Permeable Reactive Barriers

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Remediation Strategies and Technologies Workshop

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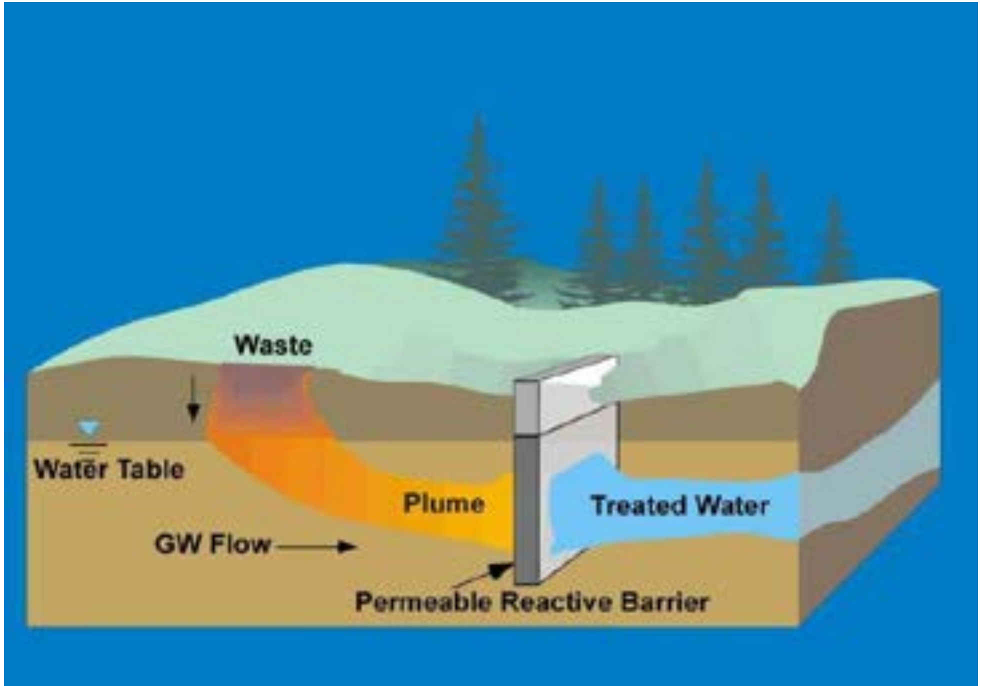
NEWMOA

ISOTEC
REMEDIATION TECHNOLOGIES

Permeable Reactive Barriers (PRB)

- A PRB is a continuous, in-situ permeable treatment zone designed to intercept and remediate a contaminant plume.

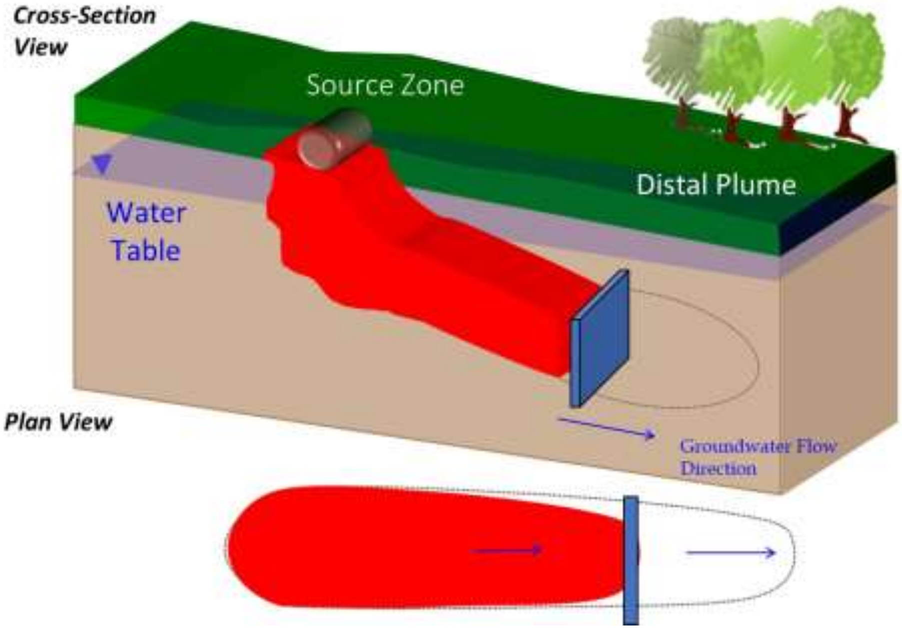
- Contaminants may be treated through physical, chemical, and/or biological processes.



