Case Study: How to Avoid Failures in the Design and Installation of Permeable Reactive Barriers

RemTech – Banff, AB

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Presenters

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- Vice President, Vertex Environmental Inc.
- B.A.Sc., Civil/Environmental Engineering, University of Waterloo
- 30+ years environmental engineering; 25 in consulting and 5 as a remedial contractor

John Clarke, P.Eng.

- Senior Project Manager, Milestone Environmental Contracting Inc.
- B.Sc. Hons., Earth Sciences, Memorial University of Newfoundland; B.Eng., Civil Engineering, McGill University
- 25+ years in environmental engineering, 21 as a remedial contractor

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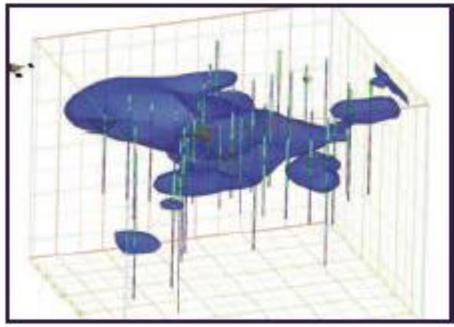
In-Situ Remediation

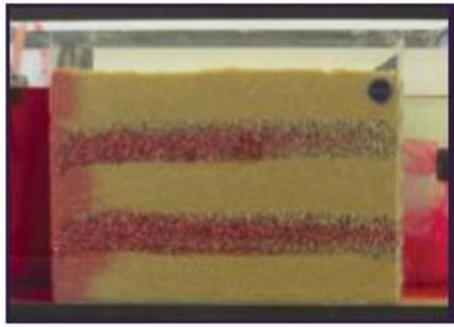
Ex-Situ Remediation

High Resolution Characterization

Treatment Systems



Remedial Design



Bench-Scale Testing

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Soil and Groundwater Remediation, Water Treatment

Passive Reactive Barrier Walls

Groundwater Cut-off Walls (soil-bentonite, cement, concrete)

Lagoon and Pond Remediation

Remedial Excavation with Shoring or Underpinning

Soil Stabilization

***In-situ* Remediation**

Landfill Closure and Capping, Mine Reclamation

Design-build Remediation / Contracting

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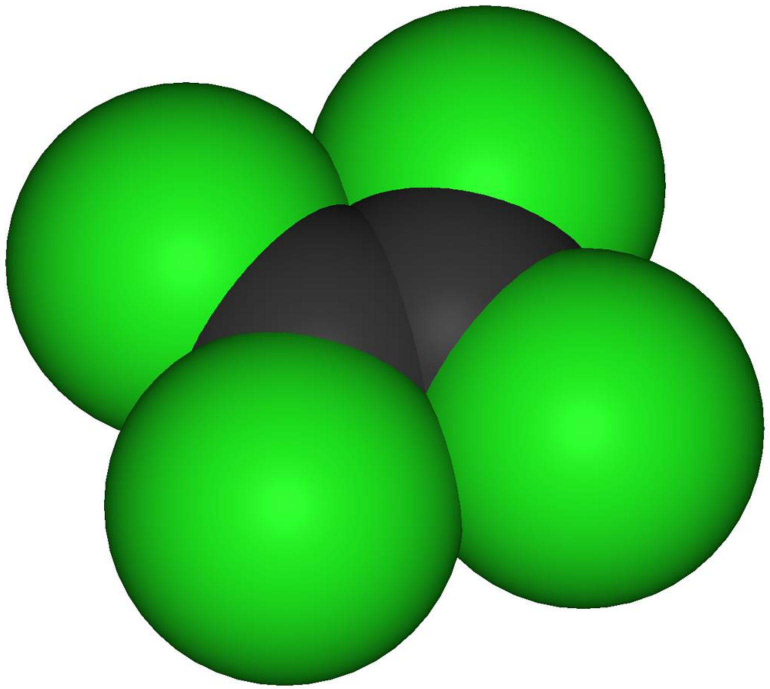
Presentation Overview



- Permeable Reactive Barriers
- Site Background & Project Objective
- Overview of Site Conditions
- Bench-Scale Testing & Preliminary Design
- High-Resolution Site Characterization
- Updated Final Design
- Full-Scale Installation
- Quality Assurance / Quality Control
- Performance Monitoring
- Lessons Learned
- Questions

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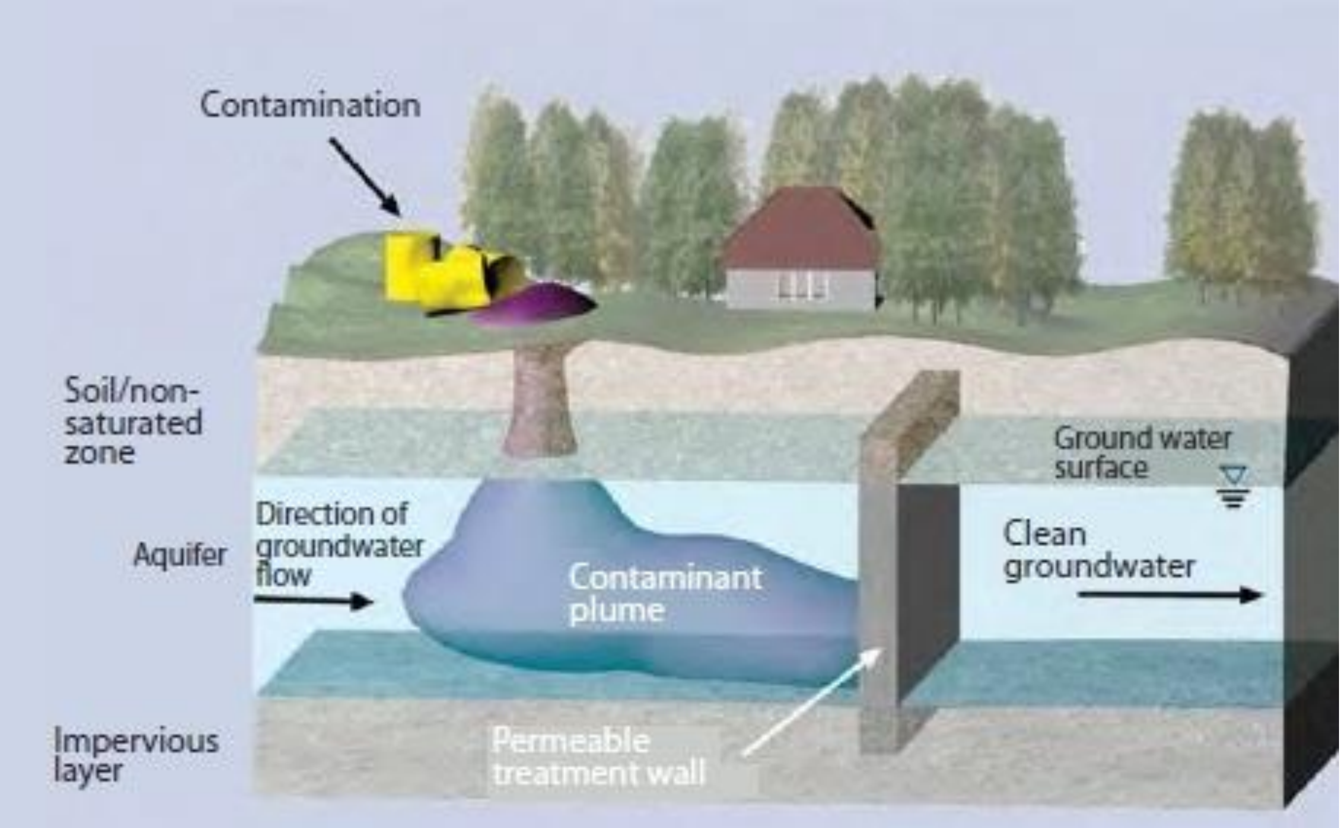
Permeable Reactive Barriers (PRBs)

Permeable Reactive Barriers (PRBs)



- PRBs intercept and treat contaminated groundwater plumes (passive)
- Allow groundwater to flow through unimpeded
- Different reactive media for different contaminants
- Original zero-valent iron (ZVI) PRBs ("Iron Walls") installed in mid-1990 still functional
- Can be dug or injected
- Sustainable (no energy use to operate)

