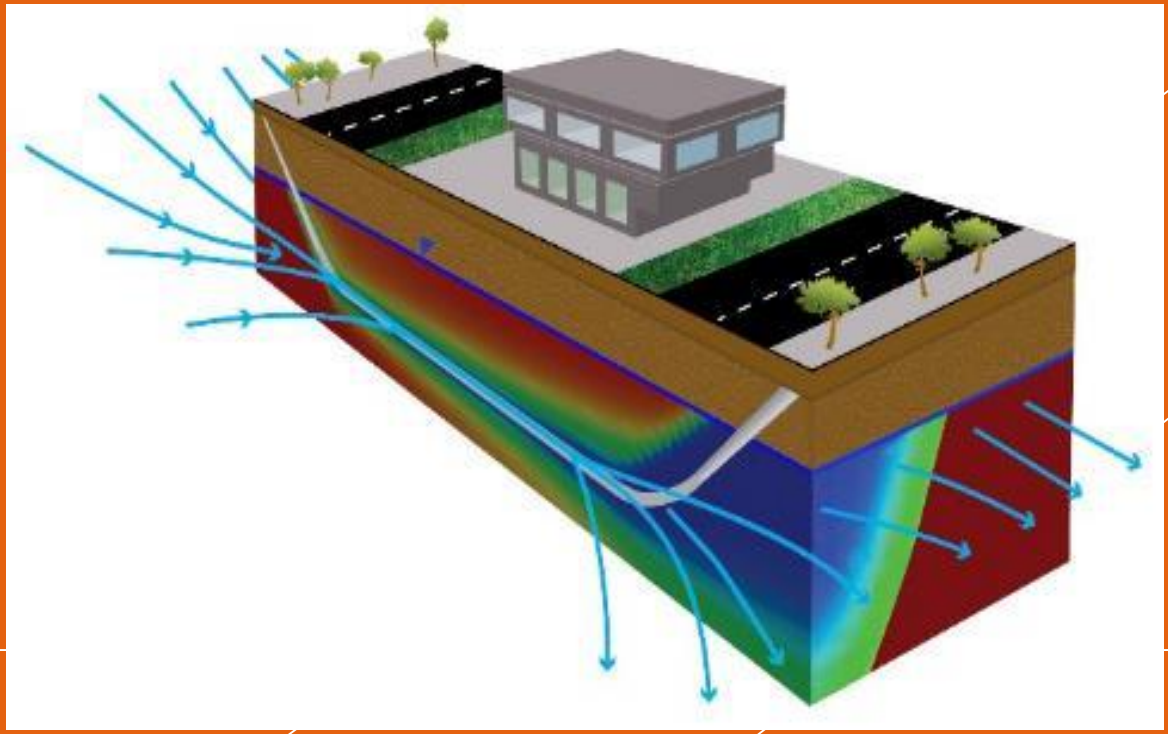
ARCADIS Design & Consultancy for natural and built assets

THE HORIZONTAL REACTIVE MEDIA TREATMENT WELL (HRX WELL™) – DEMONSTRATION OF A NEW TECHNOLOGY FOR PASSIVE IN-SITU REMEDIATION

Craig Divine, Jeff McDonough,
Jesse Wright, Jack Wang, (Arcadis)

Michelle Crimi (Clarkson University)

J.F. Devlin (University of Kansas)

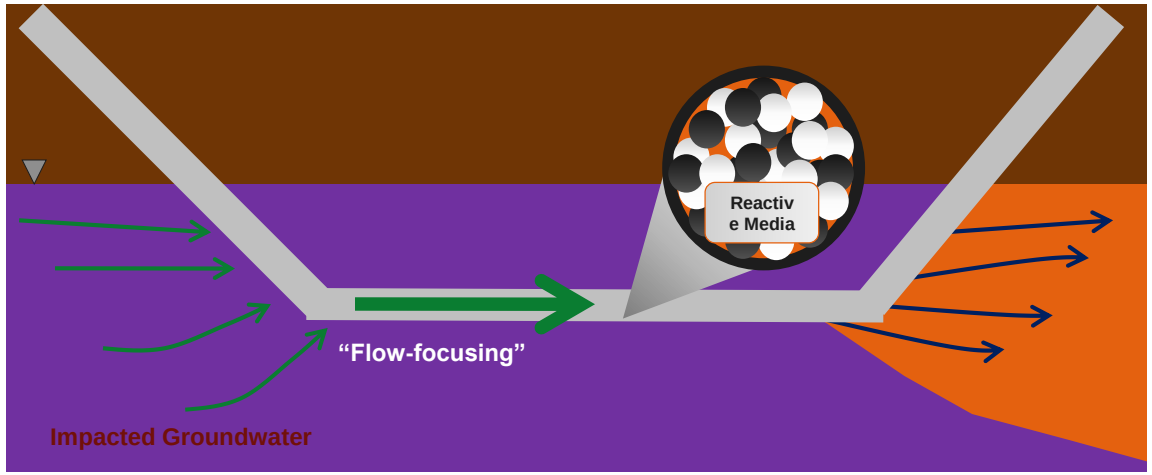


October 2018

RemTech 2018, Banff, Alberta

HRX Well Description

The HRX Well (Patent US8596351B2) is a large-diameter horizontal well installed along the groundwater flowpath that is filled with reactive media



- Passive in-situ treatment
- Many solid-phase reactive media options
- Efficient use of reactive media
- Not limited to high-permeability aquifers
- Can be applied in relatively deep settings
- Limited above-ground footprint
- No ongoing energy or O&M requirements
- Pumping can enhance treatment zone

