



*Case Study: Arsenic Groundwater Remediation Using a
Zero Valent Iron (ZVI) Permeable Reactive Barrier (PRB)
and ZVI Injection*



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SMART Remediation
Vancouver, BC
January 27, 2015

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Overview

- Introduction and Background Information
- RFP Process and Remedial Approach
- ZVI-PRB Theory
- Bench Scale Testing
- ZVI-PRB Design
- ZVI Injection Program
- ZVI-PRB Installation
- Site Restoration and Monitoring Program
- Closing Remarks and Question Period

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Introduction / Background



- Former site of tanning and lead smelting operations
- Currently a rowing / canoe club and public park
- Significant soil and groundwater impacts from arsenic
- Relatively minor chromium, lead, and mercury impacts
- Concern over discharges to the Cataraqui River and Lake Ontario

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Introduction / Background



- Soils were leachate toxic waste for arsenic
- Soil up to 16,400 ppm arsenic vs. 18 ppm Table 9 SCS
- Groundwater up to 204,000 ppb arsenic vs. 1,500 ppb Table 9 SCS

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Introduction / Background



- Groundwater flow estimated 5 m/year
- Arsenic Impacted groundwater at 2-4mbgs

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RFP Process and Remedial Approach

- Client – The City of Kingston’s Environment & Sustainable Initiatives Department
- Stakeholders – Kingston Rowing Club, Cataraqui Canoe Club, Utilities Kingston, Cataraqui River Stakeholders Group (Transport Canada, Parks Canada, Environment Canada, Ontario MOE, RMC)
- General Contractor – Milestone Environmental Contracting, Inc.
- Key Subcontractor – Vertex Environmental Inc.

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RFP Process and Remedial Approach

Original Scope



- Excavate and dispose of over 1,000 mt of soil
- Estimated \$500/mt disposal cost
- Excavation Dewatering
- Sub-Grade Cut-Off Wall Installation
- Vertical Groundwater Extraction Well
- Backfill/Restoration

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RFP Process and Remedial Approach

- Client utilized a structured RFP procurement process including a weighted evaluation of proposals
- Value-Added Environmental Solutions and methods were given higher consideration (reduce soil disposal and water treatment)
- Approx. 30 contractors downloaded the bid package
- Milestone teamed with Vertex to develop a sustainable alternative, cost-saving remedial plan: ZVI PRB with minimal soil excavation and access disruption
- Several meetings with the Client & MOE led to approval for proof-of-concept bench-scale testing

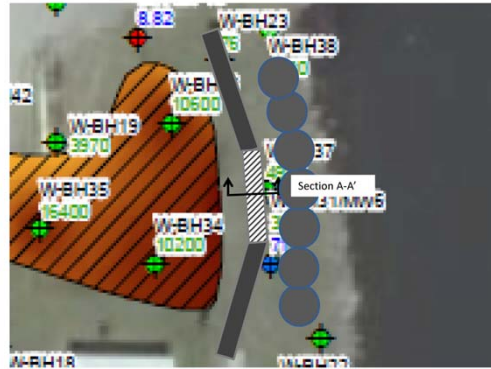
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RFP Process and Remedial Approach

Alternative Scope

- Excavate and dispose of only 150 mt of soil (PRB trench spoils)
- Complete Downstream ZVI Injection
- Install ZVI PRB Funnel and Gate Wall
- Backfill/Restoration



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ZVI and PRB Theory

- PRB to act as long-term, passive solution for in-situ treatment of arsenic contaminated groundwater via chemical reduction
- Dissolved As passes through the reactive zone and is adsorbed onto the iron particles and/or precipitated out of the solution before exiting
- ZVI can reduce both As(III) and As(V)
- Highly toxic arsenic is removed from the solution via adsorption to iron hydroxides and/or co-precipitation via electrochemical reduction
- Corroding iron also creates a reducing environment supportive for sulphate reducing bacteria growth

