Vertex Environmental Inc.

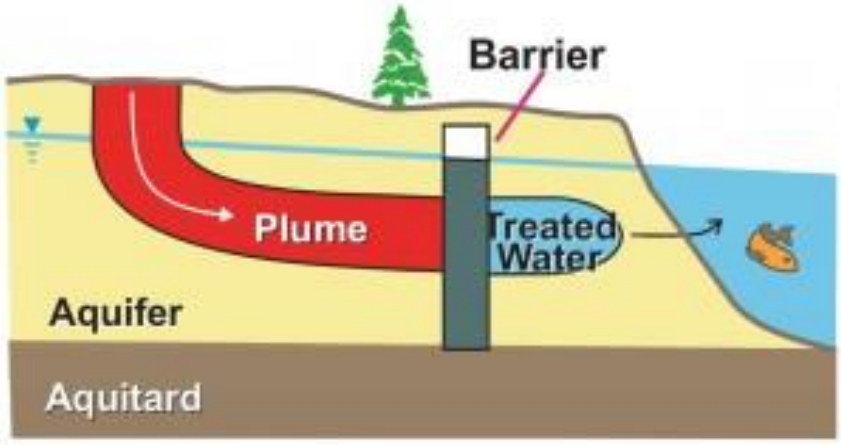
Permeable Reactive Barriers for Petroleum Hydrocarbons

October 14, 2016

Bruce Tunnicliffe

Outline

- What is a PRB?
- Trap and Treat PRB
  - Case Studies
- Slow Release Oxidant PRB
- Questions

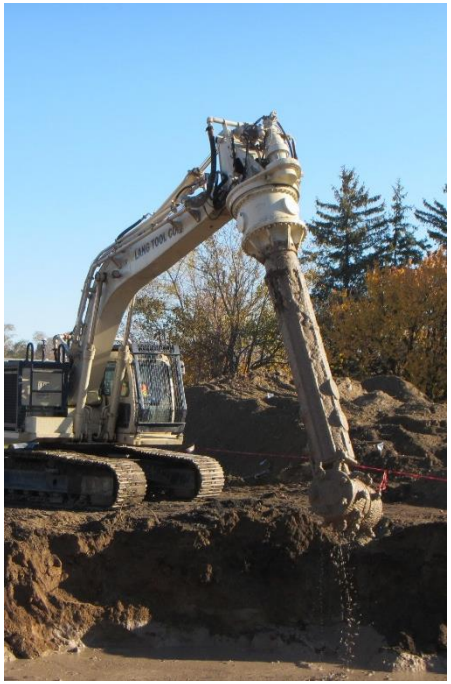


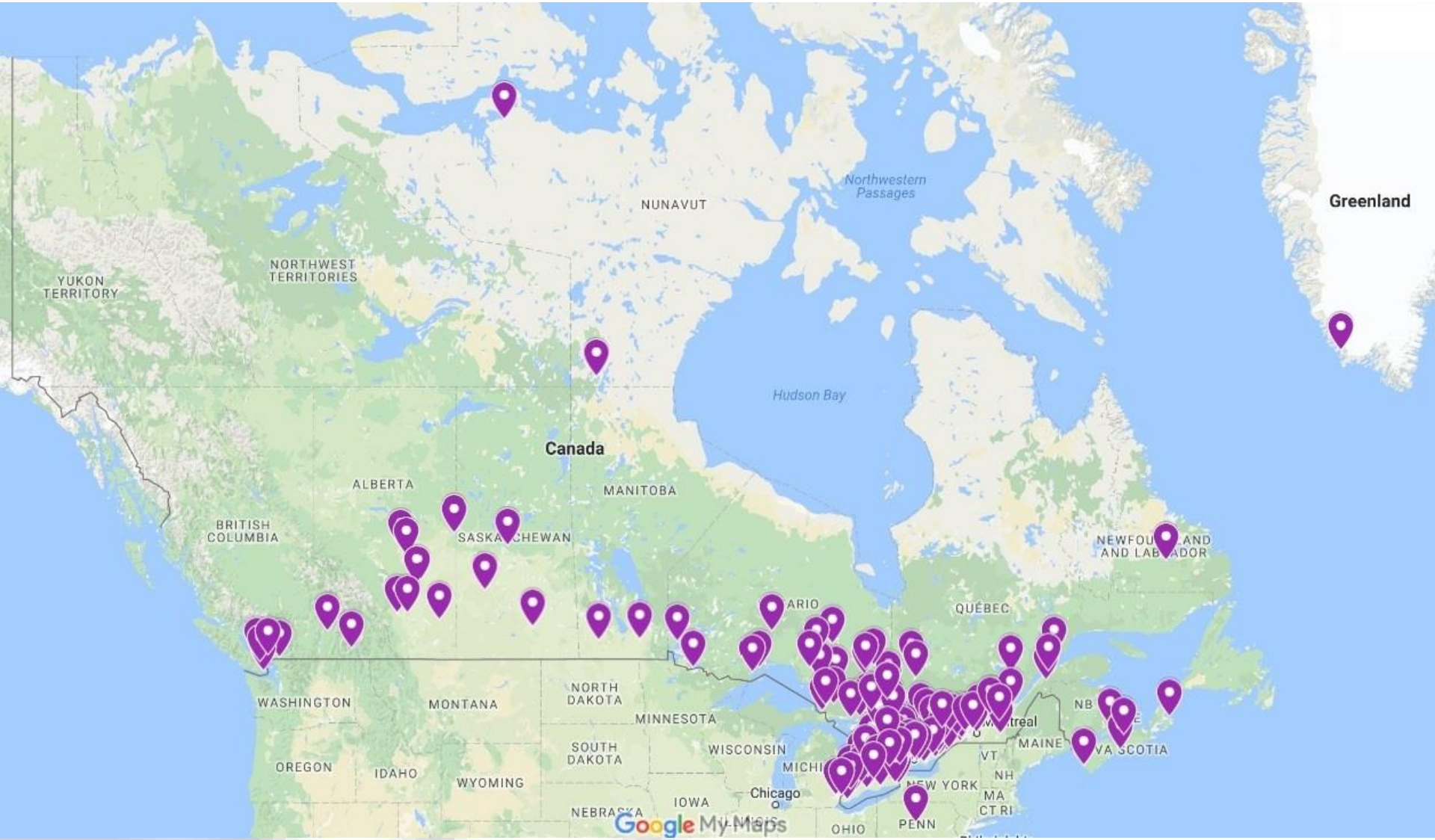
Permeable Reactive Barrier

VERTEX

Vertex Background

- Bruce Tunnicliffe
  - Engineer
  - Founder of Vertex & SMART Remediation
- Vertex Environmental Inc.
  - Environmental Contracting
  - High Resolution Characterization (MIP, LIF, HPT)
  - Treatment Systems (SVE, MPE, P&T)
  - In-Situ and Ex-Situ Remediation
    - Remedial Design
    - Implementation (bench, pilot, full-scale)

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NUNAVUT
Greenland
YUKON TERRITORY
NORTHWEST TERRITORIES
Hudson Bay
Canada
ALBERTA
MANITOBA
BRITISH COLUMBIA
SASKATCHEWAN
NEWFOUNDLAND AND LABRADOR
QUÉBEC
WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
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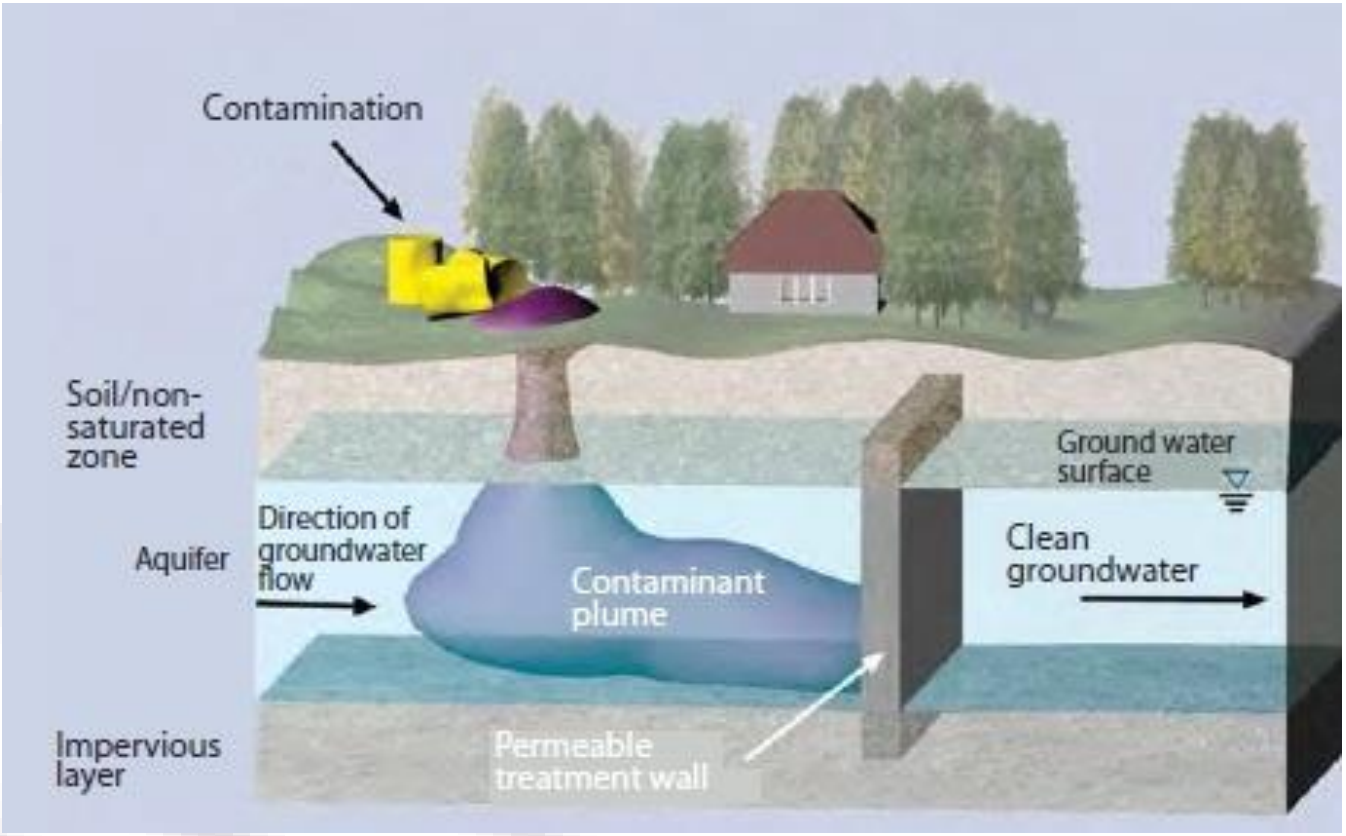
VERTEX

Permeable Reactive Barrier (PRB)



- PRBs intercept and treat contaminated groundwater plumes
- Allow groundwater to flow through unimpeded
- Passive
- Can be dug or injected
- Sustainable (no energy use to operate)

VERTEX

Permeable Reactive Barrier (PRB)

- Why Would You Require a PRB?
  - Down-gradient of PRB: Sensitive Receptor Exists
    - Property Boundary
    - Risk: Health or Ecological (i.e. residential, or creek)
    - Pressure to Act: lawsuit, public perception
  - Up-gradient of PRB: can not clean-up contamination
    - Source is not understood
    - Source would be very costly to remediate yet it poses no risk
      - “source” could be strong back diffusion from the soil or rock matrix
    - Source risk is controlled by Risk Control Measures & can not apply the Risk Control Measures beyond the PRB