Potential Reactive Media and Contaminants

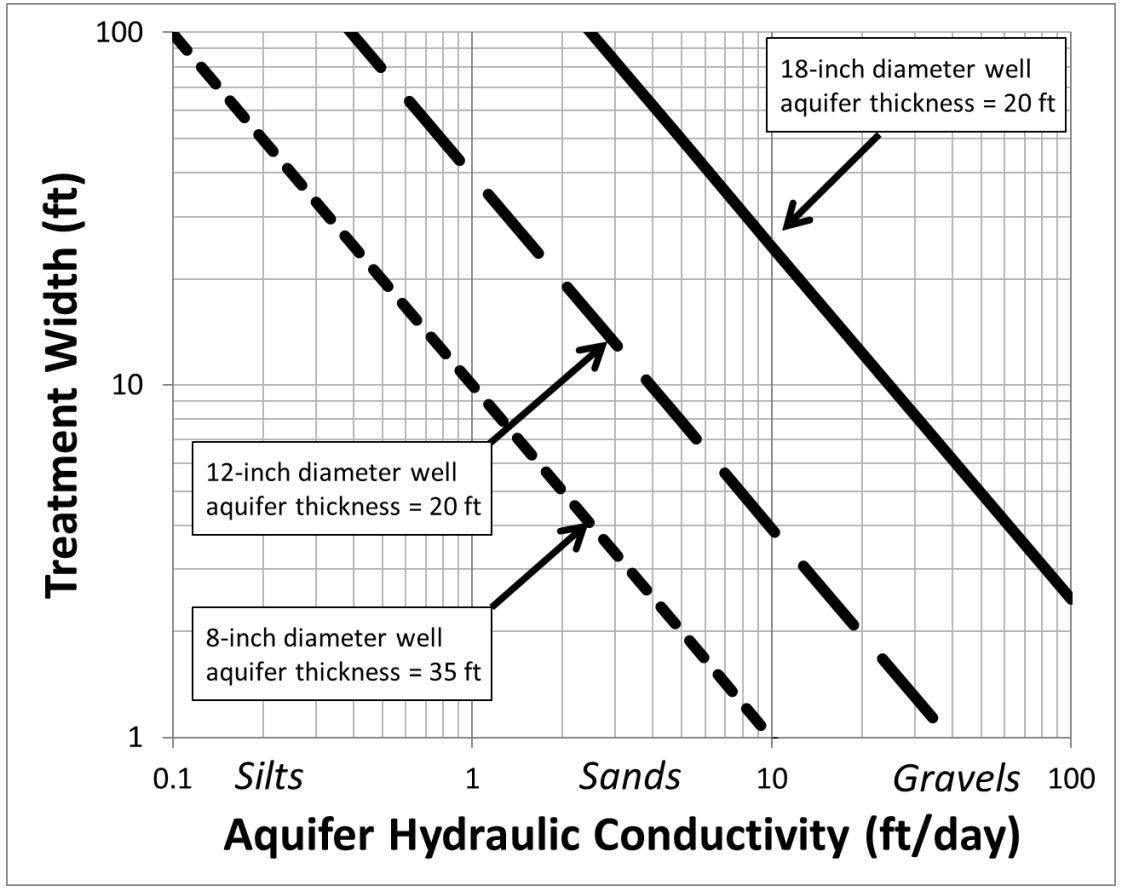
Reactive Media	Target Groundwater Contaminant
Zero valent iron (ZVI) Bimetallics (e.g., ZVI + Pd, Pt, or Ni)	Chlorinated solvents (CVOCs), nitrate, perchlorate, energetics, chromium, arsenic, other metals
Granulated Activated Carbon (GAC)	CVOCs, PFAS, hydrocarbons, Halomethanes
Ion exchange resins	Brines
Biodegradable particulate organic carbon (e.g., mulch)	CVOCs, nitrate, perchlorate
Phosphates (e.g., apatite)	Lead, uranium, other metals and radionuclides
Sustained Release Oxidants (e.g., RemOxSR+ ISCO)	CVOCs, 1,4-dioxane, hydrocarbons, polyaromatic hydrocarbons (PAHs), phenolic compounds, and energetics
Limestone, lime, magnesium oxide	Low pH, Acid Rock Drainage
Barium sulfate (barite)	Radium
Iron sulfide	Cr, High pH
Zeolites	Ammonium, radionuclides

Treatment Width

$$w_{treatment} = \frac{Q_W}{T_A i_A}$$

$$Q_W = K_W A_w i_w$$

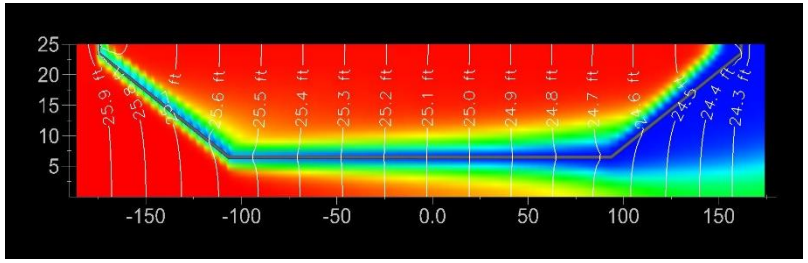
$w_{treatment}$	HRX treatment width
Q_w	Flow in HRX well
T_A	Aquifer Transmissivity
i_A	Aquifer hydraulic gradient
A_w	x-sectional area of HRX well
i_w	Hydraulic gradient in HRX well

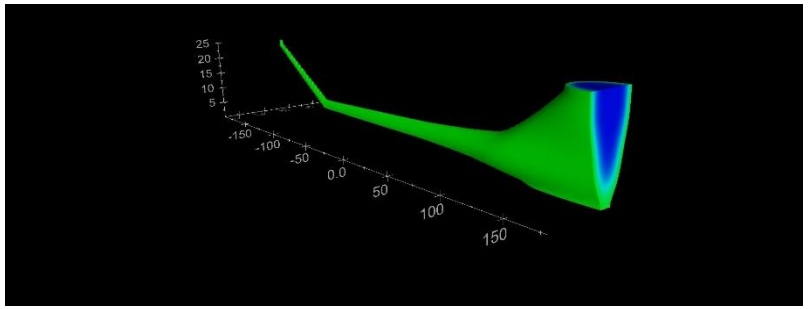


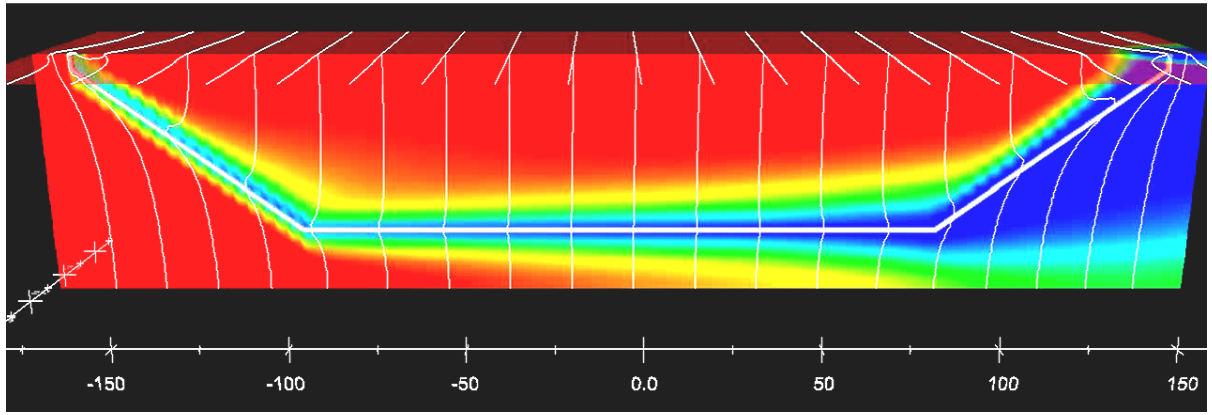
For passive configurations, treatment widths of 50+ feet are feasible

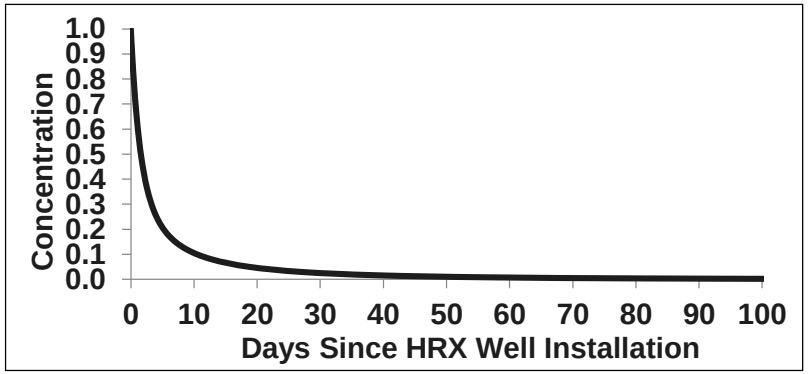
Modeling

- 300 ft long, 20 ft deep, 1 ft diameter,
- Homogeneous aquifer, K_A=2.8 ft/day, K_W=2,800 ft/day
- Treatment width = ~45 ft.



