Welcome to ITRC's Internet Training: *"Permeable Reactive Barriers for Chlorinated Solvent, Inorganic, and Radionuclide Contamination"*

"Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents"

Prepared for
Air Force Research Lab/Environics Directorate (AL/EQ), Tyndall AFB, Florida
by
BATTELLE, Columbus, Ohio

"Regulatory Guidance for Permeable Barrier Walls Designed to Remediate Chlorinated Solvents"

&

"Regulatory Guidance For Permeable Reactive Barriers Designed to Remediate Inorganic and Radionuclide Contamination"

by
Permeable Reactive Barrier Wall Team of the ITRC

www.itrcweb.org

1

This training is designed to introduce state regulators, environmental consultants, site owners and community stakeholders to three documents created by the ITRC's Permeable Reactive Barrier Walls Technical Team and the Remediation Technologies Development Forum (RTDF) Bioremediation Consortium titled, "Regulatory Guidance for Permeable Barrier Walls Designed to Remediate Chlorinated Solvents", "Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Inorganic and Radionuclide Contamination" & "Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents". The training focuses on the basic information one needs to determine and document the conditions necessary to effectively apply a permeable reactive barrier to a contaminated zone to be an effective part of remediating chlorinated solvents, radionuclides and other inorganic compounds in ground water. It provides a framework, that is, how to think about permeable reactive barriers based on science. The information contained in this manual and presentation is based on research activities of the RTDF and from experience and knowledge of the participating members.

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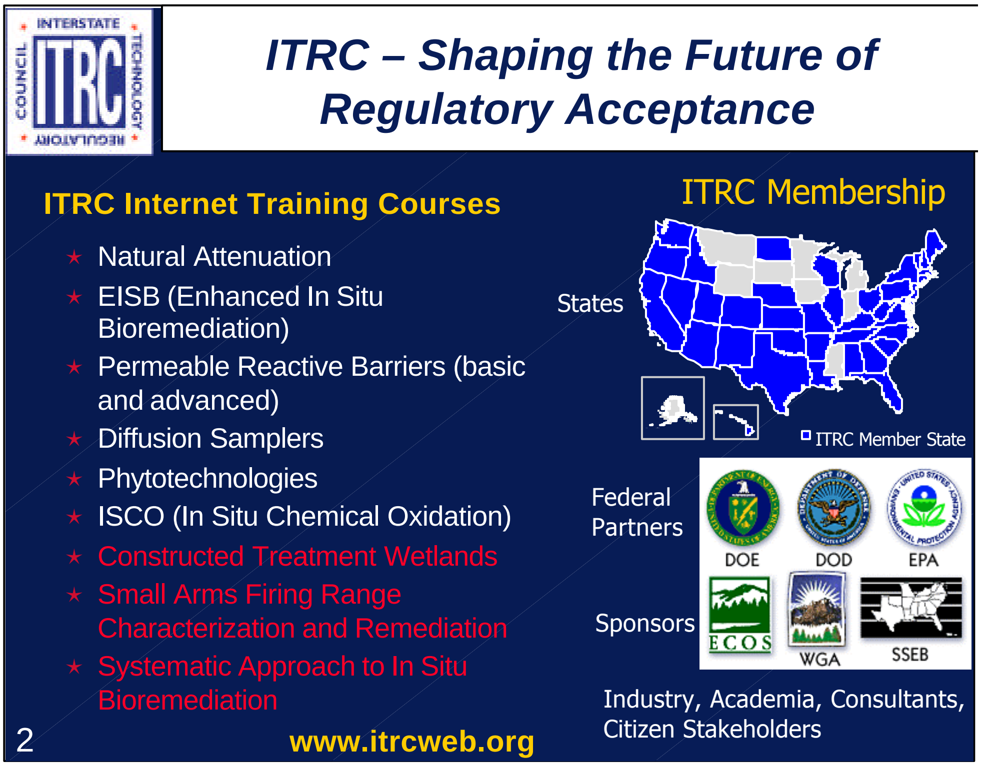
ITRC – Interstate Technology and Regulatory Council (www.itrcweb.org)

EPA-TIO – Environmental Protection Agency – Technology Innovation Office (www.clu-in.org)

ITRC Course Moderator:

Mary Yelken (Western Governors' Association/ITRC – myelken@westgov.org)



The bulleted items are a list of ITRC Internet Training topics – go to www.itrcweb.org and click on "internet training" for details.

The **Interstate Technology and Regulatory Council (ITRC)** is a state-led coalition of regulators, industry experts, citizen stakeholders, academia, and federal partners that work to achieve regulatory acceptance of environmental technologies. ITRC consists of 40 states (and the District of Columbia) that work to break down barriers and reduce compliance costs, making it easier to use new technologies and helping states maximize resources. ITRC brings together a diverse mix of environmental experts and stakeholders from both the public and private sectors to broaden and deepen technical knowledge and streamline the regulation of environmental technologies. Together, we're building the environmental community's ability to expedite quality decision-making while protecting human health and the environment. With our network approaching 6,000 people from all aspects of the environmental community, ITRC is a unique catalyst for dialogue between regulators and the regulated community.

ITRC originated in 1995 from a previous initiative by the Western Governors' Association (WGA). In January 1999, it affiliated with the Environmental Research Institute of the States, ERIS is a 501(c)3 nonprofit educational subsidiary of the Environmental Council of States (ECOS). ITRC receives regional support from WGA and the Southern States Energy Board (SSEB) and financial support from the U.S. Department of Energy, the U.S. Department of Defense, and the U.S. Environmental Protection Agency.

To access a list of ITRC State Point of Contacts (POCs) and general ITRC information go to www.itrcweb.org.

Meet the Instructors

★ **Matthew Turner**
- NJ Dept. of Environmental Protection
- 401 E. State St.
- Trenton, NJ, 08625
- T 609-984-1742
- F 609-633-1454
- mturner@dep.state.nj.us

★ **Arun Gavaskar**
- Battelle
- 505 King Ave.
- Columbus Ohio 43201
- T 614-424-3403
- F 614-424-3667
- gavaskar@battelle.org

★ **Scott Warner**
- Geomatrix Consultants, Inc.
- 2101 Webster St, 12th Fl
- Oakland, Ca 94612
- T 510-663-4269
- F510-663-4141
- swarner@geomatrix.com

3

Matthew Turner has a B.S. in Biology and a M.S. in Environmental Science. With 15 years experience in the environmental field, he is currently employed by the New Jersey Department of Environmental Protection as a Case Manager in the Site Remediation Program. He is a member of the Interstate Technology and Regulatory Council Workgroup where he has served as the leader of the Permeable Barrier Wall Subgroup since 1997. He is also a participant in the Remediation Technology Development Forum's Action Team on Permeable Reactive Barriers.

Scott Warner is a Principal Hydrogeologist at Geomatrix Consultants, Inc. with 14 years experience and expertise in hydrogeology, geochemistry, and innovative soil and groundwater treatment technologies. He has B.S. in engineering geology from U.C.L.A. and M.S. in geology from Indiana University, Bloomington. Mr. Warner has provided consultation to the U.S. Department of Energy, the U.S. Department of Defense, the U.S. Environmental Protection Agency, and many private companies on innovative remediation technologies, including the use of bioremediation, permeable reactive barriers, and related technologies. He has also provided expert witness work with respect to litigation involving environmental remediation and geochemistry. He also leads Geomatrix focus groups on VOC/DNAPL remediation, and arsenic in groundwater. Mr. Warner is a steering committee member of the Remediation Technologies Development Forum, Permeable Barriers Subgroup, and is a lead developer and instructor for the USEPA-sponsored permeable reactive barriers short course.