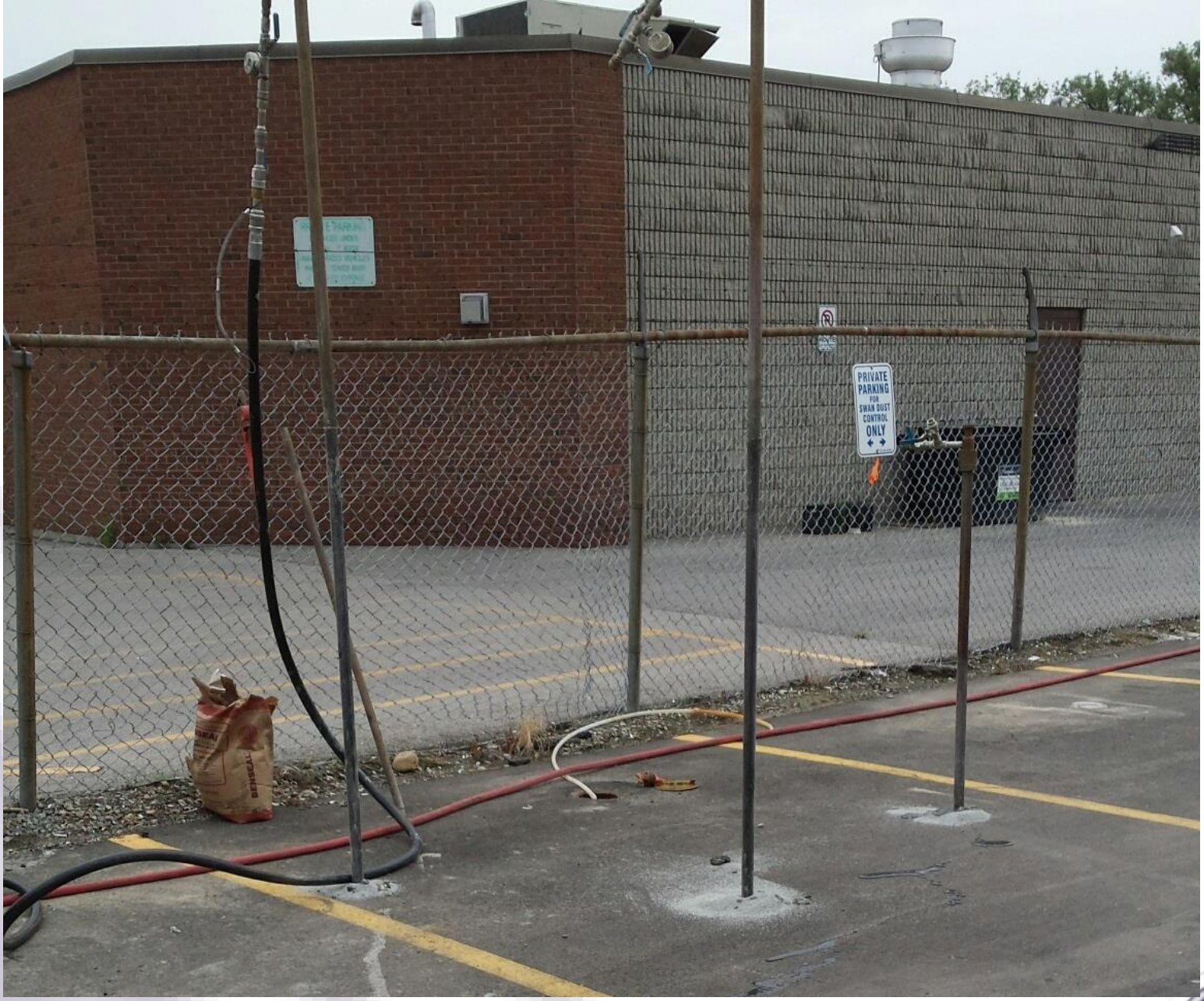
VERTEX

Source: Milestone Environmental

VERTEX

Source: Milestone Environmental


DISCOUNT


PRIVATE
PARKING
FOR
SWAN DUST
CONTROL
ONLY

Permeable Reactive Barrier (PRB)

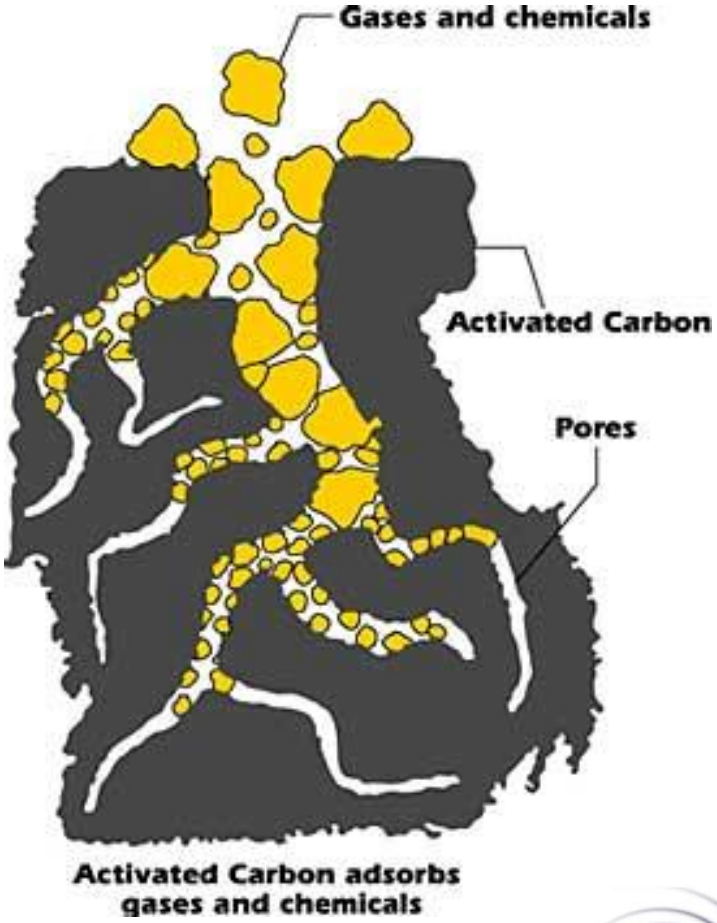
Year First Used	Contaminant Treated	PRB Material (Passive)
1995	TCE	Zero Valent Iron
1995	Nitrate	Solid Organic Amendments*
1996	Hexavalent Chromium (and TCE)	Zero Valent Iron
1997	Acid Mine Drainage	Solid Organic Amendments*
1997	Uranium	Phosphates (Apatite)
1998	Strontium-90	Zeolites
1999	Perchlorate (and TCE)	Solid Organic Amendments
1999	Phosphate	Iron and Steel Furnace Slag
2002	Arsenic	Solid Organic Amendments and Zero Valent Iron
2005	Creosote NAPL	Organophilic Clays
2010s	Petroleum Hydrocarbons!	Trap and Treat, Slow Release Oxidant

*Solid Organic Amendments = wood chips, leafy compost

PHC PRB
Trap and Treat

Trap and Treat

Granular Activated Carbon



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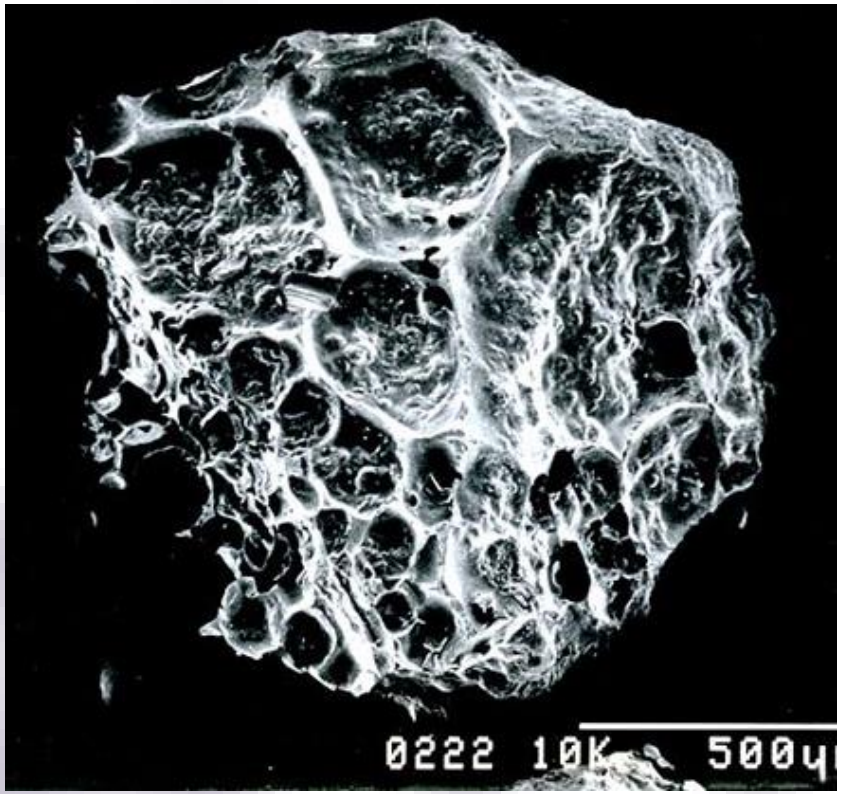
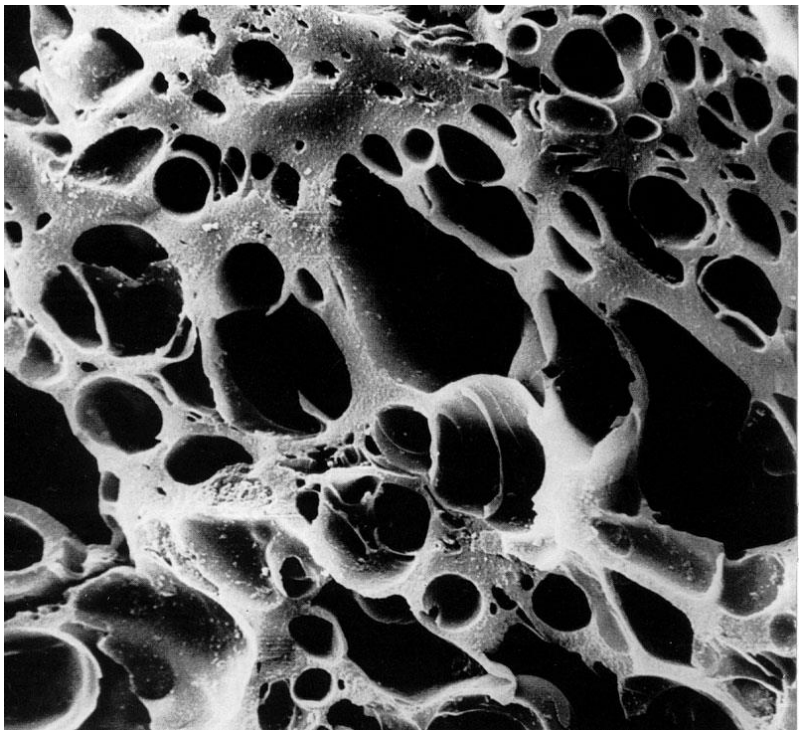
Trap and Treat

