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Using Passive Flux Meters to Design In Situ Remediation and Overcome Limitations of Other Characterization Methods: Case Studies for Two Sites

BATTELLE CHLORINATED CONFERENCE 2024

DENVER, COLORADO

6 JUNE 2024

Sustainability is our business

Agenda

Part 1 – Introduction

Site Background & Characterization Challenges

Part 2 - Approach

Passive Flux Meter (PFM) Solution & Sampling Process

Part 3 – Results

PFM Insights & Data Evaluation

Part 4 – Lessons Learned and Conclusions

Introduction

Remedial Design Characterization (RDC) Benefits

- RDC will lead to more effective, quicker, cheaper site cleanup.
- What characterization methods are available?
- What methods are available if drilling new holes is very challenging or expensive?

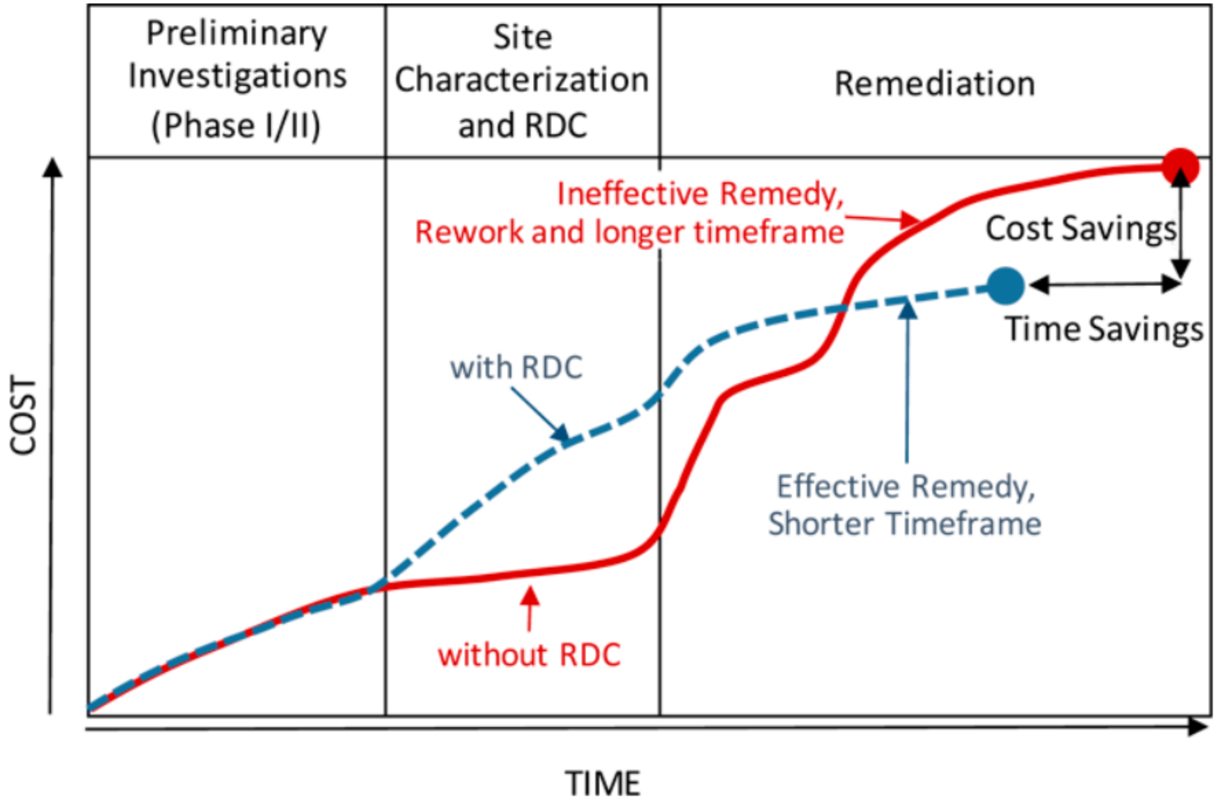


Figure 2-1. Conceptual project lifecycle costs with and without RDC.