Arun Gavaskar is a Research Leader/Group Leader in the Environmental Restoration Department at Battelle, Columbus, Ohio. He has a background in chemical engineering and environmental technology, and has worked for thirteen years in the remediation and industrial pollution prevention areas. His current research interests include the remediation of a variety of groundwater, soil, and sediment contaminants, namely, DNAPL and dissolved-phase chlorinated solvents, heavy metals, and PCBs/dioxins. He also co-chaired the Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds at Monterey, California in May 2000.

Permeable Reactive Barriers for Chlorinated Solvent, Inorganic, and Radionuclide Contamination

Presentation Overview

- Overview of PRB Tech.
- PRB Application Methodology
  - Conceptual Design
  - Site Characterization
  - Treatability Testing
- Questions and answers
- PRB Application Methodology (cont.)
  - PRB Design
  - Emplacement & Permitting
  - Monitoring
- Questions and answers
- Links to additional resources
- Your feedback

Logistical Reminders

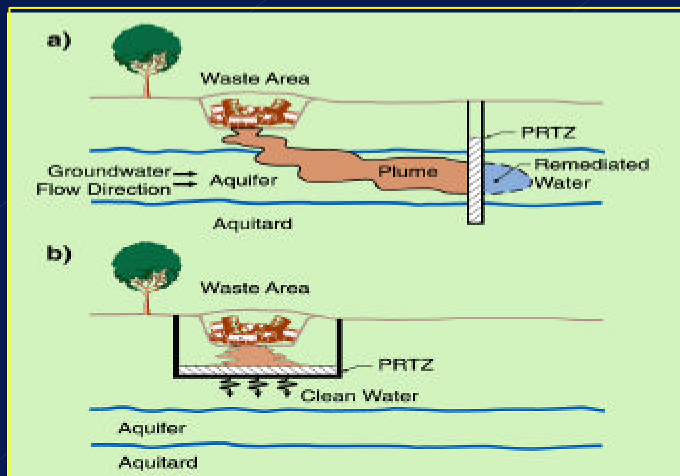
- Phone Audience
  - Keep phone on mute
  - * 6 to mute your phone and again to un-mute
  - Do NOT put call on hold
- Simulcast Audience
  - Use ? at top of each slide to submit questions

No Associated Notes

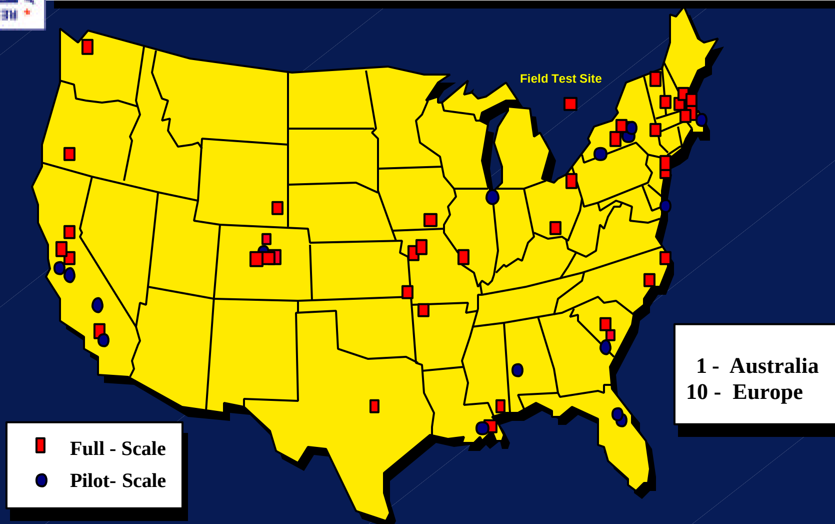
ITRC Regulatory Documents

- ITRC Documents can:
  - **Provide Information on PRB deployment**
  - **Identifies regulatory & stakeholder issues**
  - **Provides technical & regulatory & design guidance**
  - **Builds technical and regulatory consensus**
  - **Streamlines regulatory approval process**
  - **Educates stakeholders, regulators, technology implementers**

What Is A Permeable Reactive Barrier?

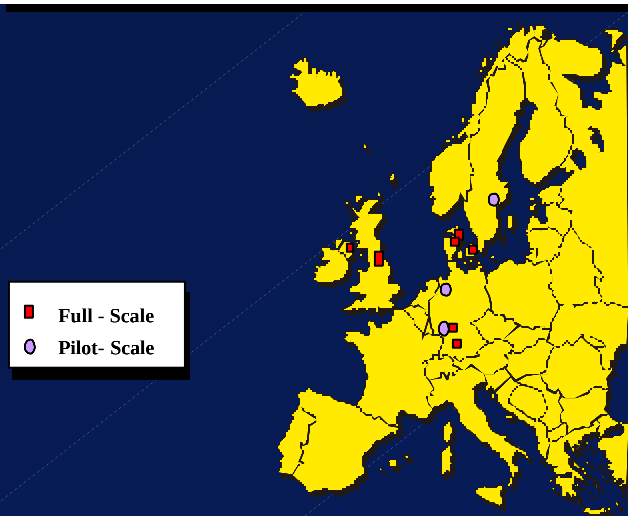


Field Installations



enviro**metal** technologies inc.