Granular Activated Carbon





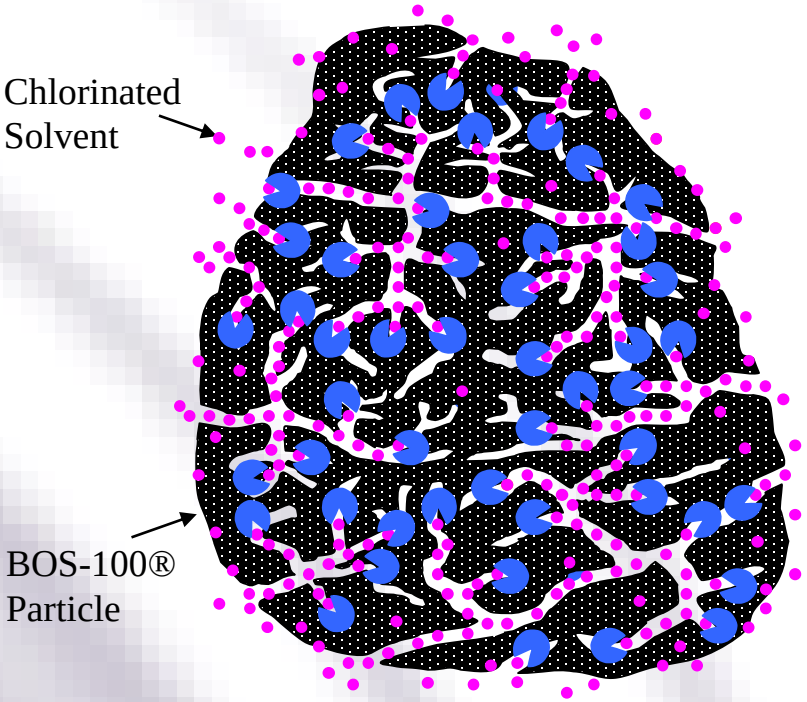
The “Trap” Part of “Trap and Treat”

Trap and Treat

- Mechanisms:
  - **Trap** the contamination within the GAC matrix
  - **Treat** within the matrix
- BOS-100®
  - For Chlorinated Solvents
  - GAC & impregnated Iron
- BOS-200®
  - For Petroleum Hydrocarbons
  - GAC & Nutrients & Blend of Microorganisms

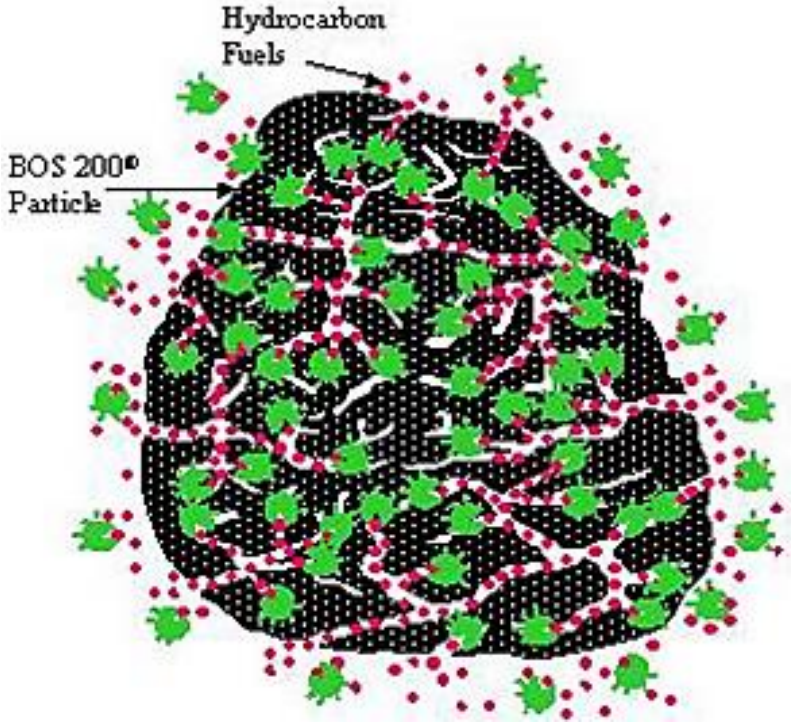
Trap and Treat

BOS-100®



GAC & Iron

BOS-200®



GAC & Nutrients & Microbes

Source: AST Environmental

Trap and Treat

Source: AST Environmental

Case Studies

Case Study #1
PRB for PHCs at Service Station

Case Study – Service Station

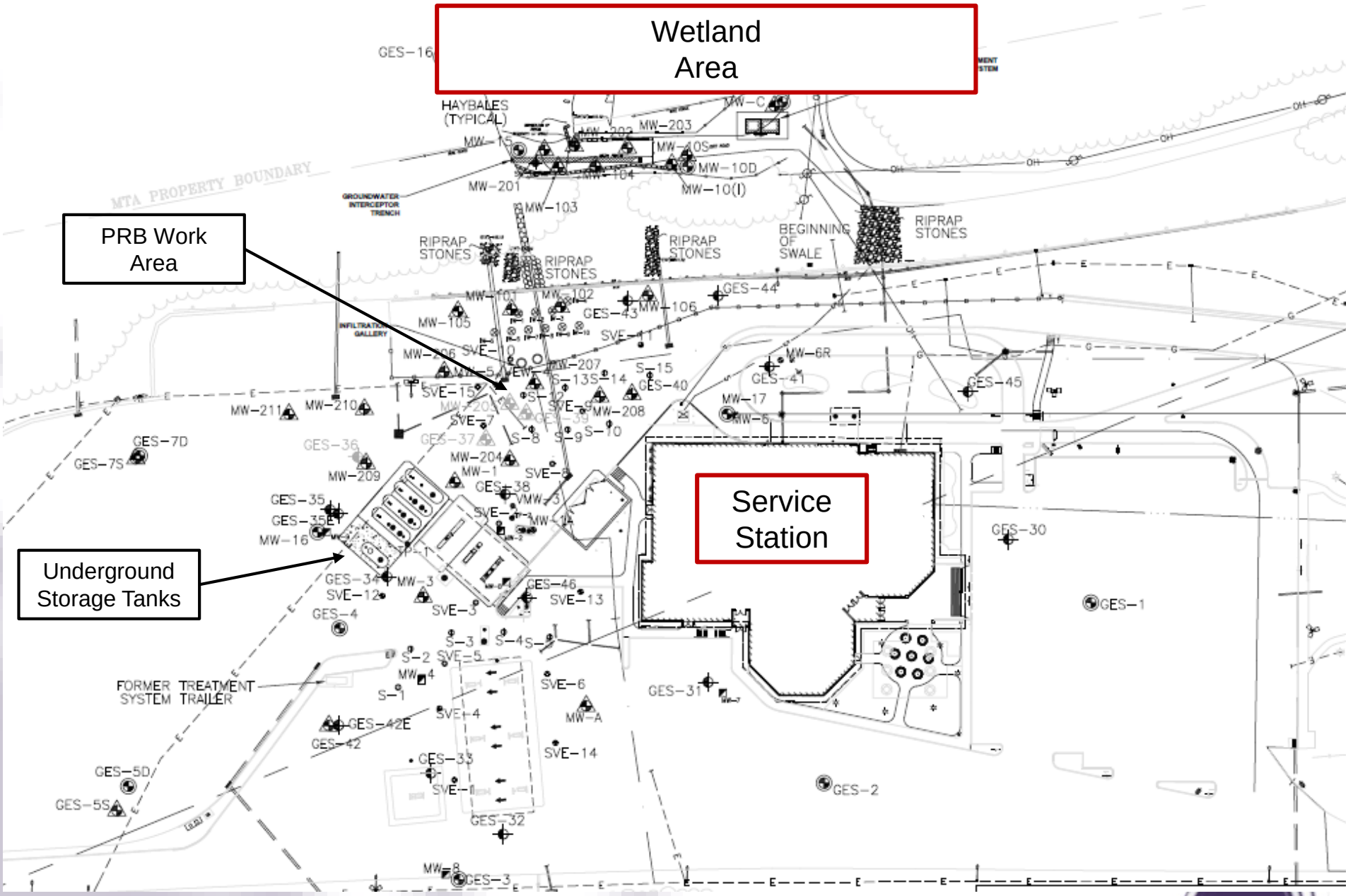
- Service Area beside Highway
  - Operating
  - Concrete Rubble to 3 m below ground, difficult access
  - Adjacent wetland
- Contamination and Work to Date
  - Contamination – mostly gasoline related
  - LNAPL on-site and in wetland
  - SVE and Pump & Treat completed for years
  - ISCO Injection (persulphate) in 2009 and again 2011
- Concentrations – recent (2015)
  - BTEX – up to 1,500 ug/L
  - PHCs – up to 10,000 ug/L
  - Mostly PHC(F1)
  - Migrating off-site
- Subsurface
  - Contamination: water table to bedrock
  - Water table ~7.5 m below ground
  - Bedrock ranged from ~10 m to ~16 m below ground

Case Study – Service Station

- PRB Required
  - Injected
  - Passive
  - Trap and Treat Selected
  - Injection from Water Table to Bedrock
- Injection – Masses
  - Pilot-Scale BOS® = ~1,150 kg
  - Full-Scale BOS® = ~11,500 kg
  - ~11,500 kg of gypsum
- Work
  - Pilot-Scale Injection: June 2015
  - Full-Scale Injection: October 2015
  - Analysis: to August 2016
- Injection – Details
  - 10 days injection
    - 1 day pilot, 9 days full
  - BOS® Slurry: 12 to 24%
  - Injection Volume: ~60,000 L

