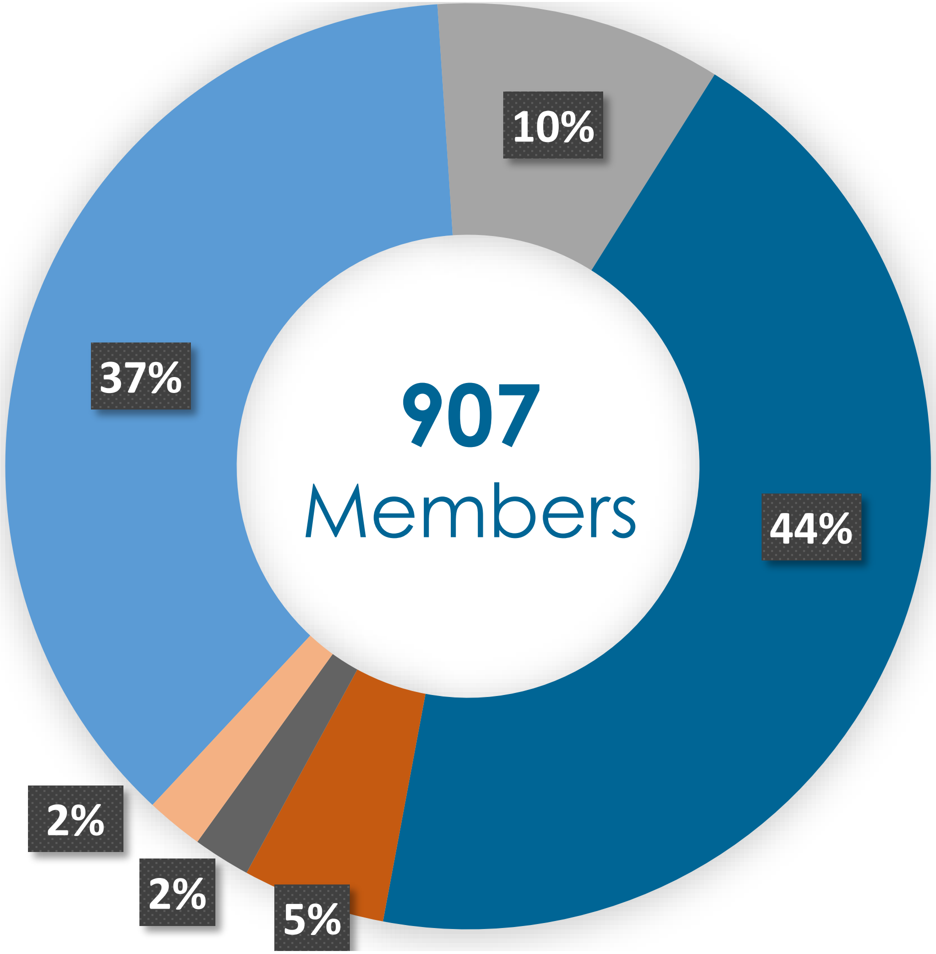
ECOS
ERIS
ENVIRONMENTAL RESEARCH INSTITUTE OF THE STATES

What is ITRC?

ITRC is a state-led coalition working to advance the use of innovative environmental technologies and approaches to translate good science into better decision-making.

As of March 7, 2019

Our Unique Network



- State/City/Local Government
- Federal Government
- Private Sector
- Academia
- Stakeholders
- International Organizations

Federal Government Participants


UNITED STATES ENVIRONMENTAL PROTECTION AGENCY


DEPARTMENT OF DEFENSE
1947 COMMEMORATION 1997


DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

Benefits to DOD and DOE

- Facilitate interactions between federal managers and state regulators
- Increase consistency of regulatory requirements for similar environmental problems in different states
- Provide harmonized approaches to using innovative technology across the nation
- Reduce review and approval times for those innovative approaches

ITRC Accomplishments

Educates state regulators on the use of innovative technologies

Promotes the use of innovative technologies

Unites state approaches to complex topics

Inspires collaboration over adversarial relationships

How Can YOU Benefit from ITRC?

Use ITRC Documents

Take ITRC Training Courses

Join ITRC Teams

2020 Teams

- Use of Soil Background Concentrations in Risk Assessment (NEW)
- Per- and Polyfluoroalkyl Substances (PFAS) Update & Training
- 1,4-Dioxane (Continuing until Dec. 2020)
- Harmful Cyanobacterial Blooms (Continuing until Dec. 2020)
- Incremental Sampling Methodology Update (Continuing until Dec. 2020)
- Vapor Intrusion Mitigation Training (Continuing until Dec. 2020)
- Advanced Site Characterization Tools (ASCT) (Due in Early 2020)
- Optimizing Injection Strategies & In Situ Remediation Performance (Due in April 2020)

Optimizing Injection Strategies and *In Situ* Remediation Performance

DRAFT

INTERNET BASED DOCUMENT

&

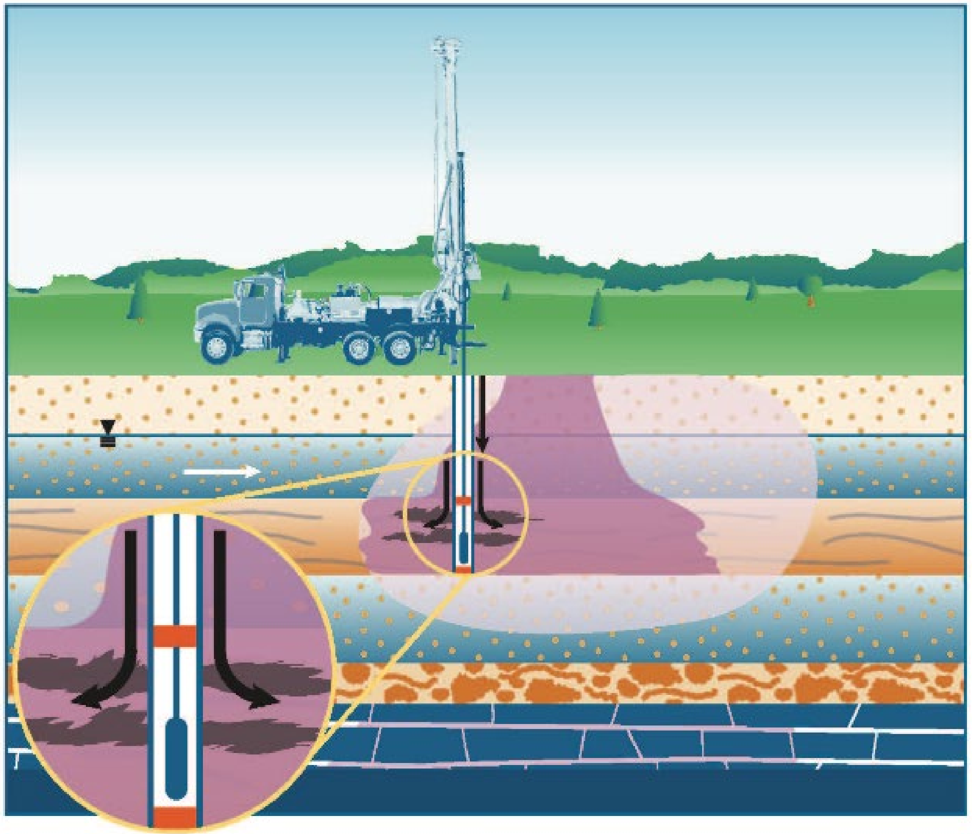
TRAINING

(GOING PUBLIC IN APRIL 2020)

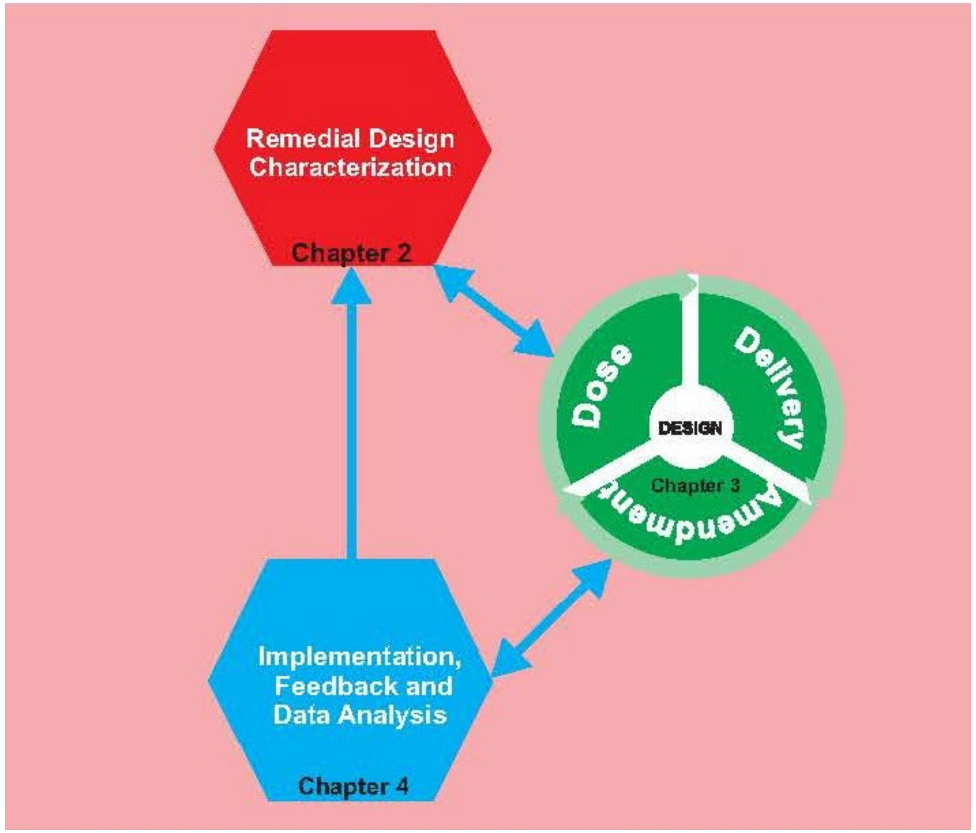
Team Leads:

Dave Scheer, Minnesota PCA

Janet Waldron, Massachusetts DEP



What is Optimization?