European Field Installations



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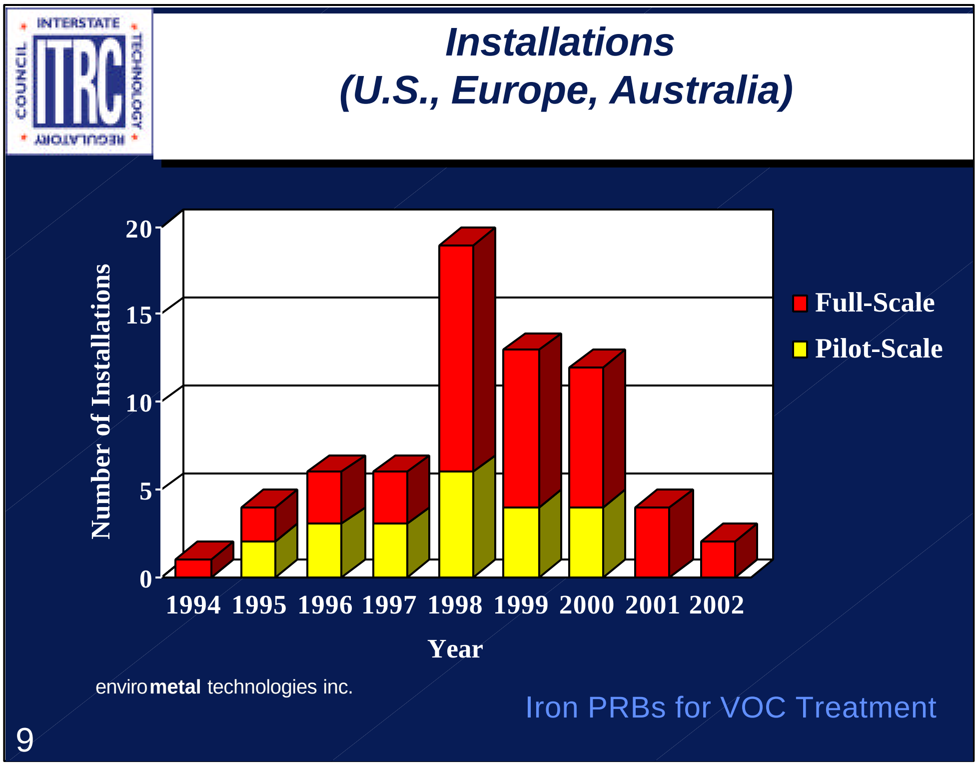
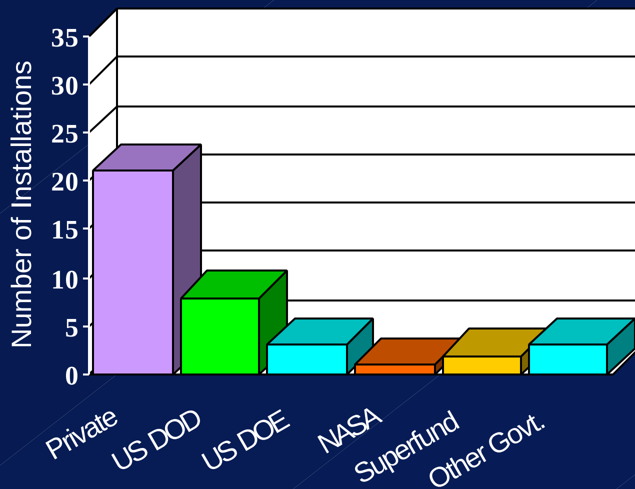
Iron PRBs for VOC Treatment



As the PRB Technology has become more accepted pilot studies are not as likely to be required. Although the number of PRB implementations has dropped in the last couple of years the length and tonnage of the systems has increased.

2002 data – as of March 2002

US Full Scale PRB Applications



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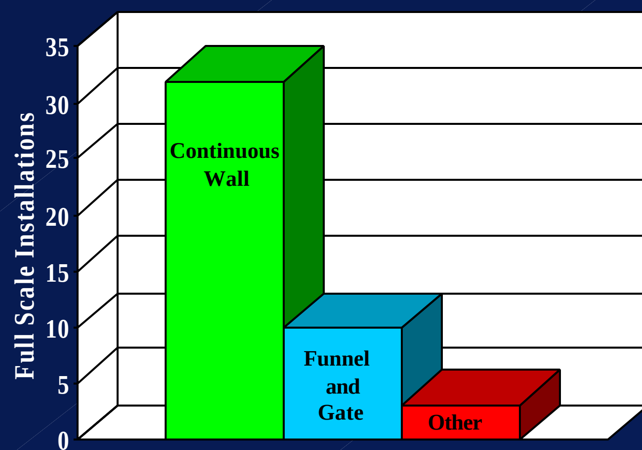
Full-Scale Systems



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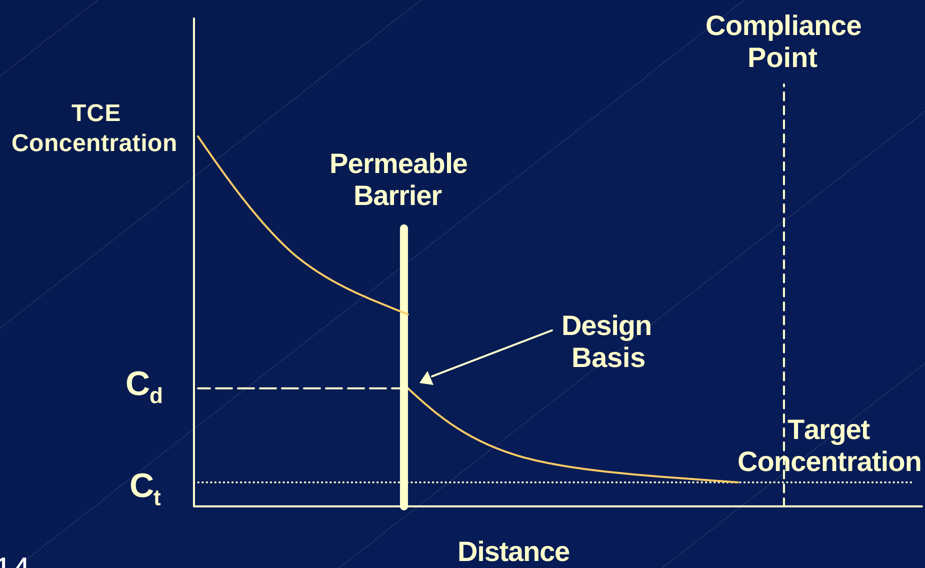
Advantages Of Permeable Barriers

- Treatment occurs in the subsurface
- Typical treatment is passive
- Potentially lower operation and maintenance costs
- Allows full economic use of a property
- No above ground structures or routine day-to-day labor attention required
- Monitoring can be focused

Treatment Mechanisms

- pH Control
- Chemical Precipitation
- Oxidation-Reduction Reactions
- Zero-Valent Metal Induced Dehalogenation
- Biological Degradation Reactions
- Sorption Reactions

Synergy with other Alternatives Example - Natural Degradation



Common Terminology

- **Treatment Matrix / Reactive Media-**
  - zone of material that promotes treatment
- **Hydraulic control system-**
  - routes affected groundwater through the treatment zone
  - prevents migration around treatment zone
  - provides the affected groundwater with sufficient residence time in the treatment zone

Reactive Media Selection Guidance

Treatment Material and Treatable Contaminants		
Treatment Material	**Target Contaminants**	**Status**
Zero-Valent Iron	Halocarbons, Reducible metals	In Practice
Reduced Metals	Halocarbons, Reducible Metals	Field Demonstration
Metals Couples	Halocarbons	Field Demonstration
Limestone	Metals, Acid Water	In Practice
Soptive Agents	Metals, Organics	Field Demonstration, In Practice
Reducing Agents	Reducible Metals, Organics	Field Demonstration, In Practice
Biological Electron Acceptors	Petroleum Hydrocarbons	In Practice, Field Demo

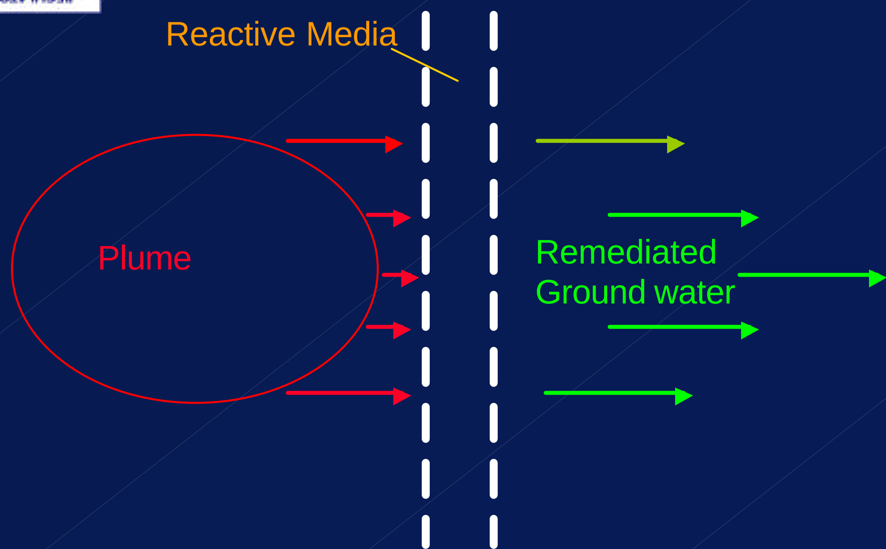
Permeable Reactive Barrier Composed of Fe(0)