VERTEX

Source: AST Environmental



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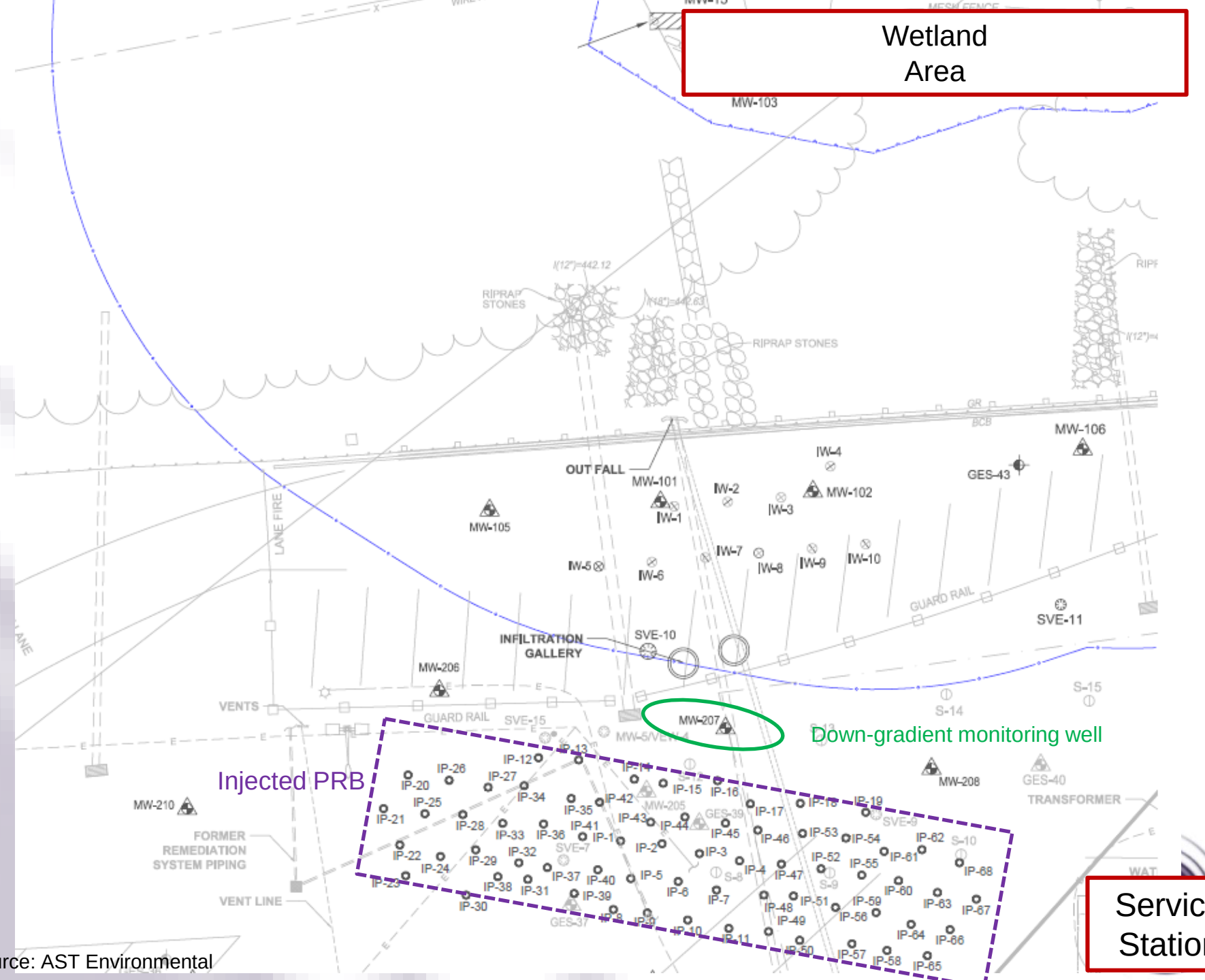
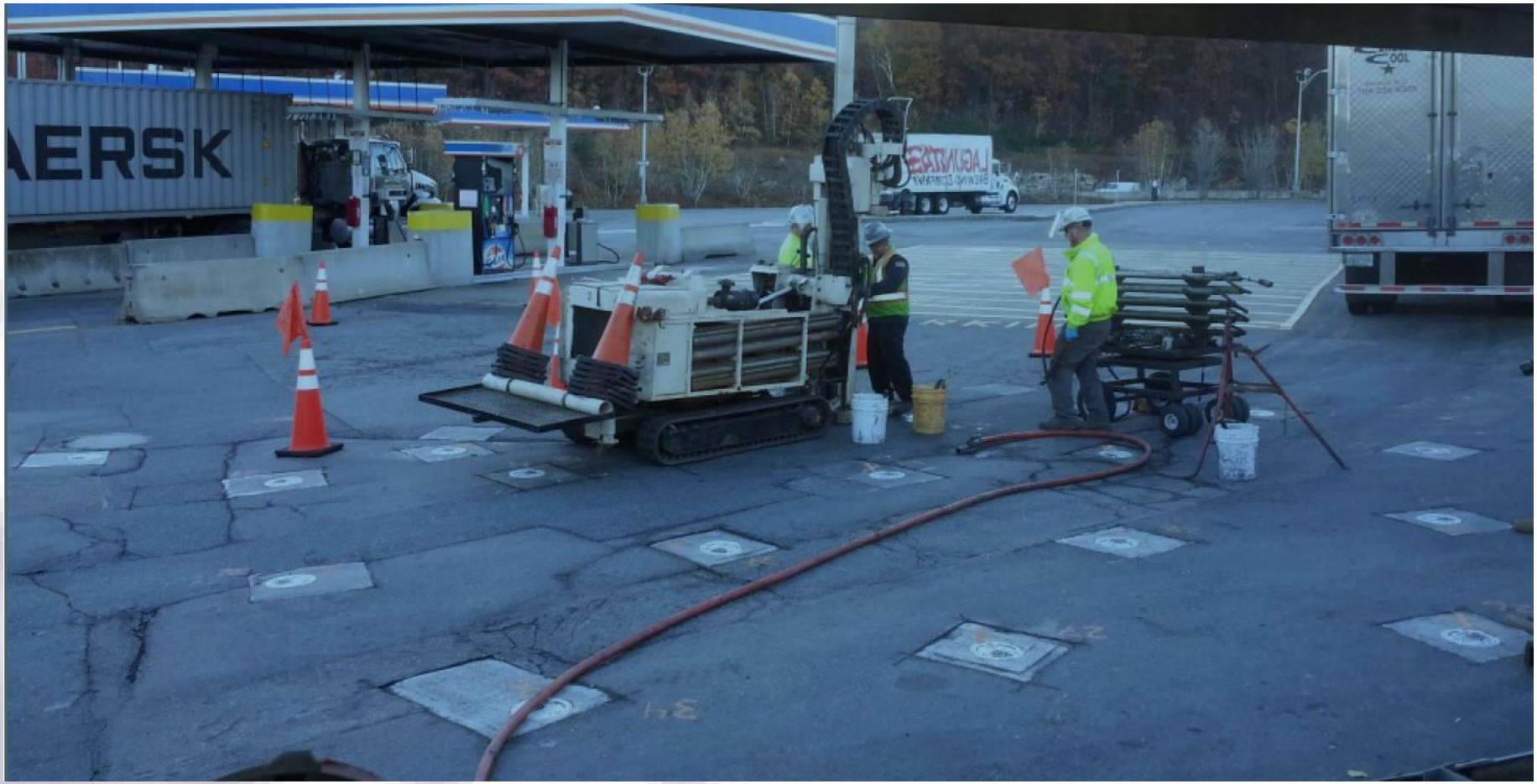


Source: AST Environmental

Case Study – Service Station



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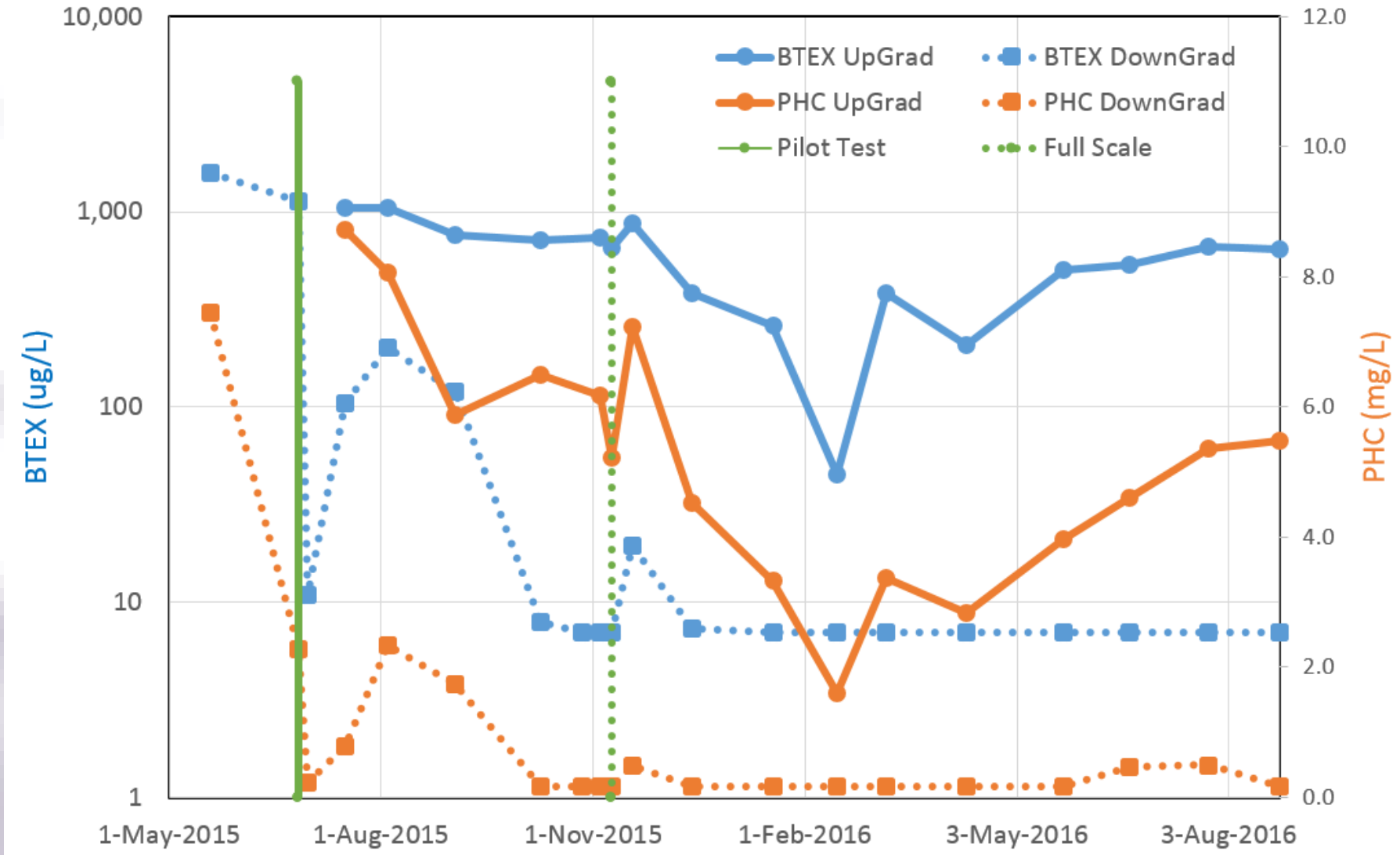