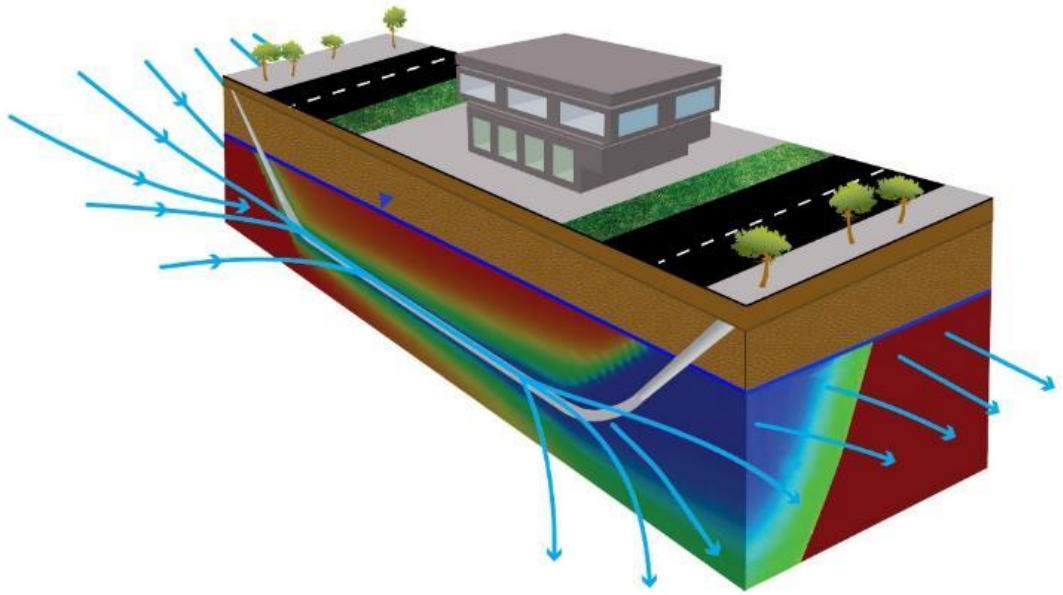






Objectives (ESTCP ER-201631)

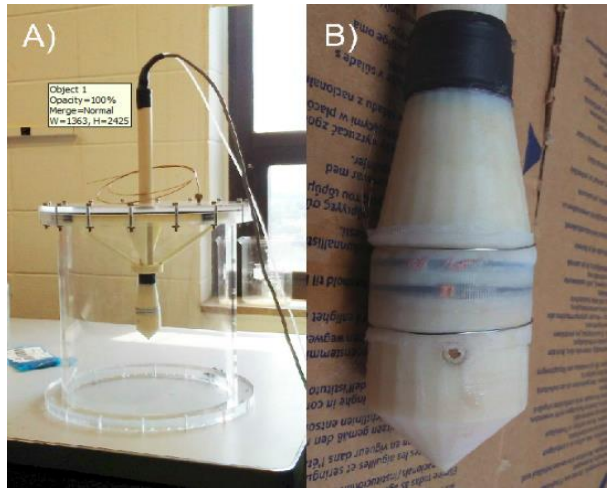
1. Full-Scale demonstration of technology to control mass discharge
2. Measure the actual performance and compare to model predictions.
3. Assess actual implementatability, cost and sustainability performance
4. Develop a user tool and guidance for conceptual design and costing.



ZVI Selection and PVP Design

Column	Iron	k (day^{-1})	
		Steady State Port 2	Profile
1	Connelly	12.8	11.4
2	Connelly	9.7	9.0
3	Peerless	14.8	12.8
4	Peerless	9.9	10.1
5	Hepure	NA	NA
6	Hepure	5.1	4.4

Photo and results of columns testing of 3 iron types



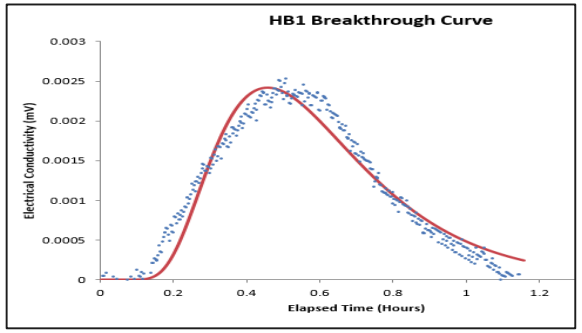
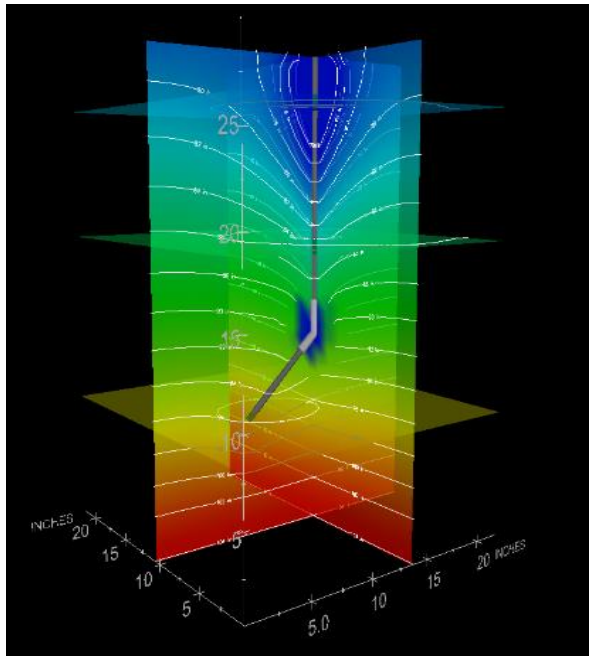
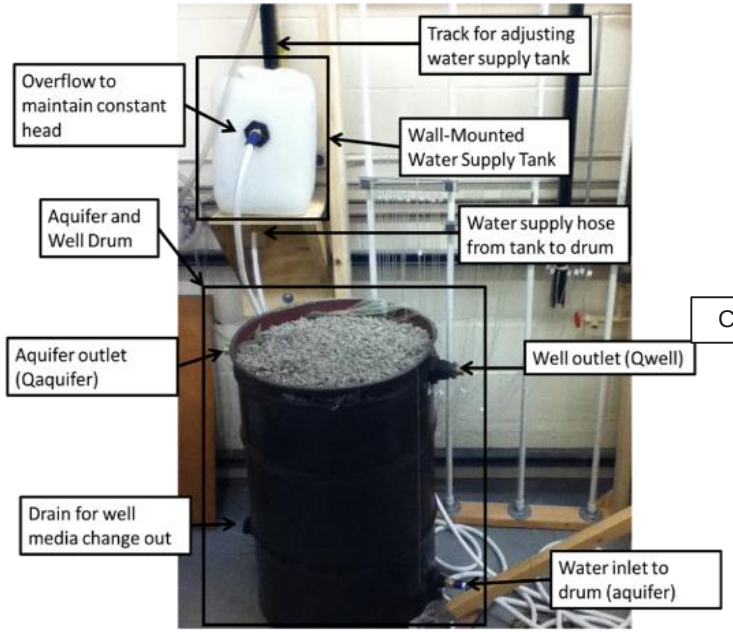