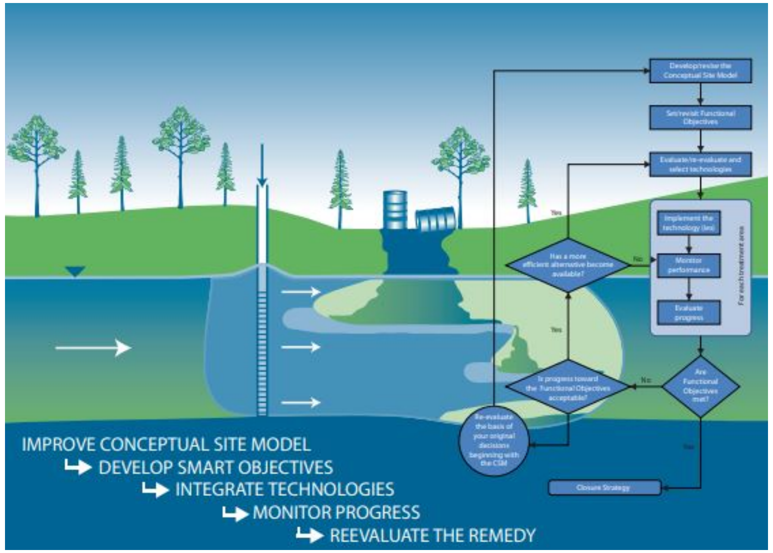


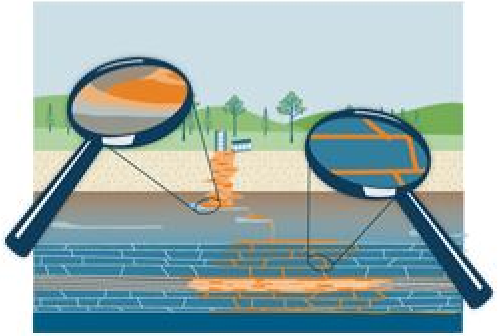
Optimization is the effort (at any clean-up phase) to identify and implement actions that improve effectiveness and cost-efficiency of that phase.

This is the EPA definition cited in ITRC's 2016 Geospatial Analysis Optimization document.

Foundation of this Document

- 2011 Integrated DNAPL Site Strategy (IDSS)
- 2015's IDSS Site Characterization and Tool Selection Document
- Optimization addressed in other contexts
  - Remediation Process Optimization (2004) (ITRC-RPO-1, 2004)
  - Performance-Based Environmental Management (ITRC RPO-2, 2007)
  - Geospatial Analysis for Optimization (2016) (GRO-1, 2016)





Purpose of this Document

High Resolution Site Characterization Tools: Downhole geophysics, MiHPT/LIF/OIP, LIDAR, ER, tracer test, GPR, Packer testing

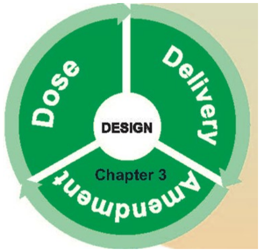
Amendment Selection Table

Delivery Factsheets

Bench or Pilot Test

Performance Monitoring

Remedial Design Characterization

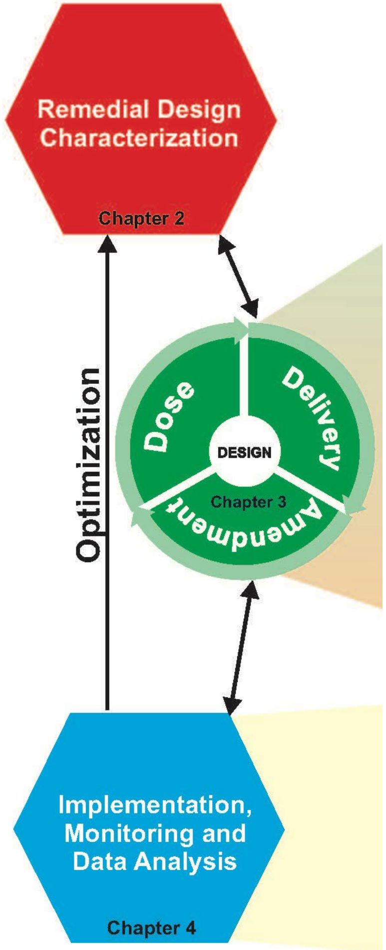


Design Wheel

Structure of this In Situ Optimization Document

- Remedial Design Characterization (Ch 2)
- Amendment, Delivery, Dose Design (Ch 3)
- Implementation & Feedback (Monitoring) Optimization (Ch 4)
- Regulatory Perspectives (Ch 5)
- Community & Tribal Stakeholder Considerations (Ch 6)

Hot links * Tables * Mouse-over Definitions * Factsheets * References * Case Studies



Who is this Document written for?

- The remediation manager who has had a failure of some type:
  - Has pushed or moved the plume where they didn't want it go
  - Amendment is reacting with the geochemistry
  - Delivery method not compatible with hydrogeology
  - Have successfully cleaned up 50% of the mass and but stalled out for the rest
- The practitioner who is just about to start an in situ remediation project and wants to make sure they have chosen the correct remedy
- This document is NOT a 101 class for remediation! It assumes a basic CSM has been established and the hydrogeology is known

The Problem & Need for Optimization

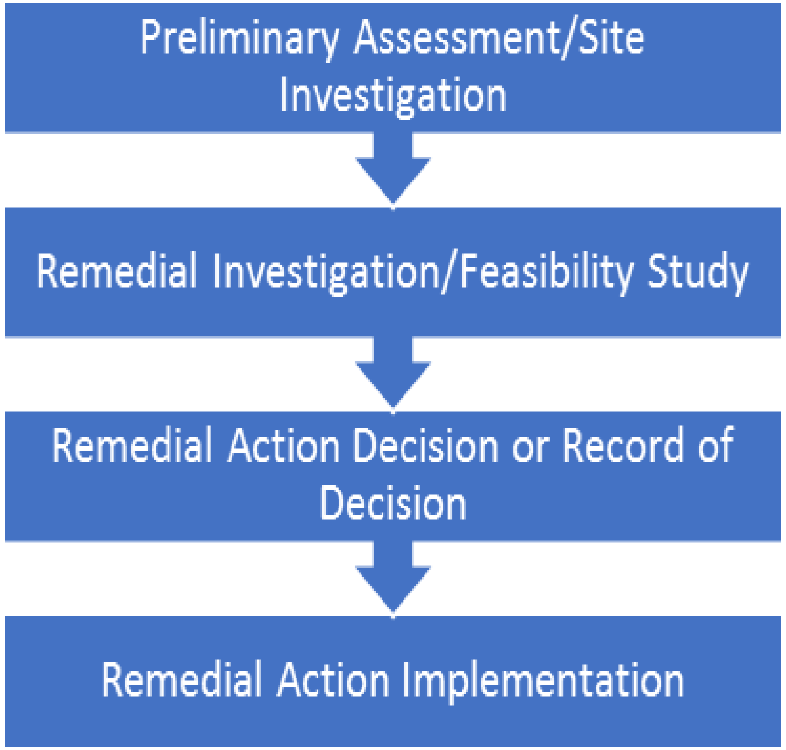
Out of all the proposals received by state regulators for remediation projects, about 40% of regulators deemed the first submittal as <u>incomplete</u>.

Why?

- ✓ proposed remedy was not fully supported by the CSM
- ✓ CSM was inadequate
- ✓ inadequate amendment placement according to the CSM

Regulatory Linear Paradigm

- Main goal: **clean up sites**.
- Traditional approach to the remedial process was linear.



Preliminary Assessment/Site Investigation

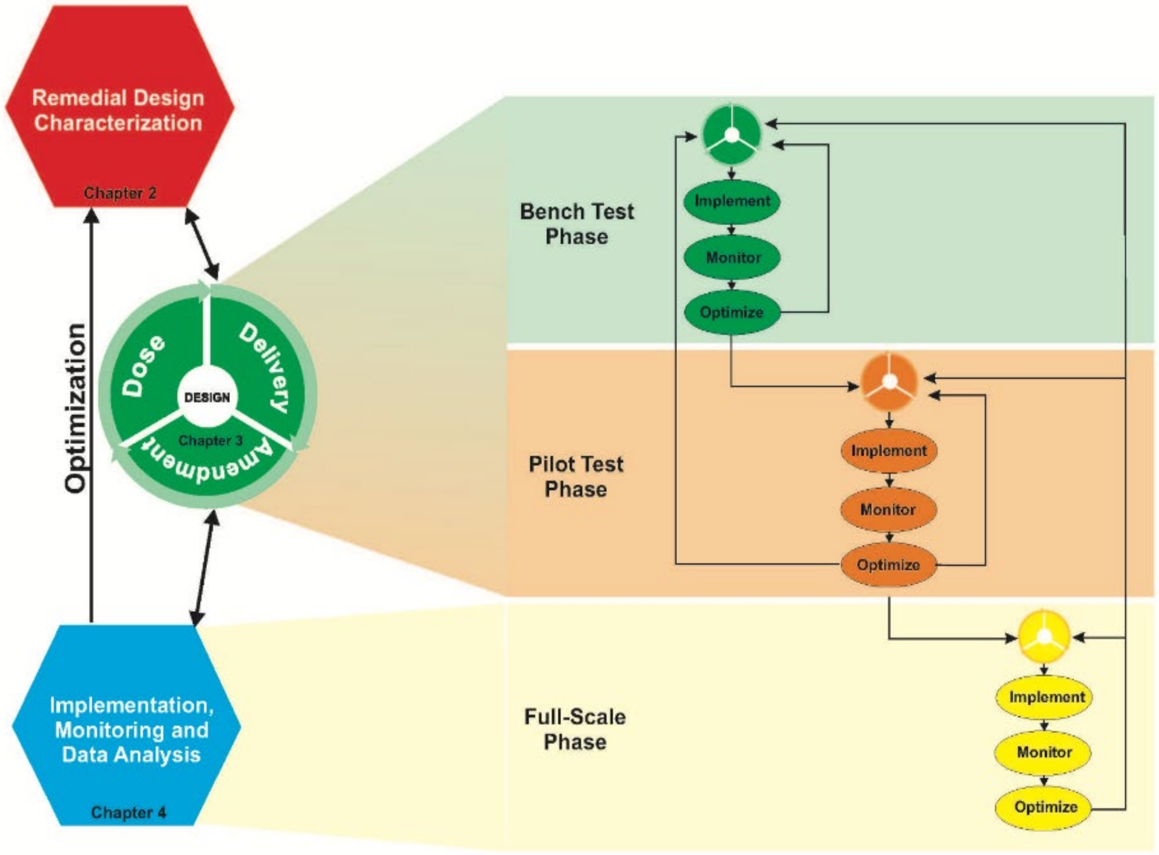
Remedial Investigation/Feasibility Study