Source: AST Environmental

Case Study – Service Station

Conclusions

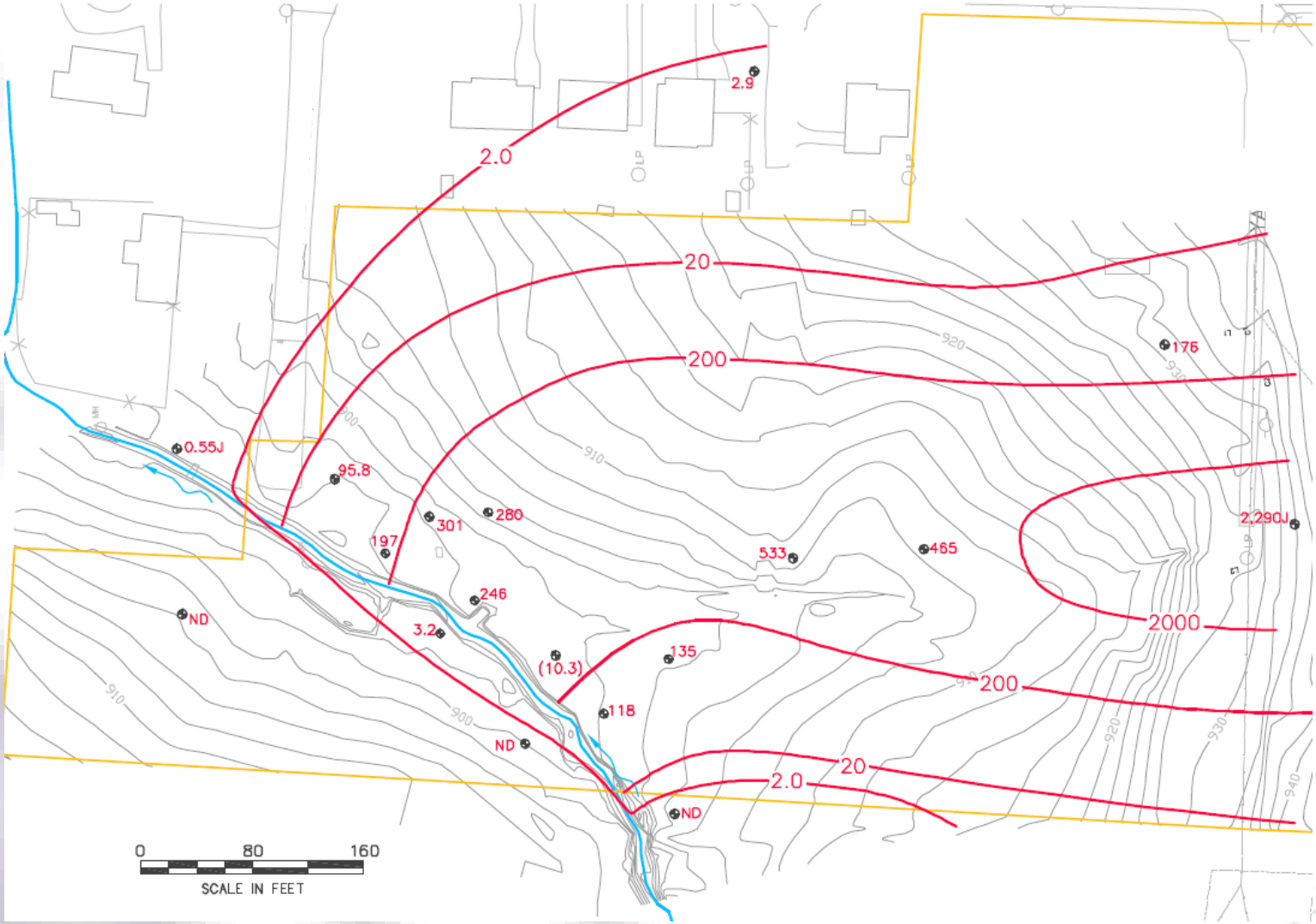
- Successful PRB injection at operating gas station
- Immediate (“trap”) and long term (“treat”) reduction of BTEX and PHCs
- SVE, P&T, ISCO – PHC mass reduction & LNAPL removal
- Trap and Treat PRB finished the remediation work
  - Long term passive solution

Case Study #2
PRB for VOCs Migrating into Creek

Case Study – VOCs in Creek

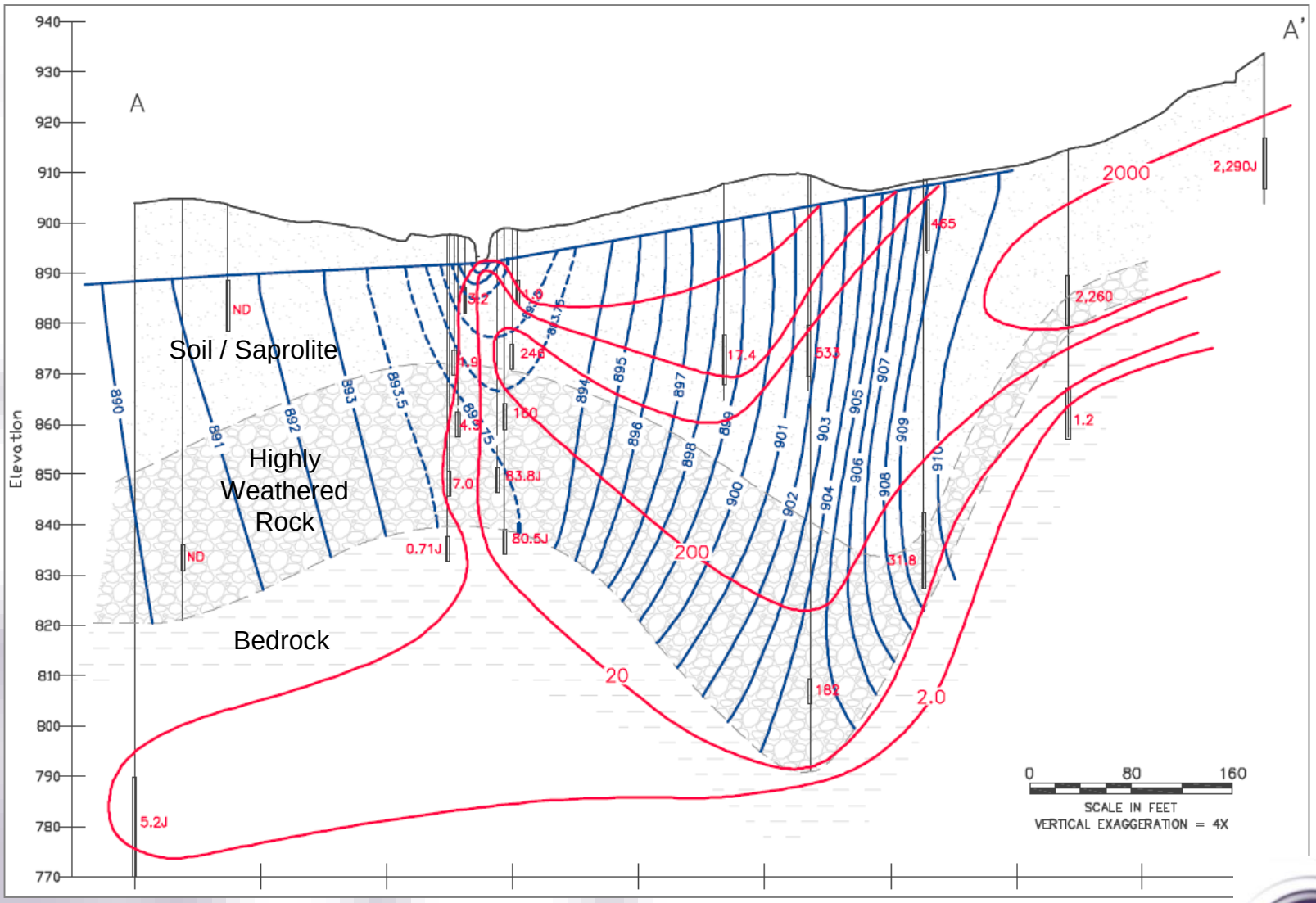
- Historical PCE groundwater contamination
  - Plume migrating into creek
- Contamination
  - Plume: >2,200 ug/L PCE up-gradient of creek
  - Porewater: 270 µg/L (0.6 m below stream)
  - Creek: up to 20 ug/L PCE in water (average 3 to 4 ug/L)
- Work
  - Trap and Treat PRB pilot (2013) and full-scale (2015) PRB
  - Used BOS-100®

