Permeable Reactive Barriers - Lessons Learned: NEWMOA Waste Site Cleanup Program Webinar

Web Presentation to the
Northeast Waste Management
Officials' Association



presented by

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Today's Presenters

- Scott D. Warner, **PG, CHG, CEG** - Principal
  - Hydrogeologist, Remediation Consultant, >25 Years Experience
  - MS Geology – Indiana University, BS Engineering Geology – UCLA
  - PRB experience since 1991including:
    - First Commercial PRB (1994) (ZVI for Chlorinated VOCs)
    - 2011 NGWA Outstanding Project Award for PRB at West Valley NY (Zeolite for removing Sr-90 at former nuclear site)
  - ITRC and RTDF Technical Guidance Documents on PRBs

- Mark Nielsen, **PE** – Principal
  - Environmental and Civil Engineer, > 25 Years Experience
  - MS Engineering (Water) – Princeton, BS Engineering, Drexel University
    - Project Director for PRB at a former zinc smelter site in the Northeast US
  - ITRC Technical Guidance Documents –
    - Project Risk Management for Site Remediation

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Today's Presentation

- Defining the Permeable Reactive Barrier
- PRB History
- PRB Design Elements
- PRB Applications –
  - Contaminants and Treatment Materials
- PRB Treatment Reactions
- Performance and Longevity
- Lessons (throughout the presentation)
- Case Study

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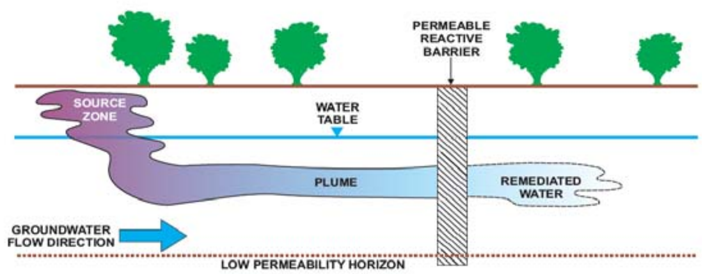
Defining the Permeable Reactive Barrier



After Warner, 2014(in press)

Definition:

An In Situ Permeable Treatment Zone Designed to Intercept and Remediate a Contaminant Plume through physical, chemical, or biological processes (ITRC, 2011)

- ***Hydraulically passive and does not require power to operate***
- ***Minimal adverse long-term impact on the environment***

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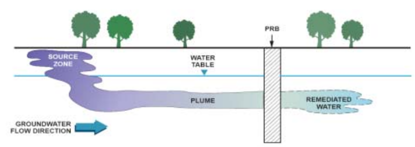
Key Contributors to PRB Development (partial list)

- University of Waterloo *(et. al.)*
- University at Buffalo (UB)
- Oregon Graduate Institute
  (now Oregon Health Sciences Univ.)
- US EPA Nat. Risk Management Lab
- Air Force Center for Environmental Excellence (AFCEE)
- CL:AIRE (UK)
  Contaminated Land: Applications in Real Environments
- Queens University, Belfast
- RUBIN: German PRB Network
- CRC-CARE: Australia

➢250+ Full-scale Installations
  ➢North America, Europe, Japan, Australia

- Industry (e.g., solvents consortium – Univ. of Waterloo)
- Remediation Technology Development Forum (RTDF - US)
- Interstate Technology Regulatory Council (ITRC - US)
- US Department of Defense contractors
- Multiple Consulting Firms



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Some PRB Highlights (approximate dates)

- 1989 Initial Work on PRBs and Waterloo Pilot
- 1991-94 First Commercial Pilot Test & Installation
- 1995 RTDF Team Begins, ACS Symposium
- 1999-00 EPA sponsored 2-day courses across U.S.
- 2000-12 ITRC, Guidance documents/Web Courses
- 2006 First Dual Wall PRB (inorganics/organics)
- 2008 First Large Diameter Boring PRB Design
- 2010 First Full-Scale Zeolite PRB
- 2011 NGWA Award for Outstanding Remediation

Courses and presentations given throughout North America, Europe, Australia

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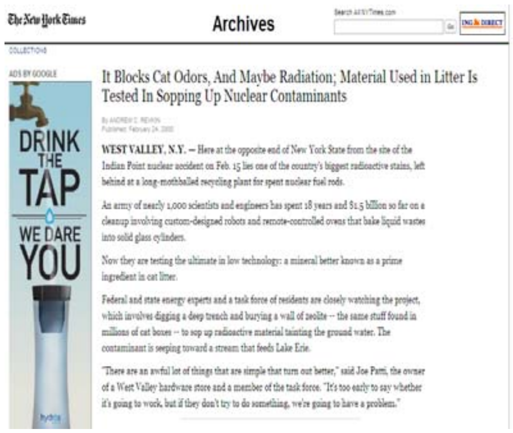
History in the News Media

Chlorinated Compounds – presented at Battelle in 1998



It Blocks Cat Odors, And Maybe Radiation; Material Used in Litter Is Tested In Sopping Up Nuclear Contaminants

WEST VALLEY, N.Y. -- Here at the opposite end of New York State from the site of the Indian Point nuclear accident on Feb. 15 lies one of the country's biggest radioactive stains, left behind at a long-mothballed recycling plant for spent nuclear fuel rods.

An army of nearly 1,000 scientists and engineers has spent 18 years and $1.5 billion so far on a cleanup involving custom-designed robots and remote-controlled ovens that bake liquid wastes into solid glass cylinders.

