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Field Demonstration of the Horizontal Reactive Media Treatment Well (HRX Well®) for Effective Long-Term Mass Discharge Reduction

ESTCP Project ER-201631

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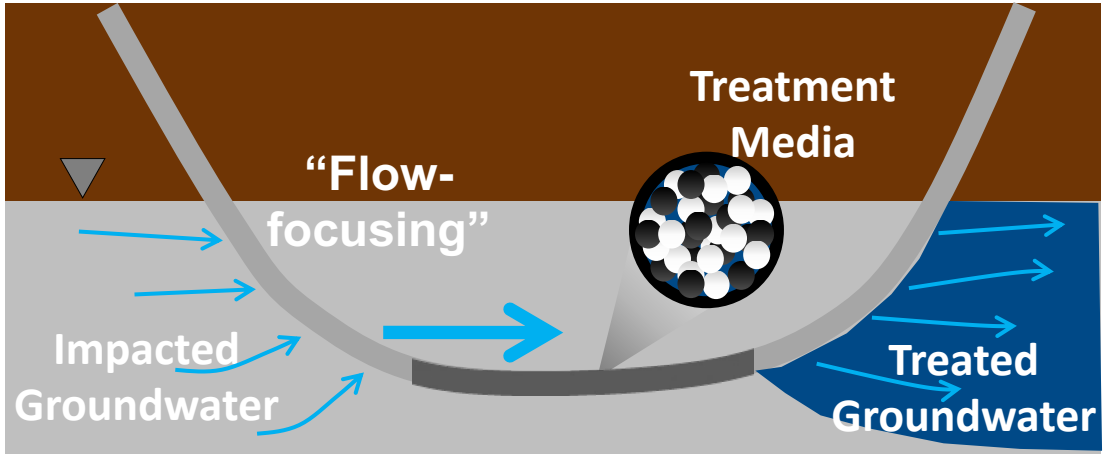
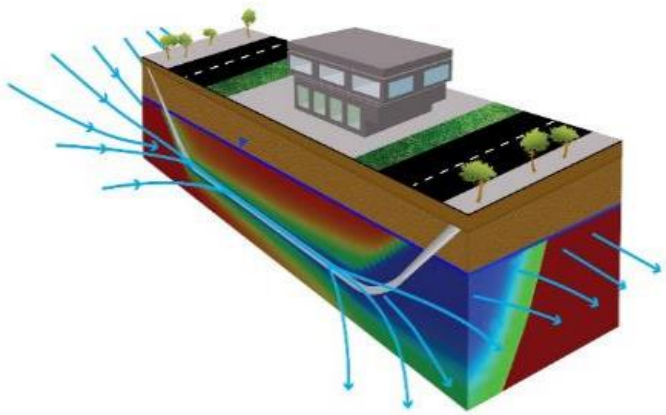
HRX Well Description

The HRX Well* is a large-diameter horizontal well installed along the groundwater flowpath that is filled with treatment media for ***long-term in situ mass flux/discharge control***





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

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*Patent US20120261125A1

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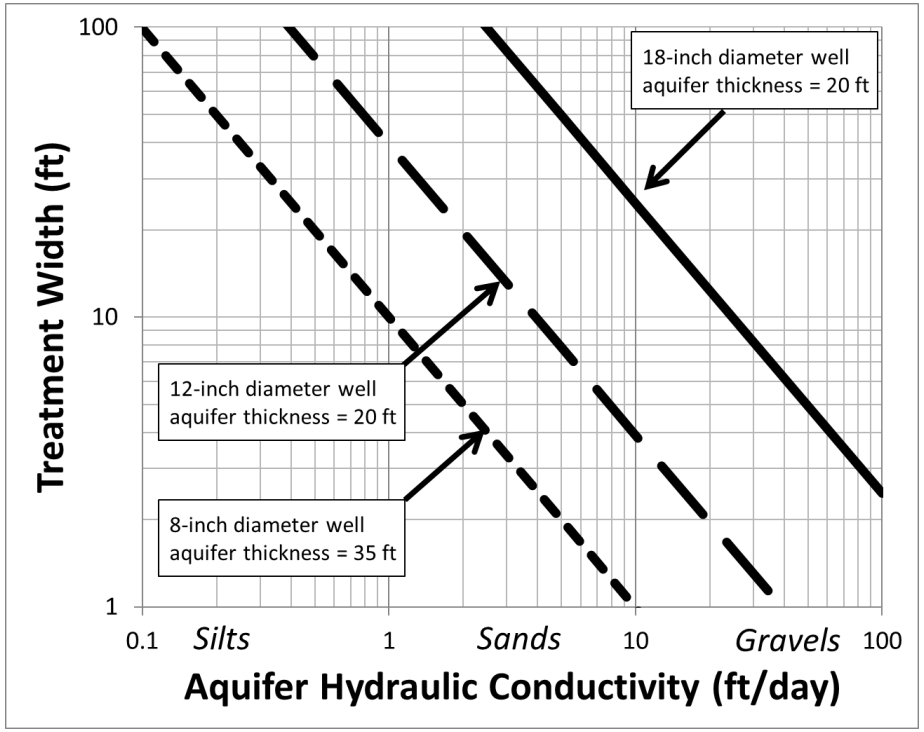
Calculated Capture and Treatment Width

$$w_{treatment} = \frac{K_{HRX} A_{HRX} i_{HRX}}{K_A \; b_A \; i_A}$$

$w_{treatment}$	HRX Well treatment zone width
K_{HRX}	Hydraulic conductivity of HRX Well
A_{HRX}	x-sectional area of HRX Well
i_{HRX}	Hydraulic gradient in HRX Well
K_A	Hydraulic conductivity of aquifer
b_A	Aquifer thickness
i_A	Aquifer hydraulic gradient