USEPA, 2003

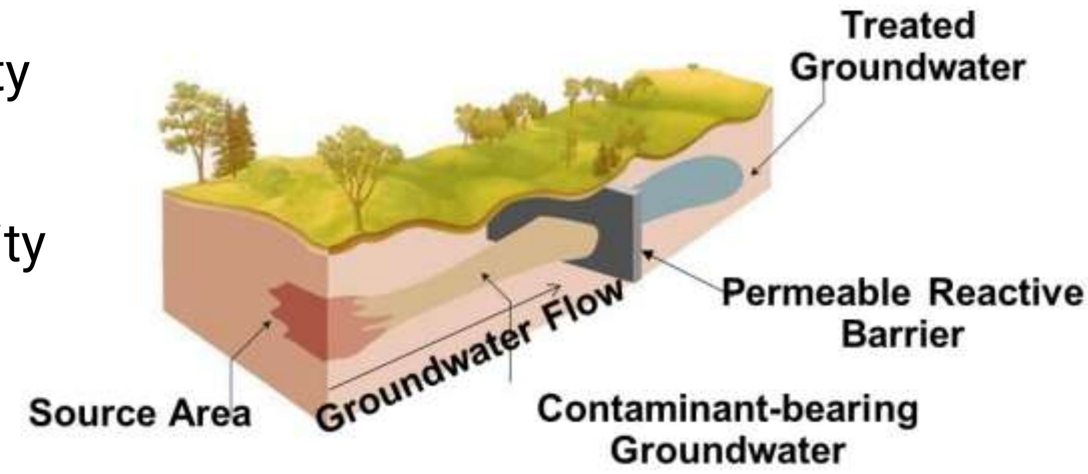
Permeable Reactive Barriers (PRB)

- Permeable
  - Groundwater flows through
  - Hydraulically passive
  - Can be designed to be more permeable than the surrounding aquifer media
- Reactive
  - Reduce groundwater concentrations within PRB
- Barrier
  - Prevent contaminants from migrating beyond



PRB Reagent Characteristics

- Persistent (years)
- Immobile or Limited Mobility
- Does not reduce permeability
- Solid or liquid reagents
  - Gas – sparge curtain
  - Electrochemical (E-Redox®)



(ITRC, 2011)

Applicable Contaminants

- Organic
  - Chlorinated VOCs
  - Petroleum hydrocarbons
  - Energetics (TNT, RDX)
  - 1,4-Dioxane
  - PFAS
- Inorganic
  - Nitrate
  - Metals
  - Arsenic
  - Radionuclides

Attenuation – PRB reduces contaminant mass (degradation, transformation)

Retardation – PRB removes contaminant from mobile form (precipitation, sorption)

- Reversible processes

PRB Reagents – Chemical Reactive

- Chemical Oxidation
  - Potassium persulfate
- Chemical Reduction
  - Zero valent iron (ZVI)
- pH Adjustment (metals)
  - Limestone

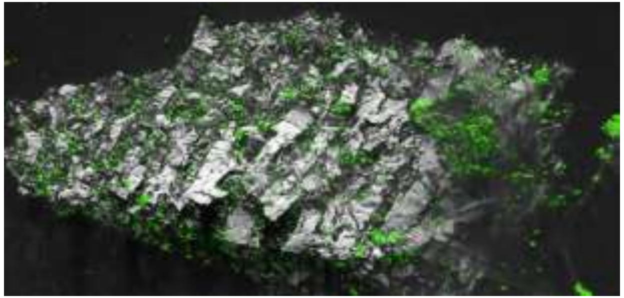
(Photo Credit: Hepure)

PRB Reagents – Enhance Biodegradation

- Bioremediation (Anaerobic)
  - Wood chips, mulch
  - Carbon substrate e- donor
    - (e.g., emulsified vegetable oil)
- Bioremediation (Aerobic)
  - Oxygen release compounds (e.g., calcium peroxide)
- Gas (Air Sparge / Biosparge)
  - Air / oxygen
  - Methane, propane

PRB Reagents – Sorbents

- Activated Carbon
  - Granular (GAC)
  - Powdered (PAC)
  - Colloidal



1 lb. contains surface area to cover more than 90 soccer fields

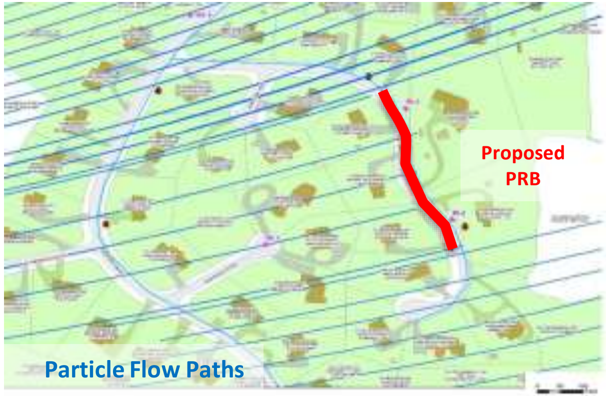
- Zeolite (aluminosilicate minerals)
- Modified Clay

