The Design of Permeable Reactive Barriers (PRBs) for the Remediation of Chlorinated Solvent Plumes

Purdue Geotechnical Society Workshop
West Lafayette, Indiana
April 19, 2013

John A. Mundell, P.E., L.P.G.
MUNDELL & ASSOCIATES, INC.
Consulting Professionals for the Earth and the Environment
Talk Outline

- The challenge of remediation
- What are PRBs and what do they have to offer?
- A couple of case histories
- Lessons learned for environmental investigation and remediation
**Groundwater Remediation 101**

- **TO BE EFFECTIVE, YOU MUST KNOW:**
  - Where the *source* of the plume impacts are coming from.
  - Where the *dissolved chemical impacts* have gone, and how they are distributed.
  - How *significant* are the impacts.

  - IF THESE REMAIN UNKNOWN, IT IS HIGHLY LIKELY THAT **YOU WILL FAIL** TO BE ABLE TO SUCCESSFULLY CLEANUP A CONTAMINANT PLUME!
Geologic Complexity

- Can cause plume movement **in directions not expected** by subsurface conditions only described by a classic ‘widely-spaced’ soil boring and monitoring well based subsurface exploration program.

- **Subsurface data density limits** the development of an accurate *Conceptual Site Model* that can adequately describe groundwater movement and plume progression, especially for large impacted chlorinated plume areas (say, greater than 1000 ft in length or greater than 10’s of acres in size).
PRBs

Basic Principles

• Design dependent on thorough site characterization.

• Collection of hydrogeologic, geochemical, microbial and geotechnical data.

• Full vertical and horizontal delineation of source area and limits of impacted groundwater.
DISTRIBUTION OF PCE CONCENTRATIONS IN GROUNDWATER

Groundwater Flow

Urban Environment

5 - 10 ppb PCE
10 - 50 ppb PCE
50 - 100 ppb PCE
100 - 300 ppb PCE
300 - 1,000 ppb PCE
>1,000 ppb PCE
DISTRIBUTION OF PCE CONCENTRATIONS IN GROUNDWATER

SITE 1

SITE 3

SITE 4

Groundwater Flow

5 - 10 ppb PCE
10 - 50 ppb PCE
50 - 100 ppb PCE
100 - 300 ppb PCE
300 - 1,000 ppb PCE
>1,000 ppb PCE
Depth Below Top of Aquifer: 0 to 10 ft
Total Saturated Aquifer 50 ft
Depth Below Top of Aquifer: 10 to 20 ft

Total Saturated Aquifer 50 ft
Depth Below Top of Aquifer: 20 to 30 ft

Total Saturated Aquifer 50 ft
Permeable Reactive Barrier

Definition

• An in-situ permeable treatment zone designed to intercept and remediate a contaminant plume.
Groundwater Remediation Approaches

- Chemical source area
- Groundwater plume
- Extracted well
- Permeable reactive barrier (PRB) wall
- Remediated plume
- Reactive treatment 'gate'
- Improper funnel wall
- Monitored natural attenuation
PRB Materials

• Treatment by physical, chemical or biological processes.

• Designed as a ‘chemical reaction vessel’ to treat contaminants, but allows groundwater to pass through.
Design Parameters:
- Size: Length, Width (thickness), Depth
- Treatment Material Type, Mass, Concentration
- Aquifer/Wall Hydraulic Conductivity, Groundwater Velocity
- Parameters: Contact Residence Time, Chemical Reaction Rate
Remediation Challenges:
- Constructability: Injection pressures, material distribution
- Aquifer inhomogeneity and anisotropy
- Aquifer geochemical variability
Chlorinated Solvent Plumes

- Parent material products:
  - Perchloroethylene (PCE)
  - Trichloroethylene (TCE)
  - 1,1,1-Trichloroethane (1,1,1-TCA)

- Breakdown products include cis-1,2-Dichloroethylene (cis-1,2-DCE) and Vinyl chloride (VC).
Typical PRB Materials

• Granular iron (zero-valent iron (ZVI))
• Solids – compost, zeolites, granular activated carbon, sawdust, peat, synthetic resins, sucrose, cheese whey).
• Bio-barrier systems (lactate, molasses, vegetable/soybean oils)
Chlorinated Solvents

• Treatment via anaerobic bioremediation.
Groundwater Remediation 101

• MOST PLUME REMEDIATION EFFORTS ARE BASED ON A LACK OF DATA AND SUBSURFACE KNOWLEDGE TO BE EFFECTIVE!