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Bench-Scale Testing



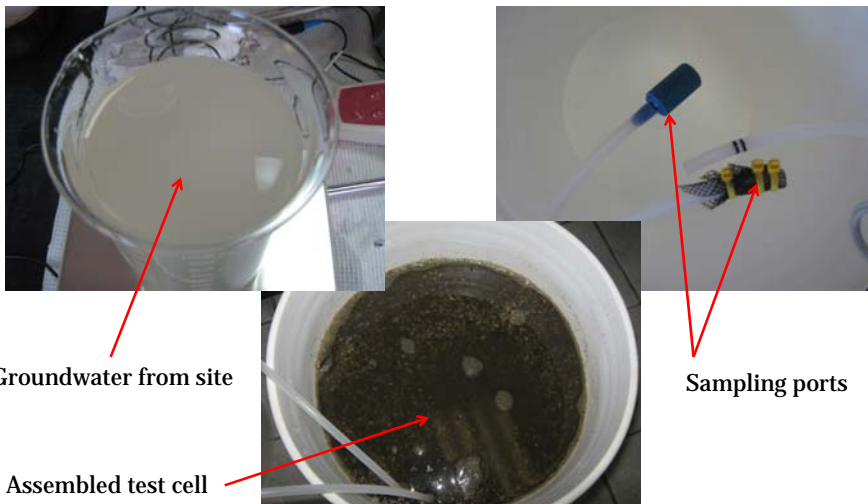
- Prepared 4 bench-scale tests and 2 control tests
- Groundwater control test (no media)
- Media control test (100% coarse sand)
- ZVI design (20% ZVI, 80% coarse sand)
- Enhanced ZVI Design (20% ZVI, 2% enhanced ZVI media, 80% coarse sand)
- Benthic sediment (150g) was added due to sulphate reducing properties

JB3

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Bench-Scale Testing



Groundwater from site

Assembled test cell

Sampling ports

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Bench-Scale Testing

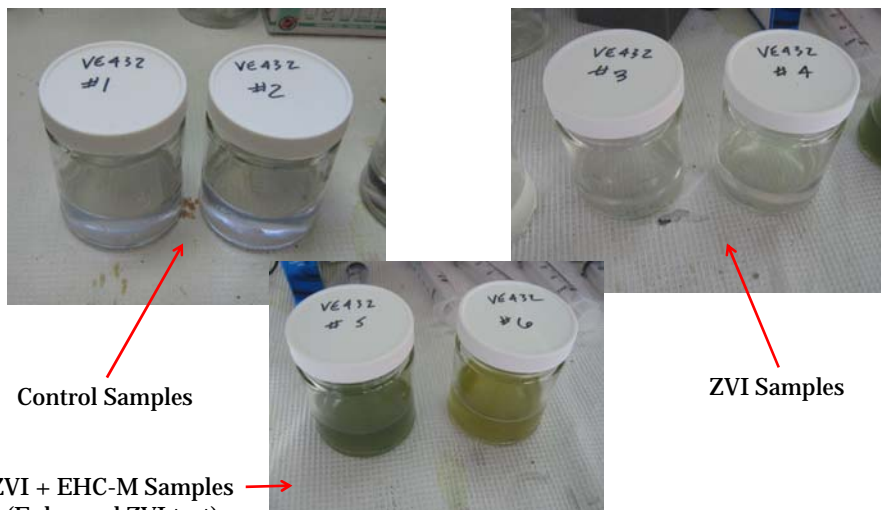


- A. HDPE Test Cell
- B. Nitrogen Tank
- C. Primary Sampling Port
- D. Secondary Sampling Port
- E. Injection Port
- F. Airlock