Remedial Action Decision or Record of Decision

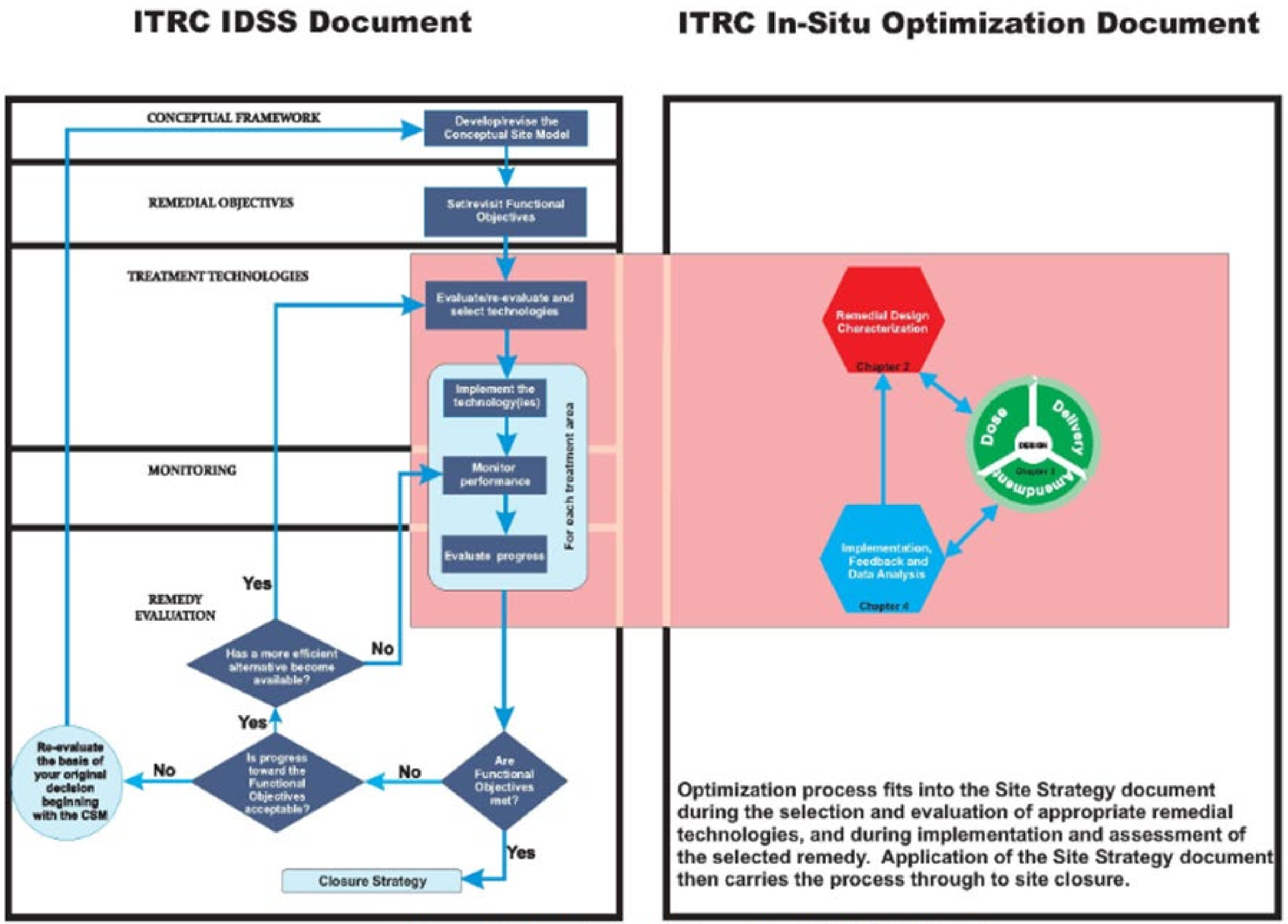
Remedial Action Implementation

Interactive/Iterative Approach

- Evolution of environmental work has led to the realization that an iterative approach is required to efficiently clean up sites.
- ITERATIVE : To state repeatedly, repetitious, repetitive
- INTERACTIVE: Acting one upon (or with) the other



ITRC Documents Support Interactive/Iterative Approach



ITRC IDSS Document

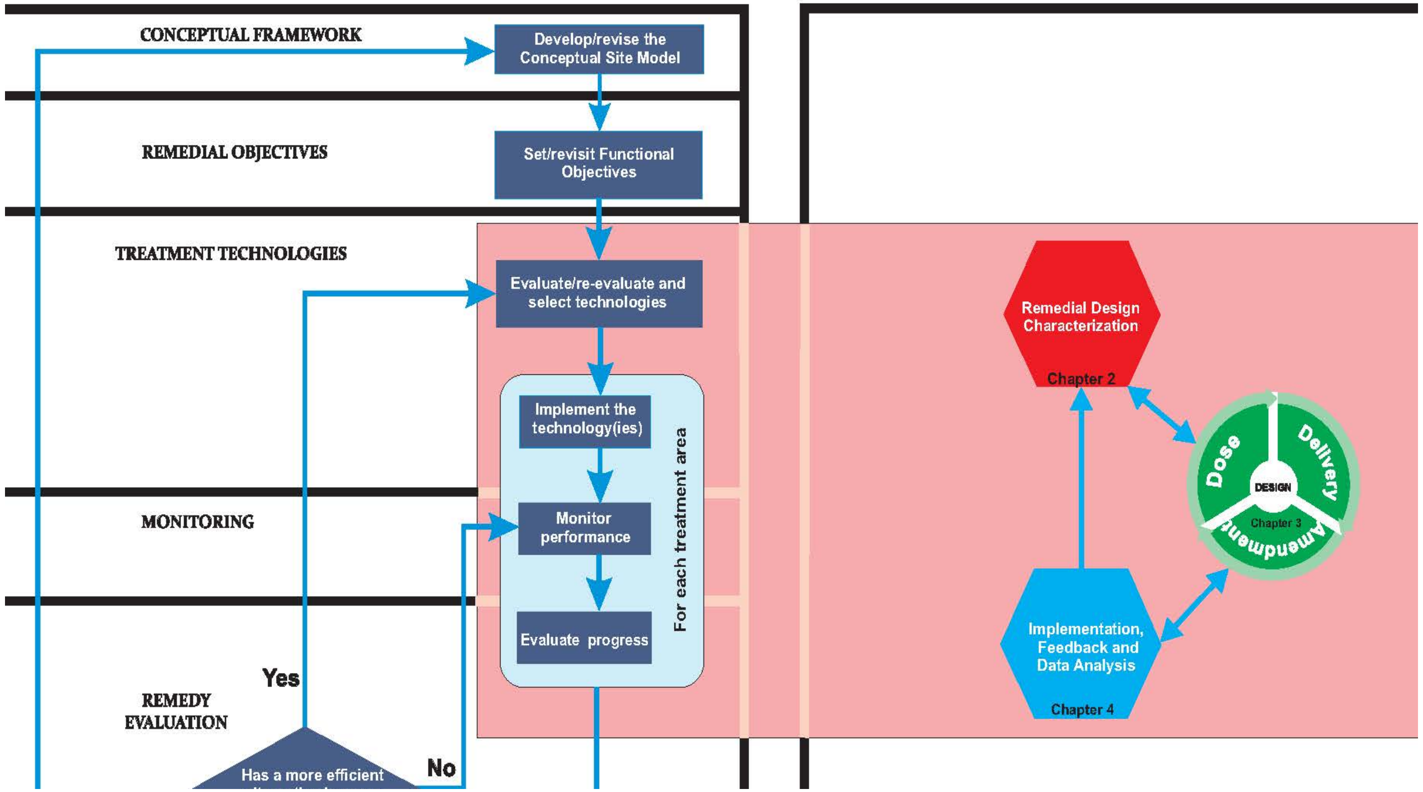
ITRC In-Situ Optimization Document

Optimization process fits into the Site Strategy document during the selection and evaluation of appropriate remedial technologies, and during implementation and assessment of the selected remedy. Application of the Site Strategy document then carries the process through to site closure.

Figure 1-1. Relationship between the (ITRC 2011c) and the in situ treatment optimization

ITRC Documents Support Interactive/Iterative Approach

- Common goal: **clean up sites**
- The interactive/iterative approach will support the conceptual site models that change with new information
- In Situ remediation is particularly suited to the adaptive approach as unknowns are refined with bench tests, and pilot tests.



CONCEPTUAL FRAMEWORK
Develop/revise the Conceptual Site Model
REMEDIAL OBJECTIVES
Set/revisit Functional Objectives
TREATMENT TECHNOLOGIES
Evaluate/re-evaluate and select technologies
Implement the technology(ies)
MONITORING
Monitor performance
Evaluate progress
For each treatment area
REMEDY EVALUATION
Yes
No
Has a more efficient
Remedial Design Characterization
Chapter 2
Dose
Delivery
Amendment
DESIGN
Chapter 3
Implementation, Feedback and Data Analysis
Chapter 4