Source: Modified from (ITRC 2015)

Source: Interstate Technology Regulatory Council: Optimizing Injection Strategies and In Situ Remediation Performance, Accessed April 2024

Introduction

Comparison of Select Borehole/Well Characterization Methods

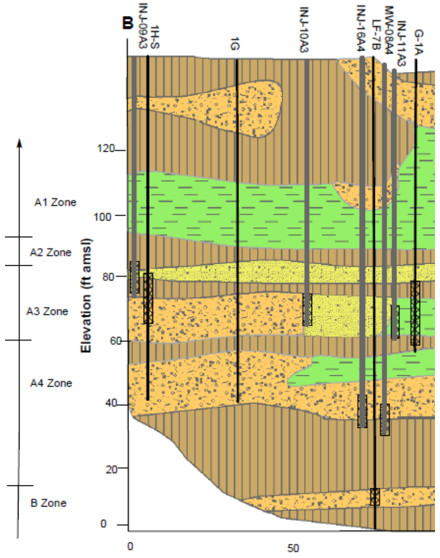
Characterization Method	Output Data	Method	High Resolution?	COC mass+ GW Flow?
PFM	Darcy Velocity and Mass Flux	Existing borehole or Well	Yes	Yes
Slug Test	K		No	No
Nuclear Magnetic Resonance (NMR)	Bound/mobile porosity, K		Yes	No
Downhole Geophysical	Various, e.g. Gamma, HPFM		Yes	No
Well Sample	GW Concentration		No	No
Membrane Interface/ Hydraulic Profiling Tool*	Mobile+ Immobile Concentration and Relative K	New Borehole	Yes	Yes
Grab GW Sample / Waterloo APS	GW Concentration, Relative K (Waterloo APS)		Yes	No
Soil Sample	Soil Concentration, Physical Properties (e.g. K)		Yes	No

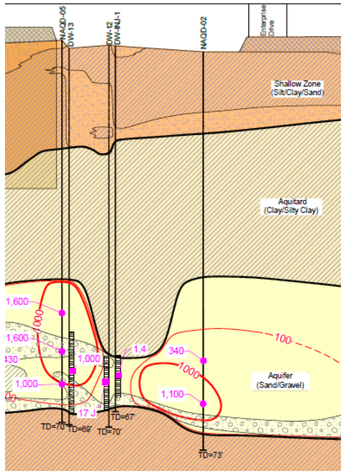
Notes
K = Hydraulic conductivity; HPFM = heat pulse flow meter
* And other direct-read tools (e.g. cone-penetrometer testing, ultra-violet optical image sensing tool, etc.)

Introduction

Site 1 and 2 – Background

	Site 1 – Former Semiconductor Plant	Site 2 – Former Chemical Manufacturing Plant
Current Status	Pump and treat system operating since 1990. 180 wells across site.	P&T system operated from 1986-2023. Full scale injections/ P&T shutdown 2024.
Water Bearing Zone	60-150 feet bgs. 10-60 ft long well screens	45-70 feet bgs (deeper aquifer). 10-30 ft long well screens
COCs	TCE, cis-1,2-DCE, vinyl chloride	1,2-DCA, EDB, TCE
Site Characterization Challenge	Very dense soils. Complex interlayered and channelized geology.	Permitting prevent using MiHPT and similar HRSC tools in deeper aquifer.
PFM Application	In 2019 and 2022, PFMs used to characterize flux zones and design in situ remediation.	In 2021, PFMs used for remedy design to characterize COC mass flux in existing wells.