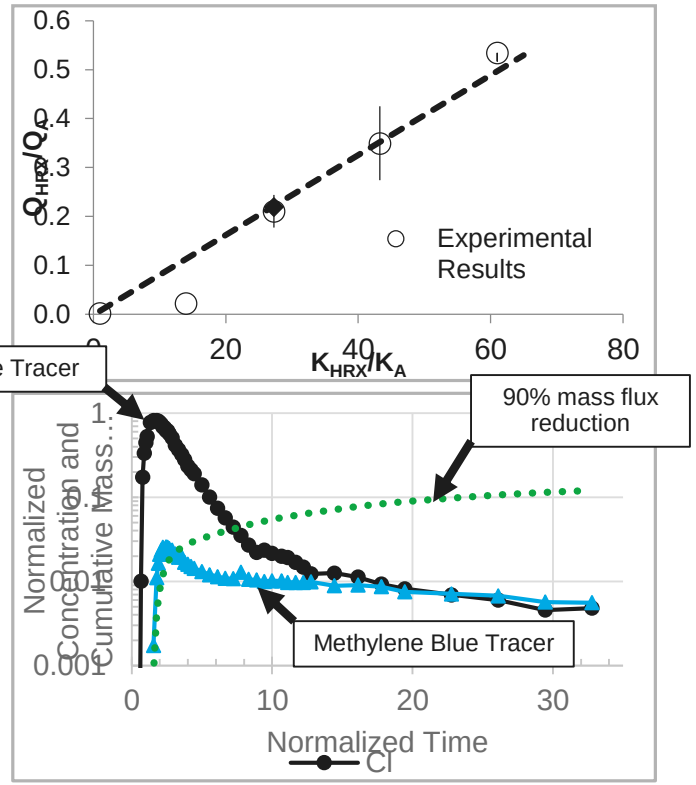
Photo and example test results of redesigned PVP

- No progressive losses in K over time (>1000 pore volumes in these tests)
- Connelly iron selected based on best overall performance
- Modified laboratory PVP accurately and measured seepage velocities

Tank Testing

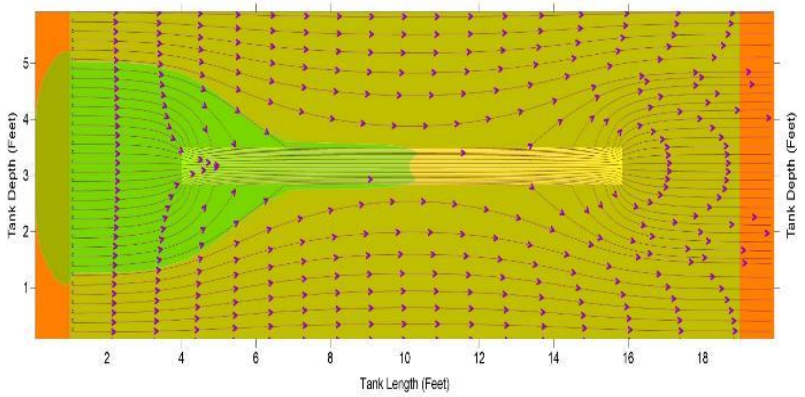


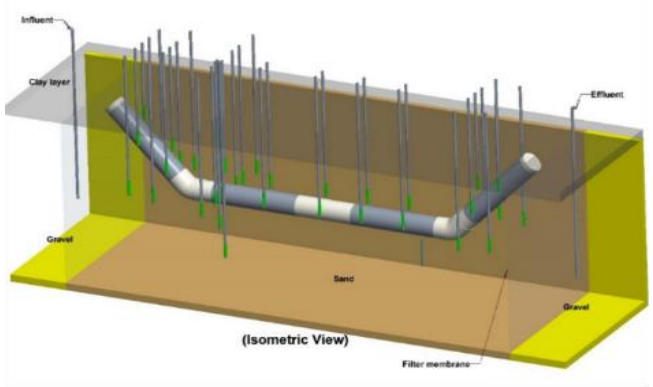


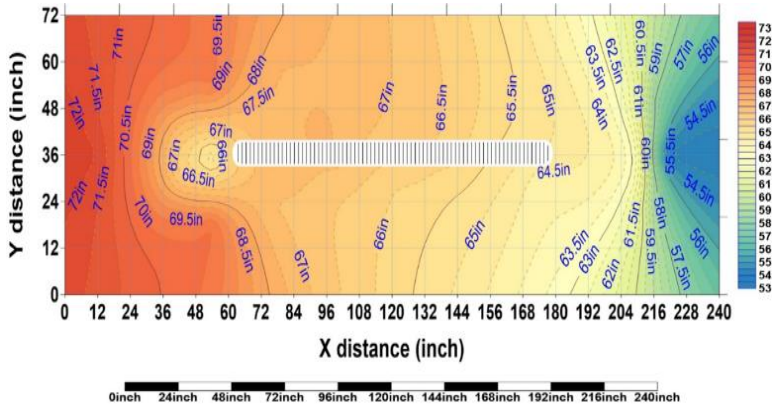


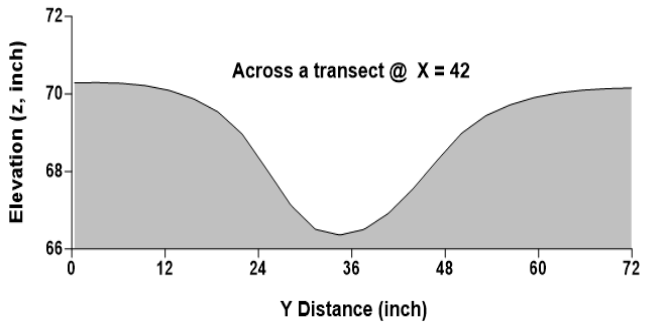
- Validated HRX Well hydraulics
- Validated contaminant treatment with GAC and ZVI
- HRX Well ZVI performance sustained over 100+ Pore Volumes