Journal of Environmental Engineering, June 1998

Contaminants Treated by the Most Common Reactive Medium -- Iron

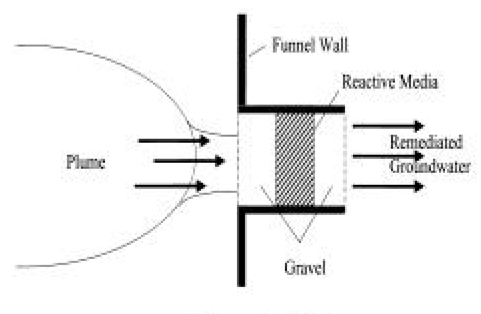
- **Inorganics:**
  - Cr, As, Hg, Cd, U, Tc
    Nitrate, Sulfate
- **Organics:**
  - Chlorinated Methanes (CT)
    Chlorinated Ethanes (TCA)
    Chlorinated Ethenes (TCE)
    Nitroaromatics (TNT, RDX)

PRB Configuration - Continuous Wall

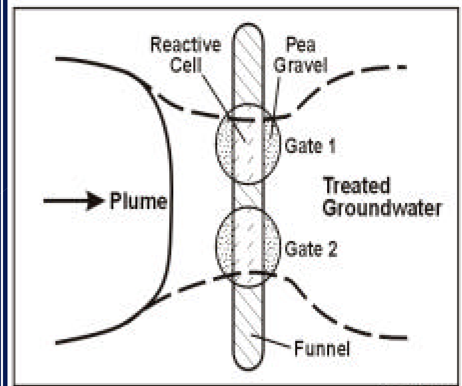


PRB Configuration

Funnel & Gate(s)