Now they are testing the ultimate in low technology: a mineral better known as a prime ingredient in cat litter.

Federal and state energy experts and a task force of residents are closely watching the project, which involves digging a deep trench and burying a wall of zeolite -- the same stuff found in millions of cat boxes -- to sop up radioactive material tainting the ground water. The contaminant is seeping toward a stream that feeds Lake Erie.

"There are an awful lot of things that are simple that turn out better," said Joe Patti, the owner of a West Valley hardware store and a member of the task force. "It's too early to say whether it's going to work, but if they don't try to do something, we're going to have a problem."

San Jose (California) Mercury News, May 1995

New York Times, 2000

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National Ground Water Association Outstanding Remediation Project 2011

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PRB Treatment for Contaminated Groundwater

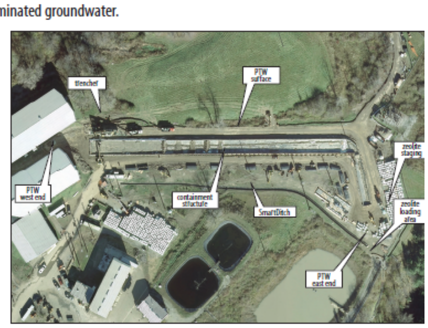
A former nuclear site in western New York helps validate why the Permeable Reactive Barrier is among the best techniques for treating contaminated groundwater.

BY SCOTT D. WARNER, CEG, CHG, M.SAME, DOUGLAS BABLITCH, P.E., AND RICHARD H. FRAPPA, PG

The Permeable Reactive Barrier (PRB) concept for treating contaminated ground water in situ is a lexicon in the area of ground water remediation. Using chiefly natural materials, PRB has developed a track record for being among the most sustainable and effective groundwater remediation methods since its formal introduction at a pilot test site in the early 1990s. Implementing these treatment materials within a hydraulically passive to semi-passive in situ treatment zone, PRB is consistent with a growing demand to use "green" or sustainable approaches.

THE PRB CONCEPT

The generally accepted definition of PRB, as modified from the Interstate Technology and Regulatory Council (2005) is:



This aerial photo shows the location of the 260-M-long PTW, which starts in the tight space between the

The Military Engineer, 2012

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National Ground Water Association Outstanding Remediation Project 2011

One-Pass Trencher used to install the 850-ft long PRB at
West Valley, New York
Courtesy, De Wind One Pass Trenching and ITRC

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Continuum of Remediation Technologies: Active to Passive

Technology Class

- **Source Removal and/or Treatment**
- **Interdiction & Active Remediation**
- **Enhanced Attenuation**
- **Monitored Natural Attenuation**

Technology Examples

- excavation
- *in situ* bioremediation
- *in situ* chemical destruction
- thermally enhanced removal
- pump and treat
- recirculation wells
- *in situ* bioremediation
- *in situ* bioremediation
- permeable reactive barrier
- phytoremediation
- permeable biotreatment system

(ITRC EACO-1, 2008)

Active → Passive

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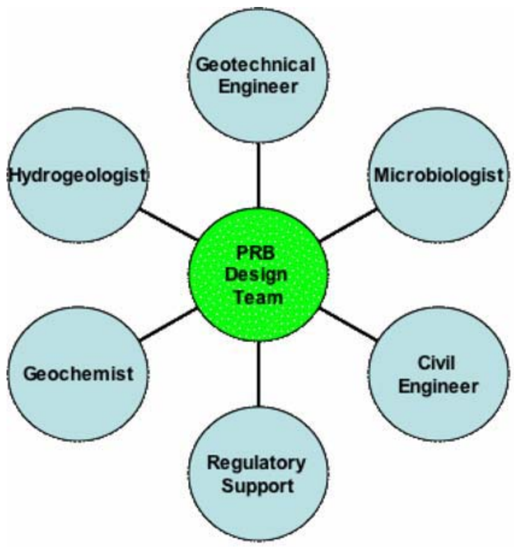
Designing the PRB – The Team



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Designing the PRB – Key Considerations and Lessons

- Define Realistic and Practical Remedial Objectives
- Establish Functional Requirements
- Focus on Site Characterization (hydraulic/chemical)
- Understand Dynamic Conditions (Temporal/Spatial)
- Understand Lessons Learned from other installations
- Design an Effective and Focused Monitoring program

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Key PRB Aspects and Applications

PRB Materials
- Zero-valent metals
- Metal Oxides and sulfides
- Clays-Zeolites (Aluminosilicates)
- Organic matter and microorganisms

Applications
- Trenches – Slurry Walls
- Caissons – Large Diameter Borings
- Pneumatic/Hydraulic Injection
- Soil Mixing – Electrokinetics
- Geochemical/Biochemical manipulation

Field of Use
- Industrial Sites (solvent spills)
- Mining tailings/ Seepage fronts
- Contaminated drainage/ storm water treatment
- Well field protection

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Treatment by PRB Applications

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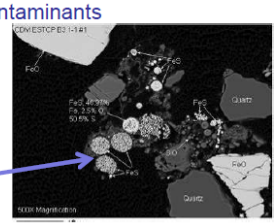
What Contaminants can be Treated?