Case Study – VOCs in Creek



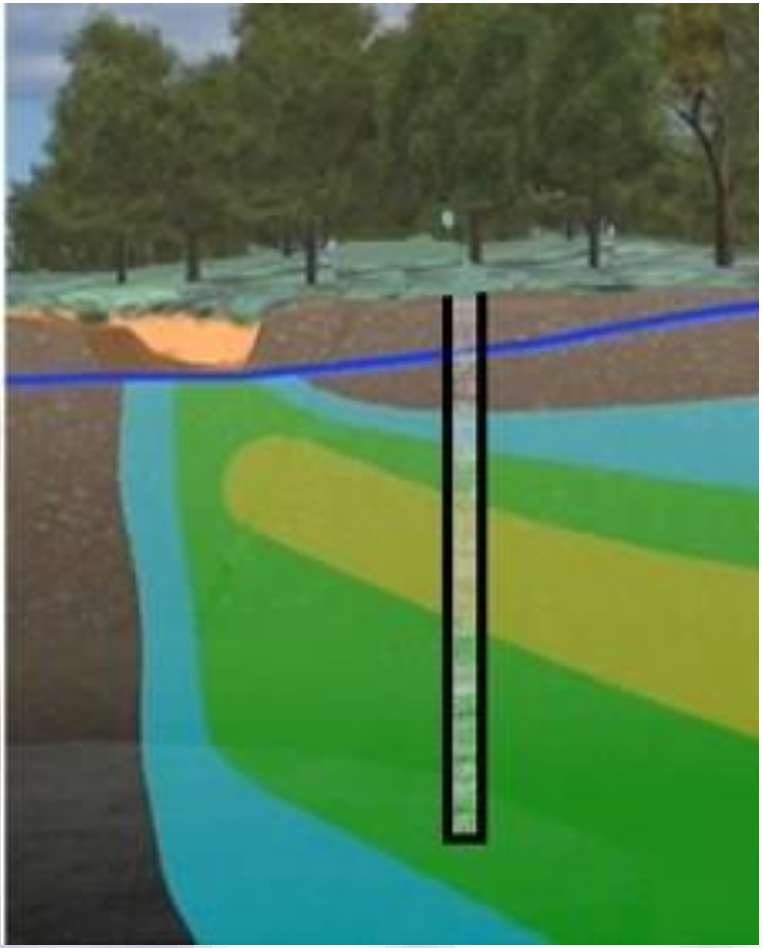
Source: AST Environmental

Case Study – VOCs in Creek

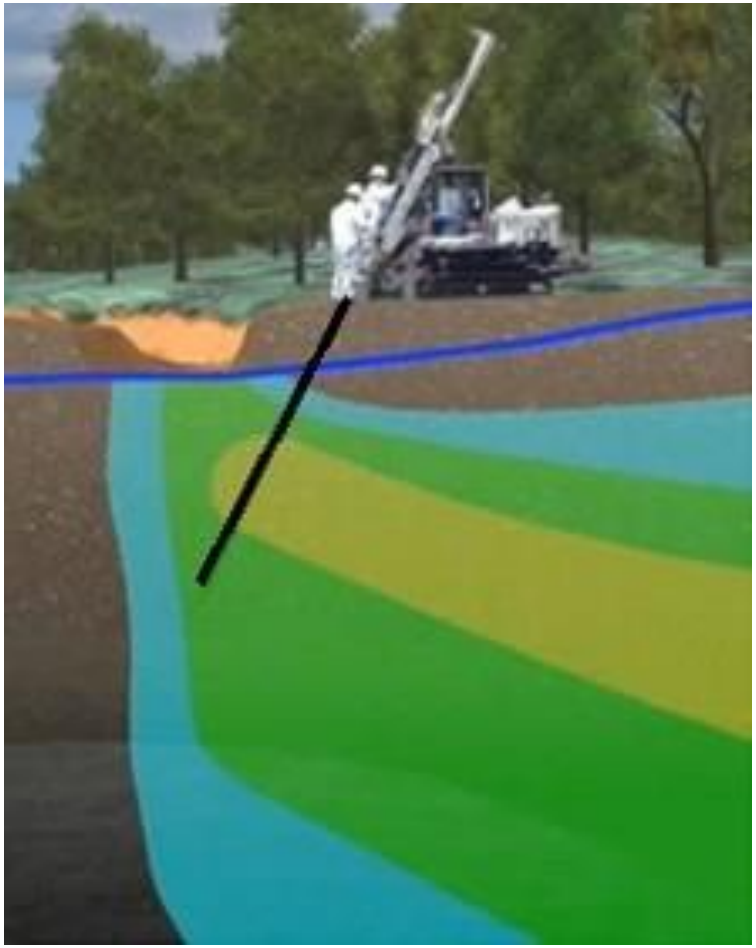


Source: AST Environmental

Case Study – VOCs in Creek



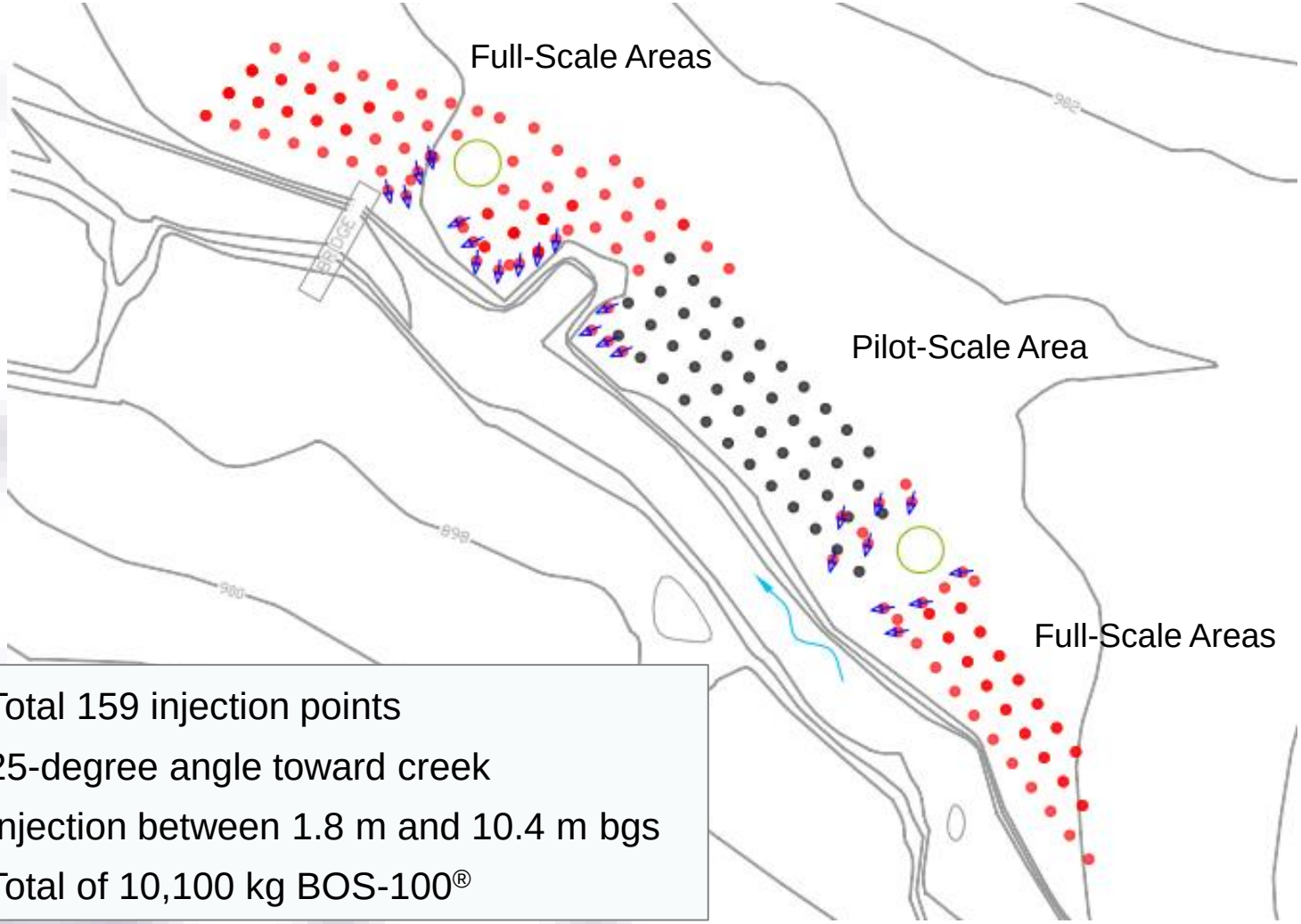
Vertical PRB



Angled Injected PRB

Source: AST Environmental

Case Study – VOCs in Creek



- Total 159 injection points
- 25-degree angle toward creek
- Injection between 1.8 m and 10.4 m bgs
- Total of 10,100 kg BOS-100®