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Bench-Scale Testing



Control Samples

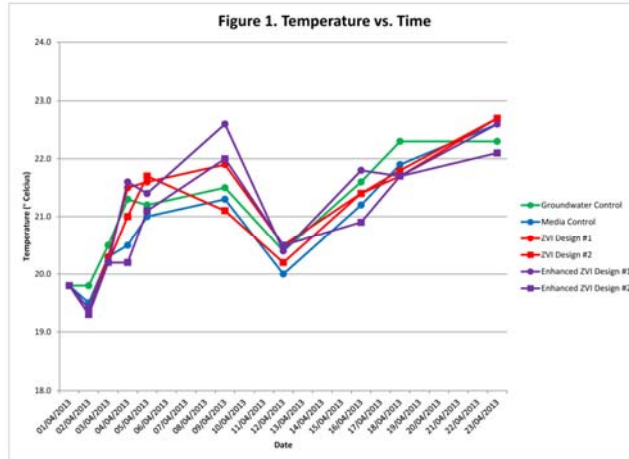
ZVI Samples

ZVI + EHC-M Samples
(Enhanced ZVI test)

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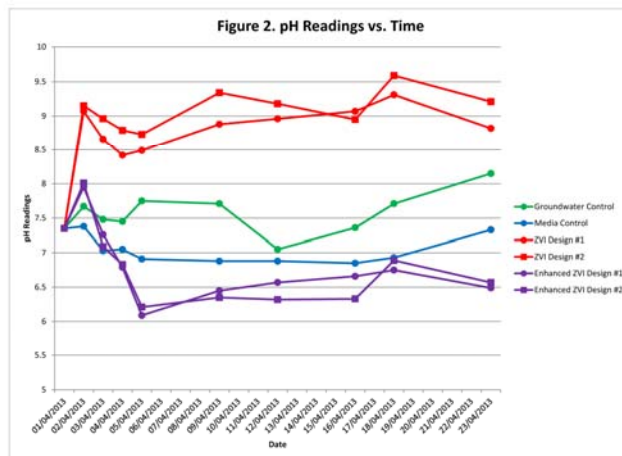
Bench-Scale Testing



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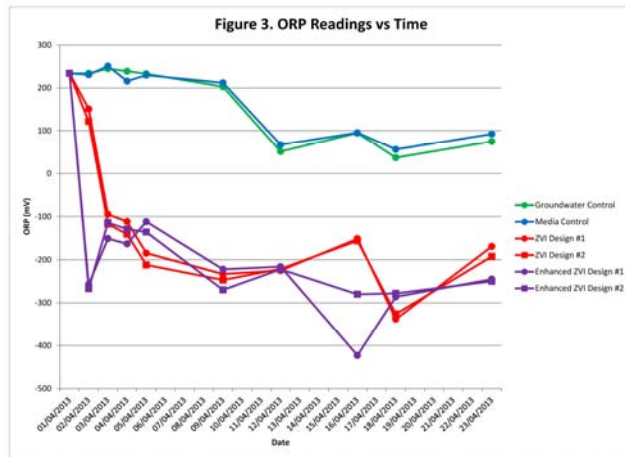
Bench-Scale Testing



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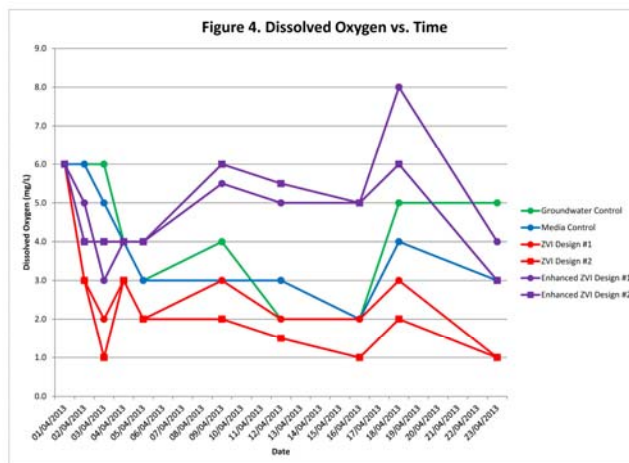
Bench-Scale Testing