INTERSTATE TECHNOLOGY REGULATORY COUNCIL ITRC

- PRBs have commonly been applied to:
  - Organics (e.g., solvents/fuels/creosote)
  - Perchlorate and energetics such Royal Demolition Explosive (RDX) or Trinitrotoluene (TNT)
  - Inorganics (e.g., radionuclides, metals, anions)

  See Table 4.1 in the PRB document for an extensive list of media and contaminants
- Future PRBs to treat emerging contaminants
- Unique monitoring methods may be required to document the treatment process
  - Monitoring for toxic intermediates
  - Mineralogy and passivation



Reactive iron sulfides, for example framboidal pyrite (Lebron *et al.*, 2010)

ITRC Guidance Document – 2011 (www.itrcweb.org

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Treatment by PRB Applications

COCs	ZVI	Biobarriers	Apatite	Zeolite	Slag	ZVI-carbon combinations	Organophilic clay
Chlorinated ethenes, ethanes	F[a]	F			L	F	
Chlorinated methanes, propanes						F	
Chlorinated pesticides						P	
Freons						L	
Nitrobenzene	P						
Benzene, toluene, ethylbenzene, and xylenes (BTEX)		F					
Polycyclic aromatic hydrocarbons (PAHs)							L
Energetics	P	F				P	
Perchlorate		F	F	L		L	
NAPL							F
Creosote							F
Cationic metals (e.g., Cu, Ni, Zn)	L	F	F		L	F	
Arsenic	F			L	F	F	
Chromium(VI)	F			L	L	F	
Uranium	F	P	F			T	
Strontium-90			F	F			
Selenium	L					L	
Phosphate					P		
Nitrate		F	F			F	
Ammonium				L			
Sulfate		F				L	
Methyl tertiary butyl ether (MTBE)		F					

[a] F = full-scale application, L = laboratory evaluation, P = pilot-scale application.

Table 4-1 in ITRC Guidance Document – 2011 (www.itrcweb.org)

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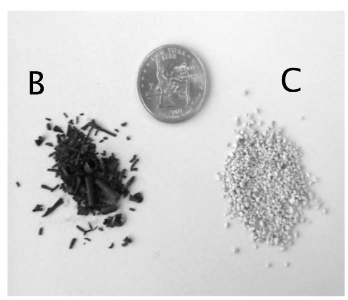
PRB Treatment Materials (examples)

A

B

C



D

(A) Compost, (B) ZVI, (C) Zeolite
(D) Granulated Bone Char

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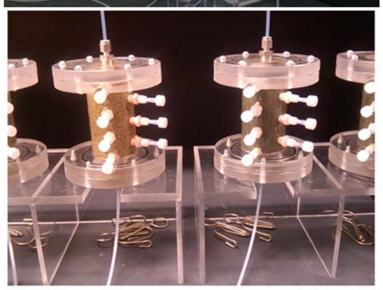
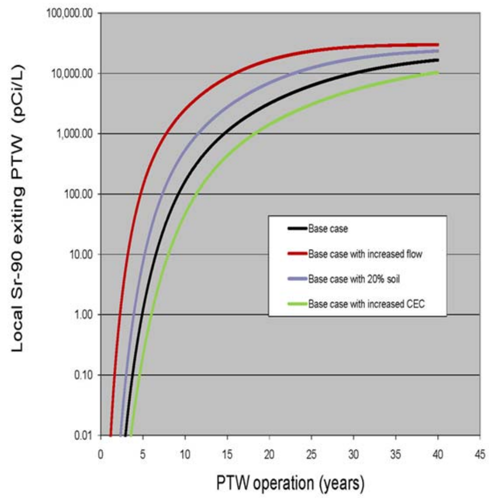
Treatability Studies as a Design Tool and Failure Reduction Method





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Example PRB Treatment Reactions

Dehalogenation by reduced iron

$$\mathbf{3Fe0 \rightarrow 3Fe^{2}+ + 6e^{-}}$$
$$Fe\ (s) + 2H20 \rightarrow Fe2+ + 2OH- + H2$$
$$C2HCl3 + 3H+ + 6e^{-} \rightarrow C2H4 + 3Cl^{-}$$
$$3Fe0 + C2HCl3 + 3H+ \rightarrow C2H4 + 3Fe2+ + 3Cl^{-}$$

Cr immobilization by reduced iron

$$CrO_4^{2-}(aq) + Fe0 + 8H+(aq) \rightarrow Fe^{3+} + Cr3+(aq) + 4H2O$$
$$(x)Cr3+(aq) + (1-x)Fe3+(aq) + 2H2O \rightarrow CrxFe(1-x)OOH(s) + 3H+(aq)$$

Sulfate reduction through biological respiration

$$C_6H_{12}O_6 + 3\ SO_4^{2}-(aq) \rightarrow 3HS- + 3H^+ + 6HCO_3(aq)$$
$$2CH_2O + SO_4^{2-} + 2H^+ \rightarrow H_2S + CO_2 + H_20$$
$$Me^{2+} + HS- \rightarrow MeS(s) + H+$$

Inorganic removal through ion exchange

$$Sr^{2+} + 2K^+(zeolite) \rightleftharpoons 2K^+ + Sr^{2+}(zeolite)$$

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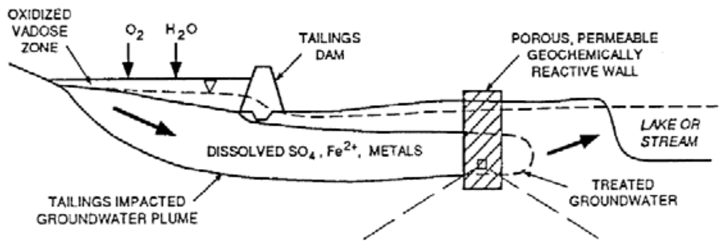
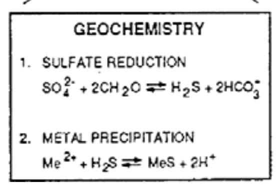
PRB – Tailings Seepage Concept