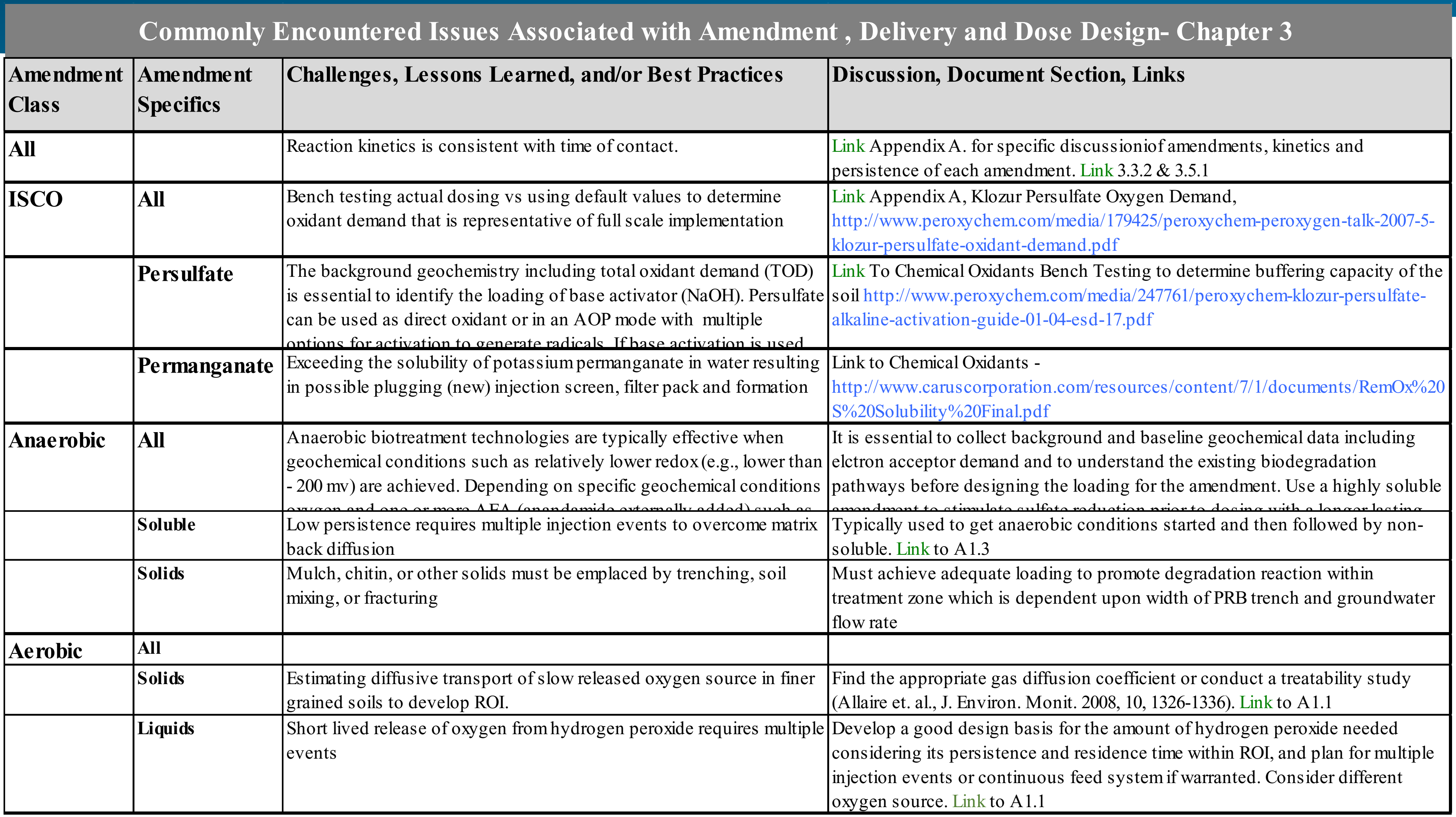
I have a failed remedy. Where do I start?

Commonly Encountered Issues Associated with Remediation Design Characterization - Chapter 2

Lithology	Contaminant	Challenges, Lessons Learned, and/or Best Practices	Discussion, Document Section, Links
All		Reliance of MW data vs a full understanding of contaminant mass distribution vs lithology vs permeability (K) available through higher resolution site characterization (HRSC) technology	Continous profiling tools such as MiHPT, MiHPT-CPT, LIF, LIF-CPT, LIF-CPT-MiHPT, MIP, MIP-CPT-MiHPT etc. or continous rock coring coupled with high density soil or rock sampling and physical and chemical analyses. link to ITRC ISC-1 2015 (https://www.itrcweb.org/Guidance/ListDocuments?TopicID=5&SubTopicID=49)
		Unrealistic expectations without a full understanding of site specific challenges - e.g. matrix back diffusion, which can lead to contaminant concentration rebound after initial improvement in concentrations post-injection	Link to Ch 2 Knowledge of delivery and amendment limitations in achieving contact and adequate residence time with mass sorbed to the soil matrix.
Bedrock		The amount of contaminant mass sorbed into bedrock secondary porosity	Link to ITRC- FracRX-1 2017, (https://www.itrcweb.org/Guidance/ListDocuments?TopicID=58&SubTopicID=60)
Soil		Lack of understanding of contaminant mass sorbed into finer grained soils.	Application of MiHPT, MiHPT-CPT coupled with high density soil sampling to determine extent and distribution of contaminant mass ITRC ISC-1 2015 (https://www.itrcweb.org/Guidance/ListDocuments?TopicID=5&SubTopicID=49)
Ground Water		Variability of K and calculated seepage velocity in contaminated intervals is needed to estimate ROI (radius of influence) 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

Table 1-1 (Appendix B) Issues commonly encountered during implementation of an in situ remedy

Tool: Common Issues Spreadsheet

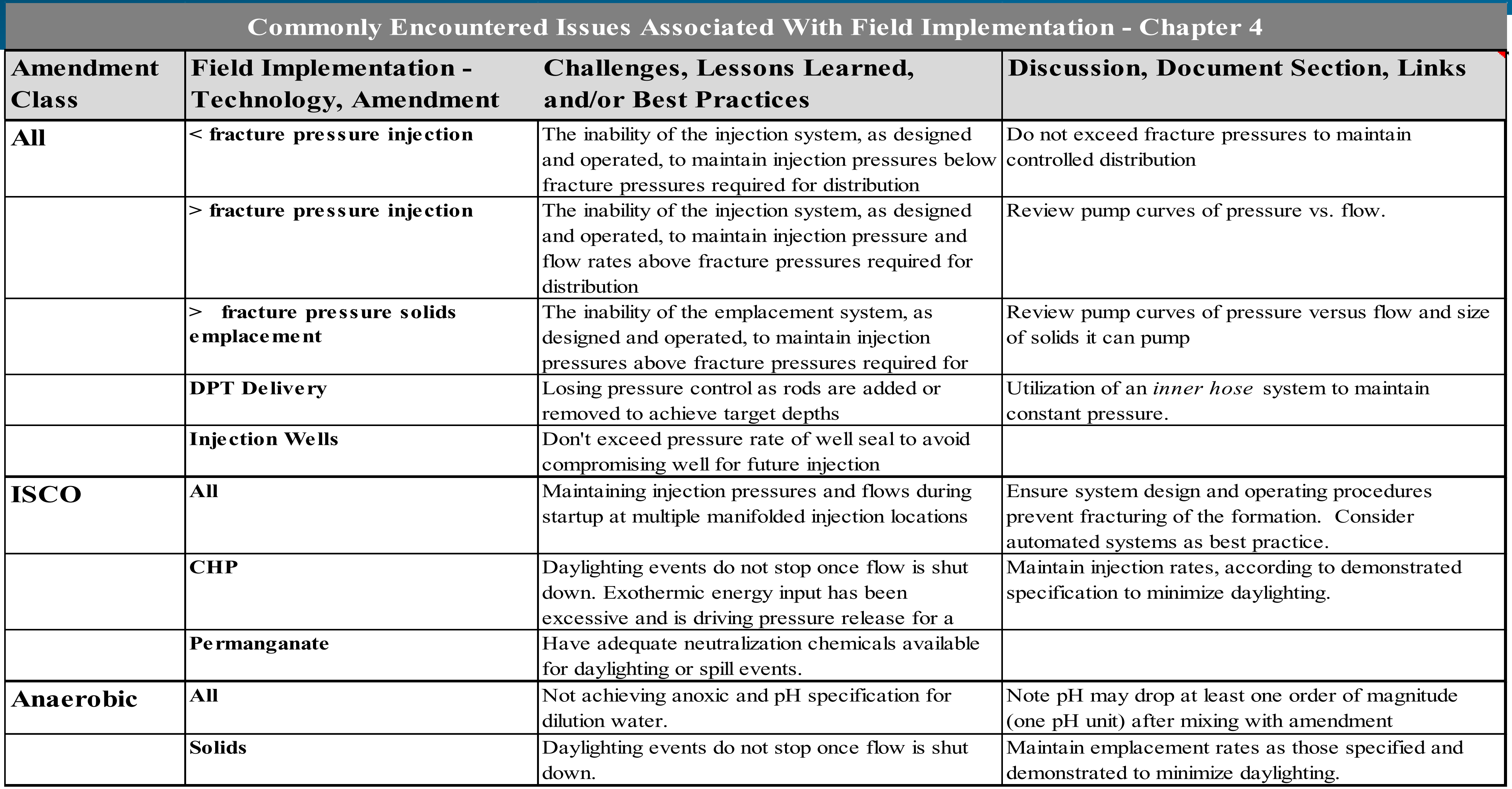


Commonly Encountered Issues Associated with Amendment , Delivery and Dose Design- Chapter 3

Amendment Class	Amendment Specifics	Challenges, Lessons Learned, and/or Best Practices	Discussion, Document Section, Links
All		Reaction kinetics is consistent with time of contact.	Link Appendix A. for specific discussioniof amendments, kinetics and persistence of each amendment. Link 3.3.2 & 3.5.1
ISCO	**All**	Bench testing actual dosing vs using default values to determine oxidant demand that is representative of full scale implementation	Link Appendix A, Klozur Persulfate Oxygen Demand, http://www.peroxychem.com/media/179425/peroxychem-peroxygen-talk-2007-5-klozur-persulfate-oxidant-demand.pdf
	Persulfate	The background geochemistry including total oxidant demand (TOD) is essential to identify the loading of base activator (NaOH). Persulfate can be used as direct oxidant or in an AOP mode with multiple options for activation to generate radicals. If base activation is used	Link To Chemical Oxidants Bench Testing to determine buffering capacity of the soil http://www.peroxychem.com/media/247761/peroxychem-klozur-persulfate-alkaline-activation-guide-01-04-esd-17.pdf
	Permanganate	Exceeding the solubility of potassium permanganate in water resulting in possible plugging (new) injection screen, filter pack and formation	Link to Chemical Oxidants - http://www.caruscorporation.com/resources/content/7/1/documents/RemOx%20S%20Solubility%20Final.pdf
Anaerobic	**All**	Anaerobic biotreatment technologies are typically effective when geochemical conditions such as relatively lower redox (e.g., lower than - 200 mv) are achieved. Depending on specific geochemical conditions	It is essential to collect background and baseline geochemical data including elctron acceptor demand and to understand the existing biodegradation pathways before designing the loading for the amendment. Use a highly soluble
	Soluble	Low persistence requires multiple injection events to overcome matrix back diffusion	Typically used to get anaerobic conditions started and then followed by non-soluble. Link to A1.3
	Solids	Mulch, chitin, or other solids must be emplaced by trenching, soil mixing, or fracturing	Must achieve adequate loading to promote degradation reaction within treatment zone which is dependent upon width of PRB trench and groundwater flow rate
Aerobic	**All**		
	Solids	Estimating diffusive transport of slow released oxygen source in finer grained soils to develop ROI.	Find the appropriate gas diffusion coefficient or conduct a treatability study (Allaire et. al., J. Environ. Monit. 2008, 10, 1326-1336). Link to A1.1
	Liquids	Short lived release of oxygen from hydrogen peroxide requires multiple events	Develop a good design basis for the amount of hydrogen peroxide needed considering its persistence and residence time within ROI, and plan for multiple injection events or continuous feed system if warranted. Consider different oxygen source. Link to A1.1

Table 1-1 (Appendix B) Issues commonly encountered during implementation of an in situ remedy