Assumes K_{HRX} = 1,000 ft/d

- For passive configurations, $w_{treatment}$ >50 ft may be feasible
- Promising for lower-permeability sites
- Larger treatment zones are possible with pumping

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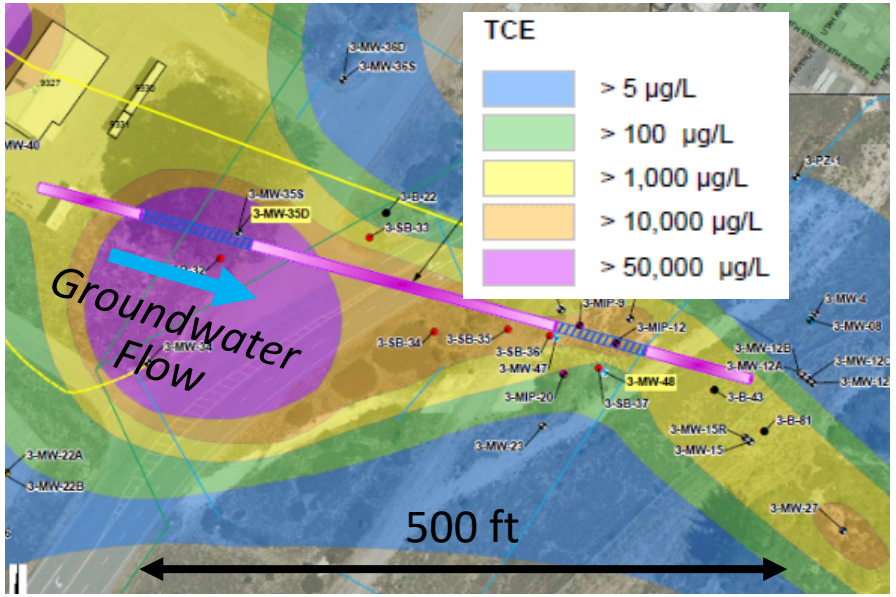
Potential Reactive Media and Target Contaminants

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

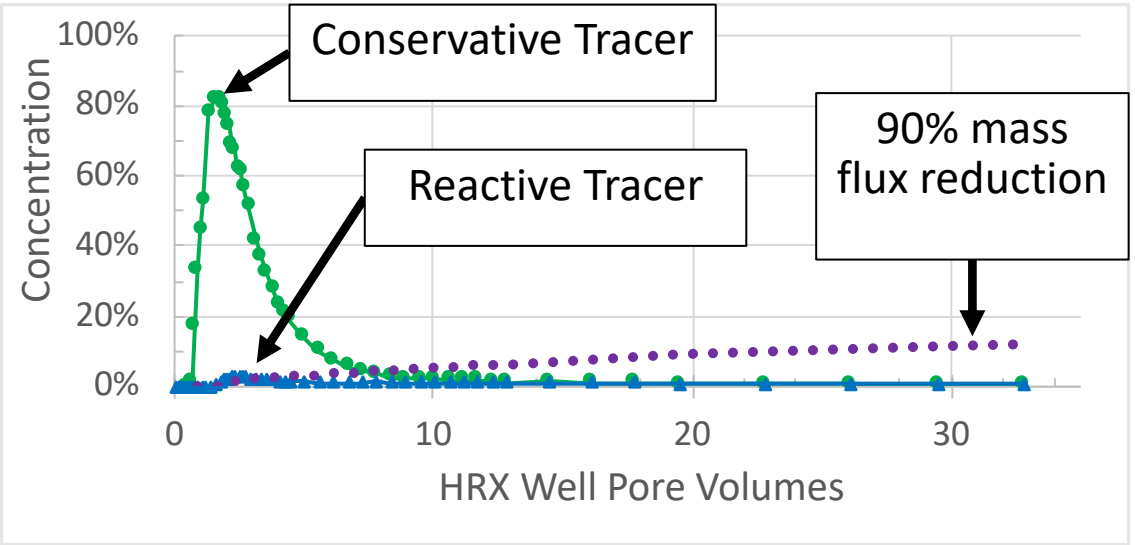
Field Demonstration Site

- Vandenberg Air Force Base (VAFB), CA
- Average aquifer thickness: 8 ft
- Depth: 20-22 ft
- Hydraulic Conductivity: 0.1-0.5 ft/day
- Low hydraulic gradient: <0.001
- Average groundwater velocity: <0.1 ft/day
- Trichloroethene (TCE): 1 to 40 mg/L