Site Background & Project Objective

Site Background & Project Objective

- Municipal client tendered a competitive bid contract for a “Pump & Treat” system to hydraulically contain contaminated groundwater plume from suspected off-site spill of PCE
- Milestone offered an alternative design to install a PRB that would achieve similar results and significantly reduce future operation and maintenance costs for the municipality
- Milestone and Vertex teamed to provide proof-of-concept for alternative design to the municipality and then to design and install the PRB
- Remedial objective was to prevent the plume of contaminated groundwater from continuing to migrate across the site by reducing CVOC concentrations to below PSS levels

Overview of Site Conditions

Overview of Site Conditions

- Contamination initially identified by former property owner in 1998
- Municipality purchased the site 2008
- Converted into a parking lot / farmers market
- Main groundwater contaminants were volatile organic compounds (VOCs); primarily tetrachloroethylene (PCE) and its degradation products
- No DNAPL suspected to be present at the site (i.e., off-site source)
- Main pathway of concern was via groundwater flow through the overburden soils

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Overview of Site Conditions

- Geology:
  - Sand and gravel fill with occasional cobbles and organic matter
  - Native soil consisting of sand, silty sand and silty clay till
  - Some reported “flowing” sands
  - Clay till served as “confining layer”
  - Limestone / dolostone bedrock
  - Soil thicknesses were approximately 6 to 7 mbgs
- Hydrogeology:
  - Water levels in the overburden at approx. 2.4 to 3.4 mbgs
  - Horizontal hydraulic gradient of approx. 0.03 to 0.06
  - Hydraulic conductivity of approx. 1.2E-07 to 3.5E-04 m/s
  - Estimated groundwater flow velocity of 40 m/yr

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Overview of Site Conditions

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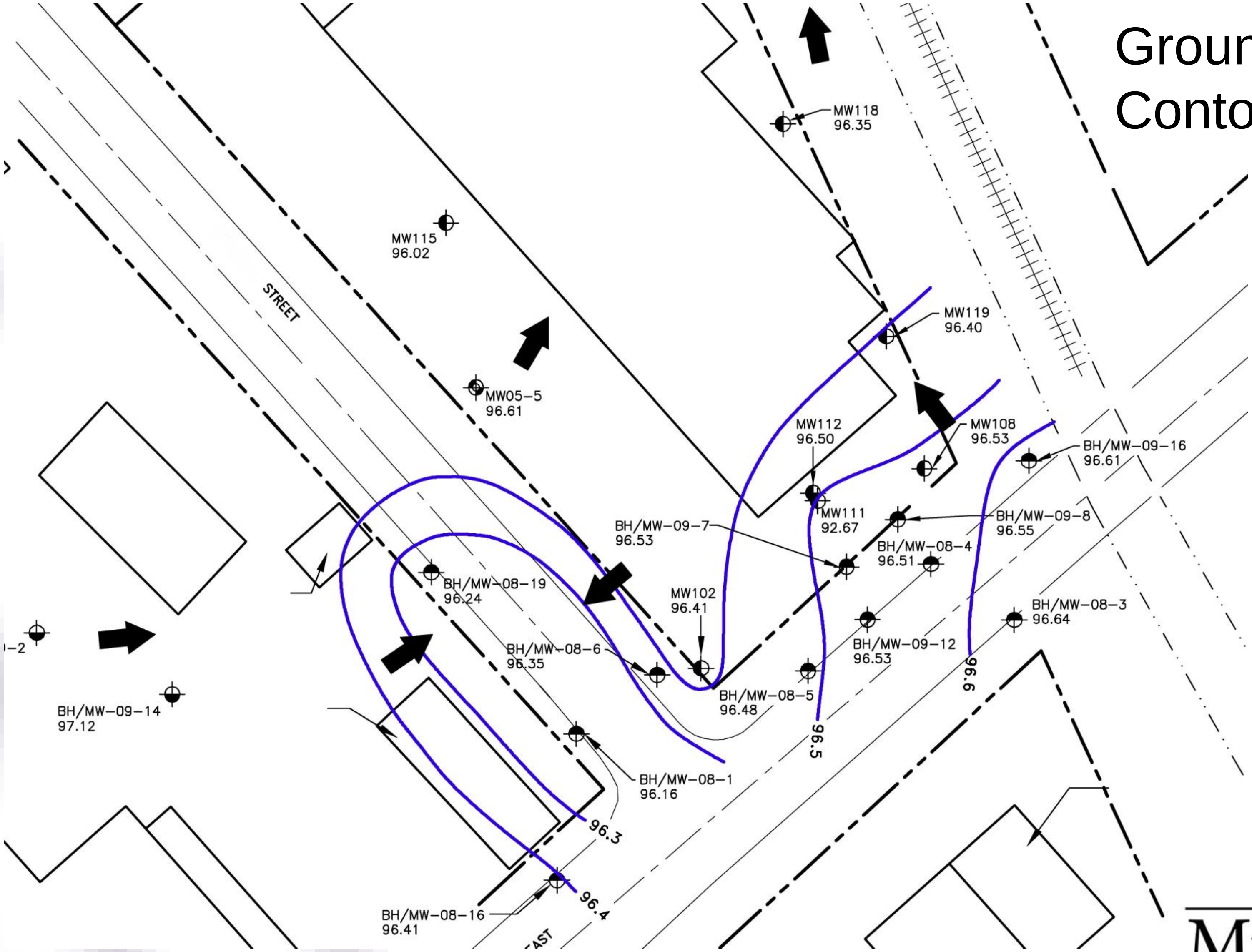
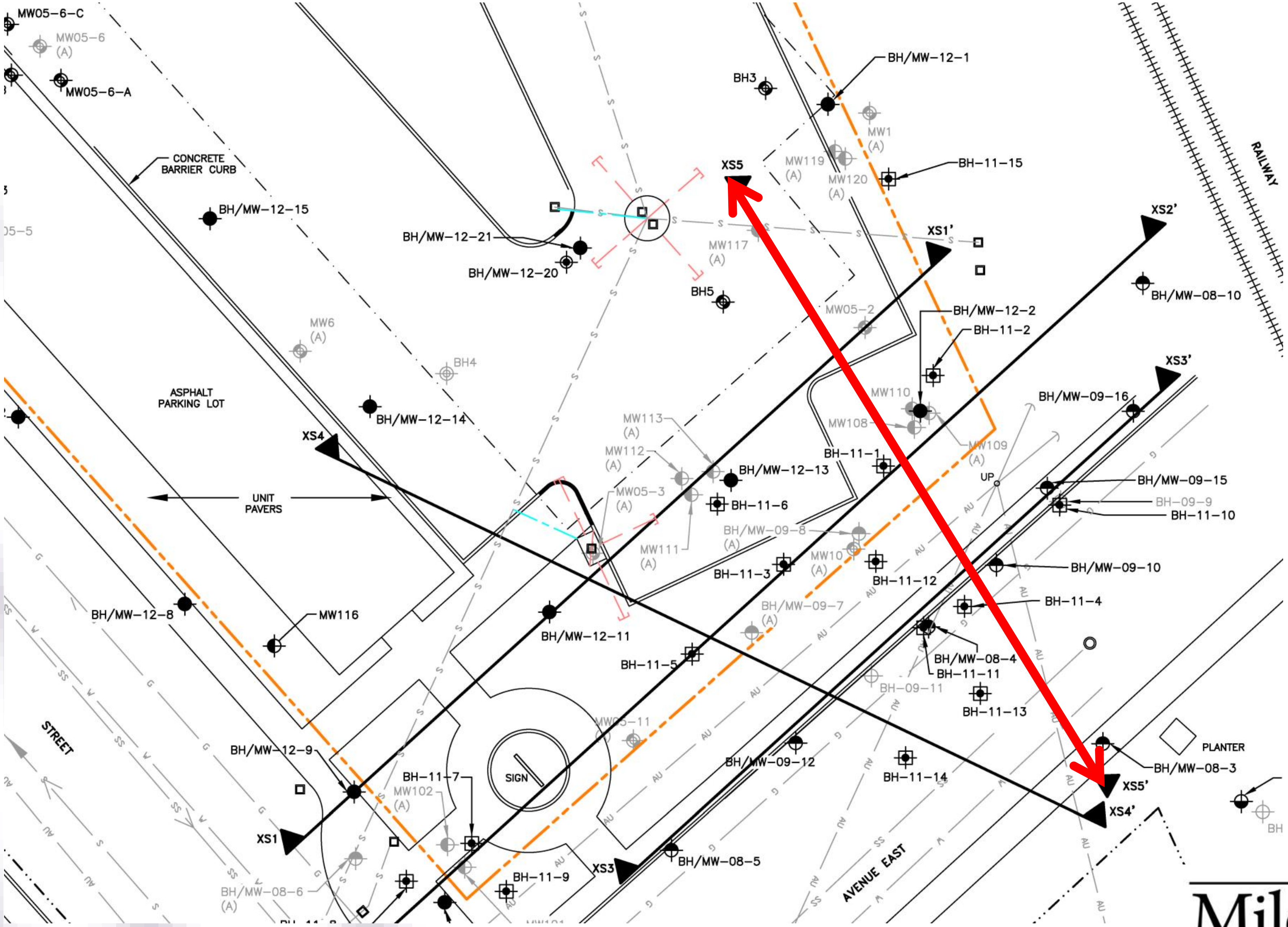
Overview of Site Conditions