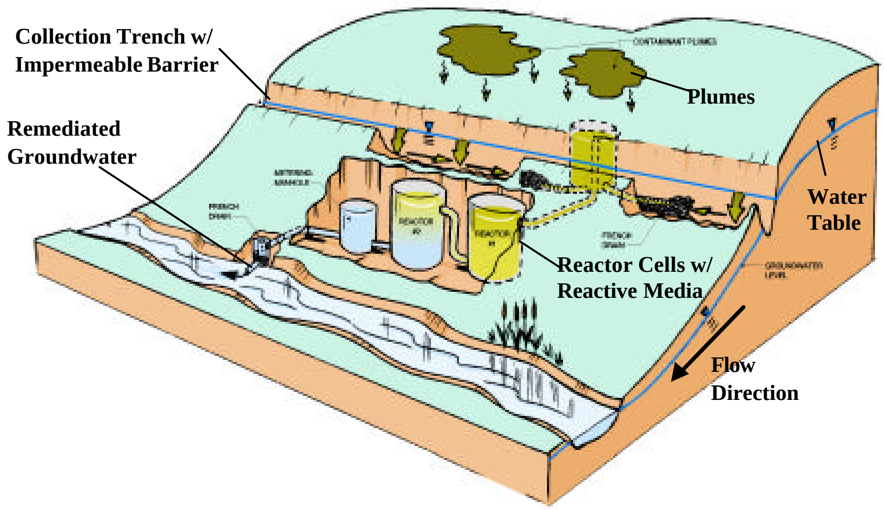
A. Funnel and Gate



Single Gate

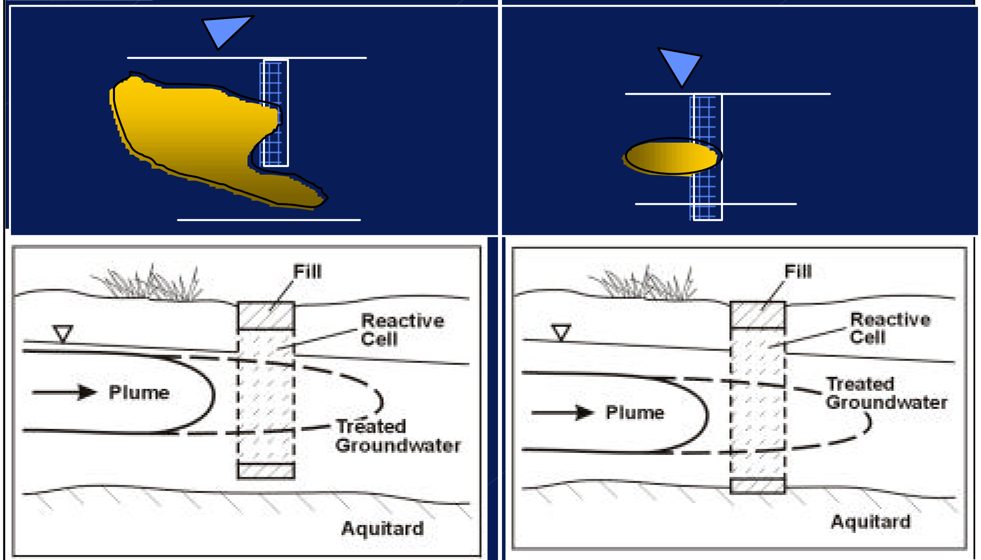
Multiple Gates

PRB Configuration - Passive Collection with Reactor Cells

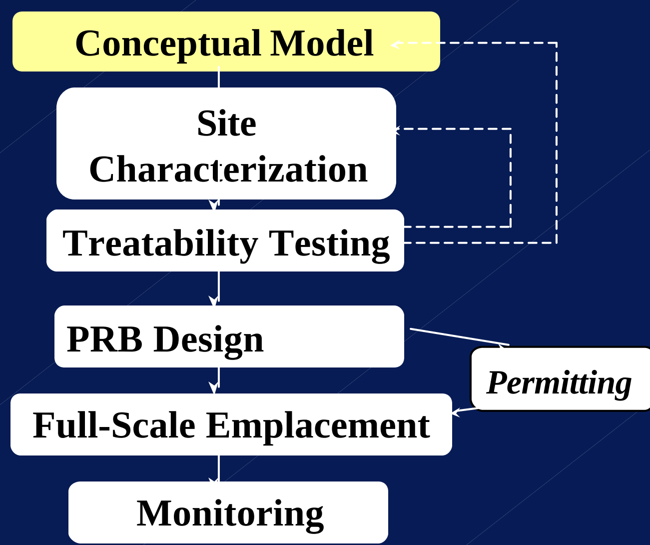


USDOE Rocky Flats Mound Site Plume, Tetra Tech EM, Inc. 1998

Barrier Hanging above Aquitard	Barrier Keyed to Aquitard



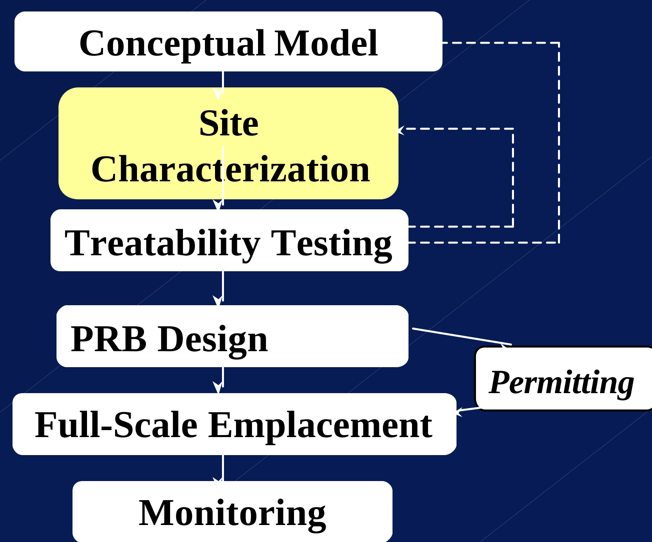
PRB Application Methodology



Conceptual Model (Using available information to determine if a PRB is suitable at a given site)

- The suitability of a contaminated site for PRB treatment is affected by the following factors:
  - Contaminant type
  - Plume size and distribution in 3 dimensions
  - Depth of aquitard
  - Geotechnical considerations
  - Constructibility
  - Groundwater flow characteristics
  - Ground water geochemistry

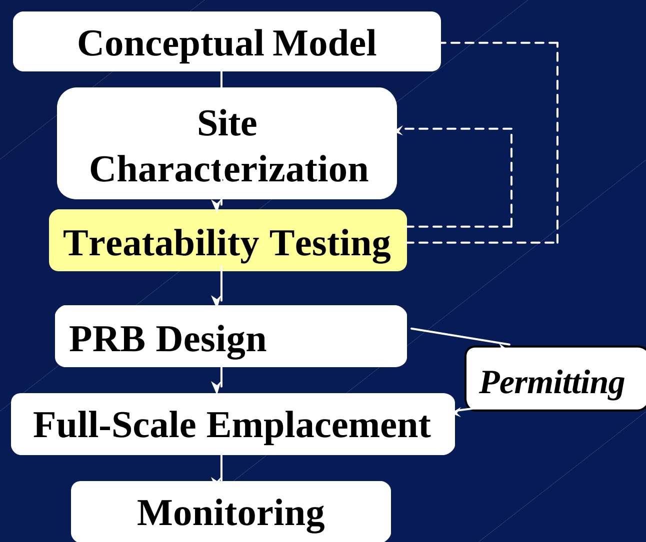
PRB Application Methodology



Site Characterization and Design Information

- Need to Know
  - **Composition of the Groundwater**
    - Types and concentrations of contaminants
    - Plume distribution
    - Geochemistry of groundwater (e.g., pH, DO, Ca, etc.)
  - **Hydrogeology of the Affected Aquifer**
    - Stratigraphy
    - Groundwater flow velocity and direction
- Used to
  - **Select the appropriate reactive media,**
  - **Conduct treatability tests, and**
  - **Design the thickness of the wall**

PRB Application Methodology



Treatability Testing for Reactive Media Selection and Design Information Gathering

- **Batch tests**
  - Quick screening of multiple reactive media
- **Column tests**
  - Final selection of reactive media
  - Obtaining design information (contaminant half-lives or reaction rates)

Degradation of CVOCs with Iron - A strong reducing agent (electron donor)

$$Fe^0 \longrightarrow Fe^{+2} + 2e^-$$

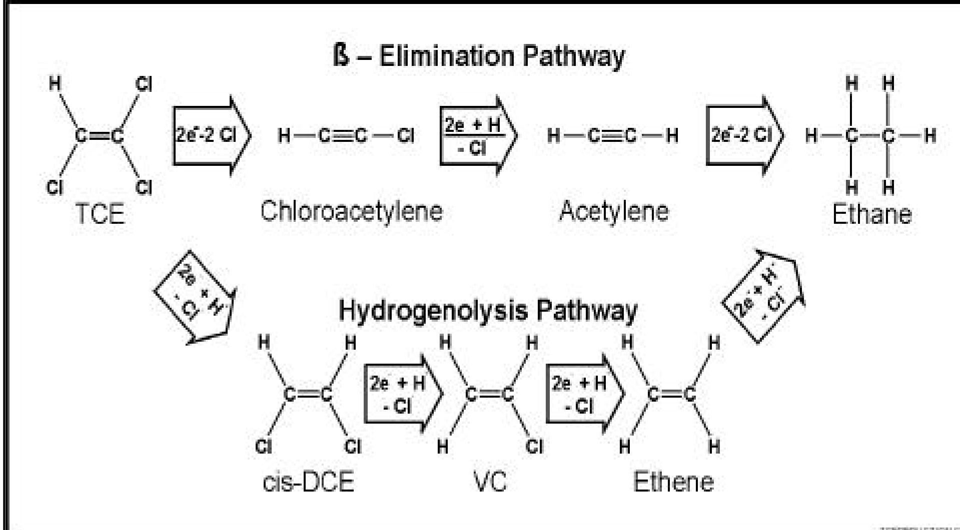
$$2H_2O \longrightarrow 2H^+ + 2OH^-$$

$$2H^+ + 2e^- \longrightarrow H_{2(g)}$$

$$X\text{-}Cl + H^+ + 2e^- \longrightarrow X\text{-}H + Cl^-$$

$$C_2HCl_3 + 3H^+ + 6e^- \longrightarrow C_2H_4 + 3Cl^-$$

Degradation of CVOCs with Iron - Beta-elimination (major pathway) and Hydrogenolysis (minor pathway)

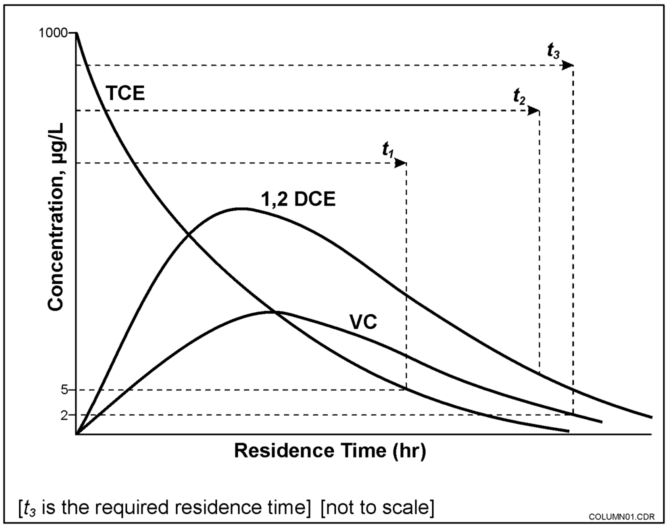


Roberts, A. L., et. al, 1996 Reductive Elimination of Chlorinated Ethylene by Zero-Valent Metals. Environmental Science and Technology,

Using column test results and site characterization information to determine PRB thickness