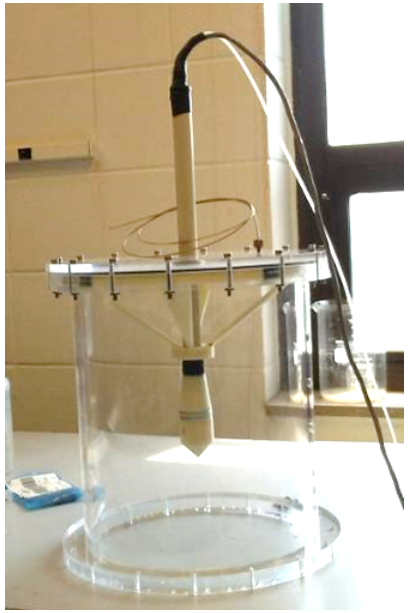


Treatability Testing

Columns Tests of Iron Types



Laboratory HRX Well Tracer Test Results



Redesigned Point Velocity Probe (PVP)

- No losses in permeability or reactivity (>1000 pore volumes)
- PVPs accurately measure in-well velocities
- Tests validate hydraulics and numerical model

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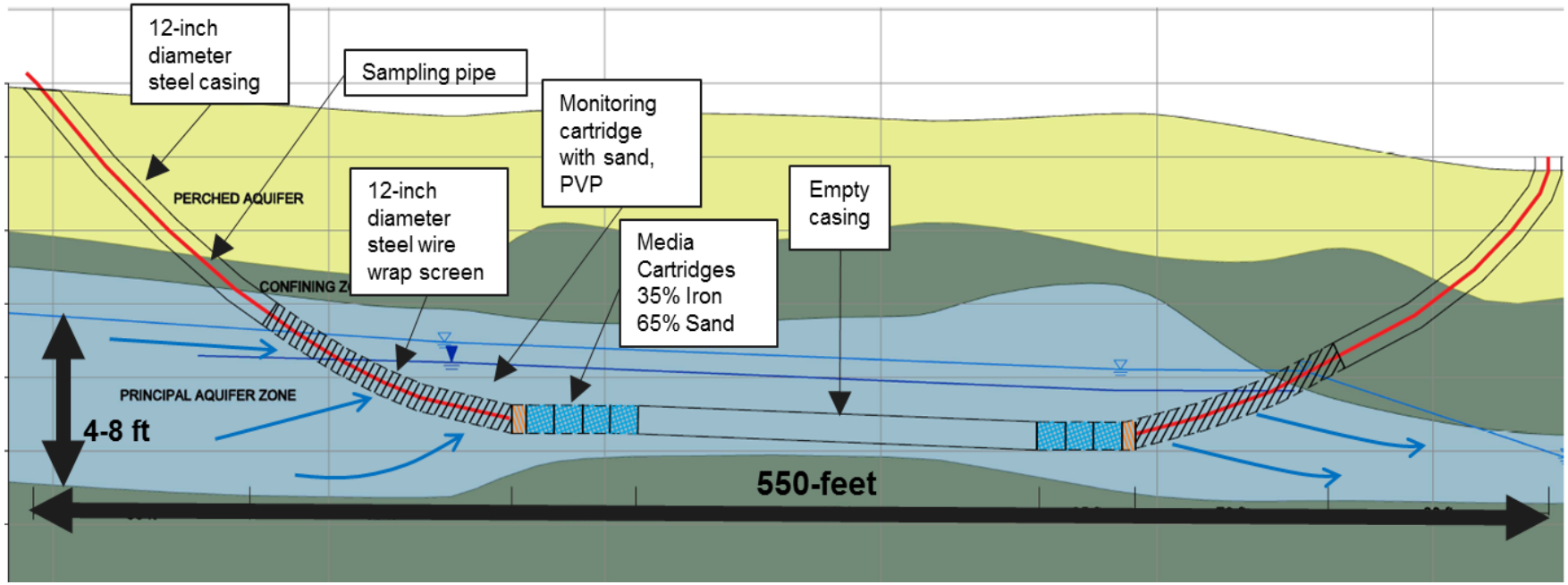
Field HRX Well Design



- Length: 550 ft; Depth: 20 ft; Diameter: 12-in;
- Target treatment zone width: 40-50 ft
- Inlet and outlet PVPs to measure in-well flow
- Target residence time: 6-20 days in ZVI (35%, 70 ft), ~100 days total
- Reactive media usage: 0.7 m^3 ZVI (1,390 lbs ZVI)

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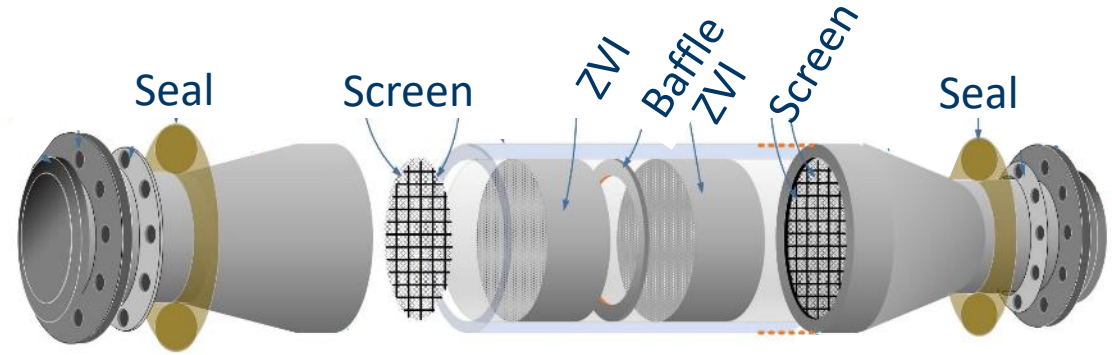
Treatment Media Cartridges*