Groundwater Elevation Contours and Flow



Overview of Site Conditions



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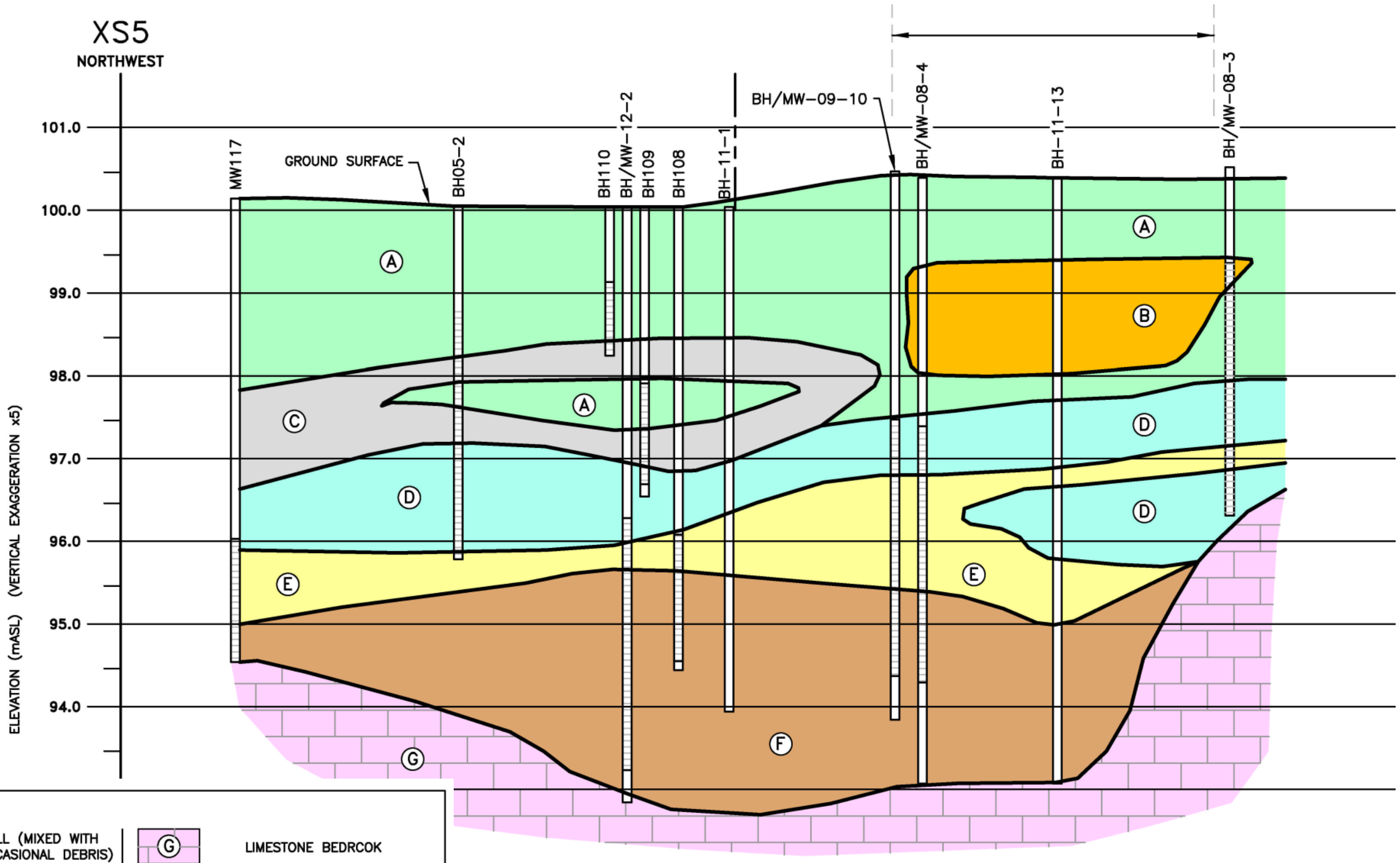
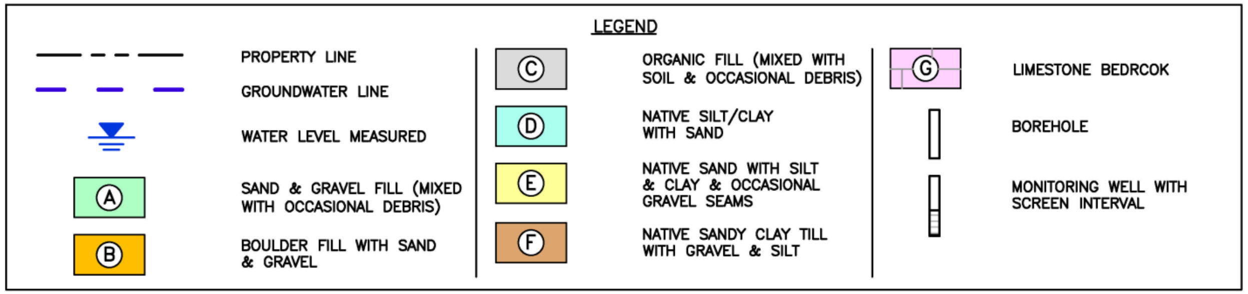
Overview of Site Conditions