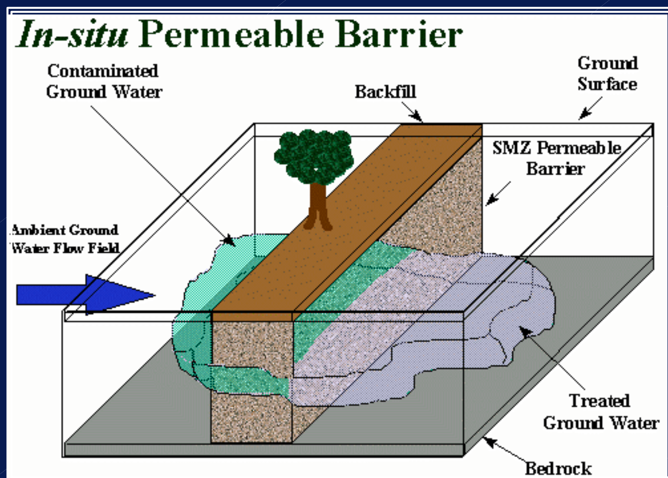
- Half-lives (or reaction rate constants) of the contaminants for a given reactive medium
  - Based on column tests
  - Used to determine residence time in the reactive medium to reduce contaminants to target levels
- The flow-through thickness of the reactive cell
  - Is determined by residence time requirement and estimated groundwater velocity through the reactive cell
  - Adjusted for groundwater temperatures and the potentially lower field bulk *density* of the reactive medium

Sizing the PRB for the Byproducts



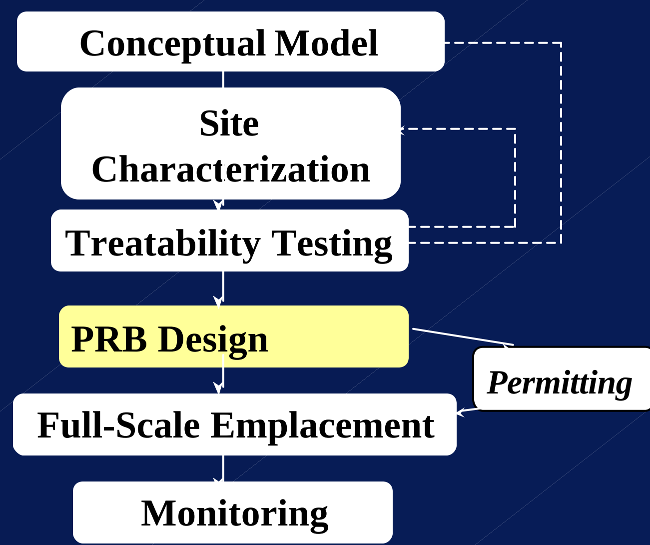
- Do column feasibility study.
- Compare results to MCLs.
- Select t_C for the last byproduct CoC to reach its MCL (e.g., t_3).

Question & Answers



Oregon Graduate Institute and New Mexico Tech

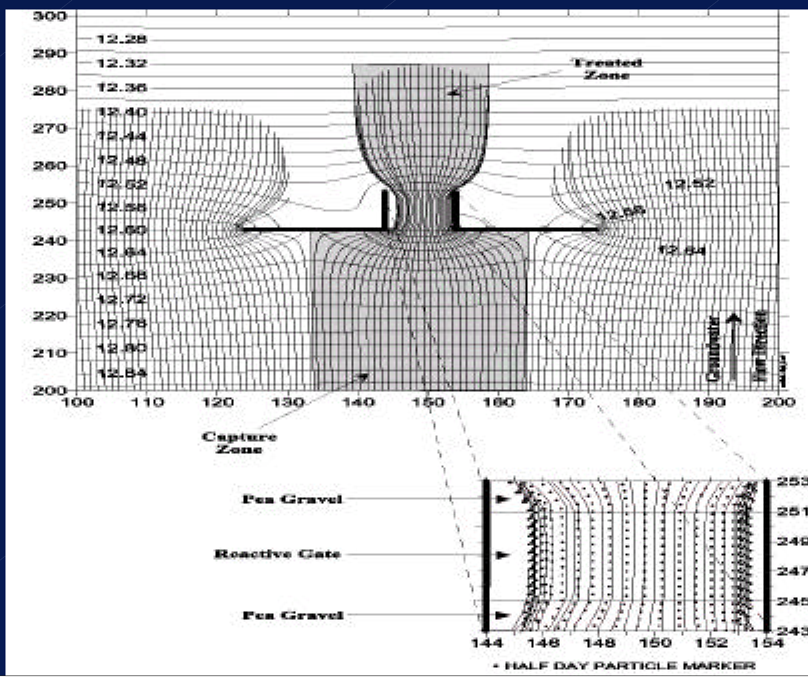
PRB Application Methodology



PRB Design Objectives and Role of Groundwater Modeling

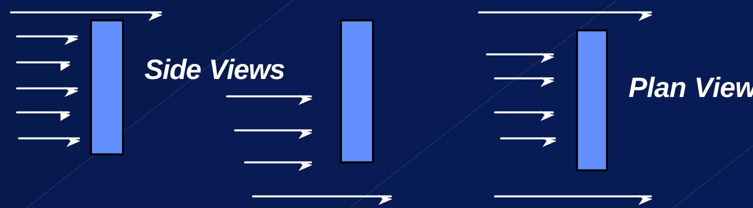
- Determine suitable location, orientation, and configuration of PRB
- Determine required thickness of PRB (for specified residence time)
- Determine required width of PRB (for specified capture zone)
- Plan monitoring well locations and frequencies

PRB Modeling Scenario

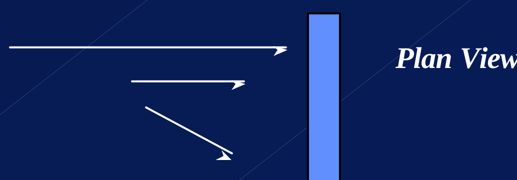


Addressing Groundwater Flow Uncertainties Through Modeling

- The plume could pass over, under, or around the PRB



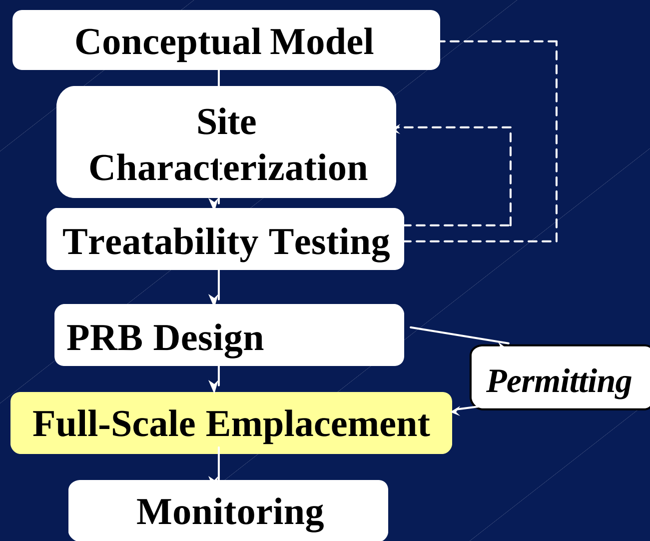
- Flux may be non-uniform creating variable velocity conditions and shifting hydraulic gradient directions



Addressing longevity issues
-- Geochemistry factors that may limit the life of the iron medium through loss of reactivity and/or plugging
(Requires long term monitoring of PRB)