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*Patent Pending

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HRX Field Installation

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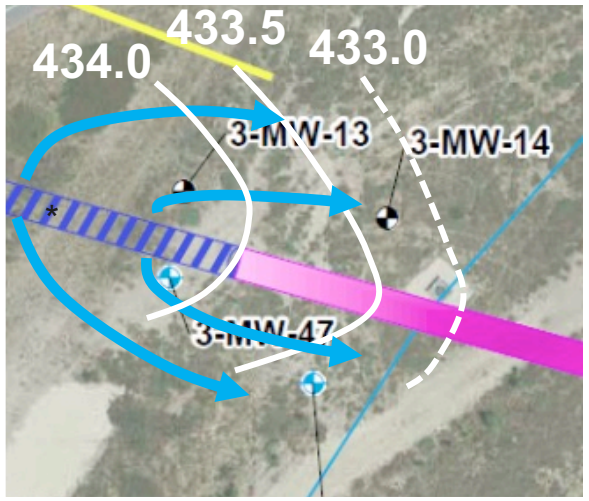
Performance Data: Groundwater Elevations

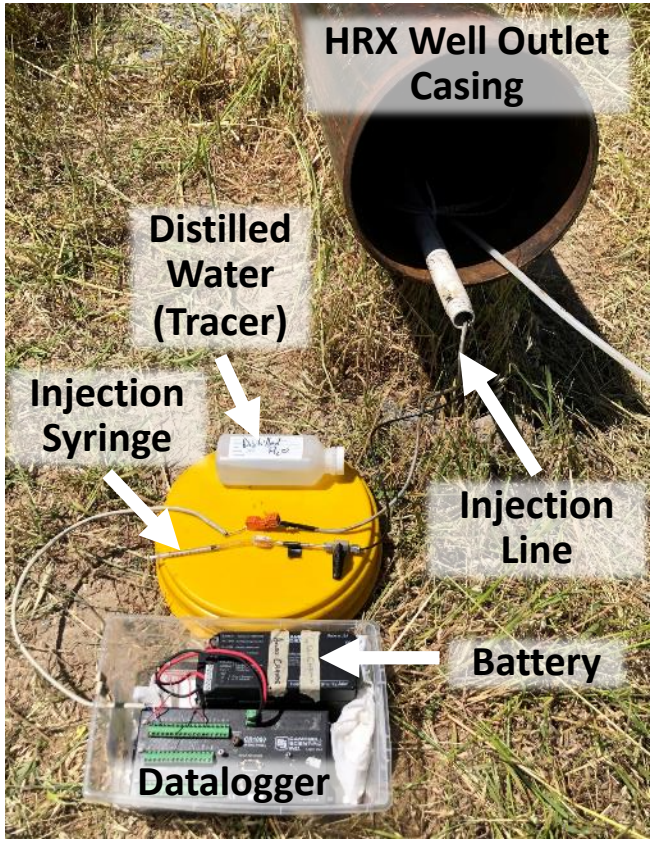
Pre-HRX Well Installation



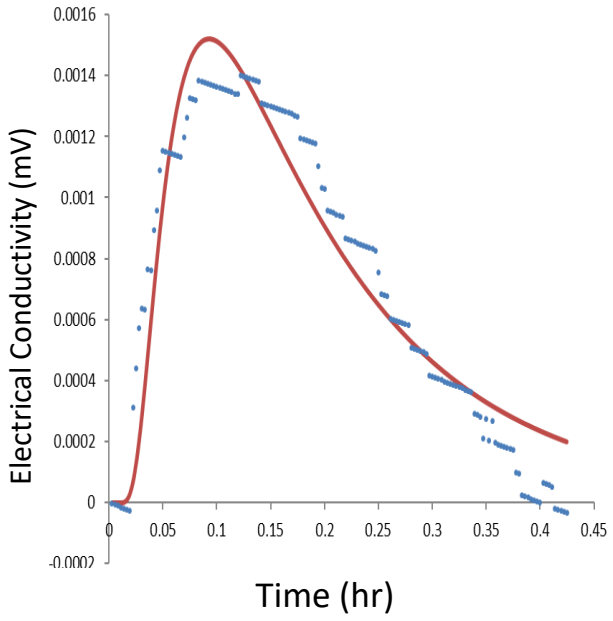
Post-HRX Well Installation

- Local gradient increased ~40x, consistent with model predictions
- Flow field clearly shows discharge from HRX Well

Performance Data: In-Well Flow



PVP Testing Equipment



PVP Test Data

- Velocity in HRX Well = ~9.6 ft/day
  - *Design Model: 7.6 ft/day*
  - *Velocity in aquifer: <0.1 ft/day*
- Flow in HRX Well = ~1.7 ft^3/d, 100x ambient flow
- ~9 day residence time in ZVI, consistent with design model