Tool: Common Issues Spreadsheet



Commonly Encountered Issues Associated With Field Implementation - Chapter 4

Amendment Class	Field Implementation - Technology, Amendment	Challenges, Lessons Learned, and/or Best Practices	Discussion, Document Section, Links
All	**< fracture pressure injection**	The inability of the injection system, as designed and operated, to maintain injection pressures below fracture pressures required for distribution	Do not exceed fracture pressures to maintain controlled distribution
	> fracture pressure injection	The inability of the injection system, as designed and operated, to maintain injection pressure and flow rates above fracture pressures required for distribution	Review pump curves of pressure vs. flow.
	> fracture pressure solids emplacement	The inability of the emplacement system, as designed and operated, to maintain injection pressures above fracture pressures required for	Review pump curves of pressure versus flow and size of solids it can pump
	DPT Delivery	Losing pressure control as rods are added or removed to achieve target depths	Utilization of an *inner hose* system to maintain constant pressure.
	Injection Wells	Don't exceed pressure rate of well seal to avoid compromising well for future injection	
ISCO	**All**	Maintaining injection pressures and flows during startup at multiple manifolded injection locations	Ensure system design and operating procedures prevent fracturing of the formation. Consider automated systems as best practice.
	CHP	Daylighting events do not stop once flow is shut down. Exothermic energy input has been excessive and is driving pressure release for a	Maintain injection rates, according to demonstrated specification to minimize daylighting.
	Permanganate	Have adequate neutralization chemicals available for daylighting or spill events.	
Anaerobic	**All**	Not achieving anoxic and pH specification for dilution water.	Note pH may drop at least one order of magnitude (one pH unit) after mixing with amendment
	Solids	Daylighting events do not stop once flow is shut down.	Maintain emplacement rates as those specified and demonstrated to minimize daylighting.

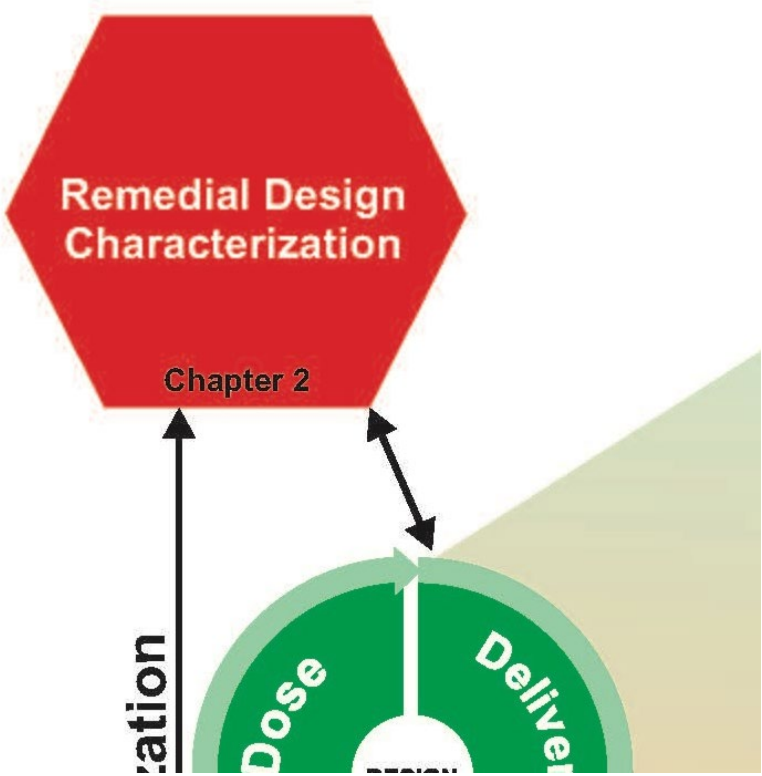
Table 1-1 (Appendix B) Issues commonly encountered during implementation of an in situ remedy

Chapter 2: Remedial Design Characterization

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 CSM.

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

Remedial design characterization (RDC) is the collection of additional data, above and beyond what are typically generated as part of general site characterization studies, necessary to develop a sufficiently detailed CSM, which enables a design basis for an in situ remedy.



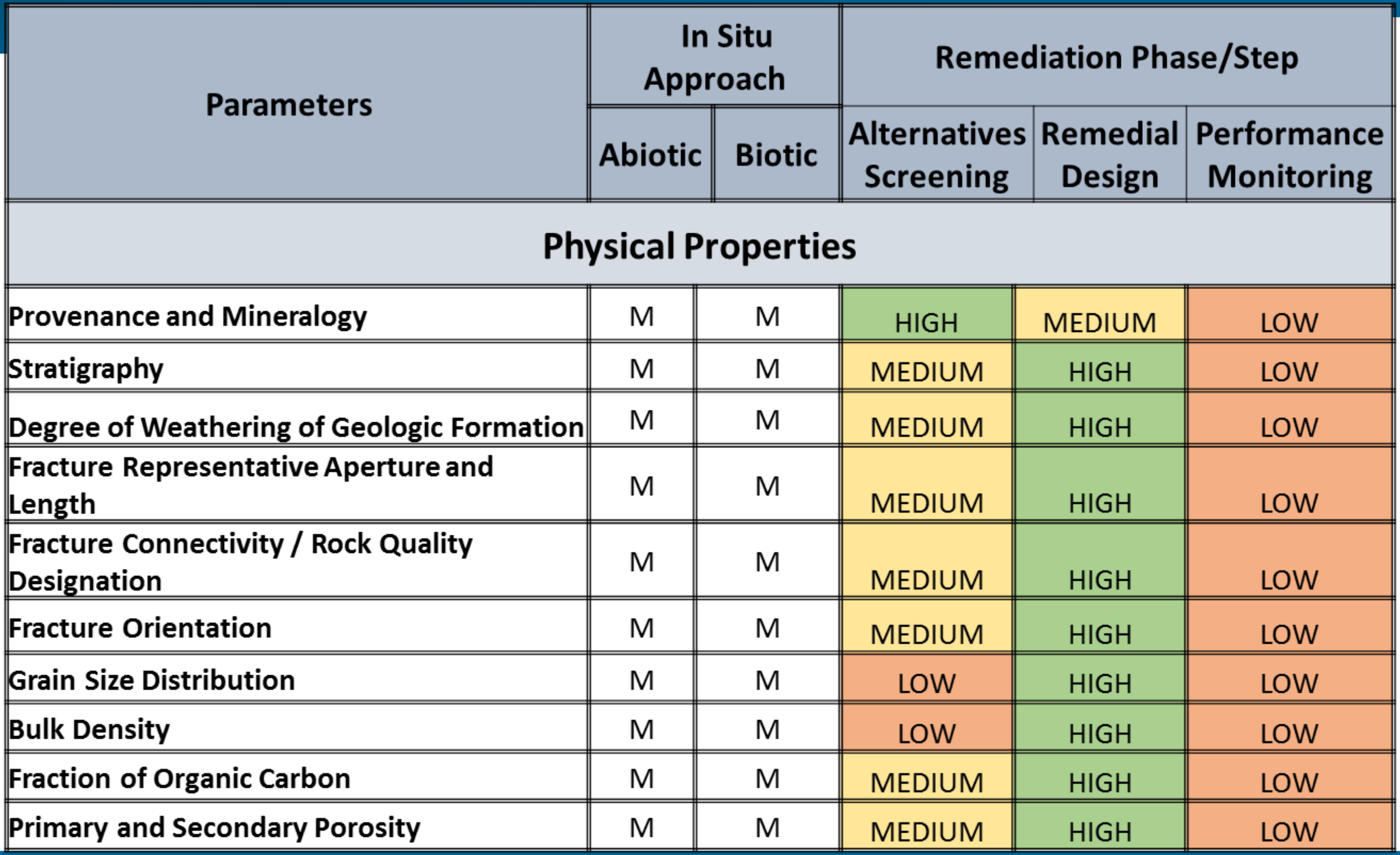
RDC: Remedial Design Characterization

Objectives:

Identify the data required to obtain a focused understanding of the geologic, hydrogeologic, geochemical, and microbial nature of the site conditions in specific support of in situ remedial actions. These parameters inform the remedial approach and technology selection.

- ✓ Geology - stratigraphy, mineralogy, fractures, soil properties that define flow regimes
- ✓ Hydrogeology – heterogeneities, aquifer properties that influence flow and transport
- ✓ Geochemistry - identify electron acceptors, competitors, and metal mobilization risks
- ✓ Microbiology - assess degradation potential

Another Comprehensive Tool for RDC



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

LEGEND
M, L = Applicability

Hi, Med, Low (colors) =Relative importance of data at the remediation phase indicated

Table 2-2 (Appendix C) Geology, Hydrogeology, Geochemistry, Microbiological Considerations Spreadsheet

Improve the CSM – Why do it?

Why spend more money on characterization, when you could be spending it on cleanup?

When in situ remedies fail, it is often due to a lack of detailed data or an insufficiently developed CSM.