- Oxygen concentration
  - high dissolved O_2, increased $Fe(OH)_3$ precipitation (rust)
  - $Fe^0 + 1.5O_2 + 6H^+ > Fe(OH)_3 + 1.5H_2$
- Carbonate alkalinity
  - precipitation of Fe, Ca, and Mg carbonates
- Sulfate concentration
  - possible sulfide formation on iron

PRB Application Methodology



PRB Emplacement Methods

- Conventional Excavation (Backhoe)
- Continuous Trencher
- Caisson
- Tremie Tube / Mandrel
- Deep Soil Mixing
- High Pressure Grouting (Jetting)
- Vertical Hydraulic Fracturing
- Geochemical Manipulation

PRB Full-Scale Systems

- Construction methods by end of 1999:
  - **20 continuous reactive walls**
    - **conventional excavation**
    - **continuous trencher**
    - **hydrofracturing**
    - **jetting**
  - **5 funnel and gate systems**
    - **slurry wall**
    - **sheet piling**
    - **HDPE impermeable wall**
  - **In Situ Reaction Vessels**

Conventional Excavation (Backhoe)

- Intersil Site, Sunnyvale, Ca., 1995
- 30 Feet Deep
- Trench Gate (backhoe) and slurry funnel wall

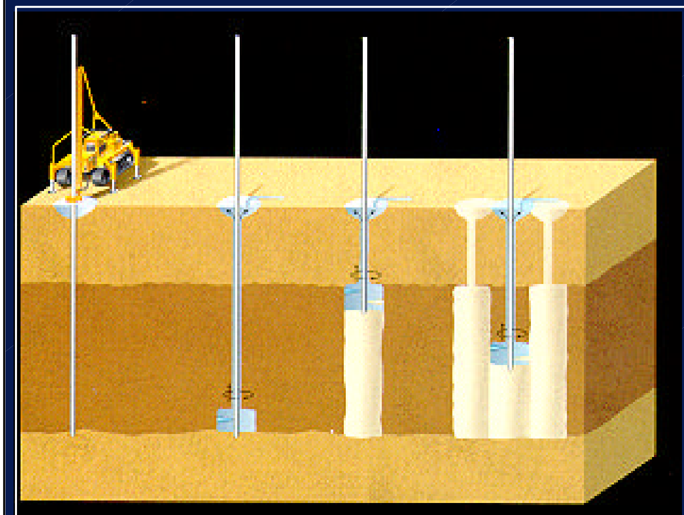
Caisson-Based Emplacement

- ★Dover Air Force Base, Dover, De., 1997
- ★Keyed 40 ft (bgs) into clay aquitard
- ★Sheet pile funnel & two 8-foot diameter caisson gates

Continuous Trencher (Elizabeth City Photo)

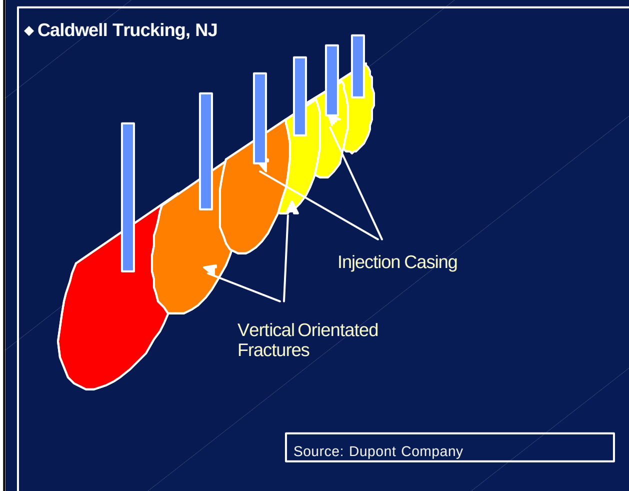
- Coast Guard site, Elizabeth City, NC 1996
- 25 feet deep wall, hanging wall configuration
- Continuous wall using continuous trencher

Schematic of Jetting Process



- Travis Air Force Base, Ca. 1999
- 50 feet deep; overlapping injection
- iron slurry injected at high pressure through nozzles

Hydraulic Fracturing



- Caldwell Trucking site, NJ
- vertical (overlapping) hydraulic fractures created
- fractures filled w/ iron slurry (3-4" thick barrier)

Tremie Tube / Mandrel

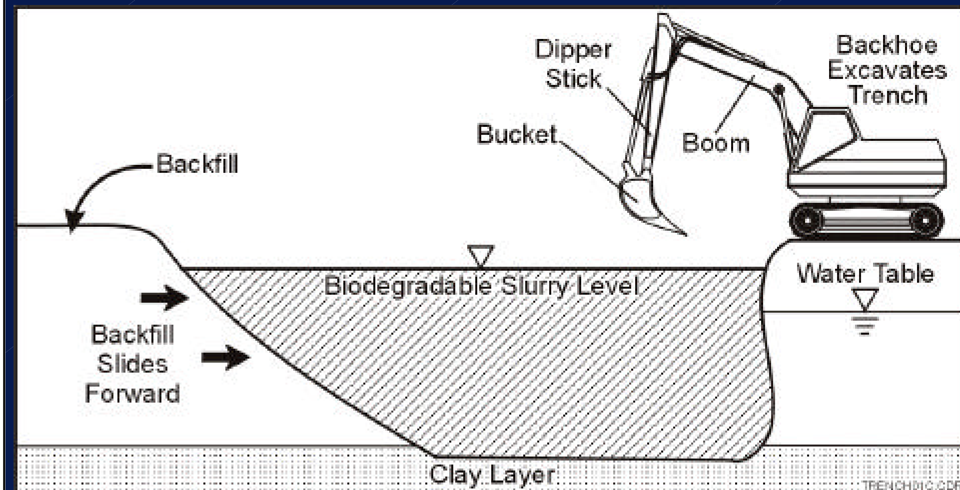
- Pilot Test at Cape Canaveral, Fl. 1997
- 43 feet deep, mandrel driven into ground at overlapping locations
- granular iron tremied into hole (4" barrier)

Deep Soil Mixing

- Iron slurry fed through hollow stem augers
- iron-soil mixture created in subsurface
- overlapping penetrations

Bioslurry

Pease Airforce Base, NH, 1999



PRB Economics

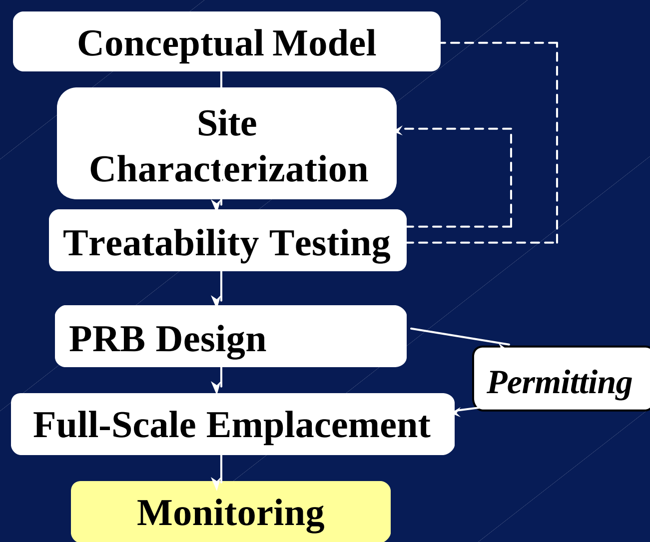
- Capital Investment
  - **Site Characterization/Treatability Test/Design**
  - **Reactive Medium and Construction**
- Annual O&M Costs
  - **Monitoring**
- Reactive Medium Maintenance Cost (may be required in the future for reactive medium replacement or regeneration)
  - **Frequency depends on longevity of reactive medium**
  - **Iron medium could last for several years**