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Bench-Scale Testing



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Bench-Scale Testing

- Within three (3) weeks arsenic concentrations in groundwater dropped from 23,100 ppb to average of 87 ppb in test cells (**99.6% reduction**) and to average of 3.6 ppb after four (4) weeks (**99.98% reduction**)
- MOE Table 9 site condition standard = 1,500 ppb
- ZVI PRB concept proven decisively
- Noting substantial cost-savings and enhanced environmental sustainability, contract was awarded to Milestone for ZVI-PRB installation

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ZVI-PRB Design

- Client requested ZVI-PRB wall installation combined with secondary ZVI injection program
- Injected PRB: based on an in-situ ZVI concentration of 1.5% by weight soil mass (Slurry = 30% ZVI, 1.5% guar gum and water)
- The ZVI injection program switches the groundwater over into even stronger reducing and anaerobic conditions due to biodegradable guar gum slurry
- the guar gum gets eaten by the aerobic microbes and uses up the dissolved oxygen relatively quickly. The anaerobic microbes (such as sulphate reducing bacteria) then take over to help complex out the arsenic as well as the chemical reduction reactions with the injected ZVI.

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ZVI-PRB Design

- Wall design retention time was >2 months, more than sufficient to achieve good treatment
- PRB lifespan estimated at >20 years
- Both “keyed” into silty clay till &/or bedrock

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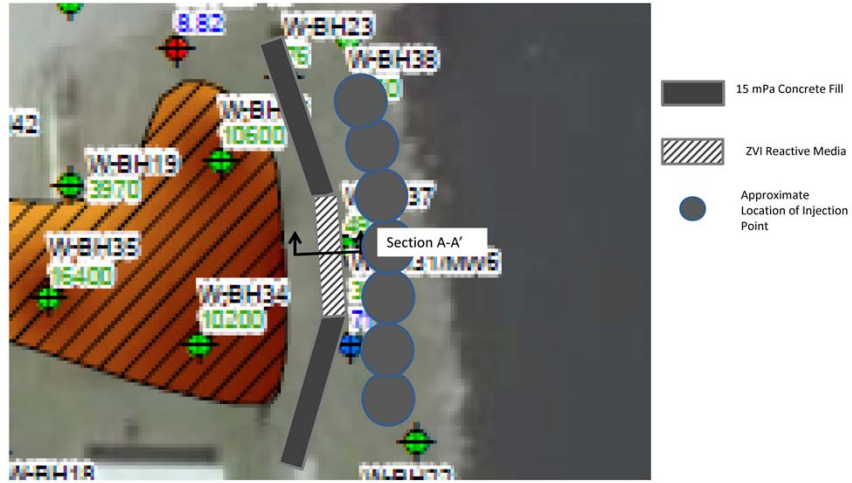
ZVI-PRB Design



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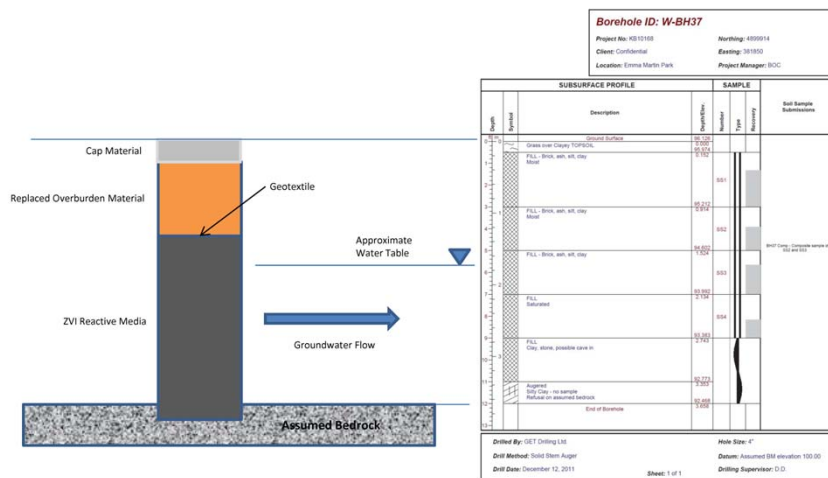
ZVI-PRB Design