Treatment for Zn, Pb, Cu, U, As, SO4, AMD,

After Waybrant (2002) and including experience from Ludwig/Benner/ ITRC/Warner



The reduction of SO_4 produces H_2S, releases HCO_3-, and results in an increase in alkalinity and pH. The reaction releases ammonia and dissolved phosphate, which is utilized by the bacteria or released into the environment. Secondary treatment can be added to promote utilization of excess solutes.

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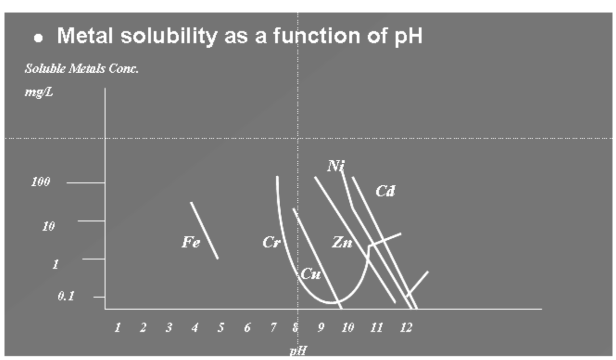
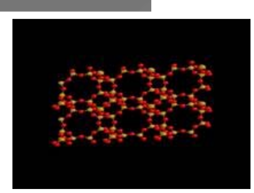
PRB and pH/Eh and Ion Exchange Control to Mitigate Metals/Inorganics



From ITRC-4

Zeolite-Clinoptilolite
(note ring structure)



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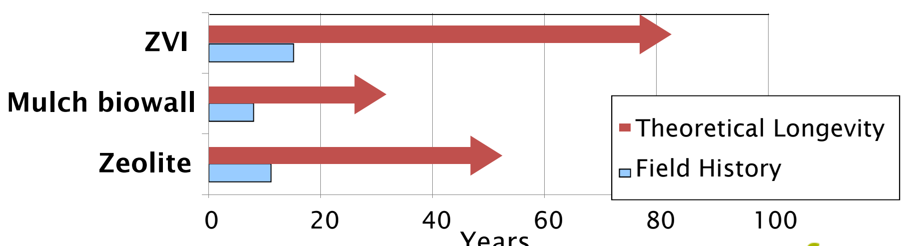
Question Break

Outcrop containing natural zeolite

Observed Longevity (ITRC, 2011)

- ZVI PRBs
  - Majority of PRBs still going strong after 15 years of field experience
- Mulch biowall
  - 8+ years of monitoring indicates mulch will last at least 10 to 15 years, but some require replenishment after 4 to 6 years
- Other emerging reactive media
  - Zeolite—11+ years
  - Apatite—varies
  - Slag—5+ years



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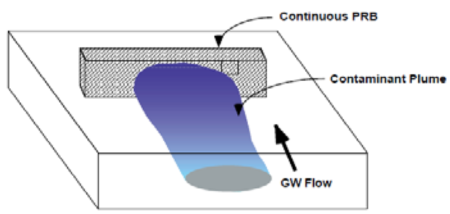
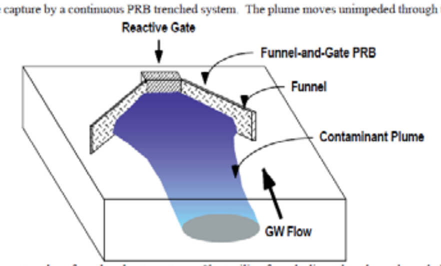
PRB Design Concepts

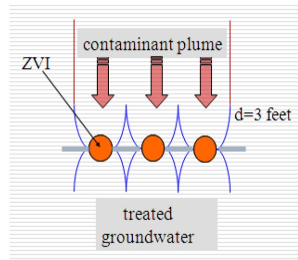


Plume capture by a continuous PRB trenched system. The plume moves unimpeded through the reactive zone.



Plume capture by a funnel-and-gate system. Sheet piling funnels direct the plume through the reactive gate.

Continuous Wall and Funnel & Gate
USEPA (RTDF), 1998



Large Diameter Permeable Cells
Aka Non-pumping Treatment Wells

Dual Wall PRB

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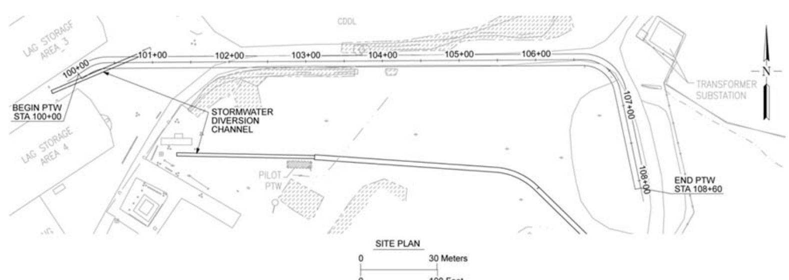
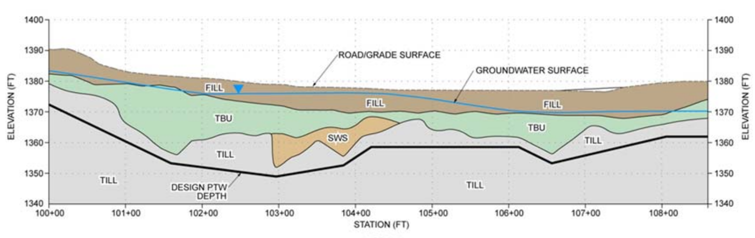
Geotechnical Characterization & Design