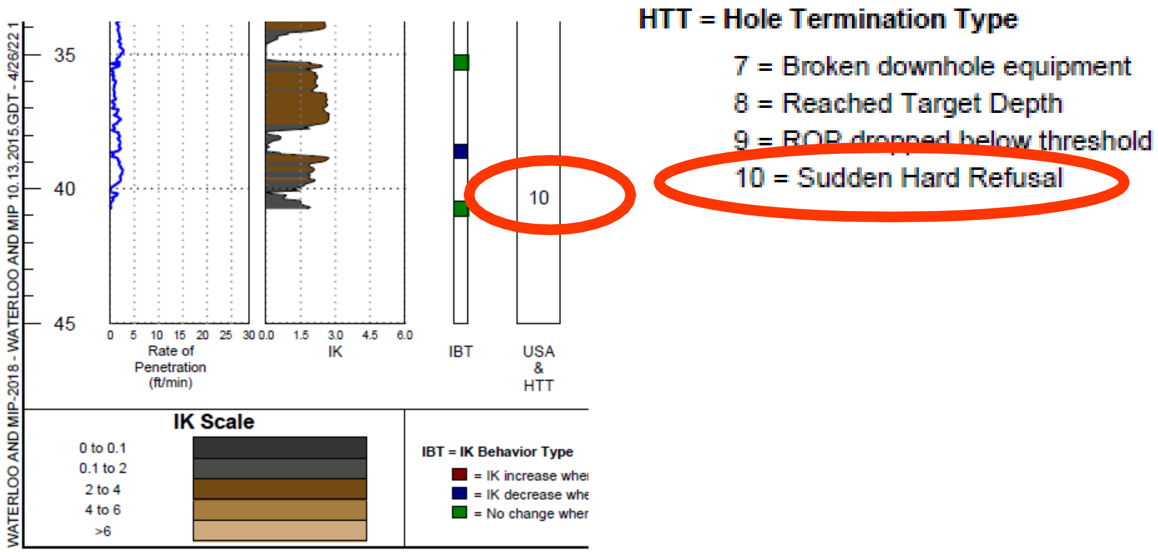




Introduction

Site 1 Challenges

1. Try pushing MiHPT with Direct Push?
2. Try pushing Waterloo APS with a 22-ton CPT rig?
3. Time for Plan C



Approach

Approach

PFM Sampling Solution

PFMs were identified as a viable alternative to standard HRSC methods. PFMs can leverage these legacy sites that have:

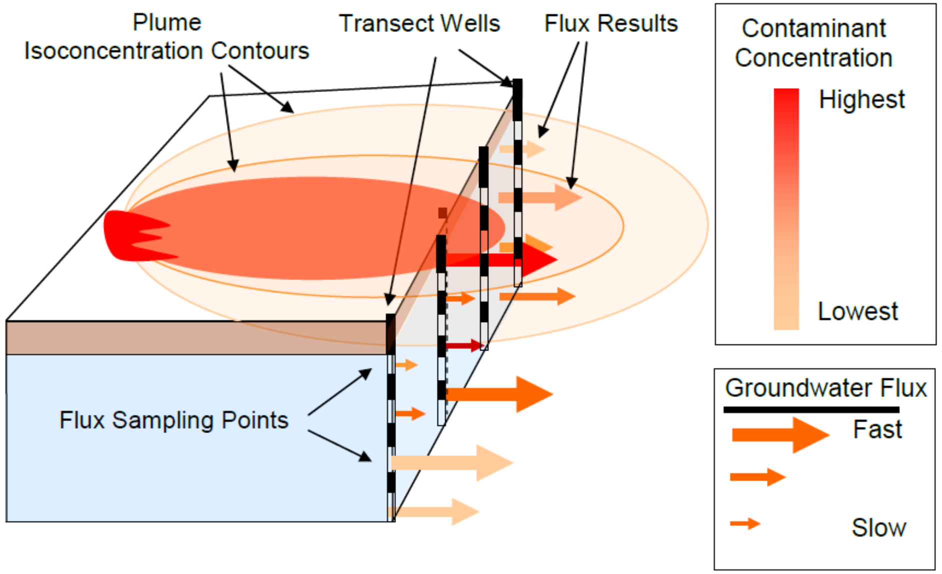
- ✓ Large Well Networks
- ✓ Long Well Screens

PFM Advantages

- ✓ Uses existing wells. No drilling required.
  - ✓ No drilling or permitting challenges.
  - ✓ Safer, lower Cost, less waste.
- ✓ Gathers exact data you need.
- ✓ Compatible with site COCs.

Approach

What is Mass Flux?