Geologic Cross-Section





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Overview of Site Conditions

PCE concentrations in groundwater April 2012

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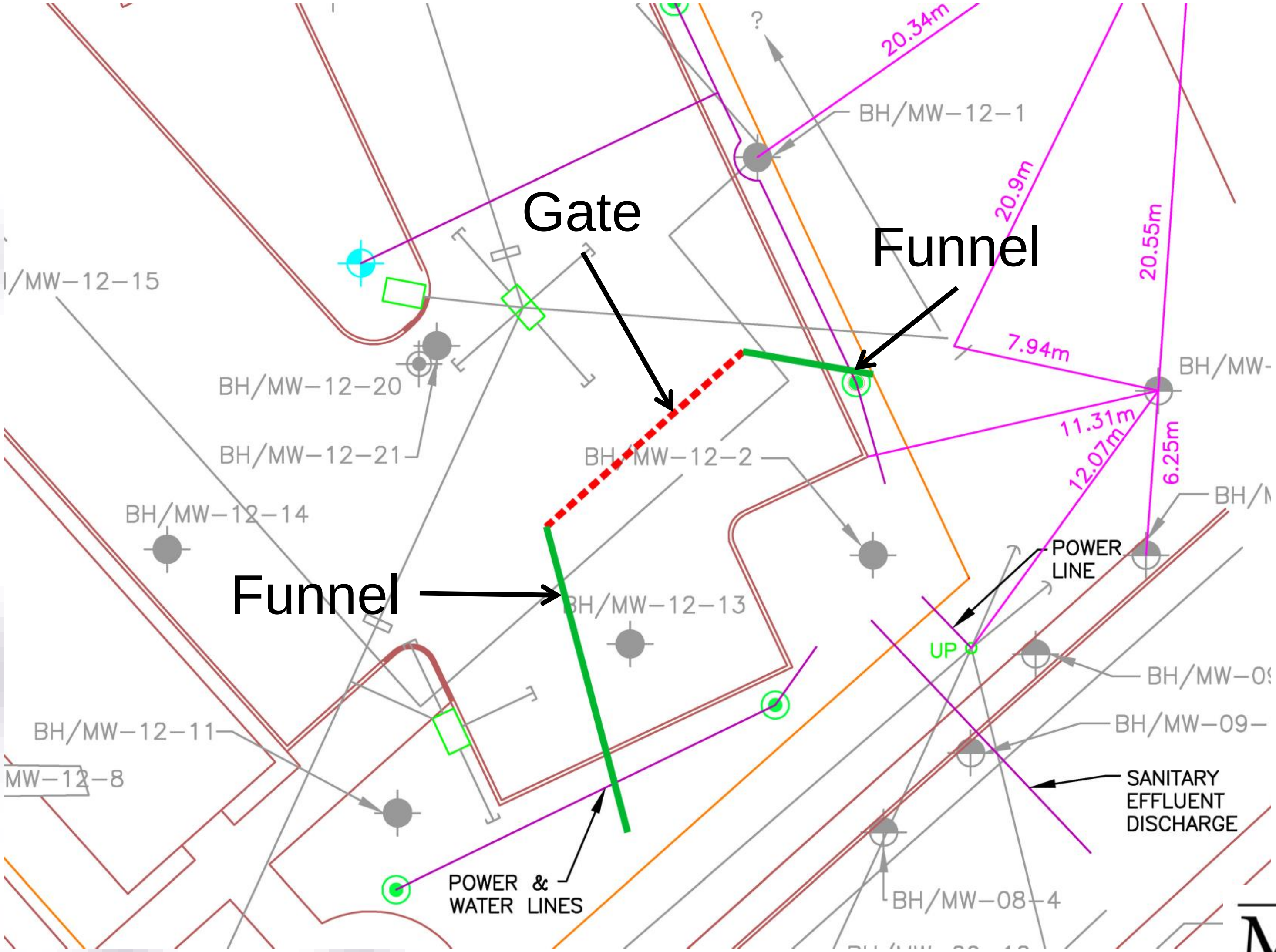
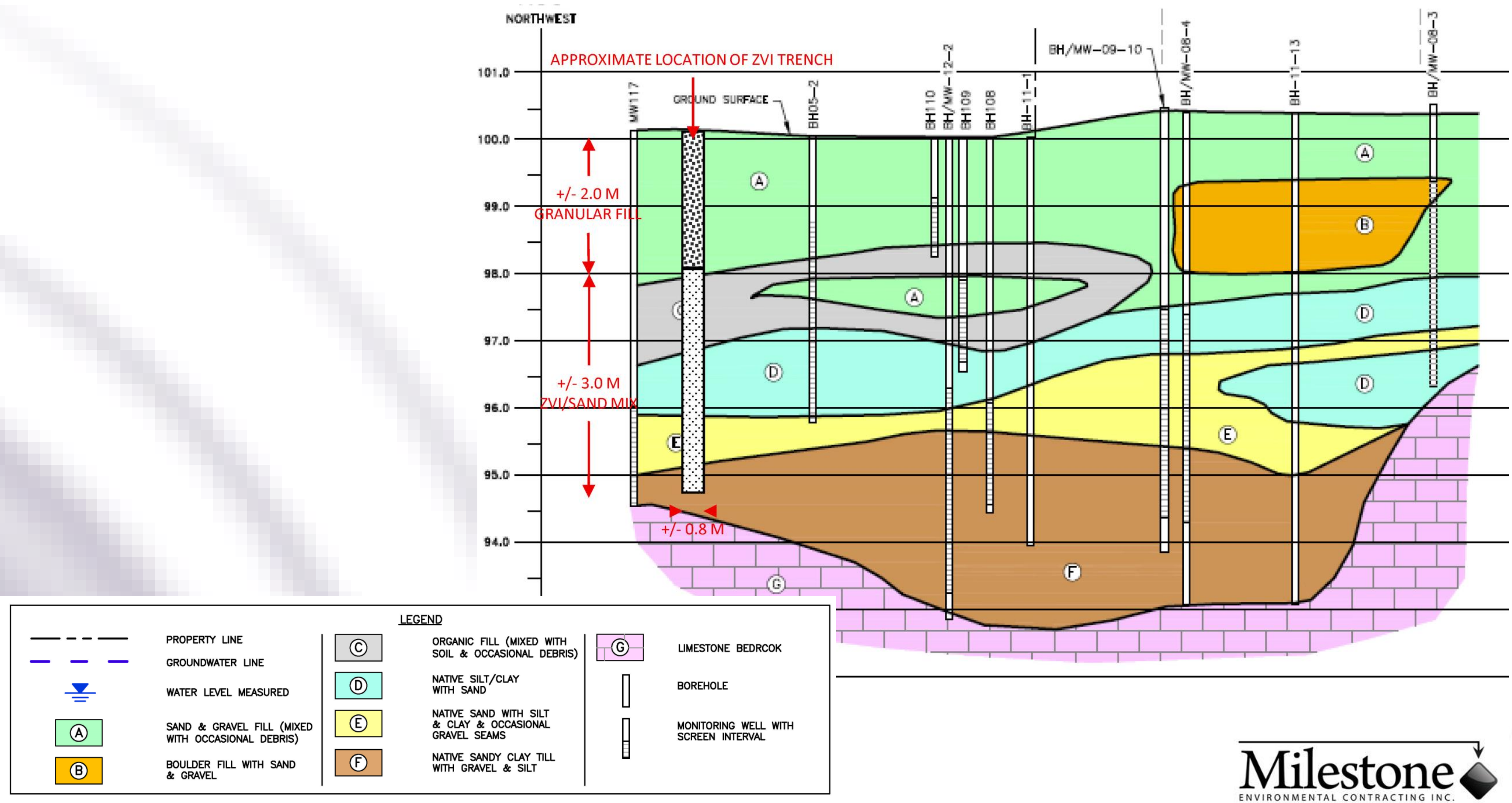
Preliminary Design & Bench-Scale Testing

Preliminary Design

Preliminary Design



Preliminary Design



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Bench-Scale Testing

- The municipal client did not have direct experience with the ZVI PRB technology
- Bench-scale treatability testing was offered to provide the needed "proof-of-concept" and assurances to client
- Samples of contaminated groundwater obtained from the site and mixed with combinations of ZVI (10%, 20% & 30%) and sand