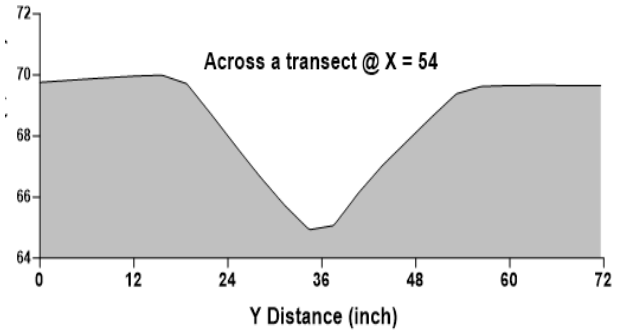
Pilot Scale Testing











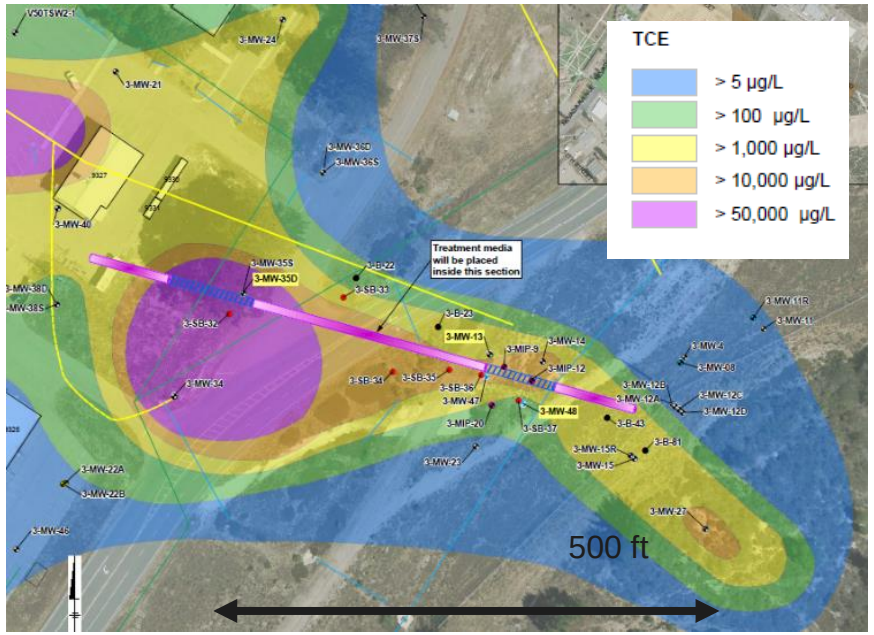
- HRX Well captured 39% of flow while representing 0.5% of test pit volume
- Verified hydraulic and reactive transport model
- Further tracer testing currently underway

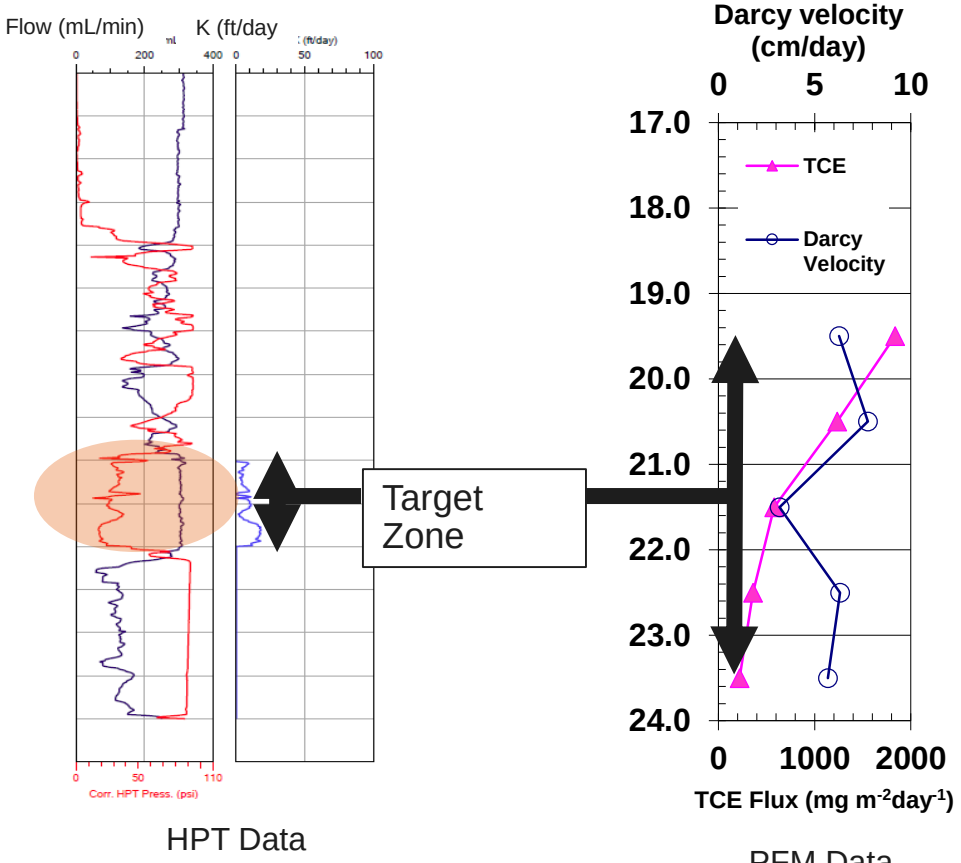
Field Demonstration

ARCADIS Design & Consultancy for natural and built assets

Site SS003, Vandenberg Air Force Base

- Objective: significantly reduce mass discharge from the source
- K = 1-10 ft/day, thickness 5-10 ft, depth ~20 ft, low ambient gw flux