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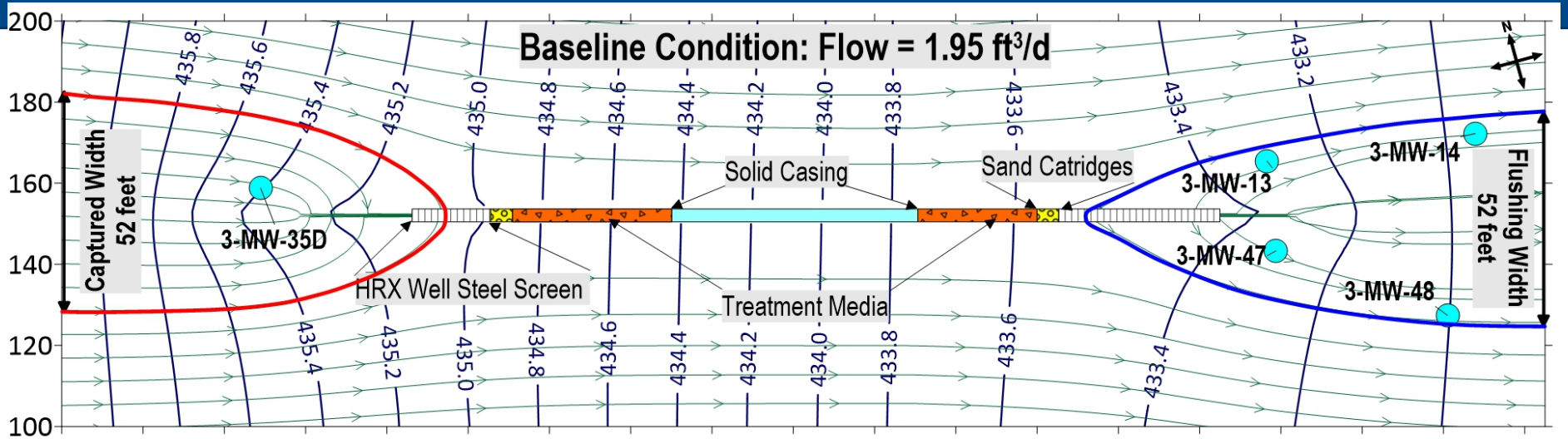
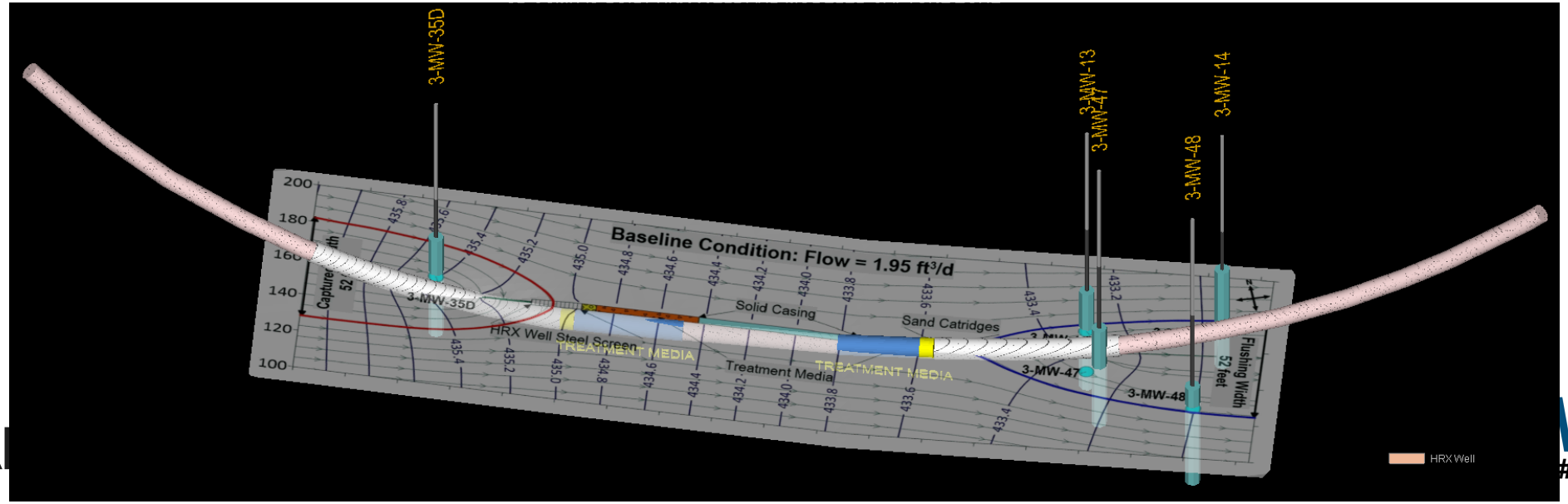
Model-Calculated Treatment Zone: Passive Operation