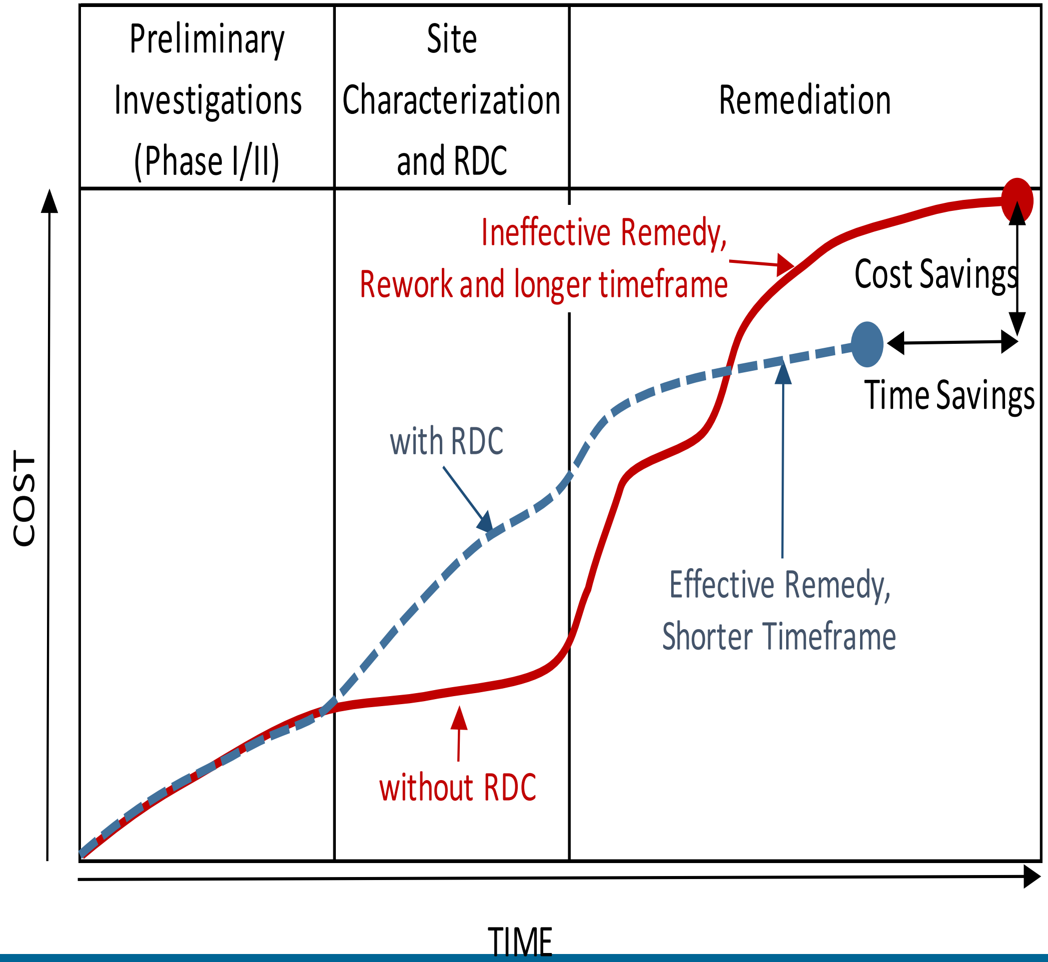
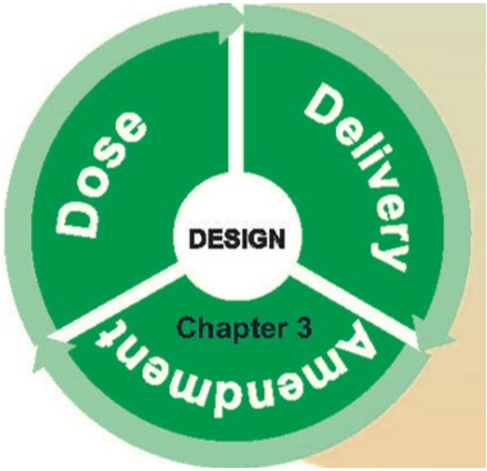
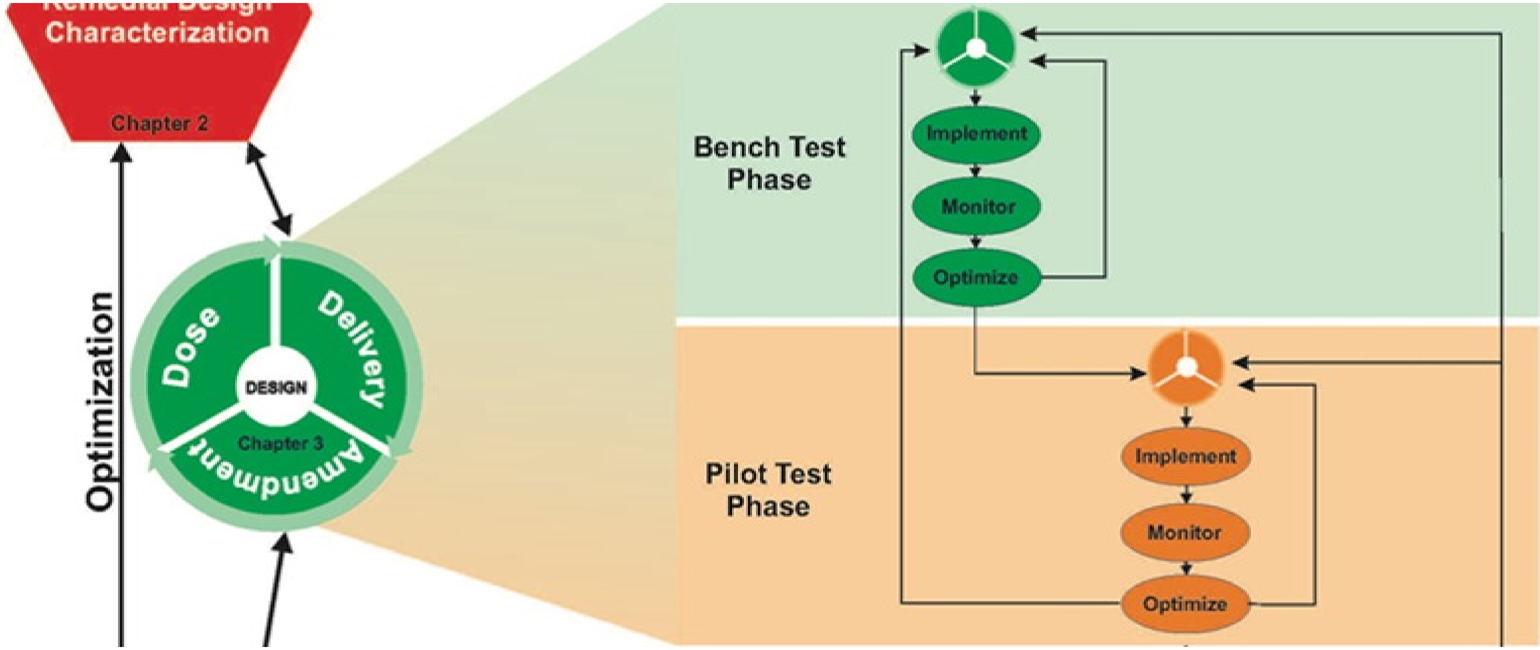


Figure 2-1. Conceptual Project Lifecycle costs with and without RDC (Modified from (ITRC 2015)

Chapter 3: Amendment, Dose, Delivery Design

THE DESIGN WHEEL





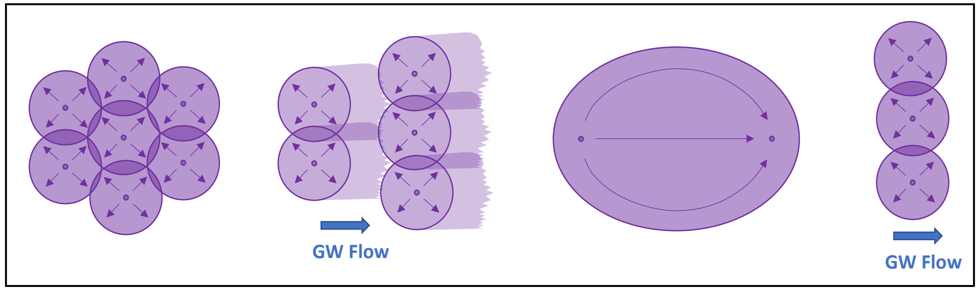
Amendment Selection Table

Treatment Type	Description/ Summary	Target COCs	Typical Injection/Emplacement Technologies Methods
Common Biotic Amendments (A.1)			
Aerobic bioremediation (A1.1) / Biological oxidation	Aerobic degradation occurs predominantly in near-surface saturated and vadose zone environments (Only for sparging. calcium peroxide doesn't work in vadose zone). Naturally occurring aerobic microorganisms are widely dispersed, and usually react efficiently with supplemental oxygen provided via amendments that release oxygen; low to moderate doses of hydrogen peroxide, calcium peroxide, or magnesium peroxide	• Petroleum hydrocarbons and some fuel oxygenates (e.g., methyl tertiary-butyl ether [MTBE]).	• Air/ozone direct injection • Air sparging • Introduction of oxygen via diffused emission • Direct vapor phase injection •
Co-metabolic aerobic bioremediation (A1.2)	Co-metabolism involves degradation of contaminants using enzymes produced by microorganisms as a result of consumption of a primary substrate such as methane, propane, ethane, etc. that may be injected into the subsurface. The microorganisms do not benefit from the degradation process and can thrive in the absence of the contaminants. Most co-metabolic processes occur under aerobic conditions and may require oxygen additions to stimulate/support degradation.	• Chlorinated solvents (TCE, DCE, VC, DCA) • Chloroform • MTBE • 1,4-dioxane • THF • Explosives • Atrazine • PAHs • Some pesticides	• Trenching/Soil Mixing • Direct push injection • Permanent injection wells • Biosparge wells for gases
Anaerobic bioremediation (A1.3)/ biological reduction	Contaminants are degraded via a reductive process by certain types of microbes under anaerobic conditions. Fermentable organic substrates are injected or placed into the subsurface to enhance the production of hydrogen, which is in turn used by the microbes in the reductive reactions.	• Chlorinated solvents • Many pesticides and munitions • Certain inorganic compounds • Petroleum Hydrocarbons (typically by introduction of electron acceptors like nitrate and/or sulfate)	• Direct push injection • Permanent injection wells • PRBs

TABLE 3-3 Details of Amendment Types and Typical Injection/Emplacement Technologies

Amendment Dosage & Delivery

- Amendment Dose Requirements
  - Background Demands
  - Target Demands
  - Volume Considerations
- Amendment Delivery Optimization
  - Grid patterns, Injection & Drift, Recirculation
  - Overcoming Delivery Problems
    - Fouling and well rehabilitation