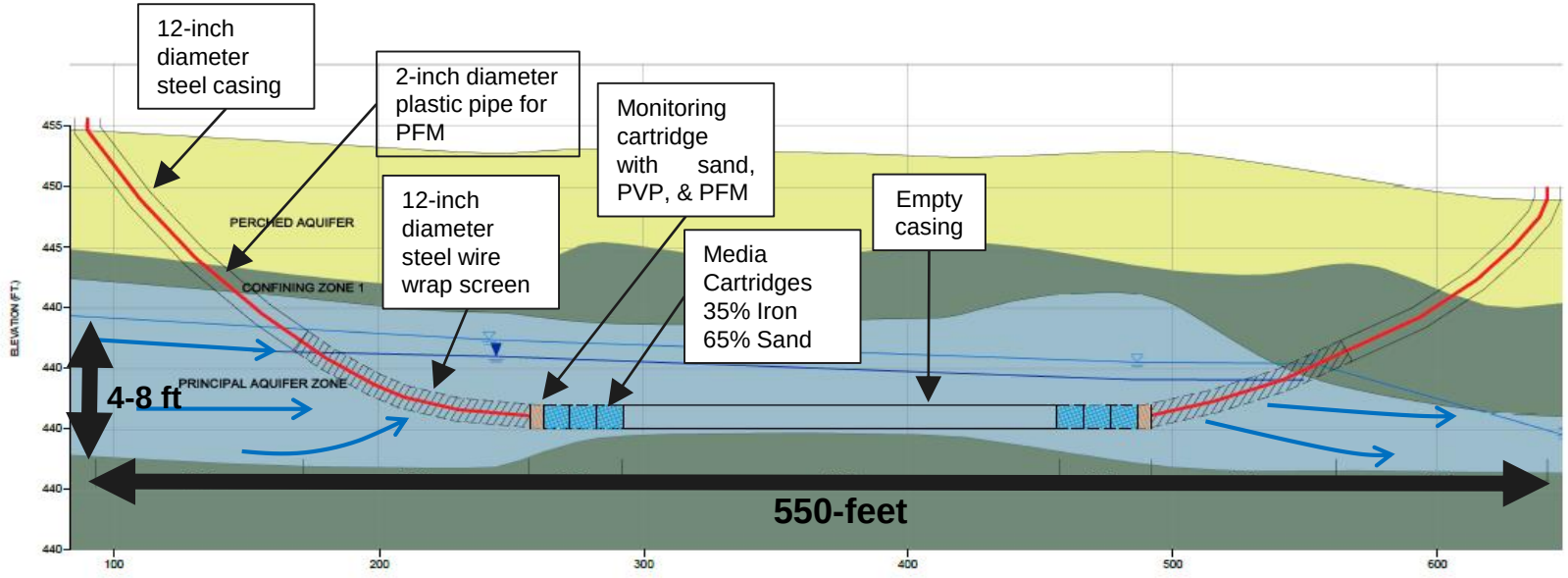




HPT Data

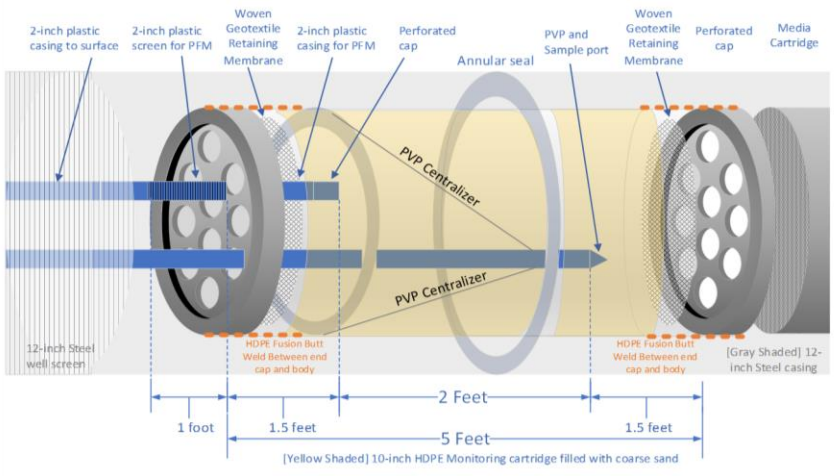
PFM Data

Field HRX Well Design

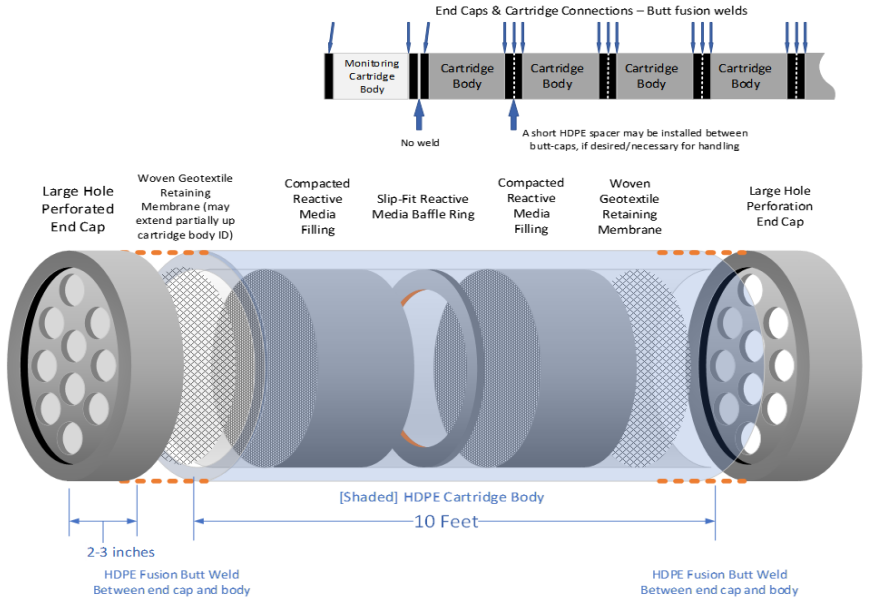


- Length: 550 ft; Depth: 20 ft; Diameter: 12-in; Reactive media: 35% ZVI (60 ft)
- Target treatment width: 56 ft, Residence time: 6-8 days
- 2 PVPs, samples, tracer testing to measure in-well velocity, flux, concentrations