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ZVI-PRB Design



Borehole ID: W-BH37

Project No: 4010103 Number: 000014
 Client: Confidential Esting: 201010
 Location: Erma Martin Park Project Manager: BOC

Depth	SUBSURFACE PROFILE		SAMPLE		Soil Sample Identification
	Description	Depth (ft)	Number	Type / Frequency	
0.00	Ground Surface	0.00			
0.00	Gravel over Capillary Claystone	0.00			
0.00	FILL: Silty, med. to clay shale	0.00	051		
0.00	FILL: Silty, med. to clay shale	0.00	052		
0.00	FILL: Silty, med. to clay shale	0.00	053		
0.00	FILL: Silty, med. to clay shale	0.00	054		
0.00	FILL: Silty, med. to clay shale	0.00	055		
0.00	FILL: Silty, med. to clay shale	0.00	056		
0.00	FILL: Clay, silty, possible sand in	0.00	057		
0.00	Argillaceous Clay, silty, sandy, medium to medium bedded	0.00	058		
0.00	End of Borehole	0.00			

Drilled By: GET Drilling Ltd. Hole Size: 4"

Drill Method: Solid Stem Auger Datum: Assumed BM elevation 100.00

Drill Date: December 12, 2011 Drilling Supervisor: D.D.

Sheet: 1 of 1

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ZVI Injection Program

- Injected PRB installed first near shoreline (3 day program)
- Two (2) test boreholes advanced & sampled to confirm depth of “confining layer”
- Total of eleven (11) temporary injection points on a 1.5 m spacing from 1.5 to 3.5 mbgs
- Total of 2,450 kg micro-scale ZVI in a 30% slurry with 1.5% guar gum and water (8,100 L total)



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ZVI Injection Program



Upper fill soils

Silty clay till
“confining layer”

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ZVI-PRB Installation



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ZVI-PRB Installation

Line of temporary points for injected PRB

Excavation for "cut & fill" PRB



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ZVI-PRB Installation



Macro-scale ZVI mixed with
concrete sand in cement truck

Macro-scale ZVI & concrete sand
mixture placed into excavation



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ZVI-PRB Installation



Geotextile
fabric
placed over
ZVI PRB



Remaining excavation
Backfilled with granular fill

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ZVI-PRB Installation

- PRB was 5.2 m long, 1.0 m wide and from 2.0 to 3.8 mbgs “keyed” 0.5 m into silty clay till
- Total of 9,000 kg macro-scale ZVI mixed with 12,600 kg “concrete sand”
- One (1) day to direct place in two (2) loads
- Vertex completed QC/QC testing on batches of ZVI/sand mixture (magnetic separation)
- Target minimum 30% ZVI by weight; results were 40.5% & 43.2%, averaging 41.9% ZVI

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ZVI-PRB Installation



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Site Restoration & Monitoring Program



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Site Restoration & Monitoring Program

- City has installed monitoring wells up and down gradient the PRB wall
- Following post construction As spike, all results have been positive



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Site Restoration & Monitoring Program

- **Measure GW Arsenic levels have been cut in half between Dec. 2013 and Oct 2014**
- **pH levels are rising which is a signal that the ZVI is starting to react**
- **ORP levels DO levels are falling - trending in the right direction**

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Award Winning Project

- **Federation of Canadian Municipalities (FCM) – Sustainable Communities Award - 2015
Brownfields Project**

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Thank You For Your Time and Attention

Questions???

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