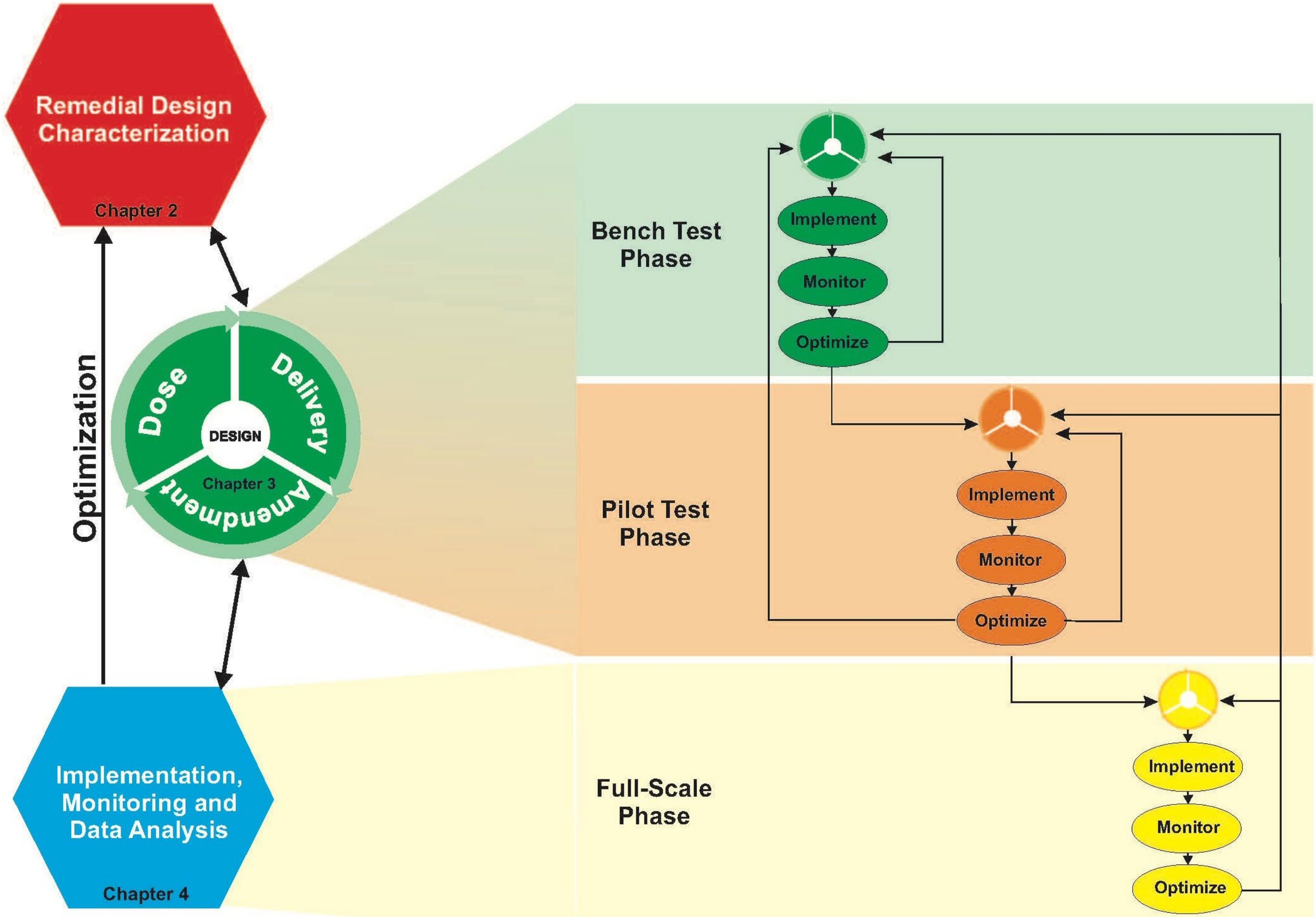


Delivery/Injection Screening Matrix (Table 3.5)

Delivery Technique / **Hydrogeologic Characteristics**	Direct Push Injection (DPI) [link # D1]	Injection Through Wells & Boreholes [link # D2]	Electro-Kinetics (This is injection through wells) [link # D3]	Solid Emplacement [Link # D4]		Permeable Reactive Barriers (PRBs) [link # D7]
				Hydraulic Delivery Through Wells & Boreholes [link # D5]	Pneumatic Delivery Through Open Boreholes [link # D6]	
Gravels	Ï (Sonic)	Ï	NA	NA	NA	Ï
Cobbles	Ï (Sonic)	Ï	NA	NA	NA	Ï
Sandy Soils (Sm, Sc, Sp, Sw)	Ï	Ï	NA	⊙	⊙	Ï
Silty Soils (Ml, Mh)	Ï	⊙	Ï	Ï	Ï	Ï
Clayey Soils (Cl, Ch, Oh)	Ï	⊙	Ï	Ï	Ï	Ï
Weathered Bedrock	Ï	Ï	⊙	Ï	Ï	⊙
Competent/Fractured Bedrock	NA	Ï	NA	⊙	⊙	⊙
K d 10^{-3} To 10^{-4} (Low Perm Soils)	Ï	⊙	Ï	Ï	Ï	Ï
K e 10^{-3} (High Perm Soils)	Ï	Ï	⊙	⊙	⊙	Ï
Depth > Direct Push Capabilities	NA	Ï	⊙	⊙	⊙	⊙

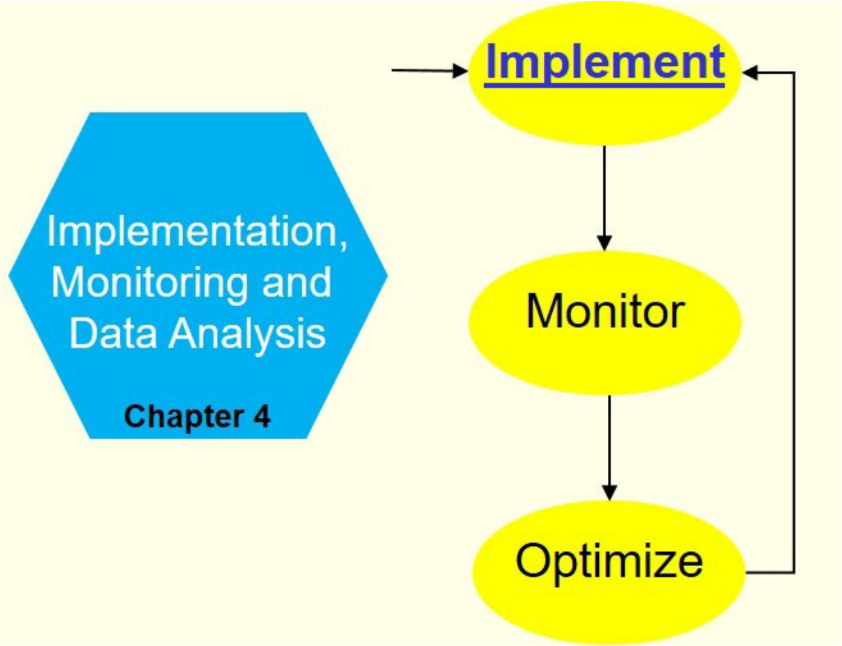
Chapter 4: Implementation, Monitoring, Data Analysis

THE OPTIMIZATION STAIRCASE



Chapter 4: Optimization Staircase

- Implementation & Optimization Staircase
  - Results of pilot or bench test may lead to another pilot or bench test before going for full scale site implementation
  - Optimization not meant to create endless cycle of testing, but a cost effective, efficient remediation strategy
- Adaptive Implementation and Feedback Optimization
  - Data set for CSM and corresponding design (amendment, dose, delivery) will never be perfect or fully complete
  - Staircase always allows for feedback to a design step or the CSM



Chapter 4: Monitoring

- Process and Performance Monitoring

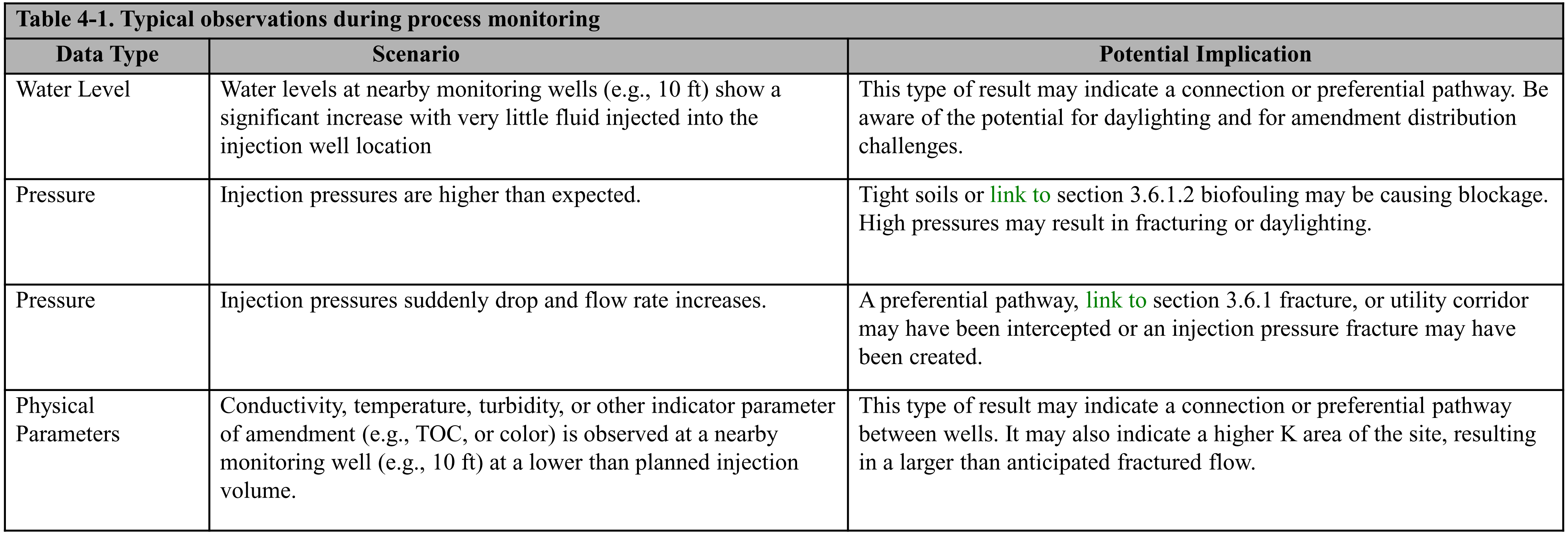
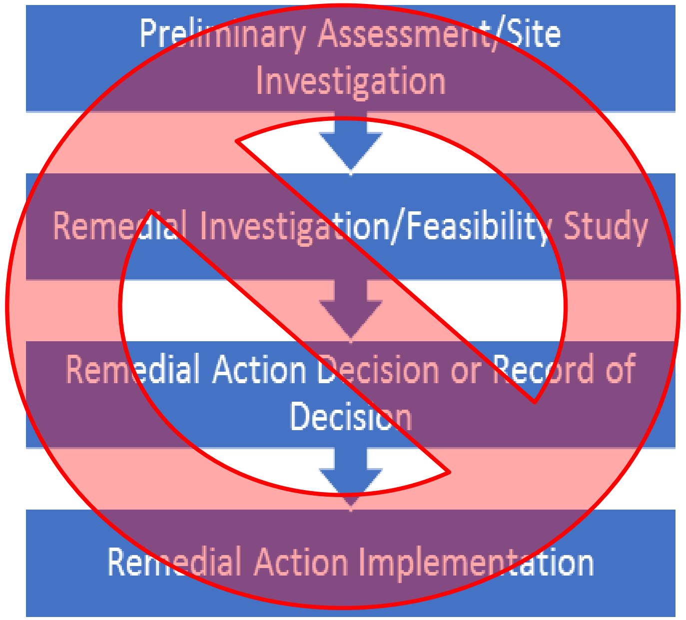