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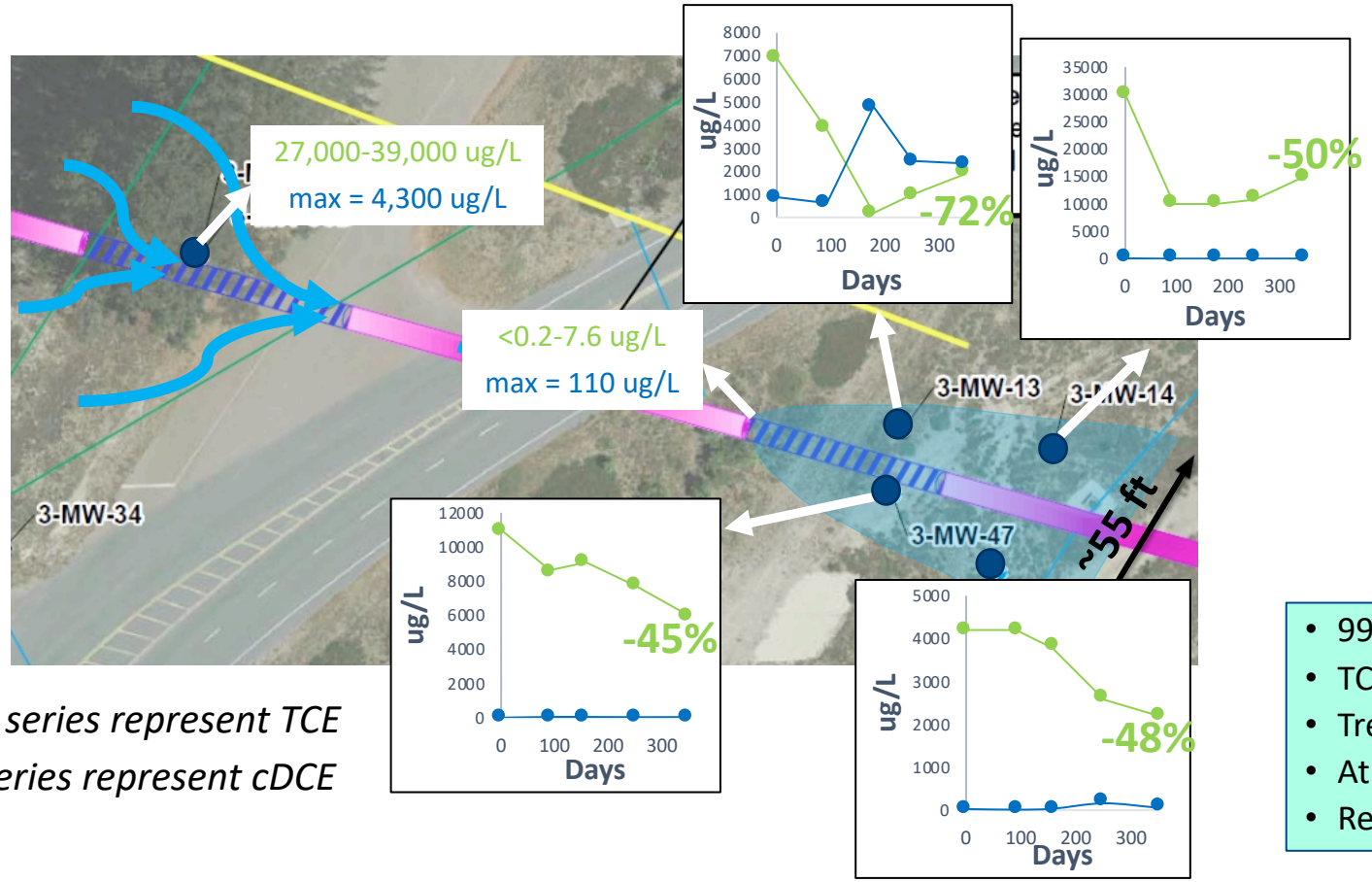
Performance Data - Concentrations



Green series represent TCE

Blue series represent cDCE

Expected vs. Actual Arrival of Treated Water

Well	Expected Arrival (days)	TCE Reduction (days)	cDCE Increase (days)	
MW-47	30-80			★
MW-13	50-125			★
MW-48	200-520			★
MW-14	180-470			?

- 99.99% TCE treatment at Outlet
- TCE mass discharge reduction ~1.7 g/day
- Treated water arrival at wells consistent with predictions
- At 350 days, average TCE treatment in wells = 54%
- Residual drilling fluid promoting significant biodegradation