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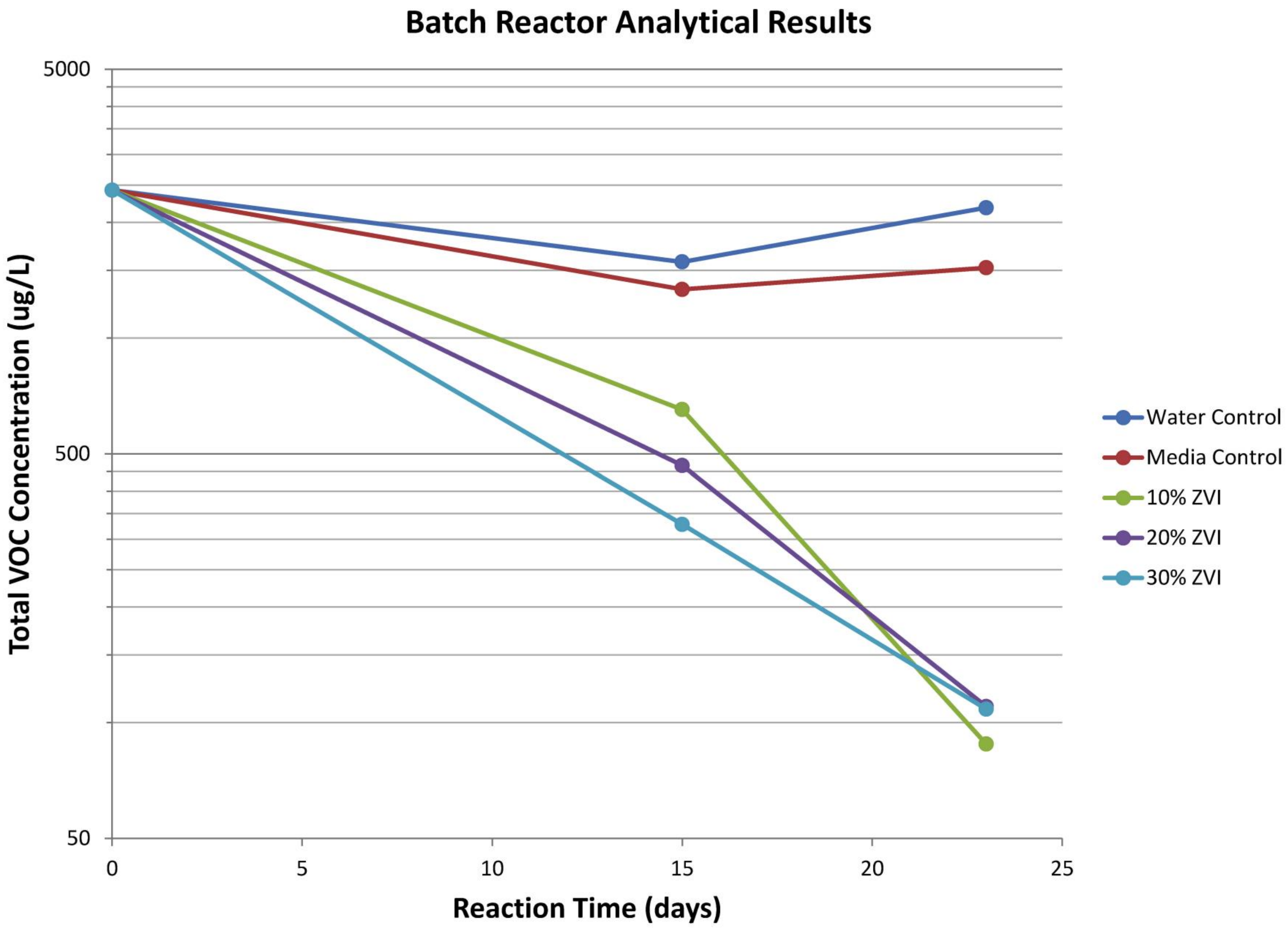
Bench-Scale Testing



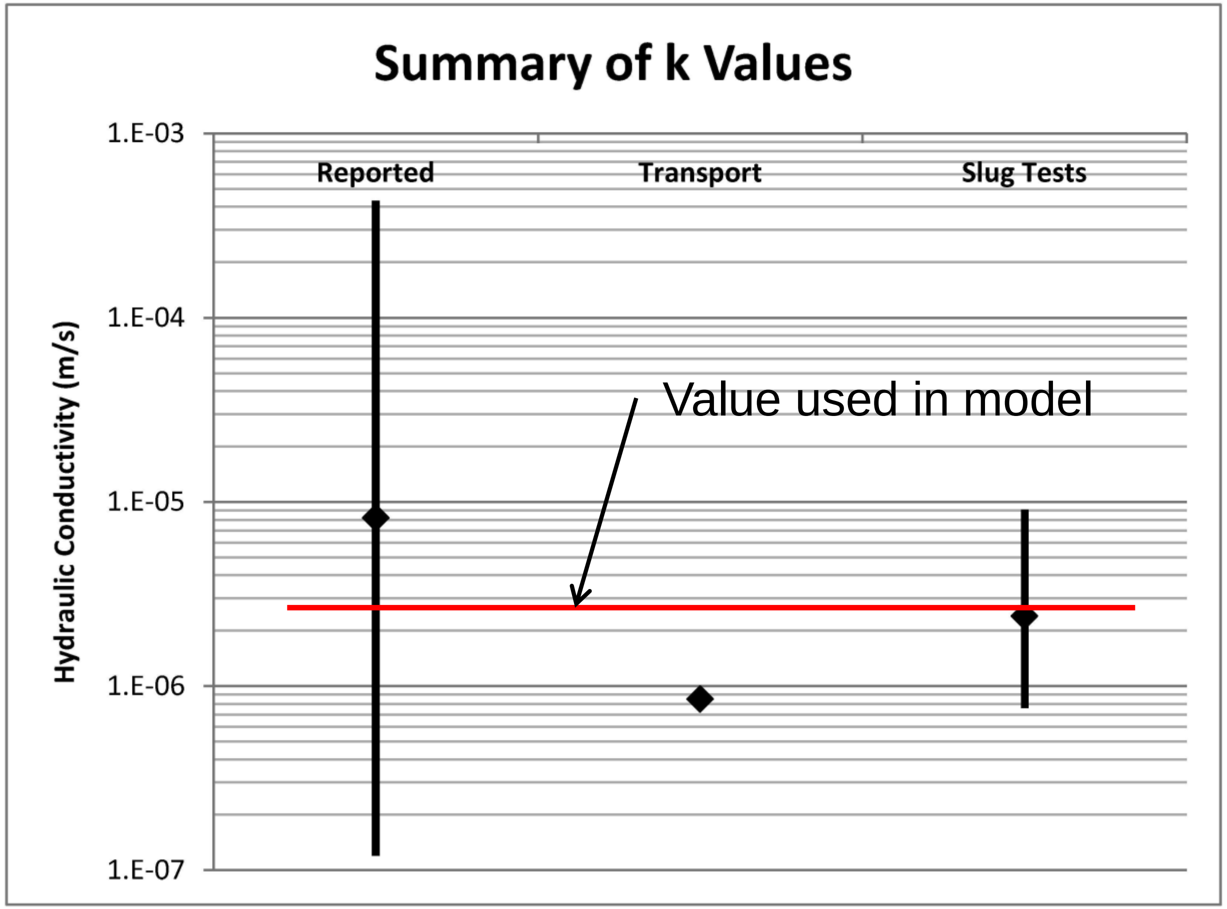
- Parameter-specific degradation half-lives calculated based on information obtained from bench-scale tests
- Compared to literature references as a reality check
- >95% reduction in total CVOCs achieved over 22 days of testing

Preliminary Design & Bench-Scale Testing

- Preliminary PRB design was determined using a computer model that assessed:
  - CVOC concentrations in groundwater and target treatment concentrations
  - Physical, geological and hydrogeological conditions of the soils at the site and in the planned PRB
  - CVOC half-lives from the bench-scale testing (first order decay)
  - Groundwater temperature conditions for site
  - Groundwater flux balance through “funnel & gate” PRB configuration
- In order to meet PSS levels using reported groundwater flow velocities a PRB 1.0 m thick would need to contain 37% ZVI

Preliminary Design & Bench-Scale Testing

- Sensitivity analysis completed on all input variables
- Model (and therefore results) most sensitive to hydraulic conductivity
- k-values varied by over 3 orders of magnitude, other parameters by <1
- Recommended additional site characterization to reduce uncertainty in predicted results