PRB Economics

Cost-Benefit Analysis

- Present Value Analysis (PV)
  - **estimate long-term costs of PRB**
- Multiple cost scenarios for varying life expectancies
- Compare PV of PRB w/ PV of other options (rather than comparing Capitol Investment and O&M Costs)
- Evaluate Costs of PRB against Benefits
  - **No annual operating requirements**
  - **no above ground structures**
  - **no above ground waste streams**

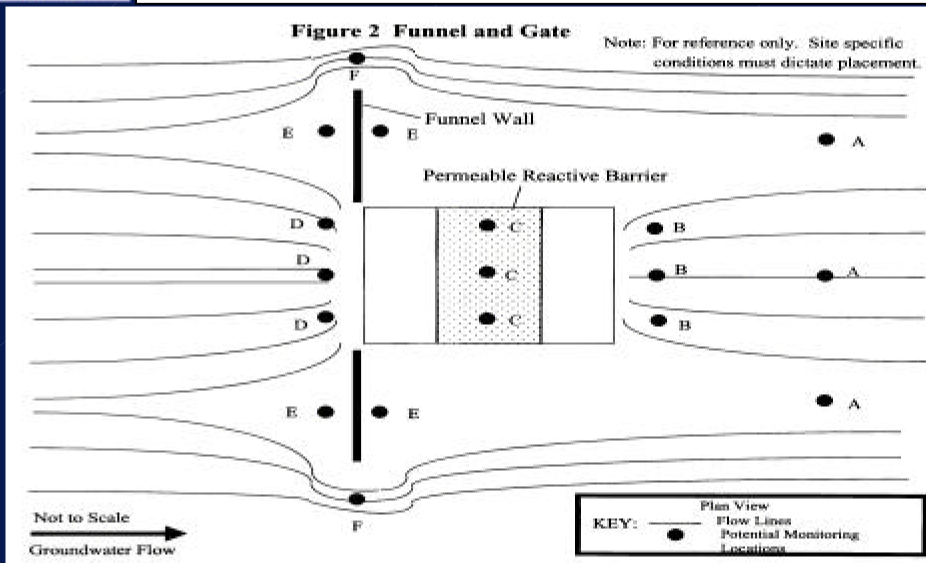
PRB Application Methodology



Monitoring

- ★ **Monitoring Comprised of Two Objectives**
  - **Compliance Monitoring - regulatory requirements, monitoring for compliance with standard**
  - **Performance Monitoring - ensure operation of wall as designed**
- ★ **Sampling Procedures**
  - **Low flow sampling method for collection of groundwater samples**
  - **Collection of representative samples where the retention time within the reactive media is not altered**

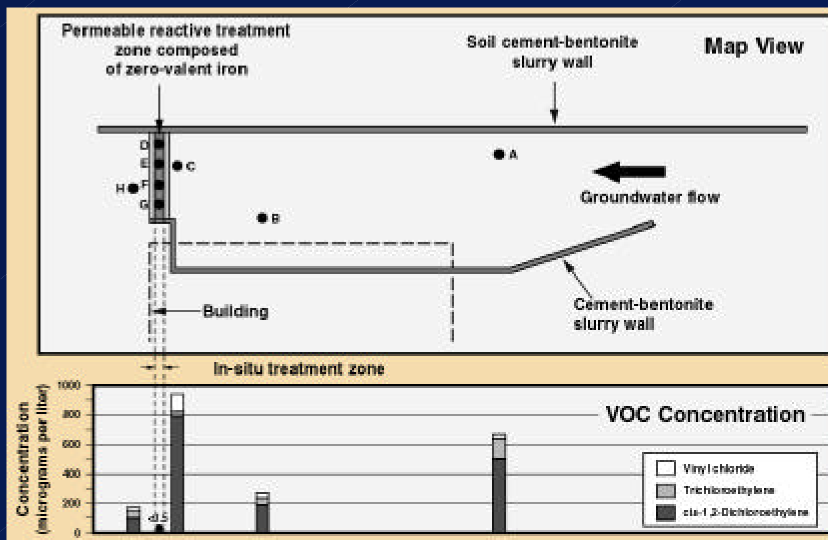
Hypothetical Monitoring Well Placement



Monitoring Frequency

- 1st quarter after installation - **Monthly**
- 1-2 years after installation - **Quarterly**
- Long term - **Quarterly** **(may be modified/decreased based on performance)**
- Post Closure - **TBD** **(based on closure method and parameters)**

Monitoring Results - Sunnyvale, Calif.



Permitting

- **NPDES** - triggered by excess generated groundwater
- **UIC** - triggered by reactive media placement
- **Air Quality** -triggered by emission generation during installation
- **RCRA Land Disposal Restrictions** (LDRs) - triggered by waste generated during site investigation or PRB installation
- **Other** site-specific permits may apply (i.e. wetlands)

“Thorough review of all site/state-specific permitting issues is necessary”

Maintenance and Closure

- Operation and Maintenance Plan
  - **Contingency Sampling Plan (necessary in the event the PRB fails to meet performance or compliance criteria)**
  - **Reactive media restoration or replacement**
- Closure plan
  - **Address whether the wall will remain in place or be removed after remediation goals have been met**

Stakeholder Issues

- Long periods for treatment
- Wall performance, & effectiveness
- Reactive material disposal
- Land access and deed restrictions
- Radionuclide concentration

Summary and Lessons Learned

Technical Presentation Wrap-up w/ Q&A

- A PRB is a cost-effective long-term viable alternative for treating contaminants (VOCs and metals) in situ (compared to pump and treat and other active remedies)
- The chemistry of treating VOCs using iron is well known
- PRBs are being installed to depths approaching 120 feet
- “Failures” in PRB performance have been due generally to failure of the hydraulic system: e.g., incomplete plume capture, residence time not maintained; incomplete site characterization

Links to additional resources: http://www.clu-in.org/conf/itrc/prb/resource.htm

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

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

•helping regulators build their knowledge base and raise their confidence about new environmental technologies

•helping regulators save time and money when evaluating environmental technologies

•guiding technology developers in the collection of performance data to satisfy the requirements of multiple states

•helping technology vendors avoid the time and expense of conducting duplicative and costly demonstrations

•providing a reliable network among members of the environmental community to focus on innovative environmental technologies

•**How you can get involved in ITRC:**

•Join a team – with just 10% of your time you can have a positive impact on the regulatory process

•Sponsor ITRC's technical teams and other activities

•Be an official state member by appointing a POC (Point of Contact) to the State Engagement Team

•Use our products and attend our training courses

•Submit proposals for new technical teams and projects

•Be part of our annual conference where you can learn the most up-to-date information about regulatory issues surrounding innovative technologies