Monitoring and ZVI Cartridge Designs

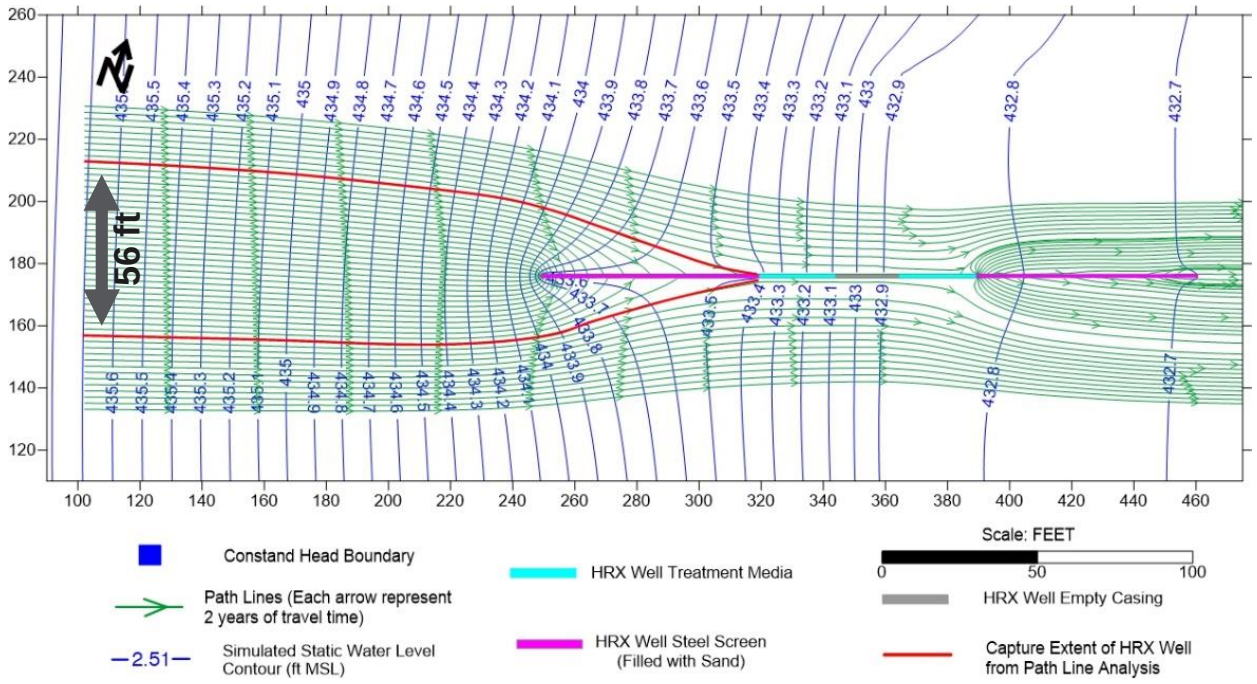


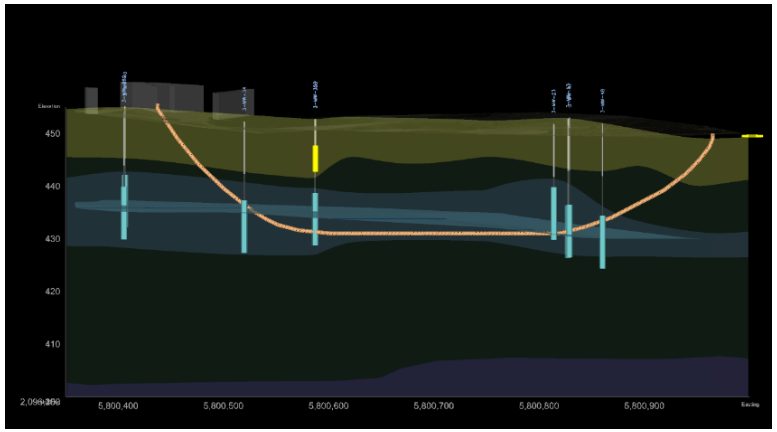
Monitoring cartridge (5 ft)

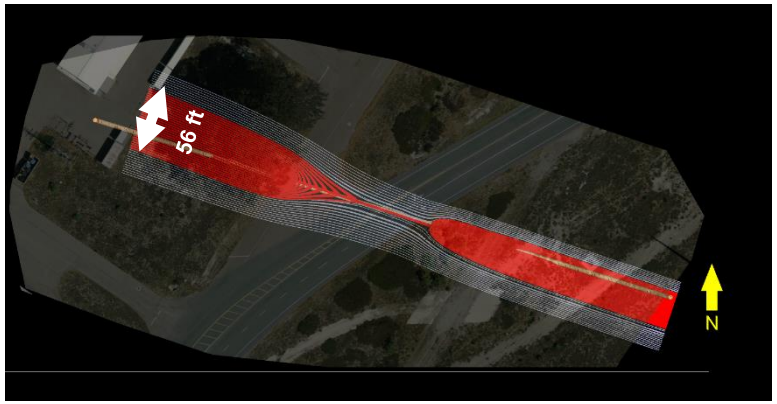


ZVI cartridge (10-ft)

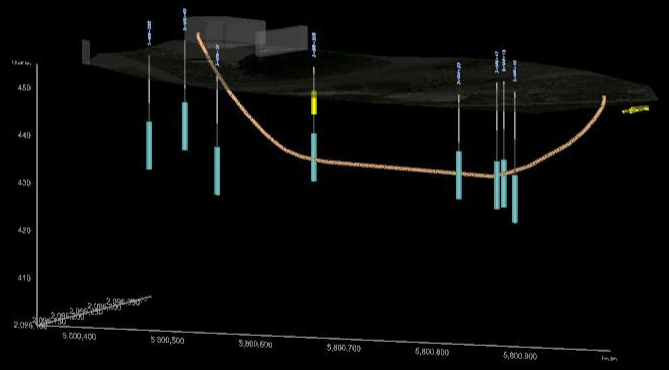
Design Model Results







3D CSM
Site 3 HRX Well and Site Features
Vandenberg AFB, CA



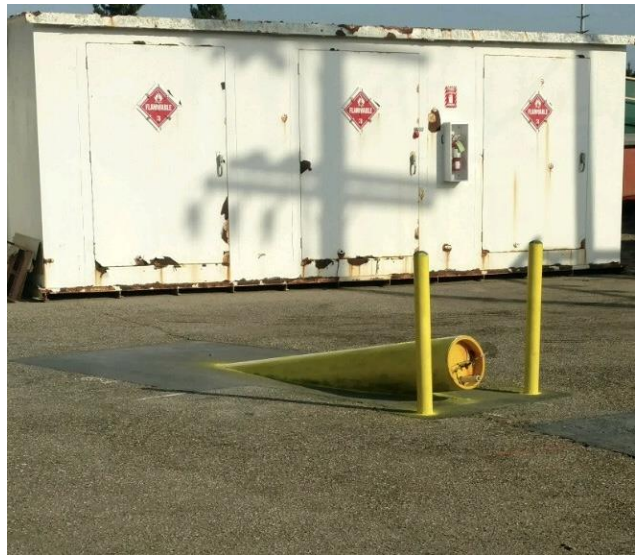
Site Wells by Type
- Shallow and Perched Wells
- Principal Wells
- Deep Wells
- ISB Wells
- ERD Wells

HRX Well

Existing Buildings

NOTES:
1) Vertical Exaggeration = 5X Horizontal

Field Installation (July/August 2018)