Mathematically, contaminant mass flux is the product of the *contaminant concentration* in groundwater and the *groundwater flux*. Thus, contaminant mass flux (J) can be calculated as follows:

$$J = q_0 \cdot C = -K \cdot i \cdot C \qquad (2\text{-}1)$$

where

q_0 = groundwater flux, $L^3/L^2/t$ (e.g., volume/area/d)

K = saturated hydraulic conductivity, L/t, (e.g., m/d)

i = hydraulic gradient, dimensionless (e.g., m/m)

C = contaminant concentration, M/L^3 (e.g., mg/volume)

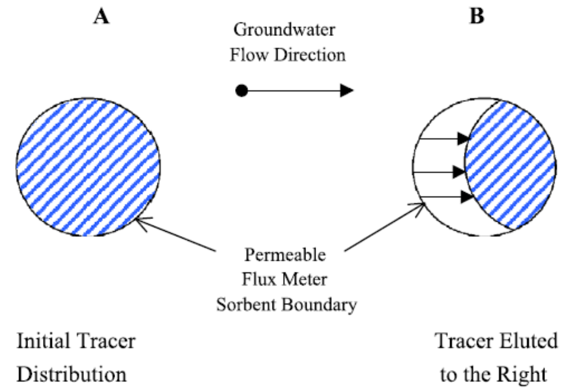
(IRTC. 2010).

"In summary, measurements of mass flux of the contaminants and footprint parameters—not just concentrations—are necessary to document cause-and-effect and to assess long term sustainability/permanence. Site-characterization and monitoring plans should be proactively designed to accommodate mass flux estimates." (USEPA 2001)

Approach

PFM Sampling Process

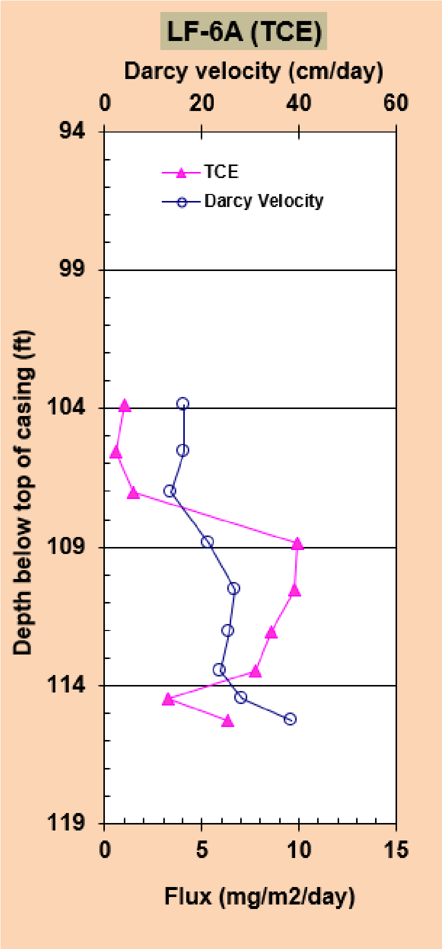
1. Manufactured by EnviroFlux LLC (EnviroFlux) and shipped to the site. Custom-made for 2-, 4-, and 6-inch diameter wells.
2. Lowered into the saturated, groundwater well screen.
3. VOCs in groundwater adsorb to activated carbon in the PFMs to determine mass flux.
4. Alcohol tracers pre-loaded in the GAC leach out proportionately to groundwater velocity to calculate Darcy velocity.
5. After 2 to 3 weeks, PFMs are retrieved from the wells, sampled at 1-2 ft intervals, and analyzed by EnviroFlux.