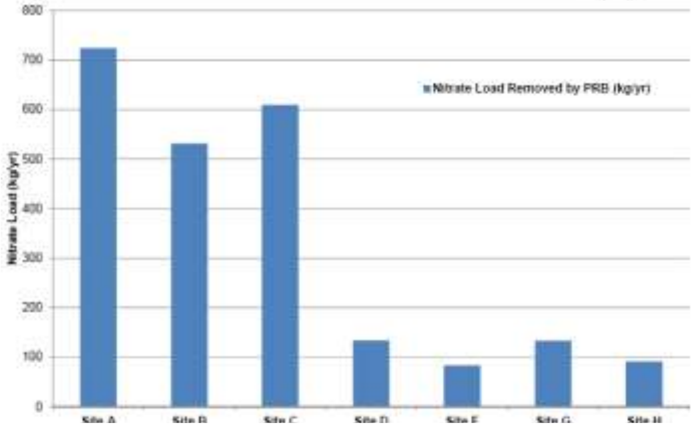
CETCO

- Combinations
  - Activated carbon + clay minerals

Locating a PRB

- Location where reducing contaminant flux will support remedial goal
  - Flux [mass/time] = Concentration x Flow
- Perpendicular to groundwater flow (or near perpendicular)
- Access / Land Usage
- Downgradient Features





(Source: AECOM)

PRB Placement

- PRBs located according to remediation objective(s)

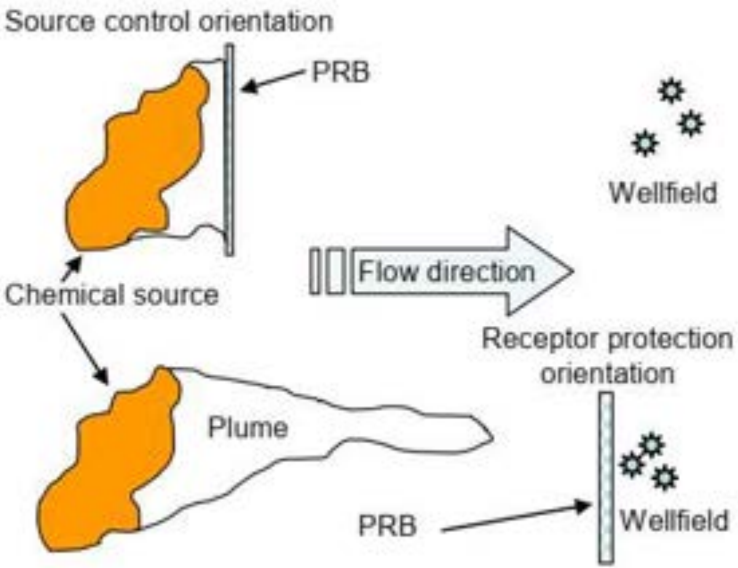


Figure 3-2. Examples of PRB receptor protection configurations.

(ITRC, 2011)

PRB versus Transect

- Transect – a line of injection points for a mobile reagent
  - (e.g., permanganate, sodium persulfate, e^- donors)
  - Not a Permeable Reactive Barrier

GW Flow Direction

Line of injection points located upgradient of building wall to apply oxidant to advect towards contamination under the building

PRB Installation Methods – Solid Substrates

Trenching

Excavator

- Max. 18-25 feet deep

One-pass trenching

- 30 – 75+ feet deep

Dewind One Pass Trenching

PRB Installation Methods – Solid Substrates

- Auger Boreholes (~12")

Cornell Cooperative Extension of Suffolk County (NY) – Molly Graffam, PhD

- Behind Bulkhead

Cornell Cooperative Extension of Suffolk County (NY))

PRB Installation Methods – Injection

- Injection Wells

\+ No depth restrictions (if rig can advance to)