Source: AST Environmental

Case Study – VOCs in Creek

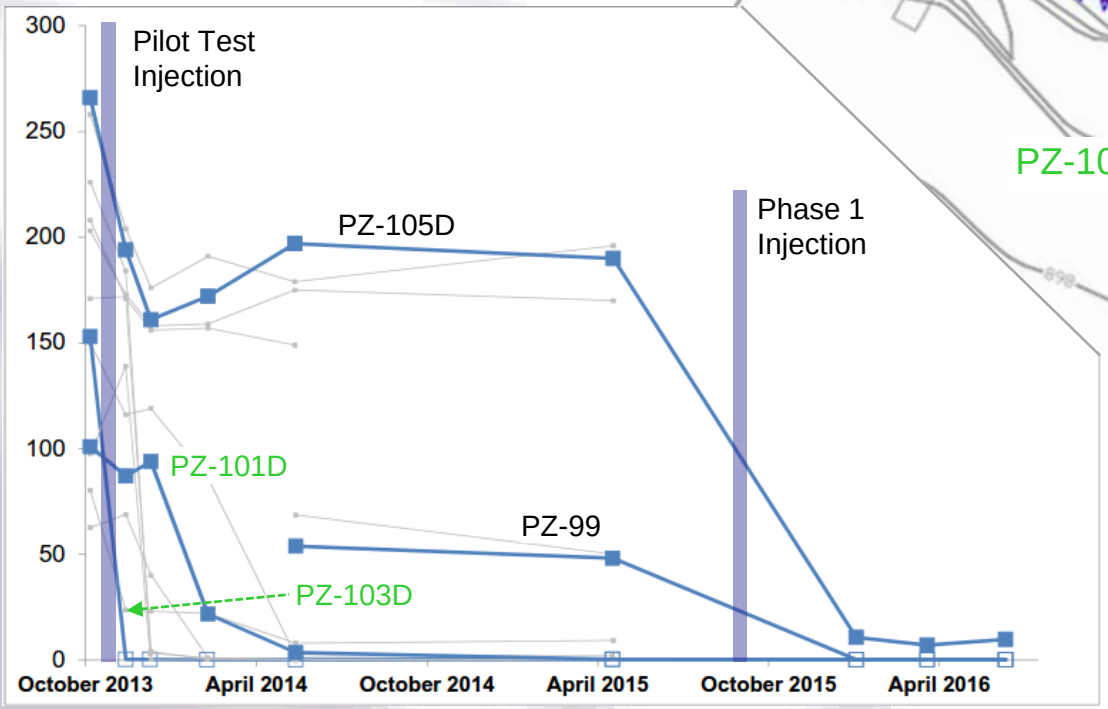
Source: AST Environmental

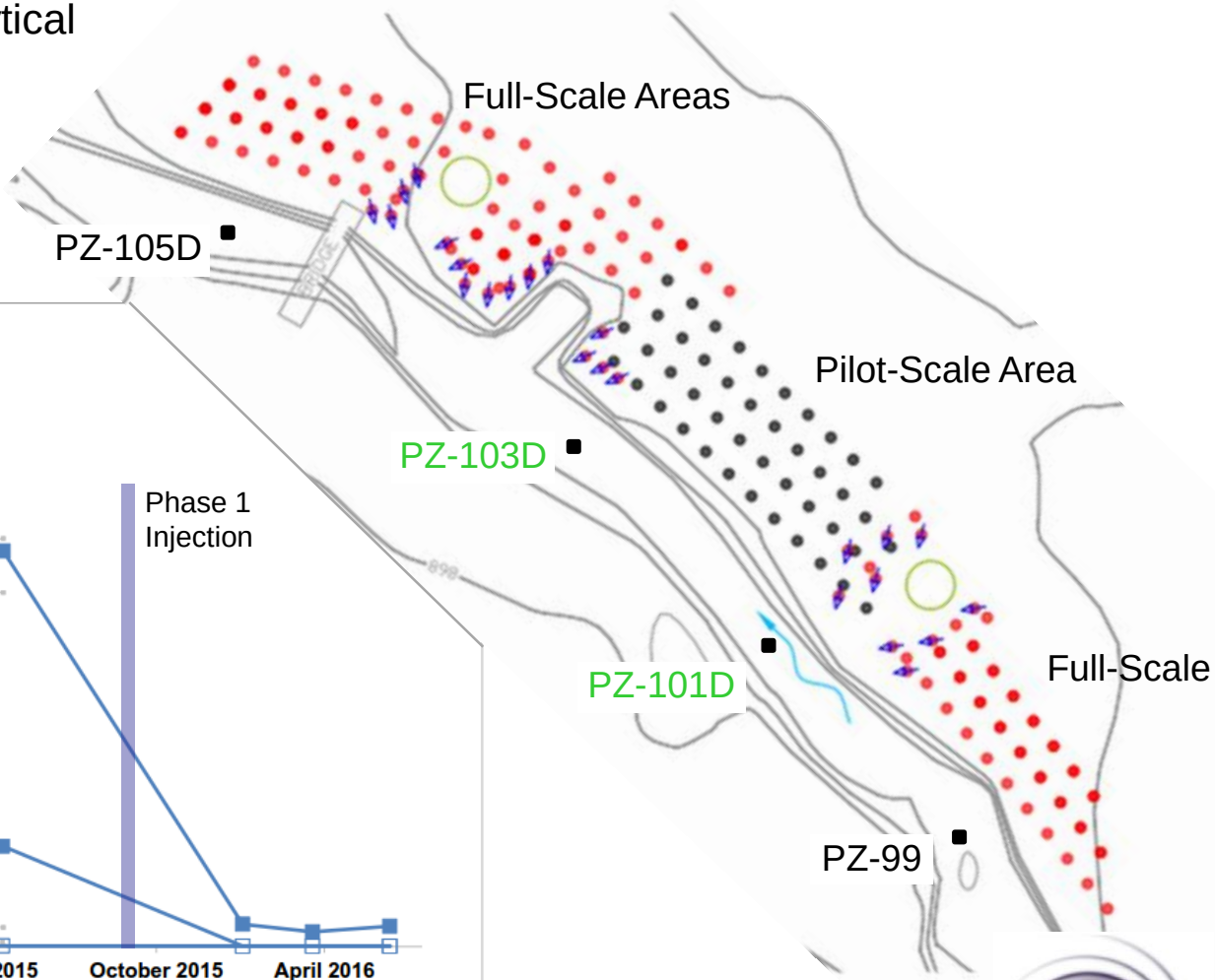
Case Study – VOCs in Creek

Source: AST Environmental

Case Study – VOCs in Creek

Subsurface Groundwater Analytical

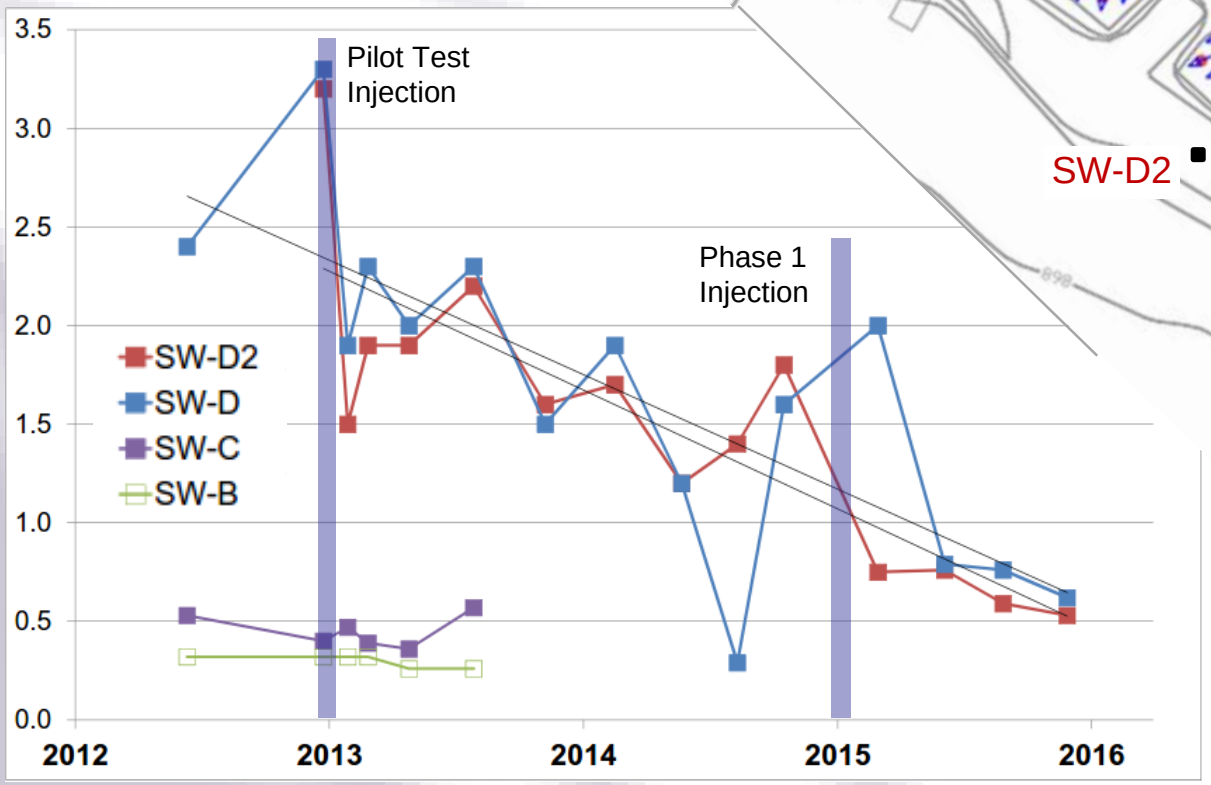


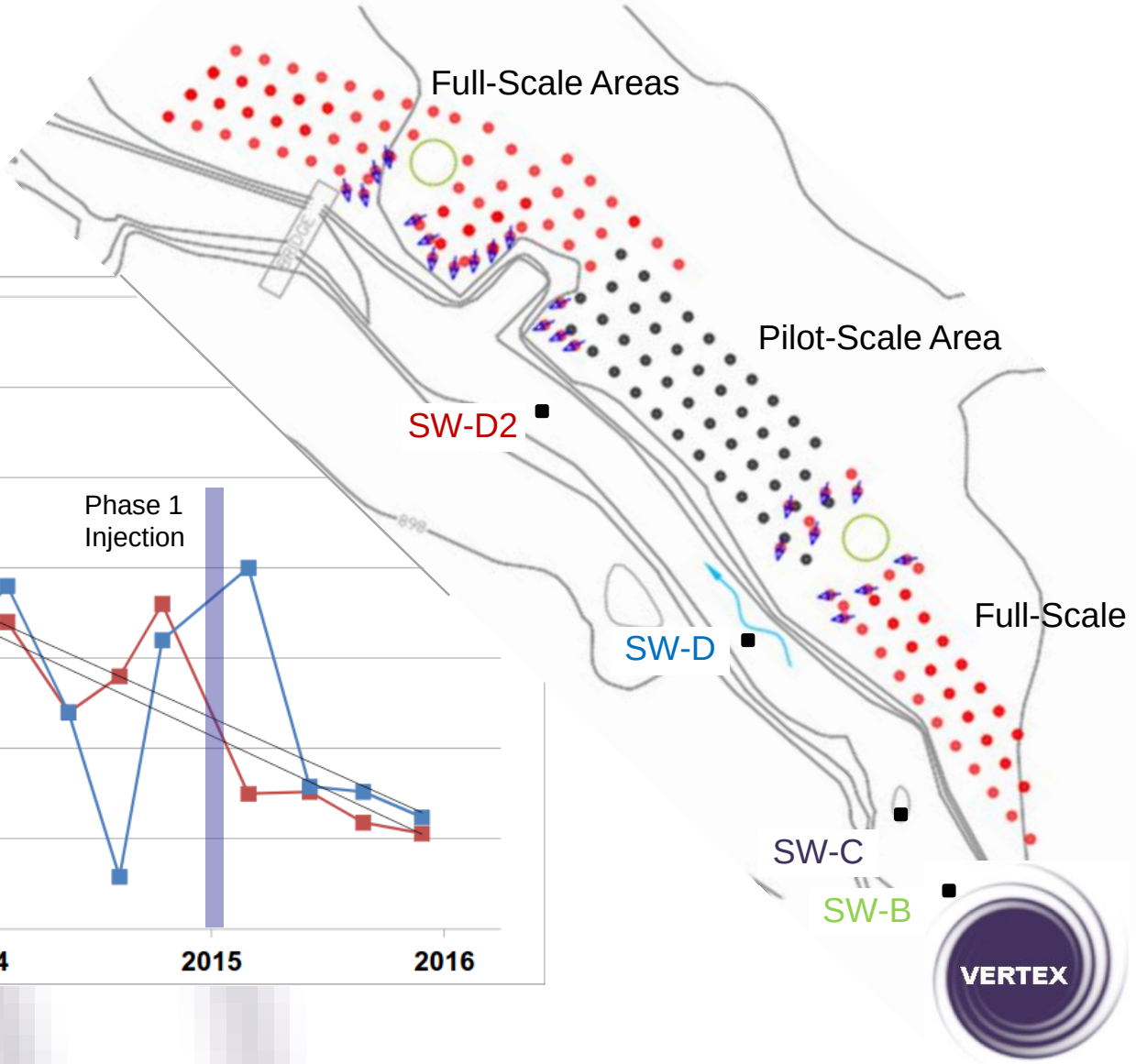


Source: AST Environmental

Case Study – VOCs in Creek

Surface Water Analytical





Source: AST Environmental

Case Study – VOCs in Creek

Conclusions

- PRB injection beside and beneath creek
- Trap and Treat of PCE beneath and within creek
  - Using BOS-100®
- Successful Injected PRB

PHC PRB
Slow Release Oxidant

Slow Release Oxidant PRB

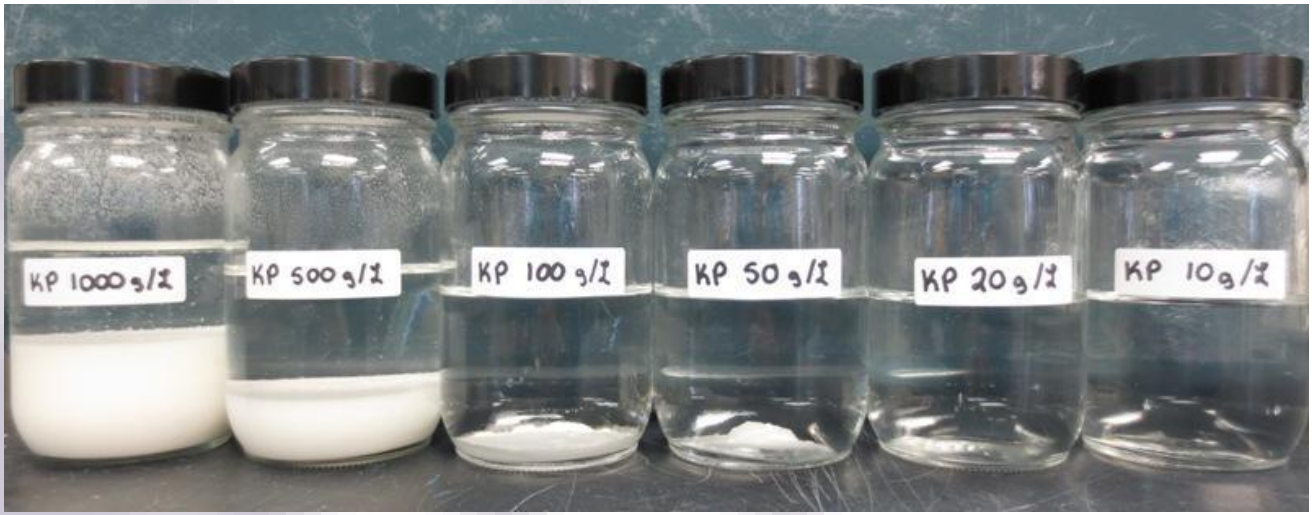
- Mechanisms:
  - Oxidant destroys organic contamination
  - Reaction occurs in the aqueous phase
- Sodium persulphate (activated) commonly used for ISCO
- Injected typically at 20% solution
- Can SP be used in PRB? Problem with solubility for SP

Temperature (^{o}C)	Sodium Persulphate Solubility (g/L)	Potassium Persulphate Solubility (g/L)
0	480	17
10	540	29
20	570	47

- SP: Sodium Persulphate: $Na_2S_2O_8$
- KP: Potassium Persulphate: $K_2S_2O_8$
- Solubility different due to ion (Na^+ vs K^+)

Slow Release Oxidant PRB

Reactors at 20°C
Sodium persulphate
Solubility = 570 g/L



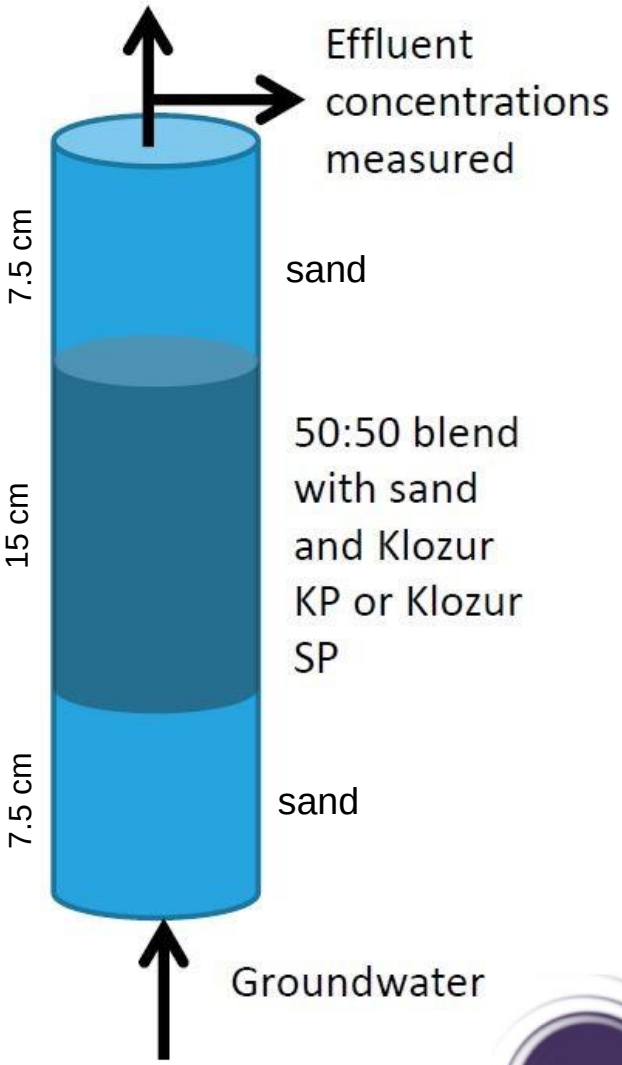
Reactors at 20°C
Potassium persulphate
Solubility = 47 g/L