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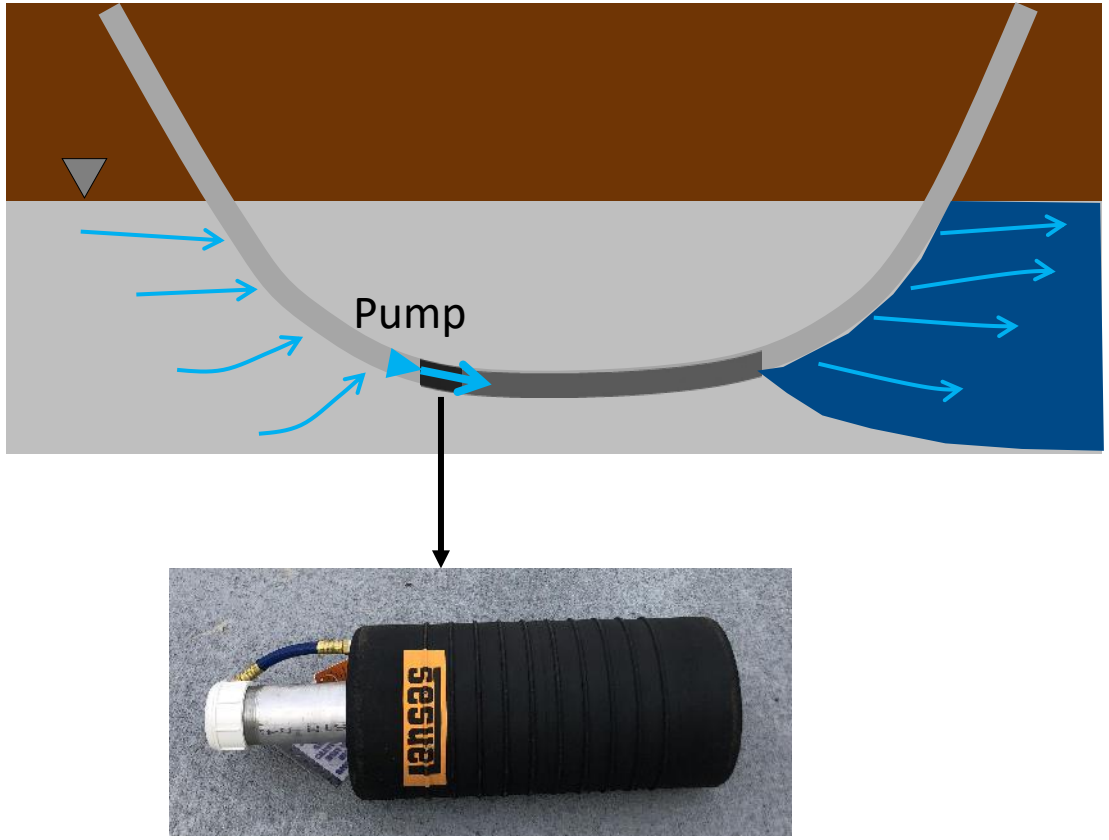
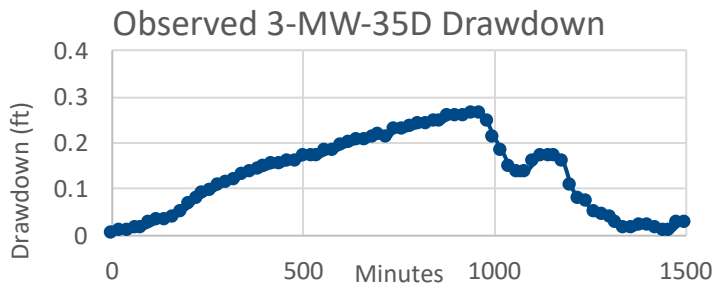
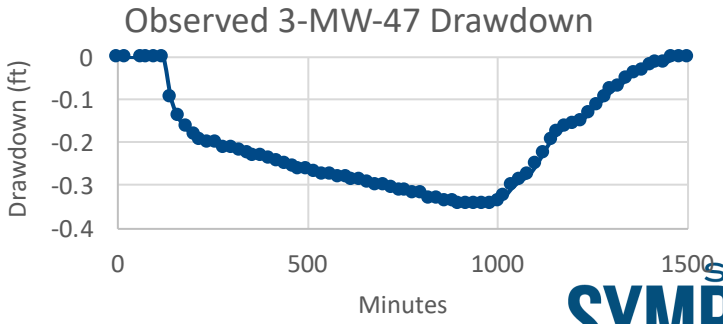
Active Operation: Pumping-Enhanced Capture