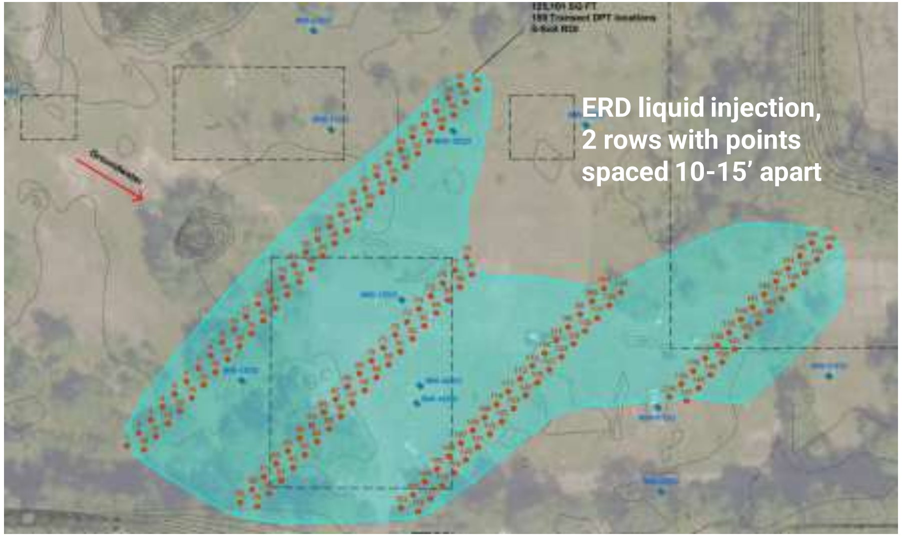
− Fixed locations / intervals

- Direct Push Injection Points

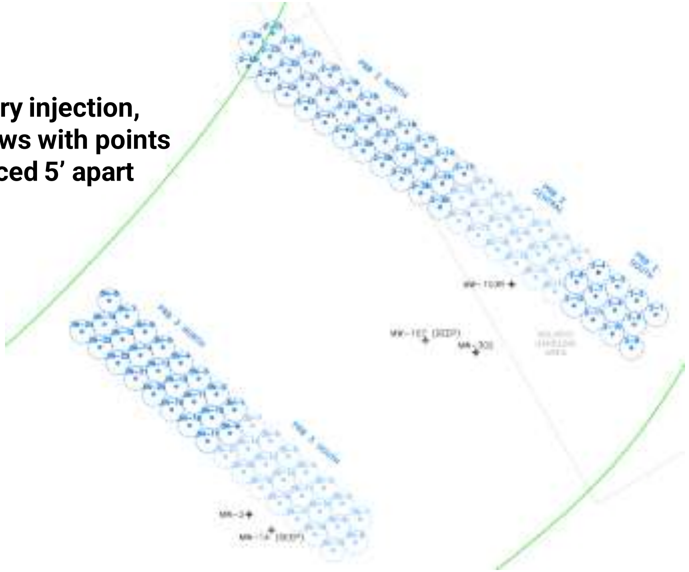
\+ Flexible locations / vertical intervals

− Drilling restrictions

PRB Installation Methods – Injection



Slurry injection,
3 rows with points
spaced 5’ apart



- Rows (1, 2, 3…) – PRB residence time, access
- Point spacing – liquid vs. solid slurry

Sparging

- Application of a gas to enhance biodegradation of contaminants
  - Air and/or oxygen
  - Methane, propane, butane

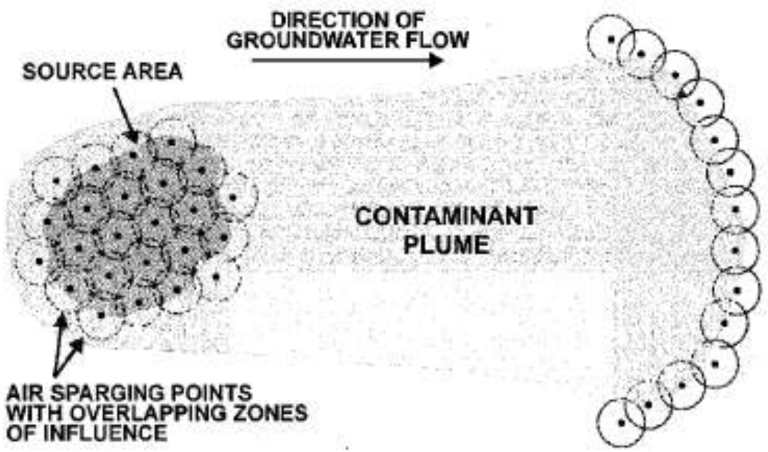
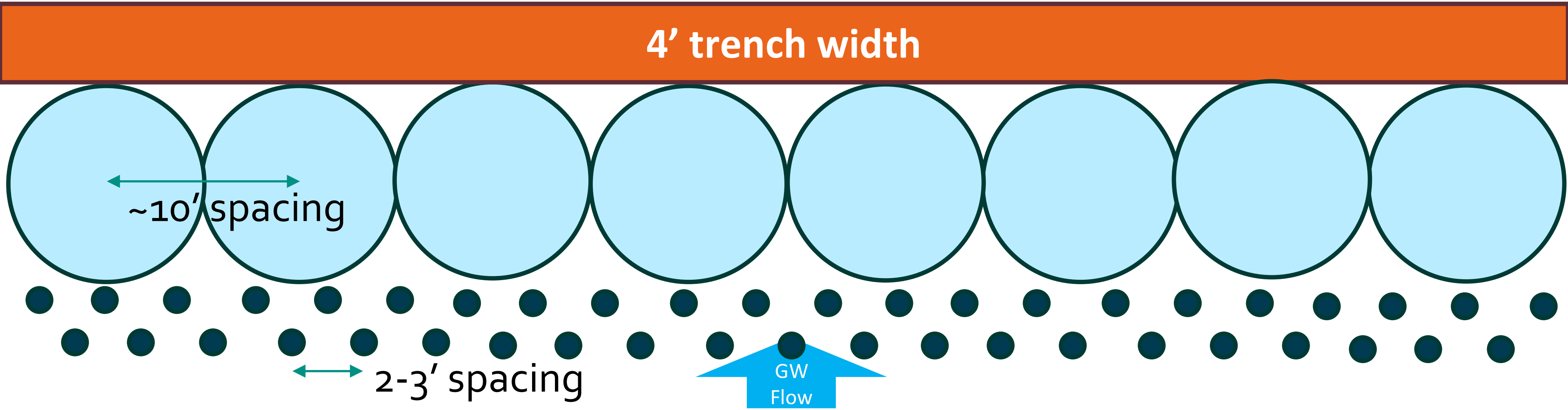


Figure 4.8 Air sparging point locations in a source area and in a curtain configuration.