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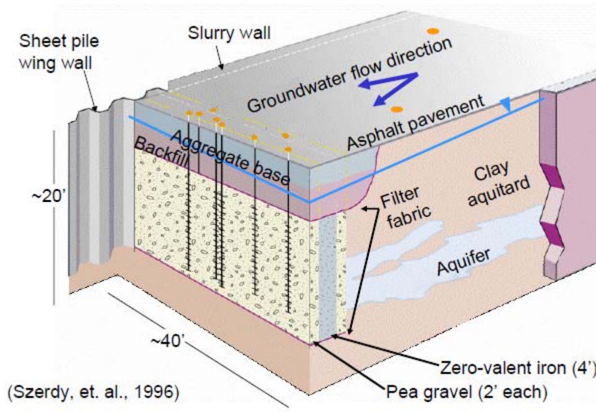
Conventional Shallow Design



(Szerdy, et. al., 1996)

Reference: Warner, et al., 1998 Jour Envir. Engineering

Innovative Designs including jetting, injection, soil mixing, large diameter borings are site/goal specific considerations

ITRC Guidance Document – 2011 (www.itrcweb.org)

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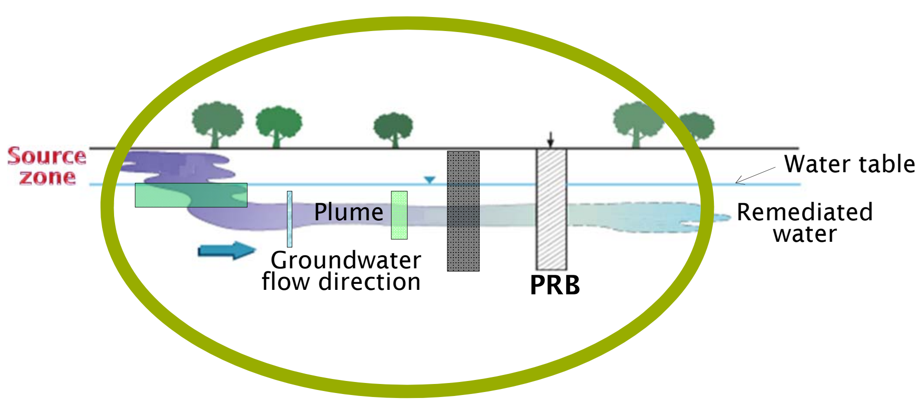
PRB Location
Control v. Containment



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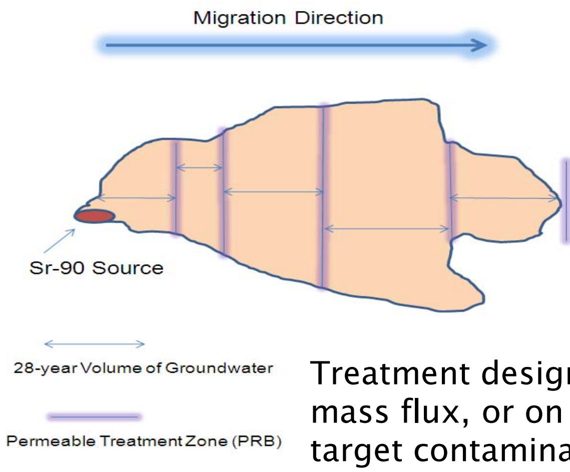
Use of PRBs to Treat "Packages" of Affected Groundwater using Mass Flux

Treatment of groundwater "packages"



Treatment design based on mass flux, or on decay of target contaminant

After Warner, 2012

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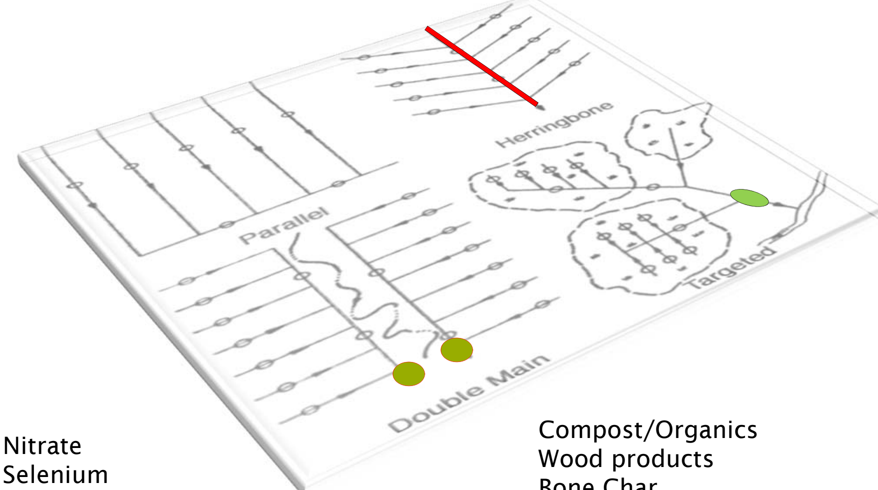
PRB Design Concepts – Drainage/Seepage Fields