Source: PeroxyChem

VERTEX

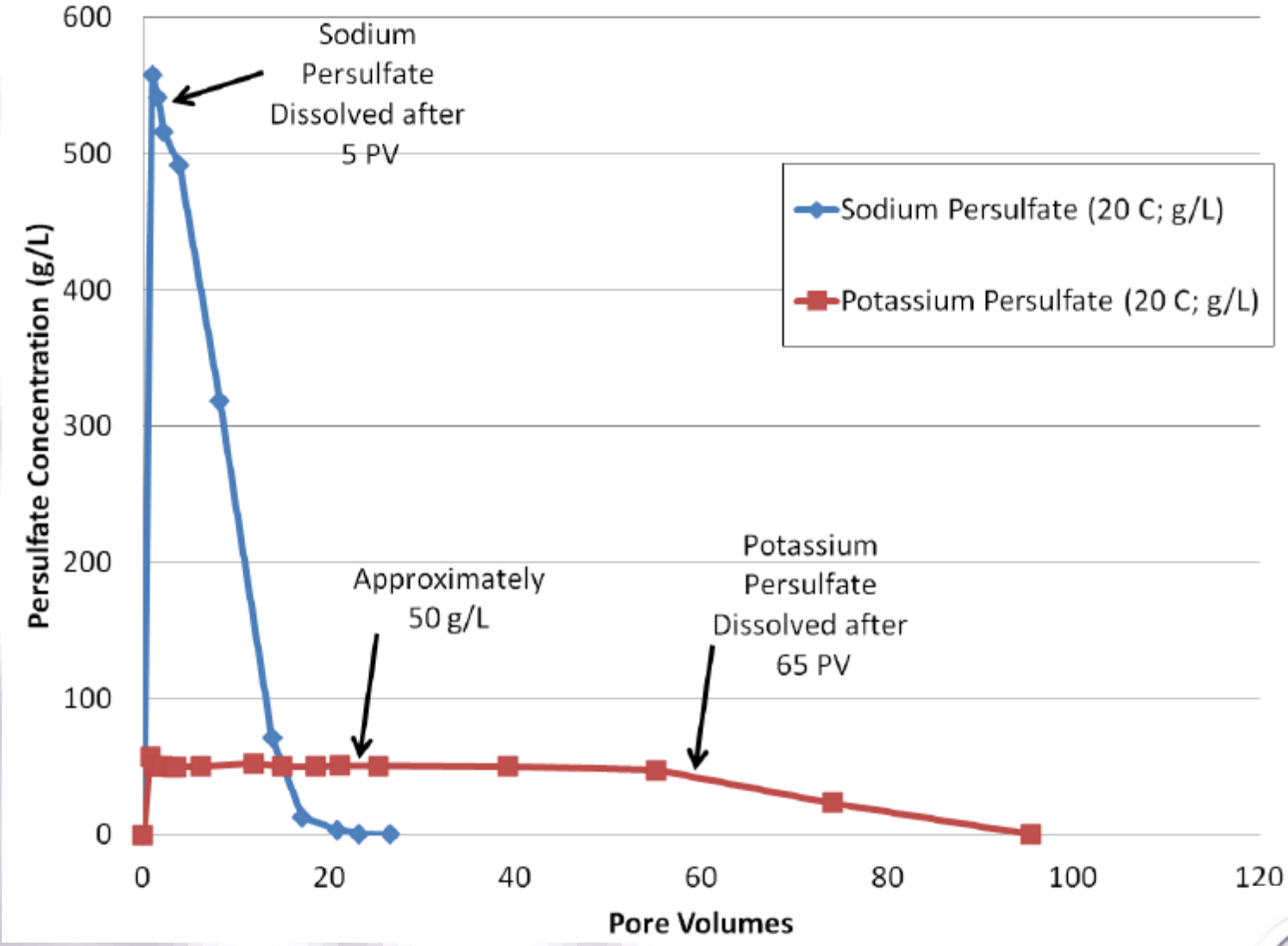
Slow Release Oxidant PRB

- Assess Use of Oxidant in PRB
  - 30 cm column
  - 15 cm oxidant/sand blend
  - 300 g of oxidant
- Four columns
  - 20°C Sodium Persulphate
  - 20°C Potassium Persulphate
  - 2°C Sodium Persulphate
  - 2°C Potassium Persulphate



Source: PeroxyChem

Slow Release Oxidant PRB: Column @ 20°C

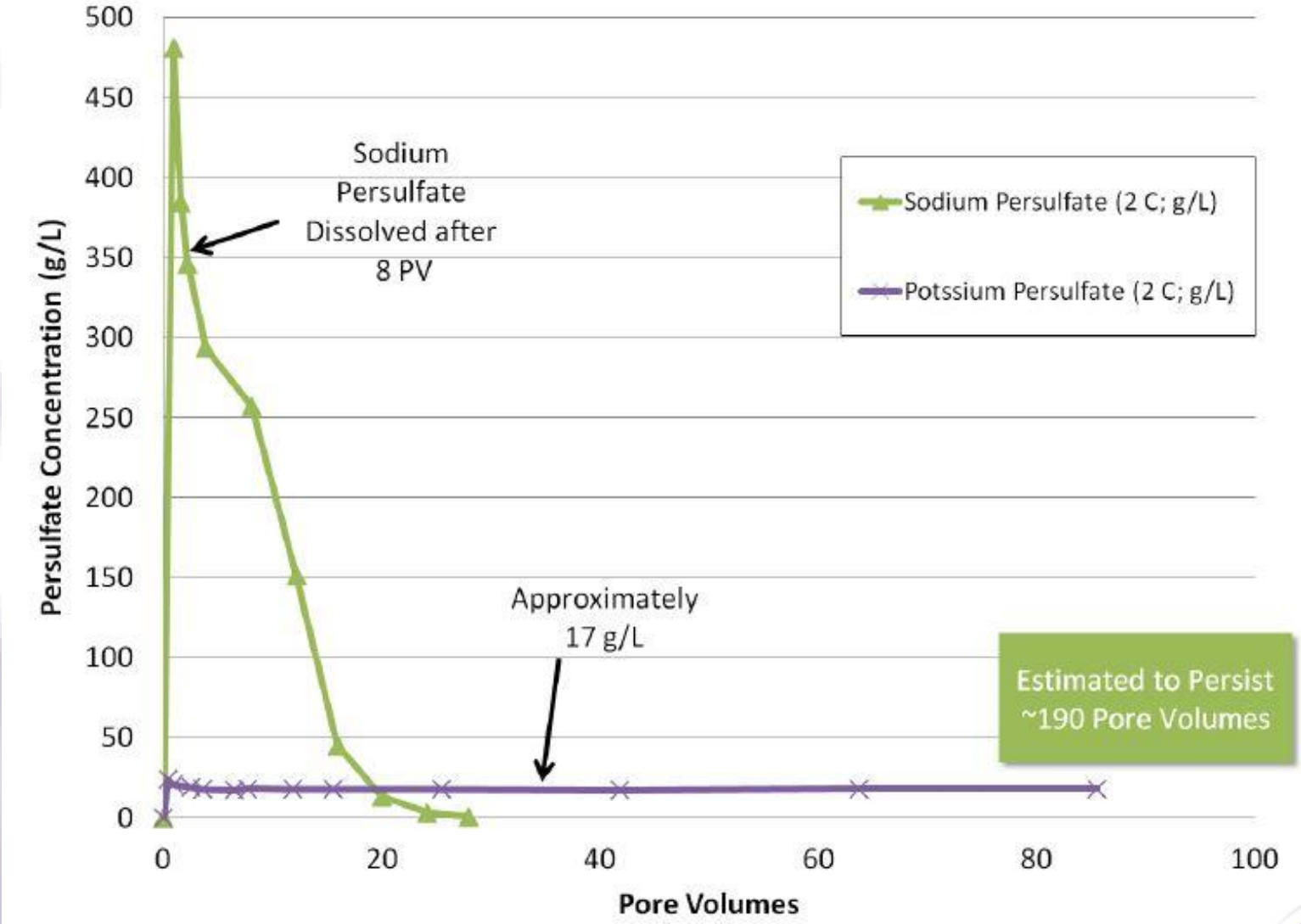


Consistent rate of potassium persulphate release – consistent with solubility limit

Source: PeroxyChem

VERTEX

Slow Release Oxidant PRB: Column @ 2°C



Consistent rate of potassium persulphate release – consistent with solubility limit

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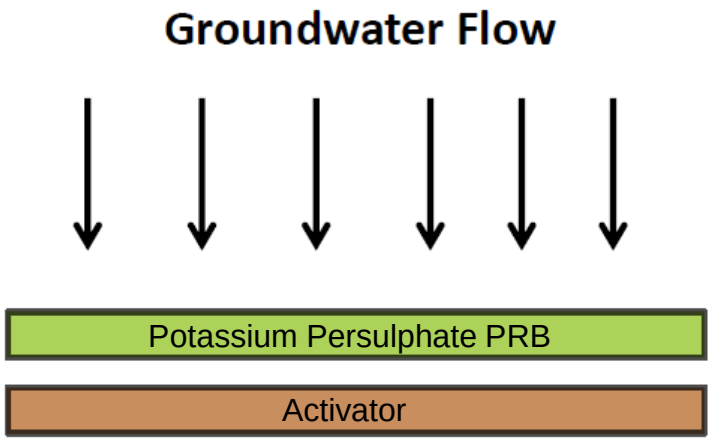
Slow Release Oxidant PRB



Conceptual Klozur KP Persistence (months)					
	Temp (◦C)	0	10	20	25
	Solubility (g/L)	17	29	47	59
Groundwater Velocity (ft/yr)	5	679	398	246	196
	10	339	199	123	98
	20	170	100	61	49
	50	68	40	25	20
	100	34	20	12	10
	500	7	4	2	2

Conceptual Design

- Oxidant PRB
- 15 m long, 3 m tall, 1.5 m wide
- 50% wt potassium persulphate

Source: PeroxyChem

Slow Release Oxidant PRB

Potassium Persulphate Soil Mixing PRB

Closing Thoughts

PHCs & Passive Treatment

- Permeable Reactive Barriers (PRBs) for VOCs (1990s)
- PRBs for PHCs becoming main stream

Why PRBs?

- Passive, Long Term
- Can be inexpensive compared to Source Treatment
- Effective way to address back diffusion issues
- Excellent for low permeability soils
- Various approaches – Injection, Dug PRB, Soil Mixing

PRBs for PHCs

- Trap and Treat – using BOS®
- Slow Release Oxidant – using Potassium Persulphate

Acknowledgements

- Mike Mazzarese, AST Environmental, Inc.
- Brant Smith, PeroxyChem

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Questions?

Thank You for
Your Time

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