Suthersan, 1999

Biosparge Curtain is permeable, reactive, & a barrier

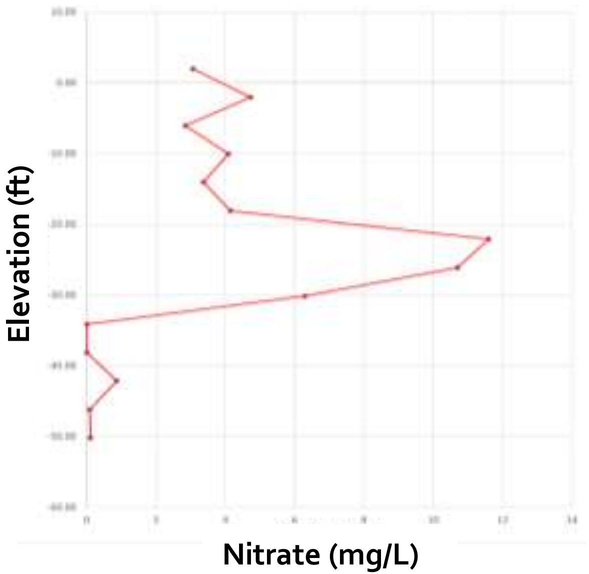
PRB Installation Methods – Injection



	Trench	Backfilled Boreholes	Injection Points
Benefits	-Continuous barrier -Longevity (15+ years) -Near surface water	-No depth restrictions -Longevity (10-15+ years) -Near surface water	-Larger residence time -No depth restriction -Less disturbance
Challenges	-Depth limitations -Larger equipment / Dewatering -Small residence time	-Small radius / residence time -Installation time	-Longevity (3-7+ years) -Set-back from surface water

Favorable Conditions

- Access
- Groundwater seepage velocity
  - Not too fast, not too slow (0.1 to 1-2 ft/d)
- Groundwater contaminant flux
  - Moderate to high
- Contamination vertically characterized

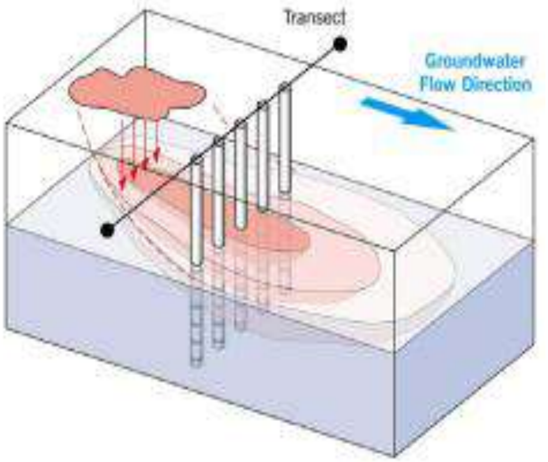


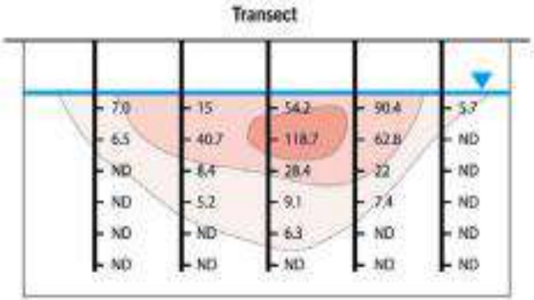
Unfavorable Conditions

- Above ground features
  - Buildings, surface water
- Subsurface Utilities
- Low permeability soils
  - $<10^{-4}$ cm/s
- Groundwater seepage velocity
  - Slow (<0.1 ft/d)
  - Fast (>5 ft/d)
- Low contaminant flux

PRB Design – Dimensions

- Length (perpendicular to groundwater flow)
  - Identify where PRB would support remedial goal(s)
  - Access
- Vertical
  - Identify where PRB would intercept flux
- Width
  - Provide adequate residence time
  - Account for variations in groundwater flow direction and hydraulic conductivity





Source: Use and Measurement of Mass Flux and Mass Discharge (ITRC, 2010)

PRB Design – Hydrogeology

- Geology and hydrogeology need to be understood laterally & vertically
  - Can vary across length of PRB
  - Groundwater velocity
  - Groundwater flow direction
  - Contaminant flux

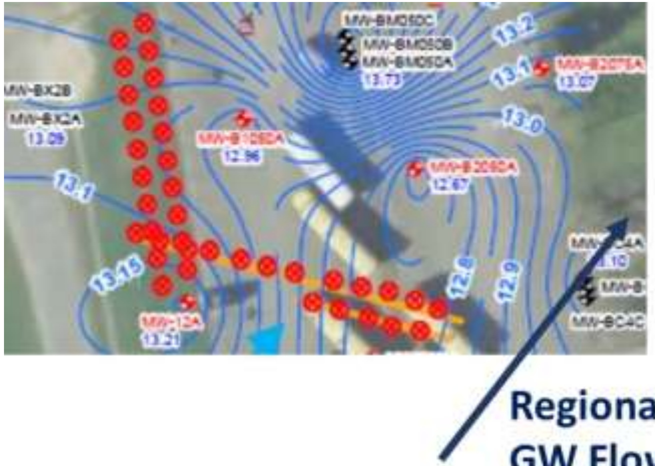
- Not homogeneous environments

Depth (ft)	Description
	19.5-23 ft. tan to brown, coarse to medium SAND
	23-23.5 ft. Clay
25	23.5-27.5 ft. reddish brown, very coarse to coarse SAND Gravel seam 26.5 ft. Clay seam - 27 ft.
	27.5-29 ft. tan to lt. brown, fine SAND and SILT
30, 35	29-36 ft. dark tan to brown, medium to fine SAND with trace silt
	36-40 ft. tan to brown, medium to fine SAND with trace silt and clay (bottom of boring)