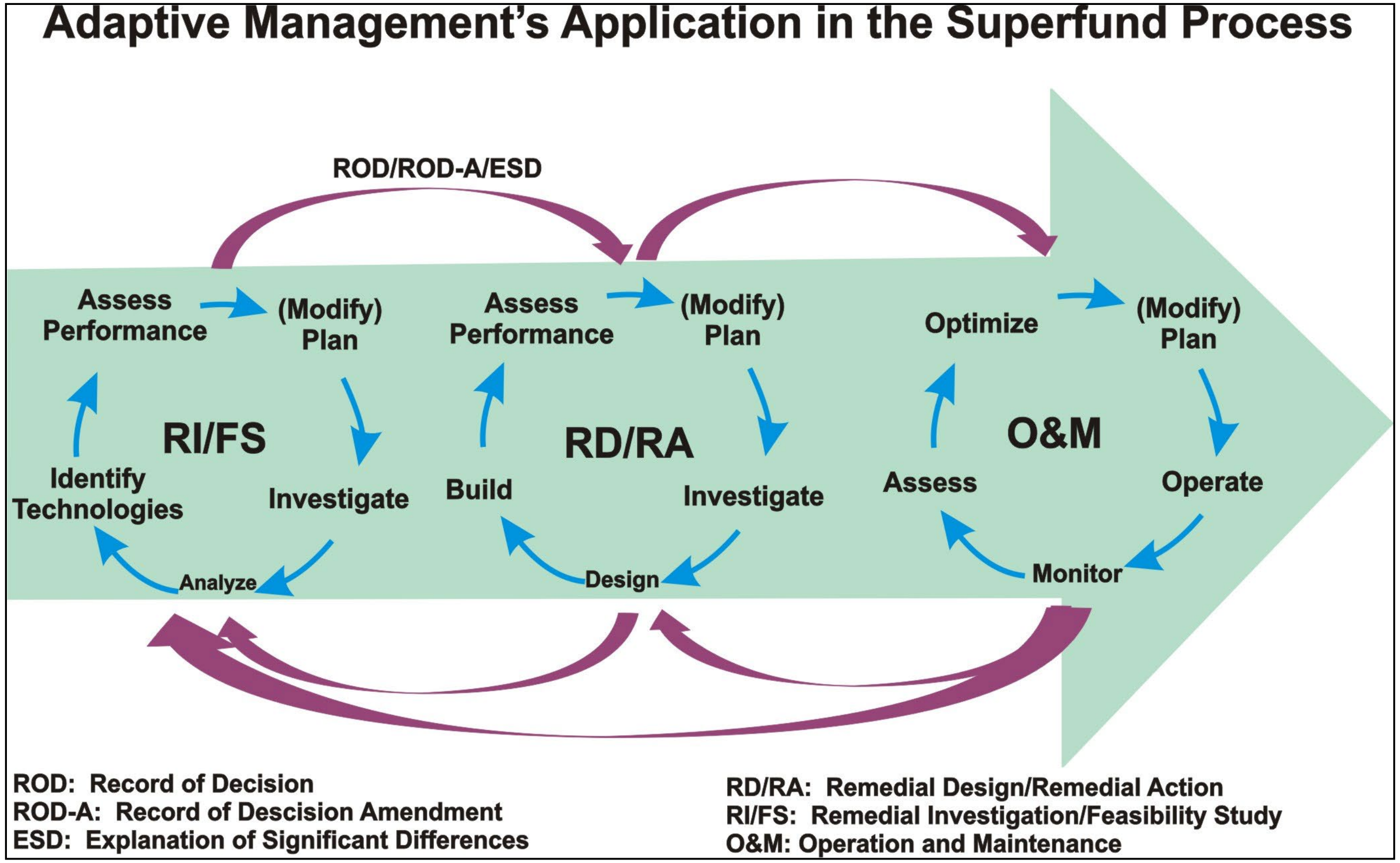
Table 4-1. Typical observations during process monitoring

Data Type	Scenario	Potential Implication
Water Level	Water levels at nearby monitoring wells (e.g., 10 ft) show a significant increase with very little fluid injected into the injection well location	This type of result may indicate a connection or preferential pathway. Be aware of the potential for daylighting and for amendment distribution challenges.
Pressure	Injection pressures are higher than expected.	Tight soils or link to section 3.6.1.2 biofouling may be causing blockage. High pressures may result in fracturing or daylighting.
Pressure	Injection pressures suddenly drop and flow rate increases.	A preferential pathway, link to section 3.6.1 fracture, or utility corridor may have been intercepted or an injection pressure fracture may have been created.
Physical Parameters	Conductivity, temperature, turbidity, or other indicator parameter of amendment (e.g., TOC, or color) is observed at a nearby monitoring well (e.g., 10 ft) at a lower than planned injection volume.	This type of result may indicate a connection or preferential pathway between wells. It may also indicate a higher K area of the site, resulting in a larger than anticipated fractured flow.

Chapter 5: Regulatory Perspectives

Adaptive Regulatory Process

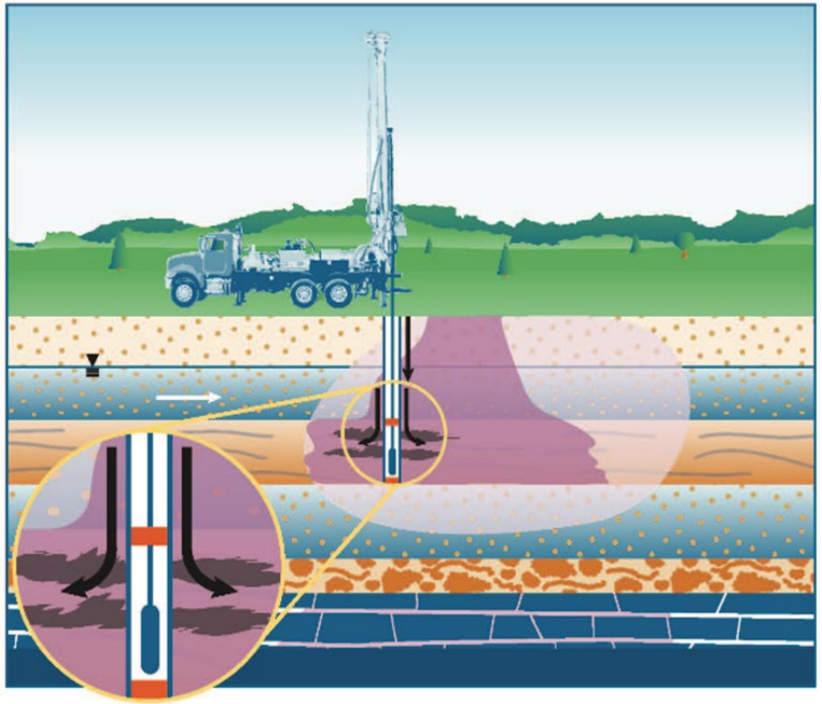


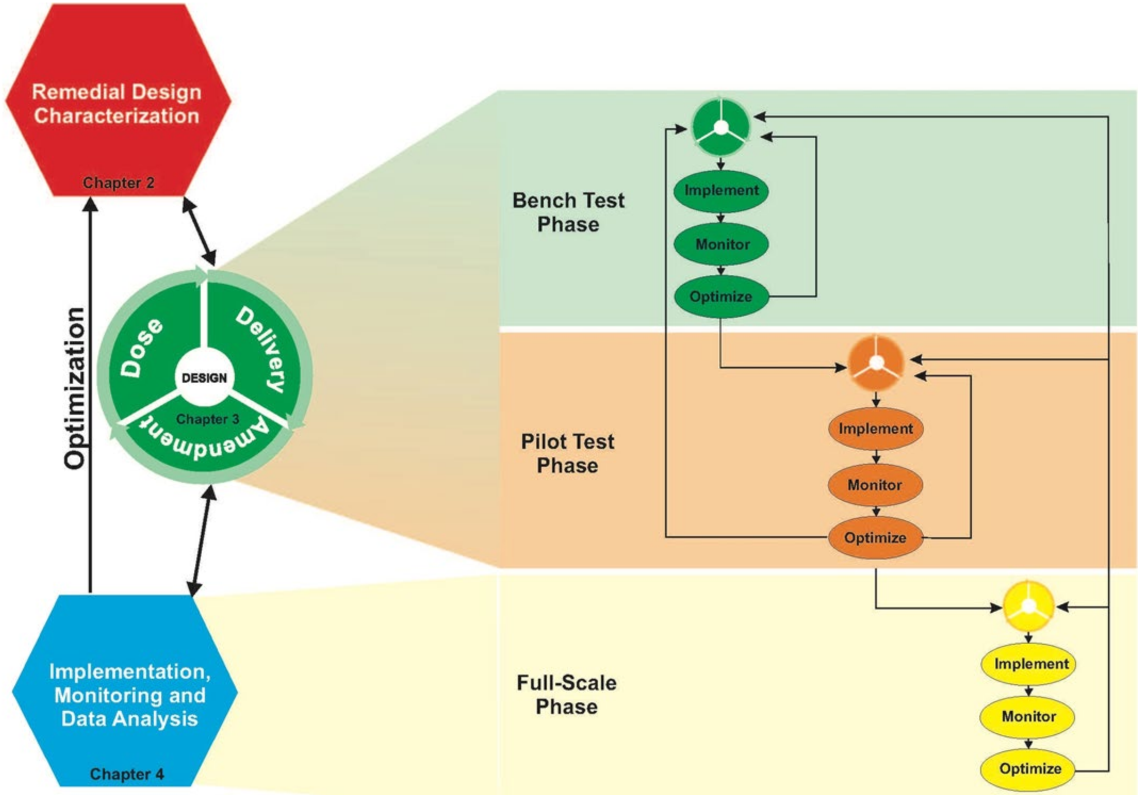

Adaptive Management's Application in the Superfund Process

ROD: Record of Decision
ROD-A: Record of Descision Amendment
ESD: Explanation of Significant Differences

RD/RA: Remedial Design/Remedial Action
RI/FS: Remedial Investigation/Feasibility Study
O&M: Operation and Maintenance

A Powerful Remediation Design Tool for 2020





Remedial Design Characterization
Chapter 2

Optimization

Dose
Delivery
Amendment
DESIGN
Chapter 3

Implementation, Monitoring and Data Analysis
Chapter 4

Bench Test Phase
Implement
Monitor
Optimize

Pilot Test Phase
Implement
Monitor
Optimize

Full-Scale Phase
Implement
Monitor
Optimize

Thank You!

Stay Updated on ITRC's Activities

itrcweb.org

facebook.com/itrcweb

@ITRCWEB

linkedin.com/
company/itrc