Nitrate
Selenium
Pesticides
Sulfate
Dissolved metals

Compost/Organics
Wood products
Bone Char
Limestone
Reduced metals

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West Valley PTW (PRB) Fall 2010

Ion Exchange – Strontium replaces Potassium

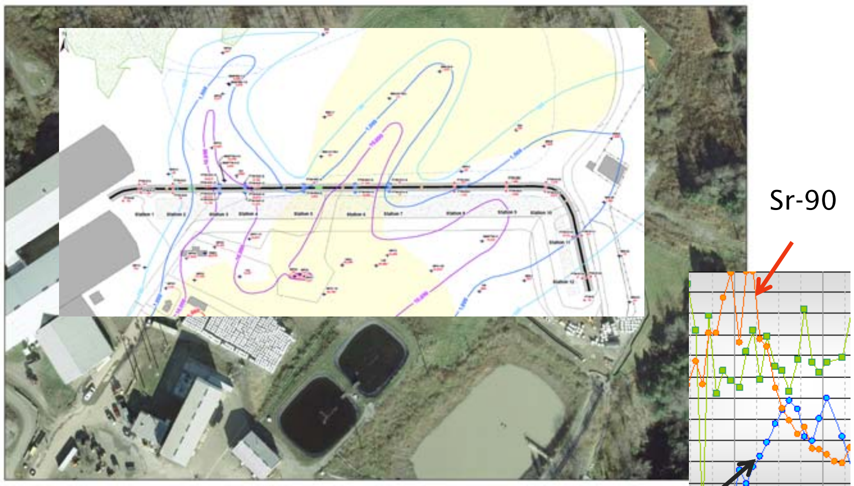

Photo previously provided courtesy WVDP

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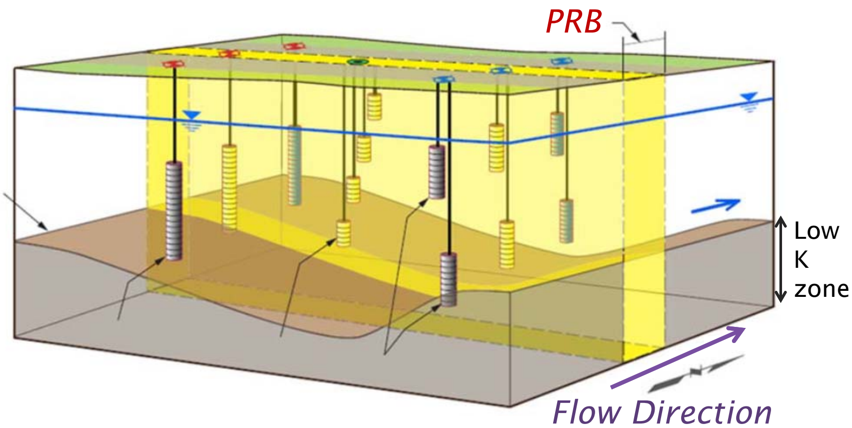
West Valley PTW (PRB) Fall 2010 Monitoring Approach



(Figure provided to ITRC courtesy of WVDP, 2010)

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Other PRB-like Uses

- **Stormwater/ waste water/ leachate Treatment for**
  - Roadways
  - Construction sites
  - Parking lots
  - Storm-drains
  - Mines/landfills

  Future Uses for
  - Well heads
  - Drinking Water Taps
  - Levees
  - Harbor Fronts

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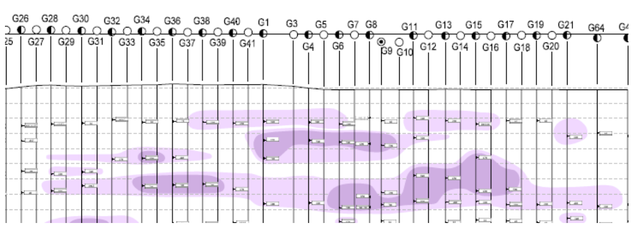
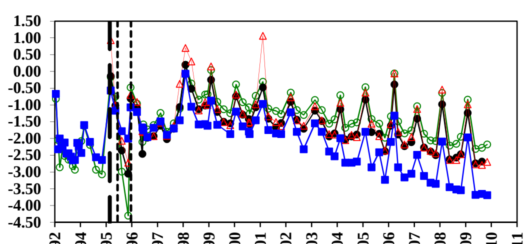
Challenges to Greater PRB Use



Where is the plume?



Transient Hydraulics

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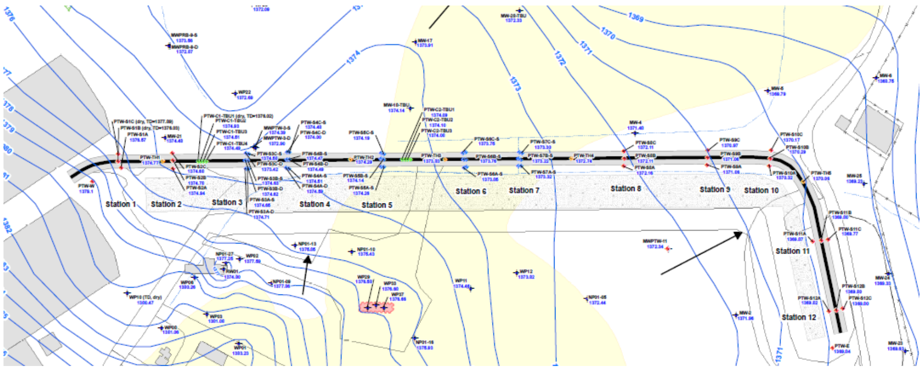
Hydraulic Characteristics: **THE** Key to Performance