PRB Design – Hydrogeology (continued)

$$v_s = K * i / \eta$$

- Groundwater velocity (vs)
  - Hydraulic gradient (i)
    - Site-specific estimate using monitoring wells (for 1 event)
- Hydraulic conductivity (K)
  - Should obtain site-specific estimates using pumping tests or rising head/falling head tests
- Porosity (h)
  - 0.2 – 0.35
- Groundwater flow direction
  - Minimum of 3 wells oriented as a triangle



Regional GW Flow

PRB Design – Reagent Dosage

- Contaminant Flux
  - Stoichiometry, bench-scale testing
- Non-target demand
  - Soil oxidant demand
  - Terminal electron acceptors
  - Other metals
- Over-dose vs. under-dose
  - Longevity / effectiveness
  - Cost, byproducts

PRB Design – Injection Volume

- Increased injection volume results in improved distribution and contaminant treatment
- 10% to 30% of total estimated pore volume within the PRB
- Site-specific considerations
  - Reagent type
  - Soil type/permeability
  - Injection depth
  - Subsurface utilities

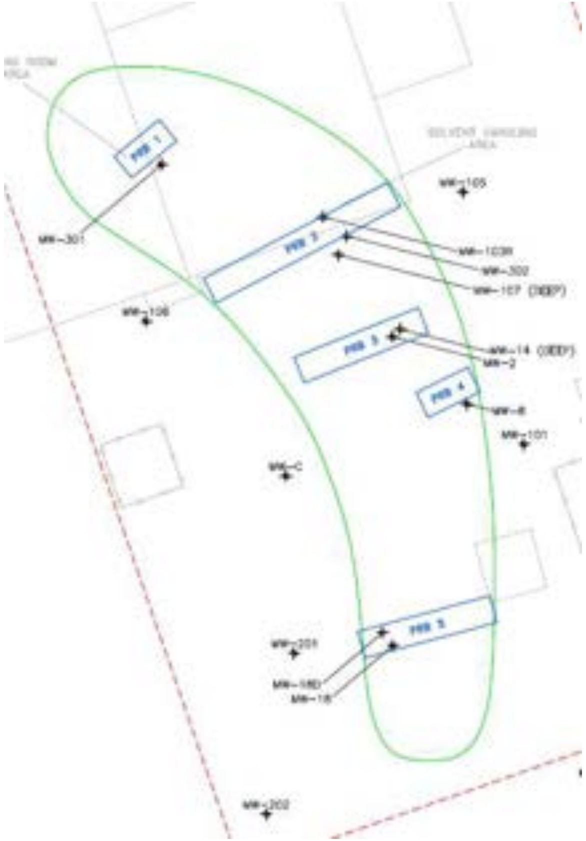
PRB Performance Monitoring

- Monitoring wells support understanding of treatment efficacy and when reagent needs to be replenished.
- Monitoring wells need to be located downgradient of PRB & at reasonable distances
- Contaminant(s) of concern
- Degradation products of remediation reagent
  - ERD carbon substrate -> total organic carbon
  - Sodium Persulfate -> sulfate & sodium
- Reaction Products
  - Metals
  - Reductive Dechlorination: lesser chlorinated products