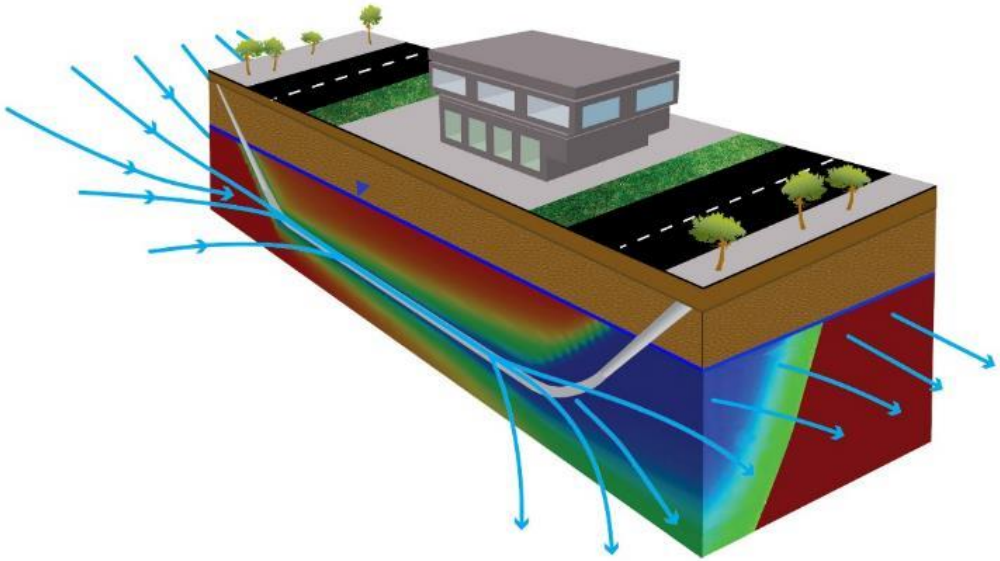
Alternatives Analysis

ARCADIS Design & Consultancy for natural and built assets

Criterion	Alternative #1 HRX Well	Alternative #2 Groundwater Extraction and Treatment System	Alternative #3 Funnel and Gate PRB
Overall protection of human health and environment	Yes	Yes	Yes
Effectiveness and permanence	Moderate to High	Moderate	Moderate to High
Reductions in toxicity, mobility, and volume through treatment	Moderate to High	Moderate	Moderate to High
Implementability	Moderate	Moderate	Moderate
Sustainability	High	Low to Moderate	Moderate to High
Lifecycle Cost*	Low to Moderate **$2.4-3.1M**	High **$3.8-4.7M**	Moderate **$3.6-4.5M**

*Full-scale costs assume a target treatment width of 150 ft

Closing



Future Performance Monitoring

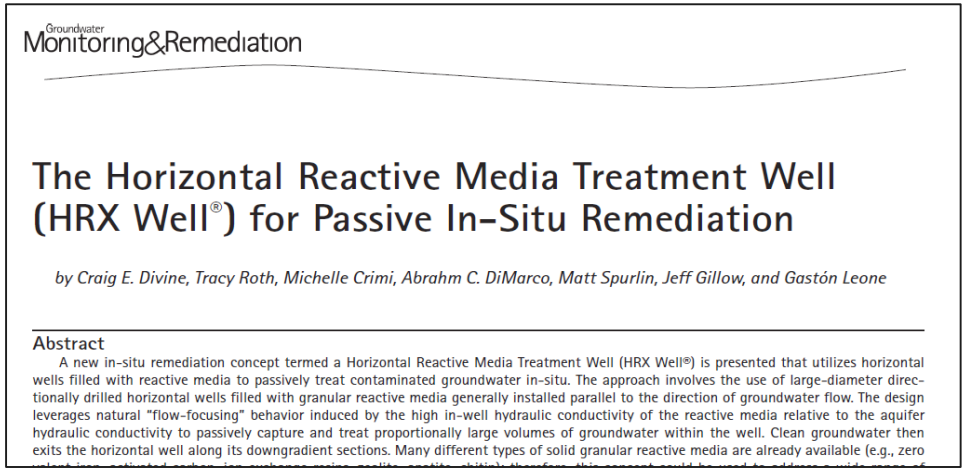
- Groundwater monitoring
- Point Velocity Probes (PVPs)
- Tracer Testing

The HRX Well offers the following advantages

- In situ mass flux control
- Passive operation or enhanced capture zone with pumps
- Many reactive media options and therefore applicable to many contaminants
- Efficient media usage, easy change-out, can use multiple types
- Limited above-ground footprint
- No ongoing energy, water, or O&M requirements
- Favorable lifecycle cost comparison to P&T and PRB

Thank You

ESTCP
Hunter Anderson, PhD (AFCEC)
Kathleen Gerber (VAFB)
Don Eley (RWQCB)
Michael Lubrecht, Dan Ombalski (DTD)
Billy Hodge (University of Kansas)
Blossom Nzeribe Nwedo, Nageshrao Kunte Pandurangarao, Simon Feng (Clarkson University)
Mike Kladias, Hoa Voscott, Kelly Houston (Arcadis)



Groundwater Monitoring&Remediation

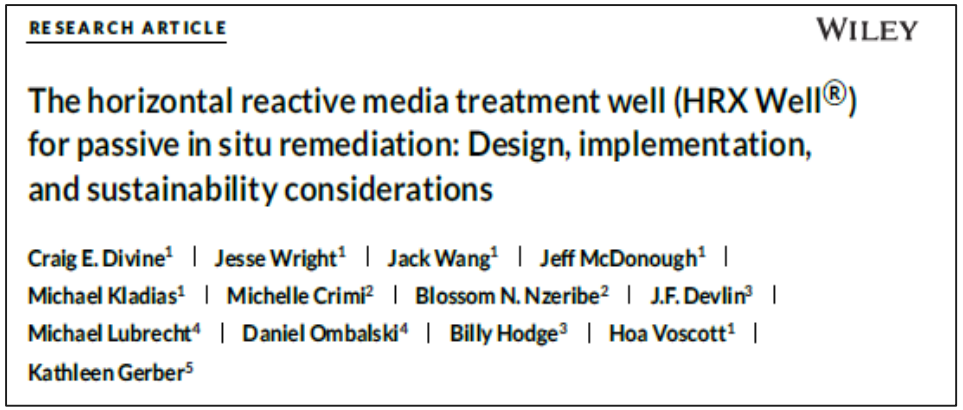
The Horizontal Reactive Media Treatment Well (HRX Well®) for Passive In-Situ Remediation

by Craig E. Divine, Tracy Roth, Michelle Crimi, Abrahm C. DiMarco, Matt Spurlin, Jeff Gillow, and Gastón Leone

Abstract

A new in-situ remediation concept termed a Horizontal Reactive Media Treatment Well (HRX Well®) is presented that utilizes horizontal wells filled with reactive media to passively treat contaminated groundwater in-situ. The approach involves the use of large-diameter directionally drilled horizontal wells filled with granular reactive media generally installed parallel to the direction of groundwater flow. The design leverages natural "flow-focusing" behavior induced by the high in-well hydraulic conductivity of the reactive media relative to the aquifer hydraulic conductivity to passively capture and treat proportionally large volumes of groundwater within the well. Clean groundwater then exits the horizontal well along its downgradient sections. Many different types of solid granular reactive media are already available (e.g., zero

Divine et al., 2018. The Horizontal Reactive Media Treatment Well (HRX Well®) for Passive In-Situ Remediation. *GWMR*, DOI: 10.1111/gwmr.12252



RESEARCH ARTICLE

WILEY

The horizontal reactive media treatment well (HRX Well®) for passive in situ remediation: Design, implementation, and sustainability considerations

Craig E. Divine[1] | Jesse Wright[1] | Jack Wang[1] | Jeff McDonough[1] | Michael Kladias[1] | Michelle Crimi[2] | Blossom N. Nzeribe[2] | J.F. Devlin[3] | Michael Lubrecht[4] | Daniel Ombalski[4] | Billy Hodge[3] | Hoa Voscott[1] | Kathleen Gerber[5]

Divine et al., 2018. The Horizontal reactive media treatment well (HRX Well®) for passive in-situ remediation: Design, implementation, and sustainability considerations. *Remediation*, DOI: 10.1002/rem.21571