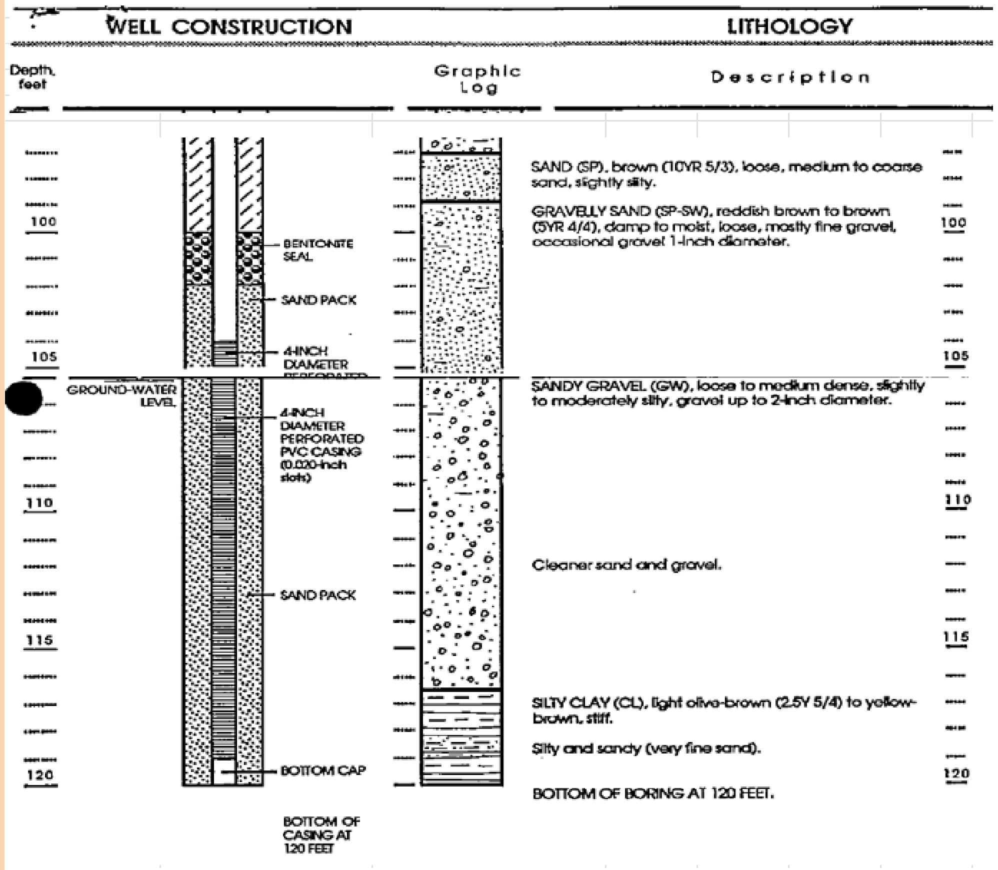


Results

Site 1 Results

✓ PFM data brought new insight to old wells with poor quality boring logs





Note: PFMs provide Darcy Velocity (DV), mass concentration (C) and mass flux

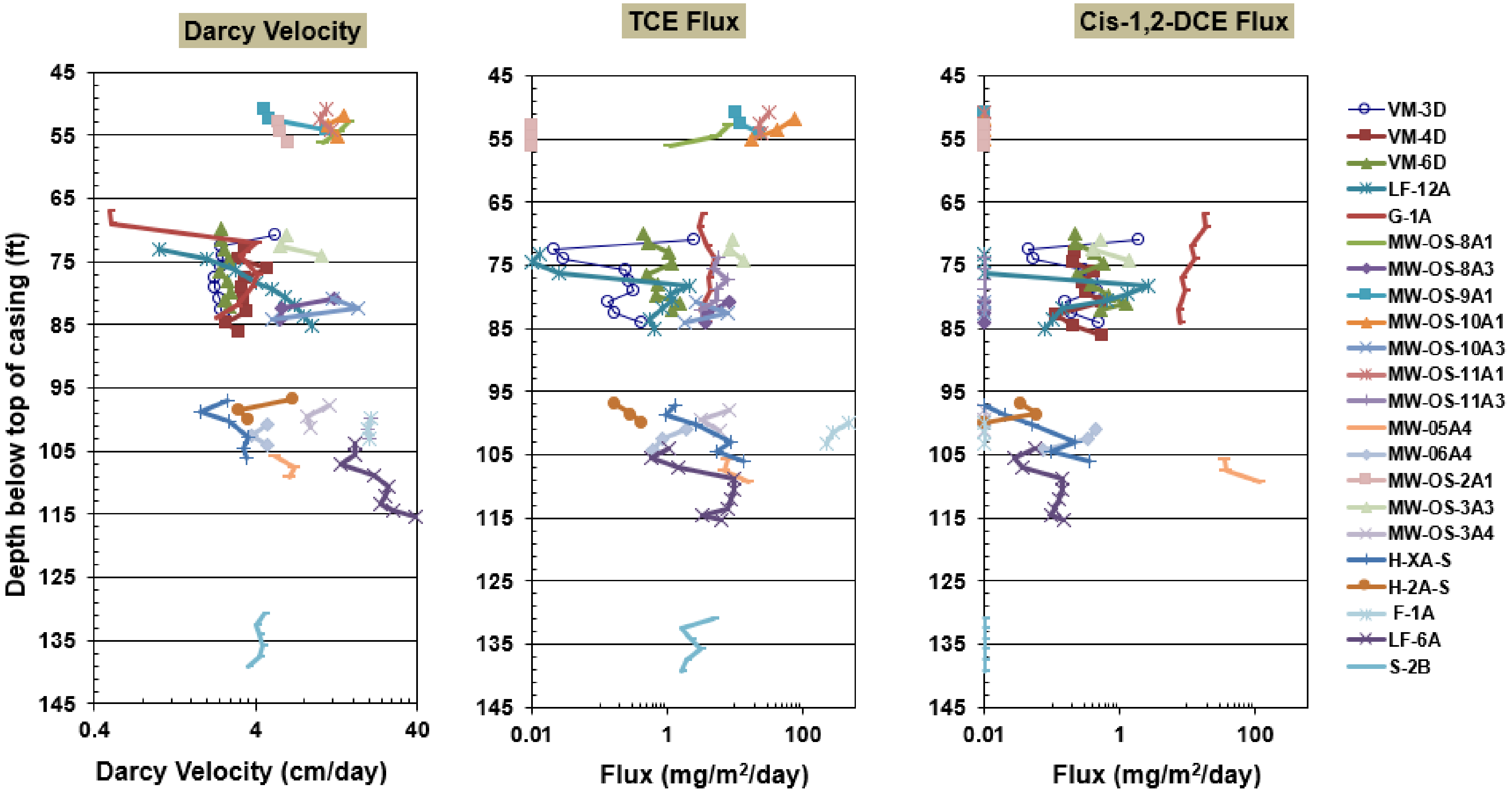
DV = K* i

- i (gradient) changes over time
- Can solve for K or i

Mass flux = C*DV

Site 1 Results

- Data provided rapid assessment of:
  - Areas/depths to focus remediation.
  - Assessment of depth discrete VOC speciation