High-Resolution Site Characterization

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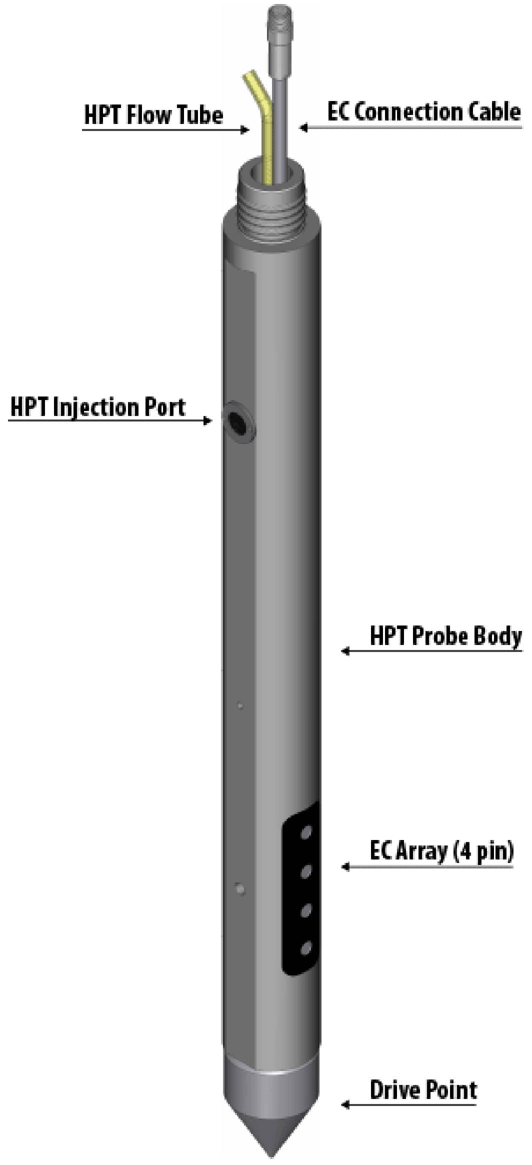
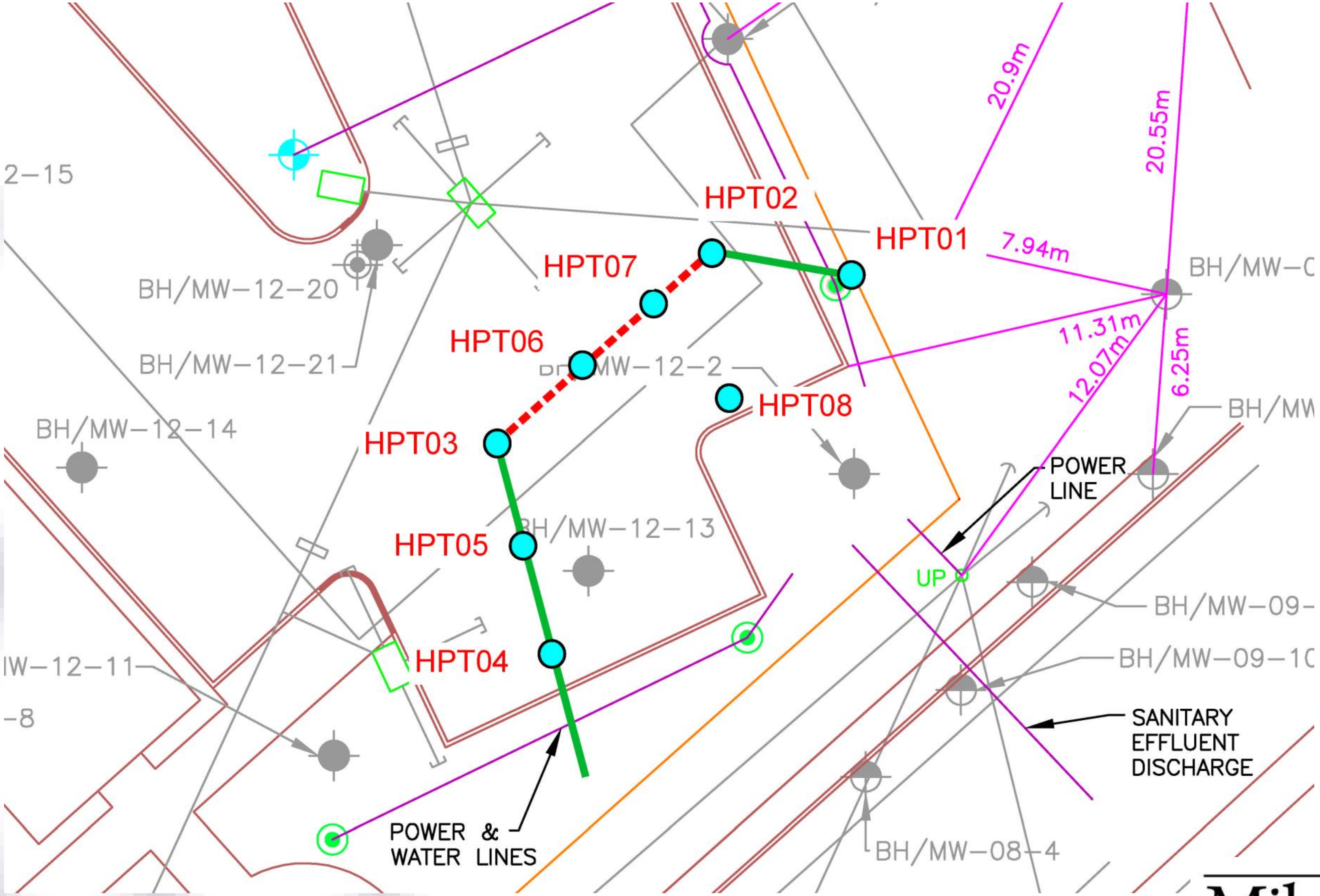


Hydraulic Profiling Tool (HPT)

- Direct-push
- Assess formation permeability
- Water injected into the ground; flow and back-pressure measured
- EC: Estimate of soil type
- Identifies location of water table (no wells)
- Result: Empirical estimate of hydraulic conductivity on a cm scale
- HPT deployed at the site to find preferential flow paths in the saturated zone and to define lower “confining layer”

High-Resolution Site Characterization



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High-Resolution Site Characterization

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High-Resolution Site Characterization