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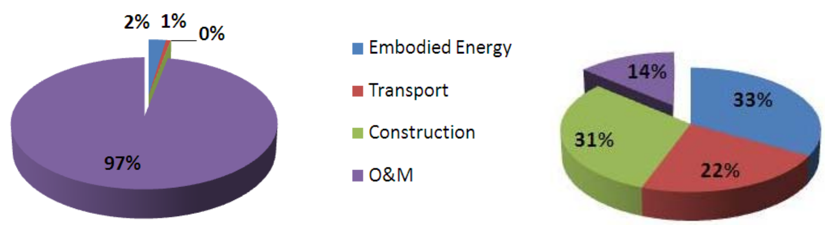
Carbon Footprint Comparison: Pump & Treat vs. PRB (conceptual)



Pump & Treat
80-year Carbon Footprint Distribution

PRB
80-year Carbon Footprint Distribution

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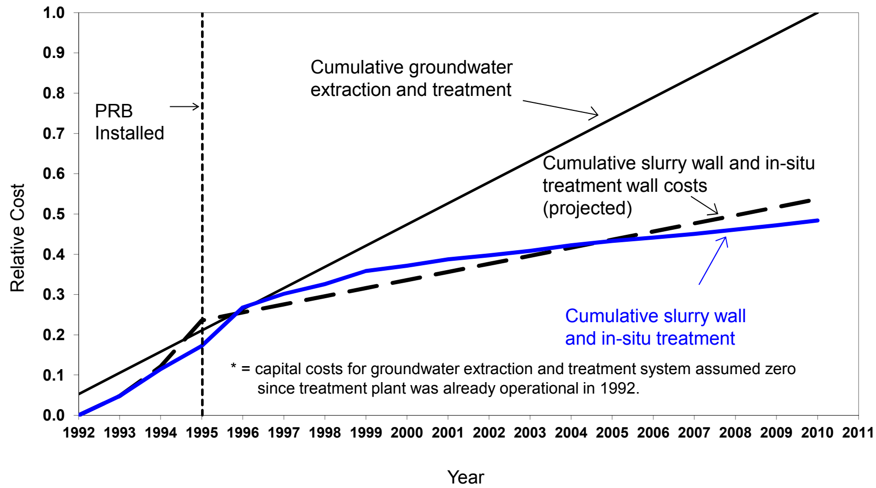
Financial Benefits of PRB-based Treatment



Based on previously published information

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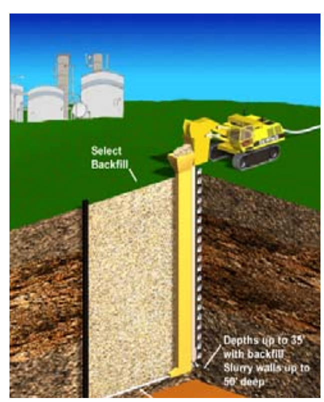
Assessing Effectiveness

Rule: Performance and Longevity are not equivalent

- Performance
  - ✓ How the system meets Design Intent or Functional Requirements
    - ➢ Attainment of water quality objectives
    - ➢ Hydraulic system performance
    - ➢ Financial goal attainment
    - ➢ Sustainability goal attainment
- Longevity
  - ✓ Duration and Durability of the Treatment
    - ➢ Treatment media life
    - ➢ Flux maintenance
    - ➢ Geotechnical sustainability / durability
    - ➢ Sustainability goal attainment



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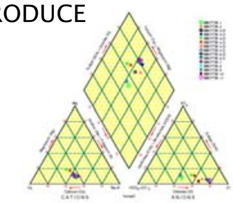
Assessing Effectiveness



Rule: Performance and Longevity are not equivalent

- Performance
  - ✓How the system meets Design Intent or Functional Requirements
    - Concentration reduction – within the PRB, downgradient
    - Changes in geochemical parameters – pH, DO, TDS/SpC,
    - Hydraulic system performance – water levels, gradients
    - "Aging" parameters – e.g., secondary minerals, H_2

Notes: ZVI System

pH ↑ DO ↓ TDS ↓ H_2(g) ↑

To Date –
the longest duration commercial PRB is 20 years old with continuing performance

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Question Break

Large Diameter Boring Installation

Conventional Excavate and Fill Installation with Sheet Piles

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Case Study

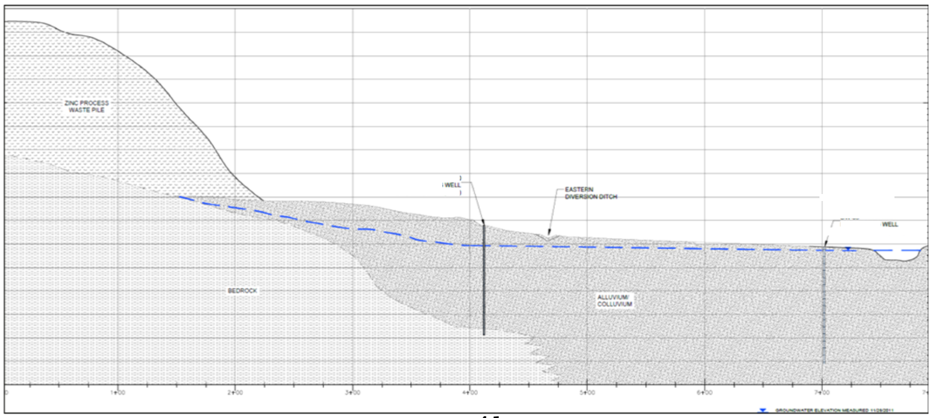
Application for Groundwater Remedy at a Former Zinc Smelter Site