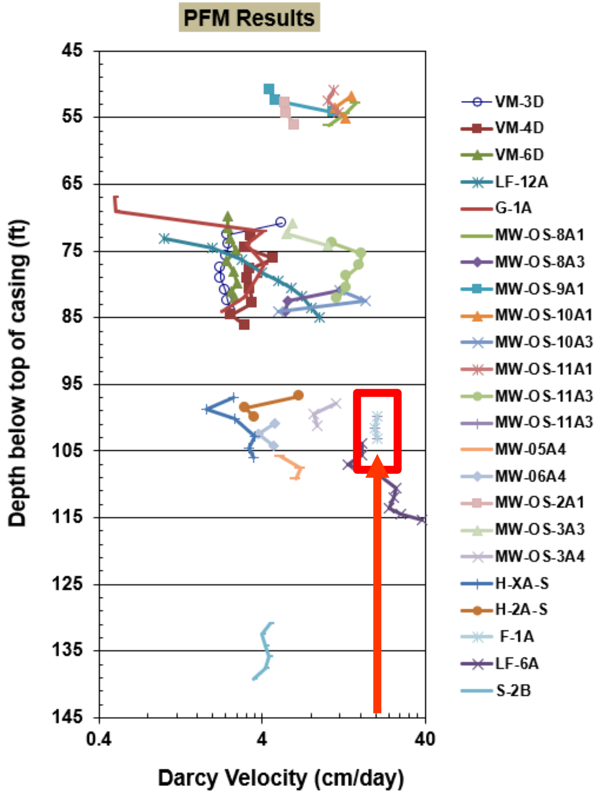


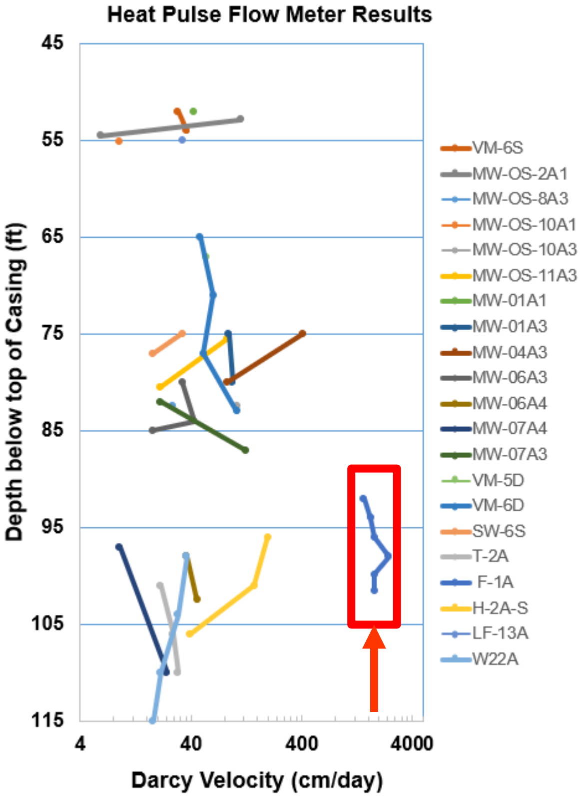
Site 1 Results

PFM Comparison to Heat Pulse Flow Meter

In 2020, heat pulse flow meter (HPFM) testing was performed to characterize groundwater velocity and flow direction in wells.

Although performed at different times, DV magnitude can be qualitatively compared between the two methods.