Water quality field parameters (pH, DO, ORP) **ARE REALLY IMPORTANT!**

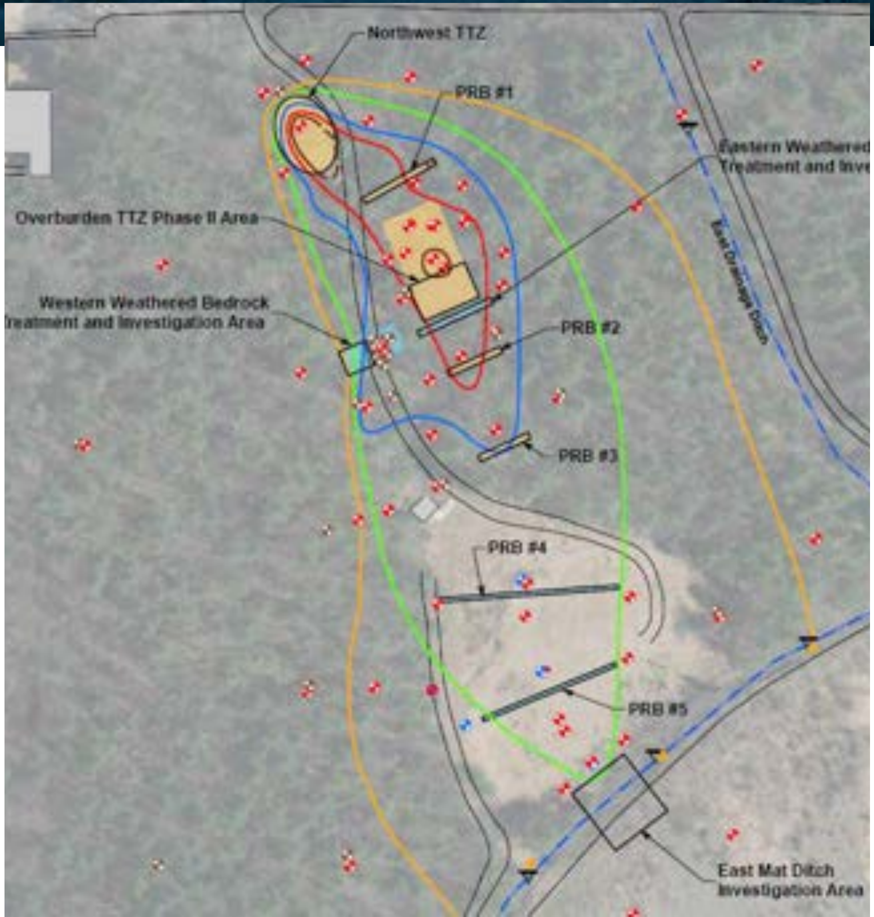
PRB Examples – DPT Injection Points

- 3-acre plume



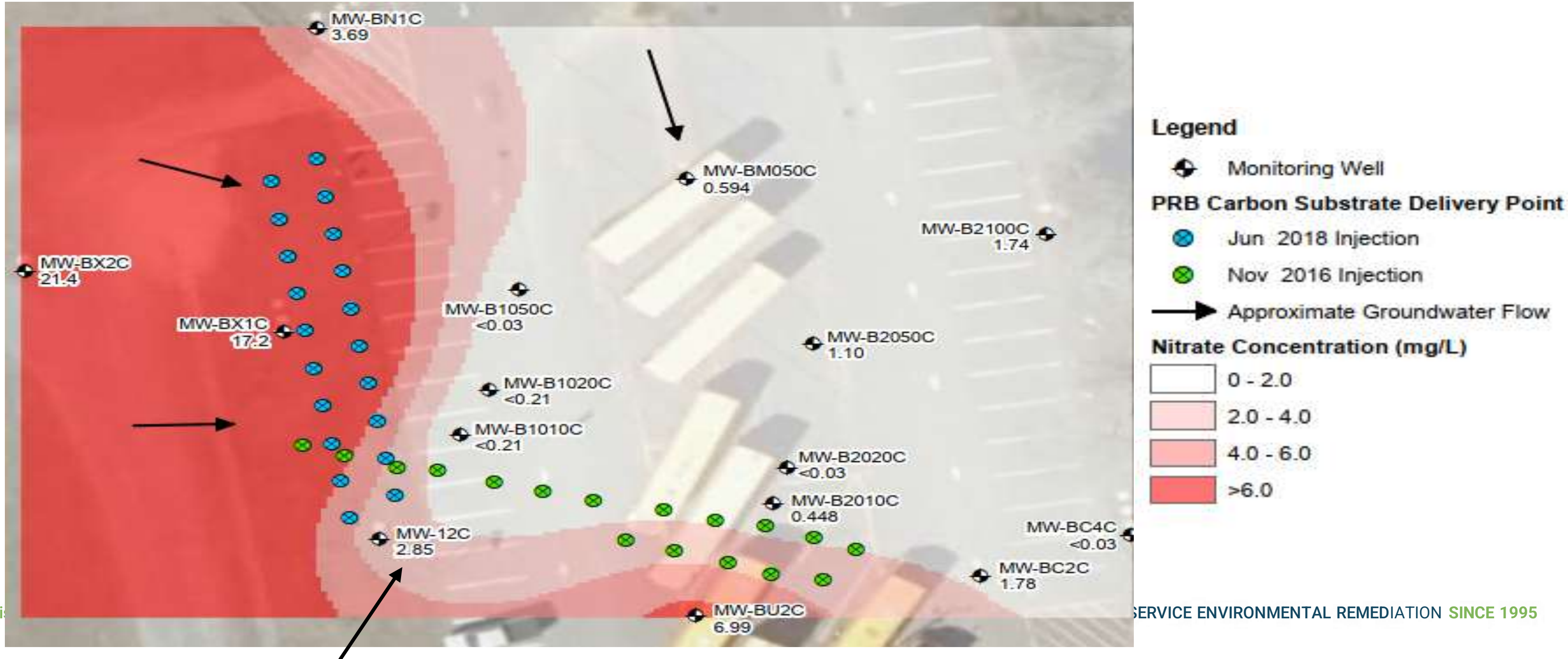
PRB Examples – Overburden & Weathered Bedrock