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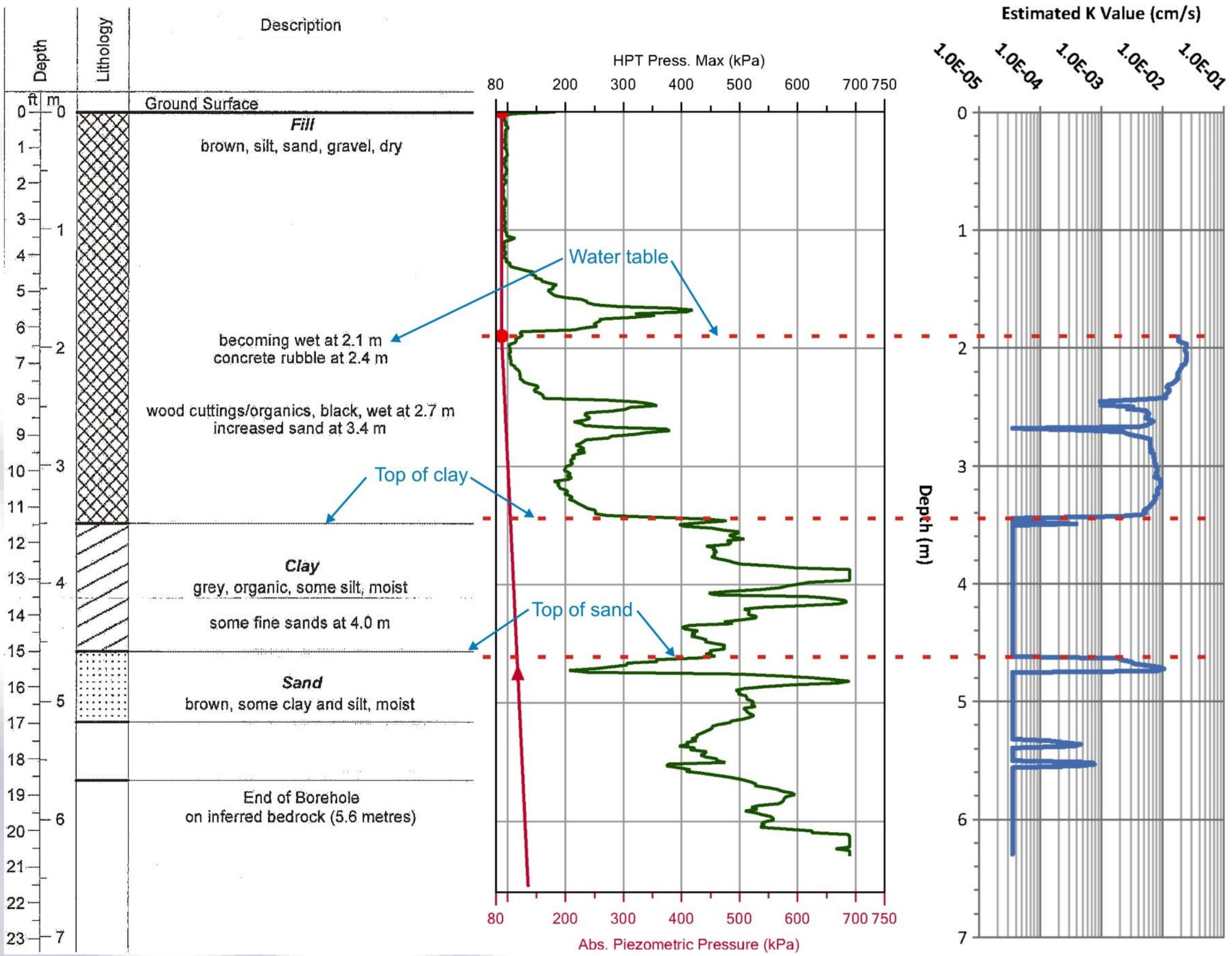
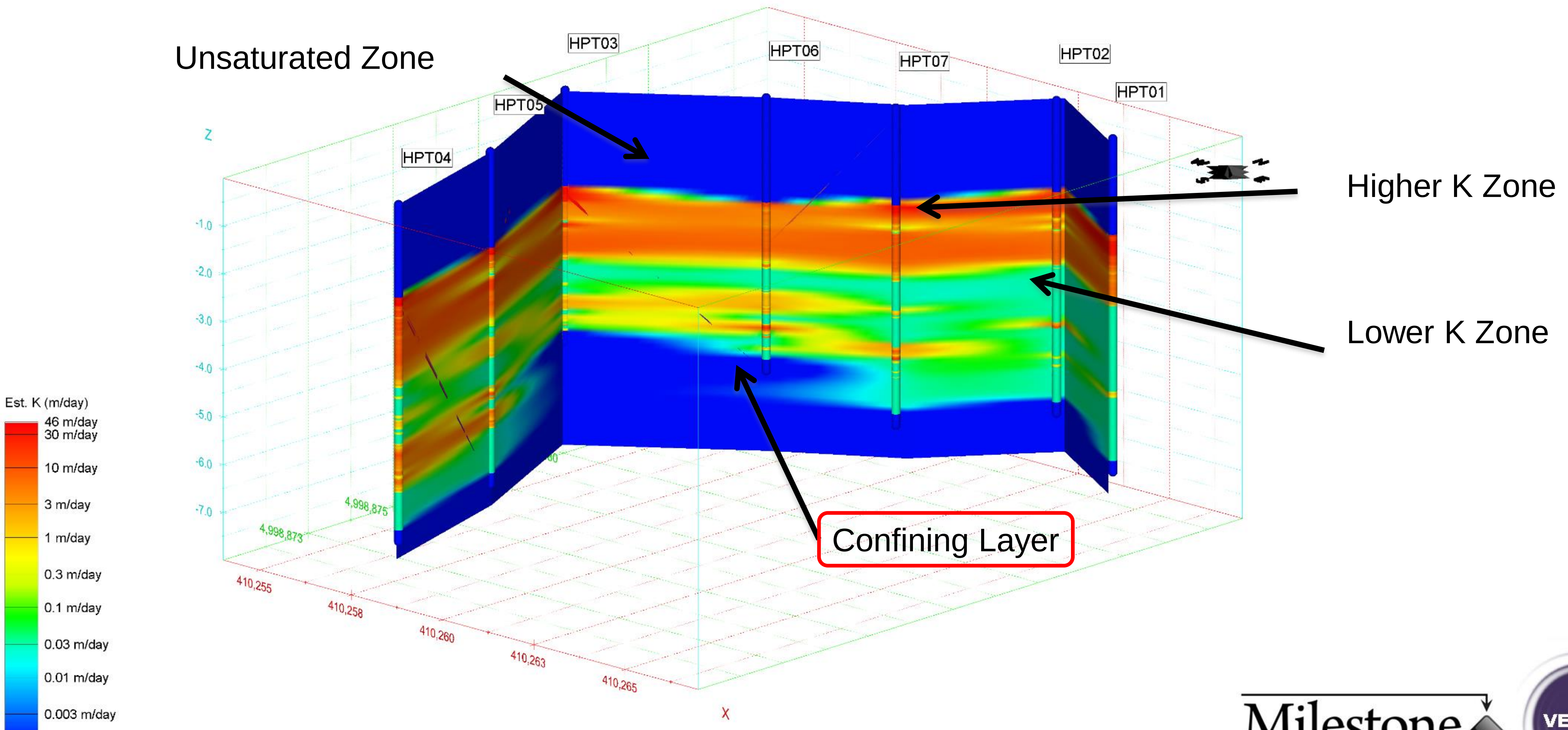
HPT Case Study – HPT vs BH



HPT Case Study – PRB Visualization



HPT - Hydraulic Conductivity Estimates

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Updated Final Design

Updated Final Design

- Data from the HPT testing activities was used to update the preliminary design for the PRB:

Parameter	Preliminary Design	Final Design	Delta
SW Funnel Depth (m)	5.3	5.3 to 6.3	0.0 to +1.0
Gate Depth (m)	5.3	5.0 to 5.6	-0.3 to +0.3
N Funnel Depth (m)	5.3	5.0	-0.3
Thickness (m)	1.0	0.9	-0.1
Height (m)	3.3	3.1 to 3.7	-0.2 to +0.4
ZVI Concent (%)	37%	30%	-7%

- In order to meet PSS reduction using updated site data a PRB containing 30% ZVI would now only need to be 0.9 m thick (~27% savings)

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Full-Scale Installation

Full-Scale Installation

- Cut and fill method PRB, with biopolymer slurry (in case of flowing sands)
- Completed over 6 days on-site
- ZVI mix for 12 m long PRB "Gate": 22 tonnes ZVI, 51.2 tonnes coarse sand
- Concrete wing walls for "Funnels" were 12 m long and 6 m long

Full-Scale Installation

- Strip asphalt
- Cut / fill (using trench box) the “Funnel” wing walls with concrete
- Excavate PRB “Gate” section using biopolymer slurry (on-site tank: 30,000 liters water, 300 kg of guar gum) for sidewall support
- Coarse sand for PRB “Gate” delivered in cement mixing truck
- ZVI added to truck and blended

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Full-Scale Installation

- Backfill PRB "Gate" section with ZVI / sand mixture and avoid gravity separation through slurry
- Break slurry and pump back from trench into on-site tank for off-site disposal (approx. 9,000 liters)
- Place and compact granular trench cap
- Restore surface asphalt
- Remove excavation spoils from site