  • The remediation takes too long or is never achieved.
  
  • The remediation costs too much.
  
  • The plume’s risk to human health and the environment is never able to be controlled.
Case History No. 1

- Multiple sources
- Small plumes
- Complicated geology
SITE

WEST

Intersection with Line 2

Line 4

Projection of MMW-P-11S and D
Electrode Number

MMW-P-11S and D

Projection of MMW-P-02

Projection of MMW-P-03D

MMW-C-01

Projection of MMW-P-04

Silt and Clay

Sand and Gravel

Limestone

Shale

Depth (ft)

Distance Along the Profile (ft)

Resistivity (Ohm-meters)

Elevation (ft)

Interpreted Top of the Till from the Resistivity and Seismic Data

Projected Location and Depth of Nearby Wells and Borings Along the Profile Line

Top of Bedrock From Seismic Data

Increased Zones of Silt and Clay (Shallow); Shale Bedrock (Deep)

Increased Zones of Sand and Gravel (Shallow); Limestone Bedrock (Deep)
Multiple Source Areas
Multiple Source Areas
In-Situ Bioremediation with Soybean Oil

Figure 13 - Typical Cross-Section CAP18TM Injection
Chemical Source Area A
August 2007

- Radius of Influence < 10 ft
- Near-Surface Fine-grained Soils
- Geoprobe Drill Rods
- 38 Injection Points with 225 to 600 lbs (22 to 66.5 gallons) of CAP18 each
- Groundwater Table
- Vadose Zone
- Slight Rise During Injection
- Upper Sand and Gravel
- Basal Till Surface
- CAP18 Injection at 3 ft Intervals into Saturated Formation
Multiple Source Areas

- CAP 18 Injection August 2007
- CAP 18 Injection February 2009

Graph showing concentrations of chlorinated solvents over time with specific dates marked:
- 1/18/2007
- 10/15/2007
- 7/11/2008
- 4/7/2009
- 12/01/2010
- 9/29/2010
- 6/26/2011
- 3/22/2012

Concentration Chlorinated Solvents (ug/L)

Concentration Ethene (ug/L)

Date

- PCE
- TCE
- cis-1,2-DCE
- Vinyl Chloride
- Ethene
Case History No. 2

- Long plume
- Complicated geology
- How to clean it up?
Midwestern Geologic Complexity
White River Outwash Valley

Till Plain
Plume Search Area – Based on Hydrogeology
Resistivity Profile Line 1

Interpreted Top of the Till from the Resistivity Data
LEGEND

MW-32
Mundell Monitoring Well Location

RP-8-M
Mundell Remediation Progress Monitoring Piezometer Location

MW-19
Astbury Monitoring Well Location

Approximate plume delineation of 50 ug/L of total chlorinated VOCs

Approximate plume delineation of 500 ug/L of total chlorinated VOCs

Approximate plume delineation of 5,000 ug/L of total chlorinated VOCs

Buildings

Chlorinated Plume Delineation
Source Removal and Treatment

Permeable Reactive Barriers

Remediation of Chlorinated Plume

LEGEND

- **MW-32**: Mundell Monitoring Well Location
- **RP-8-M**: Mundell Remediation Progress Monitoring Piezometer Location
- **MW-18**: Astbury Monitoring Well Location

- Yellow: Approximate plume delineation of 50 µg/L of total chlorinated VOCs
- Pink: Approximate plume delineation of 500 µg/L of total chlorinated VOCs
- Blue: Approximate plume delineation of 5,000 µg/L of total chlorinated VOCs

Buildings
Permeable Reactive Barriers

Source Removal and Treatment

Philosophy:
- Source Treatment with Multiple PRBs
- Spacing at year travel time intervals
- Pilot test – for design
- Monitor – Observational approach

Remediation of Chlorinated Plume
Pilot Study – EHC PRB

Philosophy:
- Injection radius of influence
- Multi-row for contact time
- Geochemical monitoring
- Pilot test – for design
- Predict speed of remediation
Lessons Learned

- Most PRB failures are from a lack of subsurface data collection prior to final design.
- Wrong location, thickness and depth of PRB.
- PRB material under-designed for chemical concentrations.
THANKS!