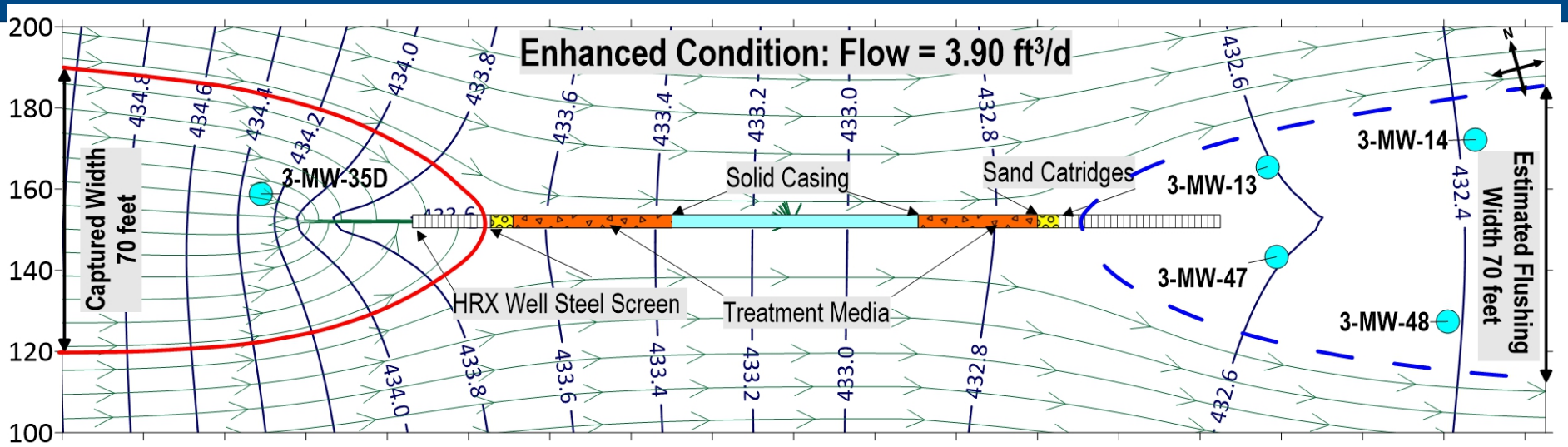


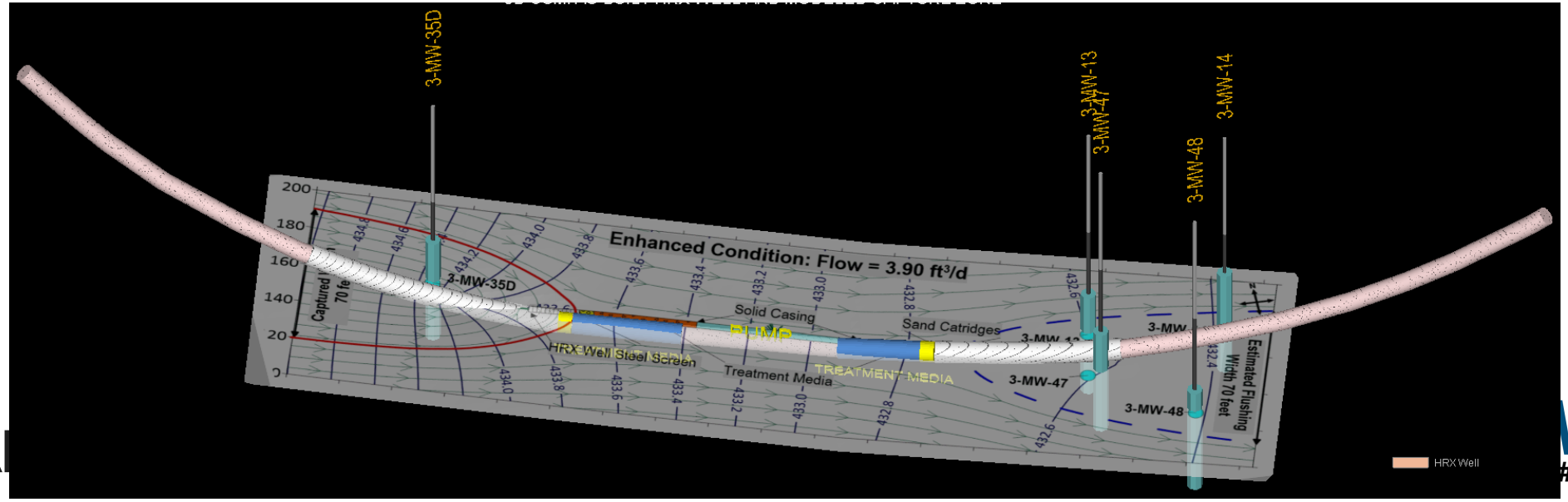
- Temporary packer and pump installed to enhance flow
- In-well flows increased ~2x
- Drawdown/drawup observed in aquifer





Model-Calculated Treatment Zone: Active (Pumping) Operation





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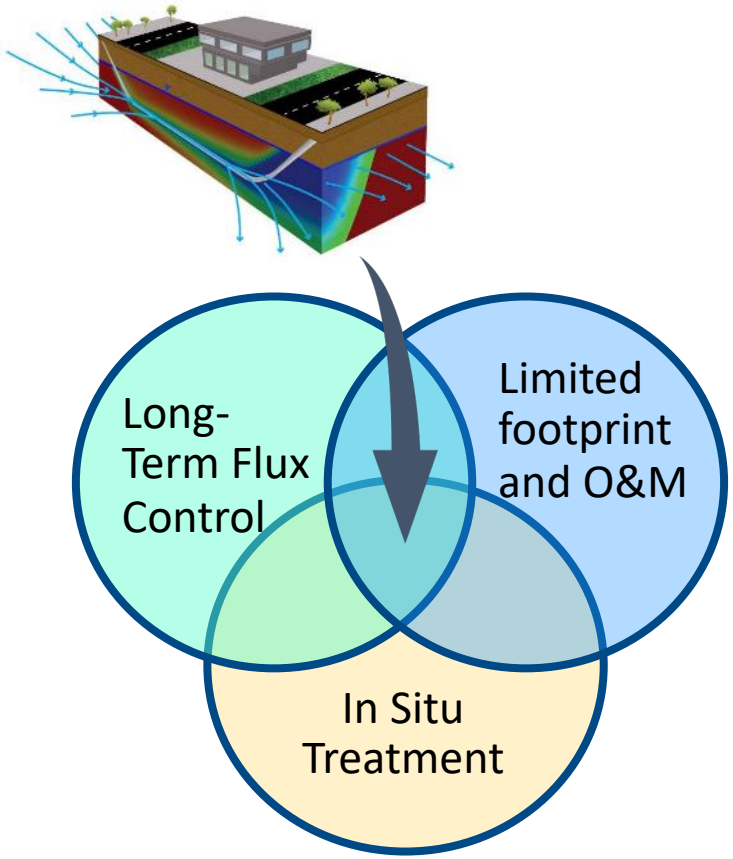
Summary and Conclusions

- Flow focusing hydraulics verified, >50 ft treatment width under passive operation
  - Capture can be enhanced by pumping - expands applicability for high-permeability sites
- Near-immediate >99% TCE mass flux reduction and performance consistent with expectations
- Efficient media usage, many media options now available, cartridge removal/replacement straightforward
- Limited footprint, can access under surface infrastructure
- Low energy, water, and O&M requirements
- Well-suited for long-term mass flux control for recalcitrant contaminants, including chlorinated solvents, PFAS, etc.



Acknowledgements

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Additional Resources

ER-2016 Final Report and Design Tool anticipated 1Q2020. https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201631/ER-201631

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

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