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Full-Scale Installation

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Full-Scale Installation

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Full-Scale Installation

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Full-Scale Installation

Quality Assurance / Quality Control

Quality Assurance / Quality Control

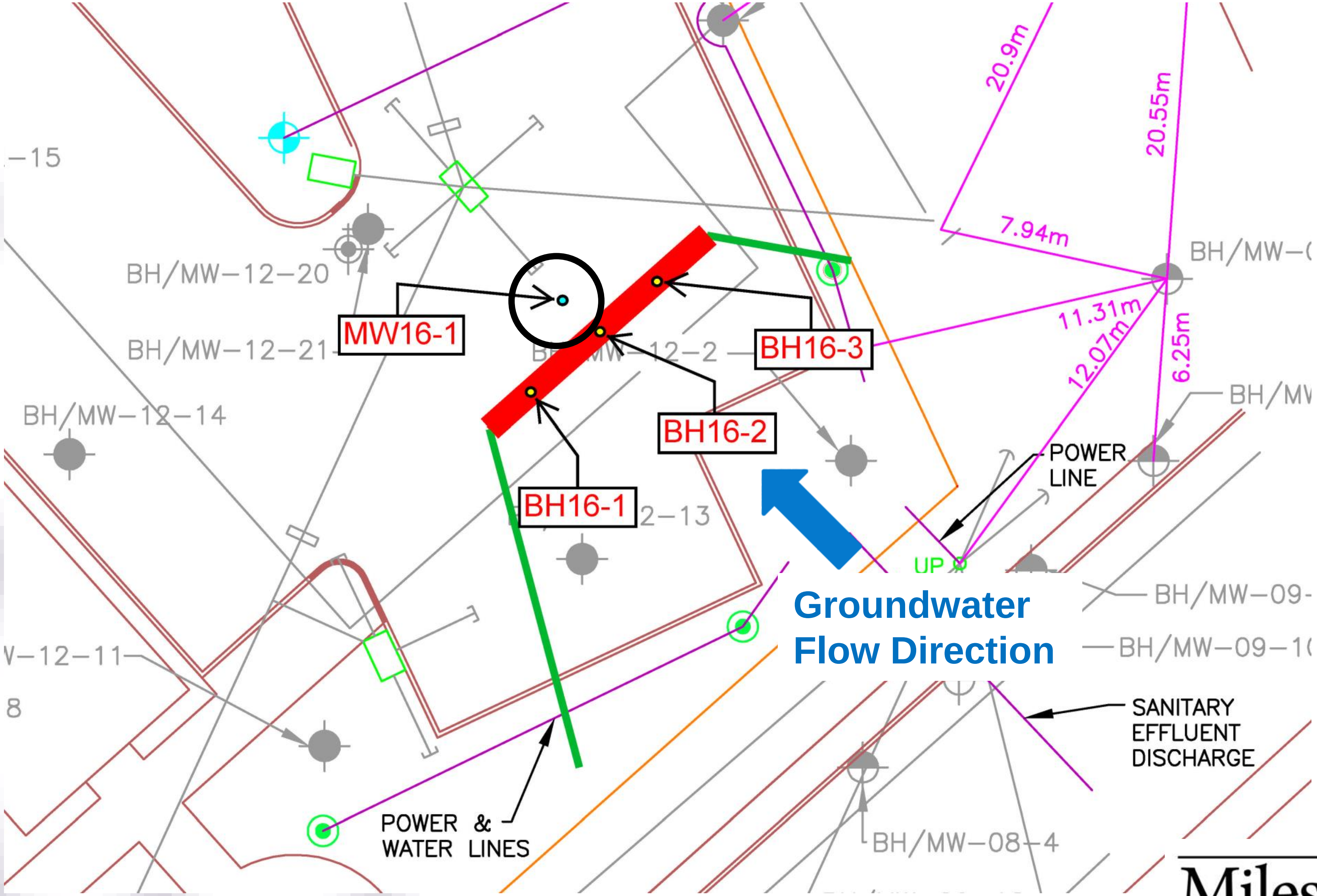
- Samples of ZVI / sand mixture collected from each batch mixed on-site and subjected to magnetic separation testing
- Post-installation boreholes drilled through “Gate” portion of PRB and subjected to magnetic separation testing (similar results)
- One monitoring well drilled approx. 1.5 m downgradient of PRB for groundwater sampling and analysis

Date	Batch	ZVI (%)
26/04/2016	1	32.3%
26/04/2016	2	31.9%
26/04/2016	3	31.5%
28/04/2016	4	33.7%
28/04/2016	5	34.2%
Average		**32.7%**

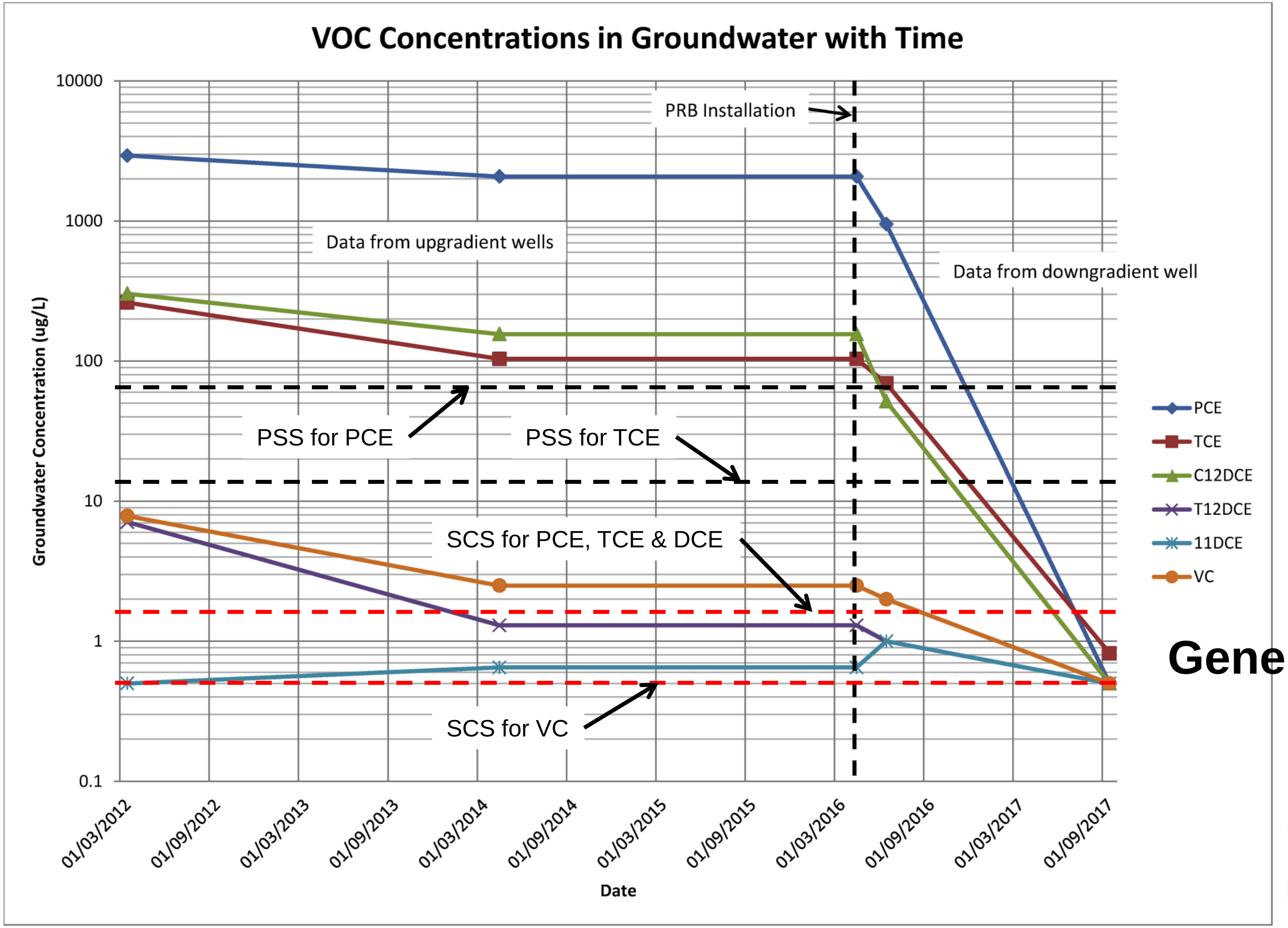
Target ZVI Concentration = 30%

Performance Monitoring

Quality Assurance / Quality Control



Performance Monitoring



Generic Standards Met!

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Lessons Learned

Lessons Learned

- Thoroughly review and validate existing ESA data
- Develop a CSM and preliminary design
- Complete a sensitivity analysis
- Identify any significant data gaps that result in unacceptable uncertainty
- Collect additional site data, if needed, to resolve uncertainty
- Complete bench-scale testing, if needed, to assess site-specific response
- Refine design to tolerable certainty / safety factor

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Lessons Learned (cont'd)

- Ensure that field installation is as per design
- Implement a robust QA/QC programme as confirmation
- Large boulder / debris along trench alignment can cause trench to widen: have additional admixture material on-site to accommodate
- Allow ZVI / sand admixture to set / settle prior to placement of granular cap: top up as required
- Ensure on-going communication between contractor and consultant during installation to ensure any design modifications needed to accommodate field conditions are undertaken with overall design context / goal in mind

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Lessons Learned (cont'd)

- **Start with a qualified team of consultants & contractors**
- **Communication is key between entire project team**
- ***<u>Have fun and slay dragons!!!!!</u>***

Questions?

Thank You for
Your Time

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