- PCE plume in overburden and weathered bedrock
- Selected Remedy = enhanced reductive dechlorination
- Full Scale Treatment
  - Source area: injection point grids
  - 5 PRBs
  - 74 direct push injection points in overburden
  - 51 injection wells in weathered bedrock



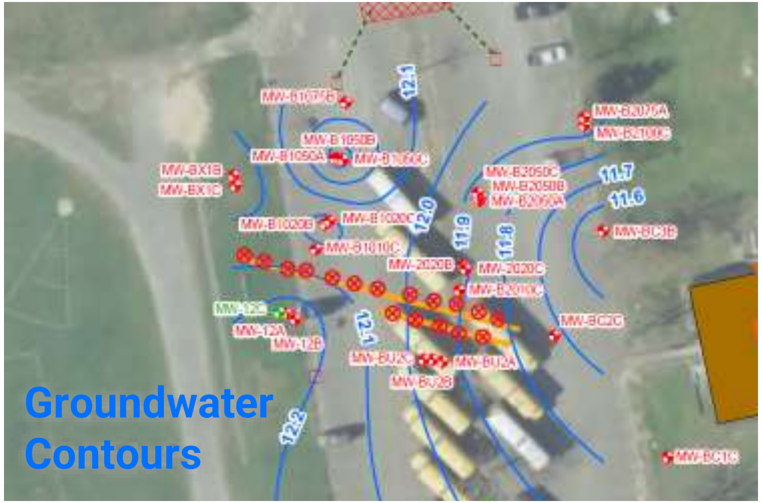
PRB Examples – Injection Points for Nitrate

- ~5 years post EVO injection



Lessons Learned – GW Flow Direction

- Site-specific features influence groundwater elevation and flow direction
  - Stormwater retention tank, irrigation well, leachfield



Lessons Learned – GW Flow Direction

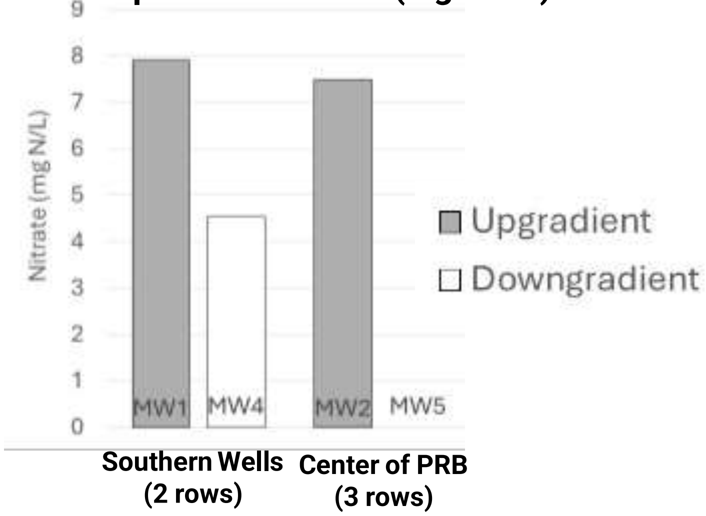
- Groundwater flow direction can vary seasonally

October January

Lessons Learned: Injection Rows

- Multiple rows recommended
  - Minimize contaminant flowing through barrier without reaction
  - Increase residence time (safety factor)

Wood Chip Borehole Denitrification PRB
1-month post installation (high tide)



Lessons Learned: When to Refresh?

- Reagent consumed
- Contaminant degradation effectiveness / breakthrough
- Water quality parameters
  - For Anaerobic Barrier – DO, ORP, electron acceptors (e.g., sulfate)

https://www.istockphoto.com/photos/refill-coffee

Recommended Resources

Technical/Regulatory Guidance

Permeable Reactive Barrier: Technology Update

June 2011

Prepared by
The Interstate Technology & Regulatory Council
PRB: Technology Update Team

Final

Design Guidance for Application of Permeable Reactive Barriers for Groundwater Remediation

Prepared for

Project Officer: Alison Lightner
Air Force Research Laboratory
Tyndall Air Force Base, Florida

Contract No. F08637-95-D-6004
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By

Arun Gavaskar, Neeraj Gupta, Bruce Sass, Robert Janosy, and James Hicks

BATTELLE
Columbus, Ohio

March 31, 2000

Study sponsored by

SERDP

PERMEABLE REACTIVE BARRIERS FOR REMOVAL OF NITRATE FROM GROUNDWATER THROUGH INJECTION OF EMULSIFIED VEGETABLE OIL

Engineering Design Manual

JUNE 2023

PREPARED FOR:

SOUTHEAST NEW ENGLAND PROGRAM

PREPARED BY:

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PRB Summary

- Wide array of PRB options
- Small remediation footprint
- Cost effective groundwater treatment approach for large plumes
- Groundwater flow direction, velocity, and vertical contaminant distribution critical to design

Thank you

Chemical Oxidation & Surfactant Injections

Bioremediation

Activated Carbon Injectates

Soil Mixing

Metals Remediation

Bedrock Injections

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Treatability Laboratory

Lessons Learned – Bench Scale testing

- Column testing