Overview

- Former zinc smelter in Northeast US
- Produced over 33 million tons of slag
- Zinc concentrations in groundwater downgradient of waste pile range up to approximately 300 mg/L
- In-situ treatment was proposed to reduce metals concentrations in groundwater (primary COC is zinc)
- Initial baseline and post-construction monitoring of surface water and groundwater was conducted

Application for Groundwater Remedy at a Former Zinc Smelter Site

- Site Conditions
  - Waste pile sits over bedrock/overburden
  - Groundwater flows in overburden and weathered bedrock into floodplain deposits



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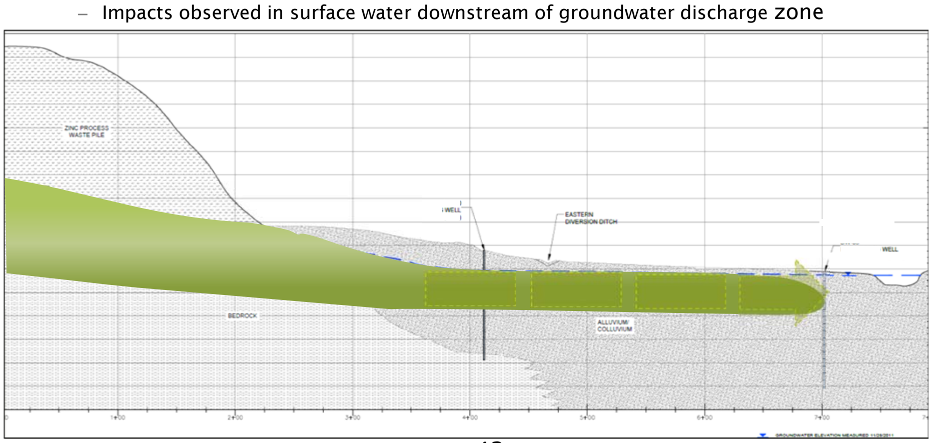
Application for Groundwater Remedy at a Former Zinc Smelter Site

- Zinc concentrations in shallow groundwater downgradient of waste pile range up to approximately 300 mg/L
  - Elevated zinc concentrations extends into floodplain to adjacent creek
  - Impacts observed in surface water downstream of groundwater discharge zone



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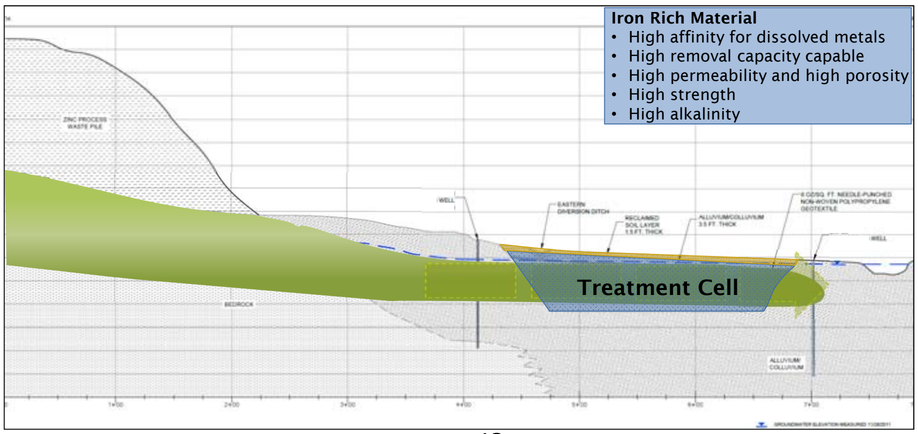
Application for Groundwater Remedy at a Former Zinc Smelter Site

- Iron Rich Material ("IRM") identified as reactive media for groundwater treatment
- Treatment cell located within high groundwater flow/mass flux zone



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Application for Groundwater Remedy at a Former Zinc Smelter Site

- Cell construction performed over a 5 month period
- Approximately 26,000 cubic yards of IRM were placed within the cell
- Additional monitoring wells installed within the cell to evaluate treatment performance
- Zinc concentration reductions ranging from 20 to 80% observed in downgradient wells over 3 year post-construction period
- Slow reduction in stream concentrations

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Thank you!

Q & A

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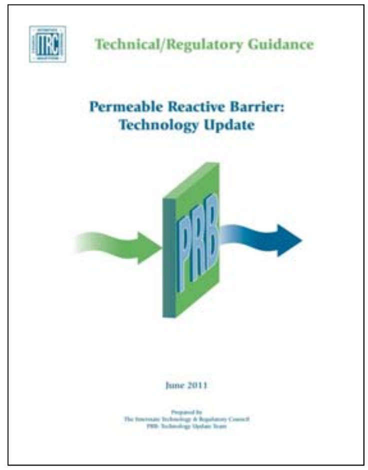

http://www.itrcweb.org/prb

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