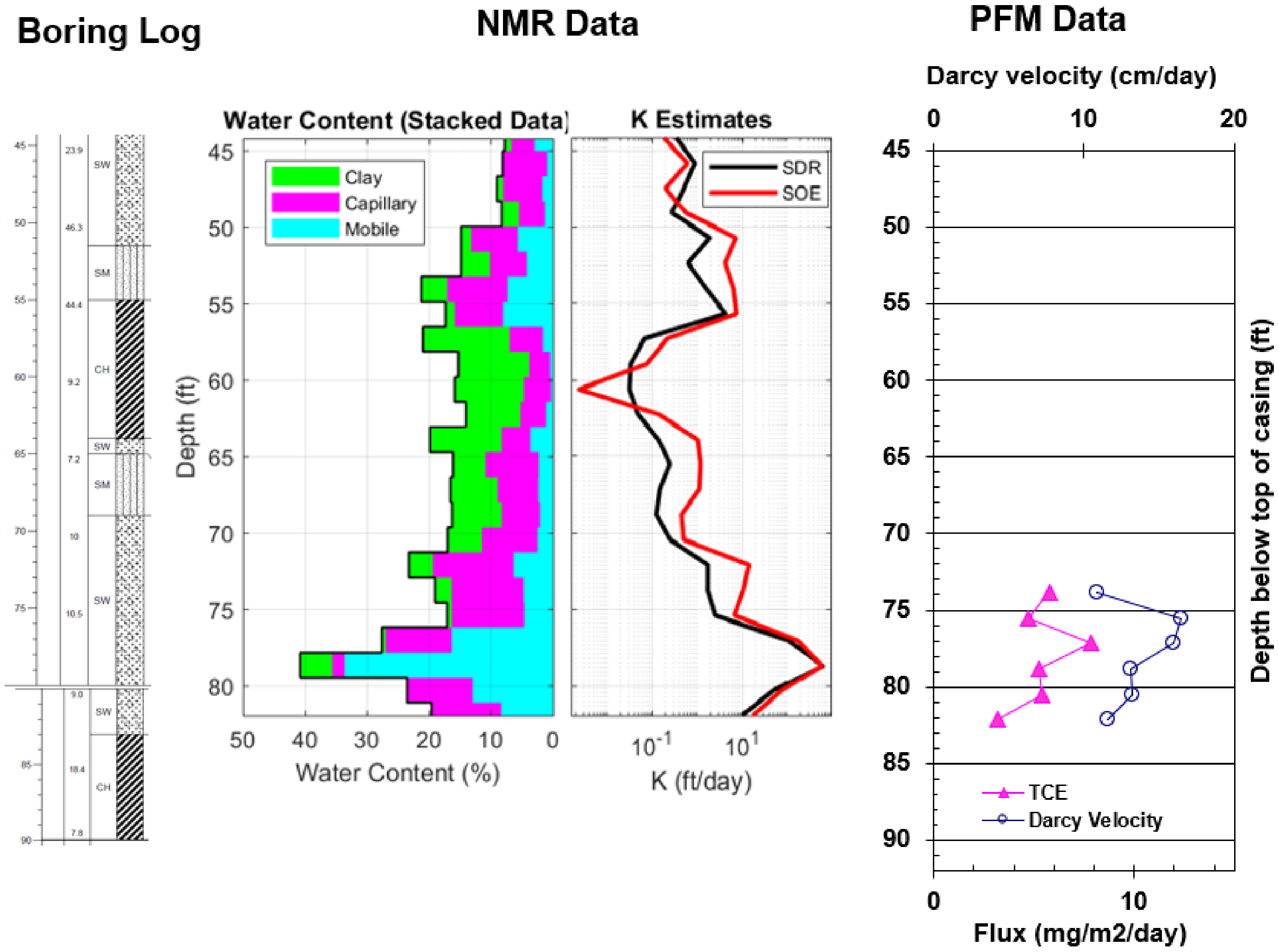


Well F-1A among the highest Darcy velocity measured using both PFM and HPFM testing

Site 1 Results

PFM Comparison to NMR (MW-OS-11A3)

- In 2019, NMR performed to characterize lithology/ hydrogeology zones.
- PFM is limited to screened interval but provides COC mass flux.
- NMR provides high resolution data through well casings.
- Good correlation.

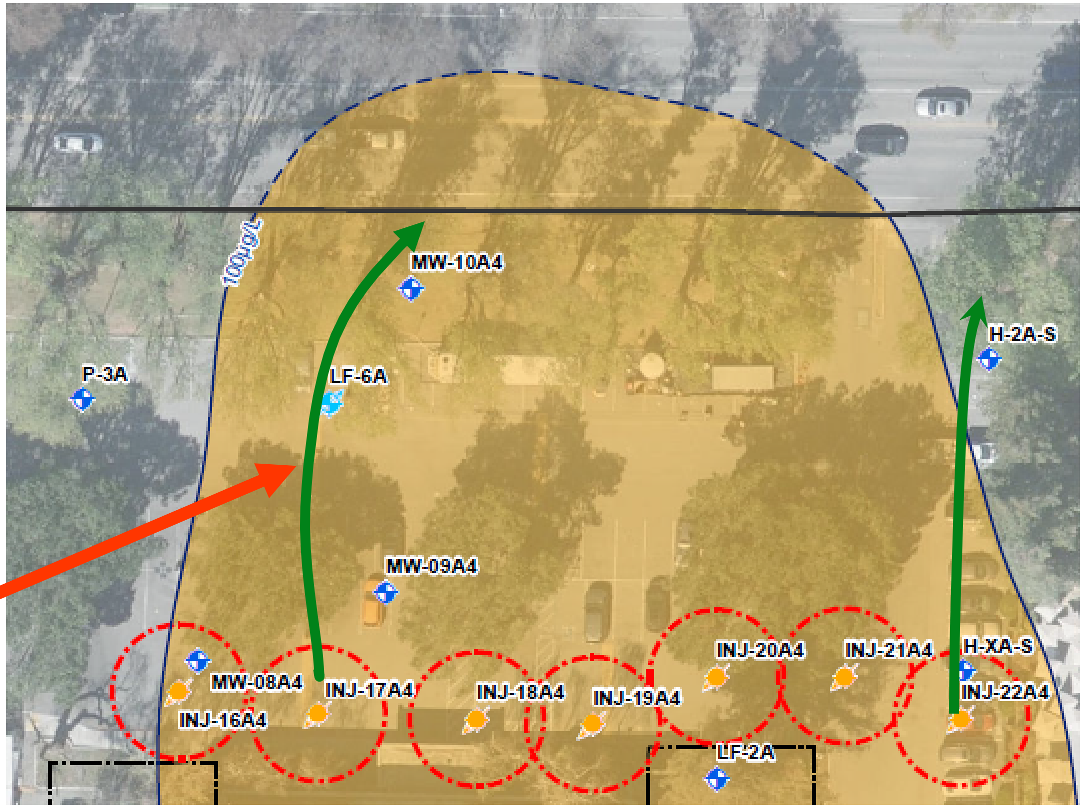


Site 1 Results

Site 1 EVO Injection Results

- EVO was injected into injection well transect
- Total organic carbon (TOC) in EVO used as a tracer to infer transmissive zones
- High DV and TCE zones identified using PFMs correlated with high TOC migration from injections (100 feet vs 20 ft estimated ROI)
    - Likely high K channel deposits

Injected EVO migration pathway (confirmed using TOC samples).

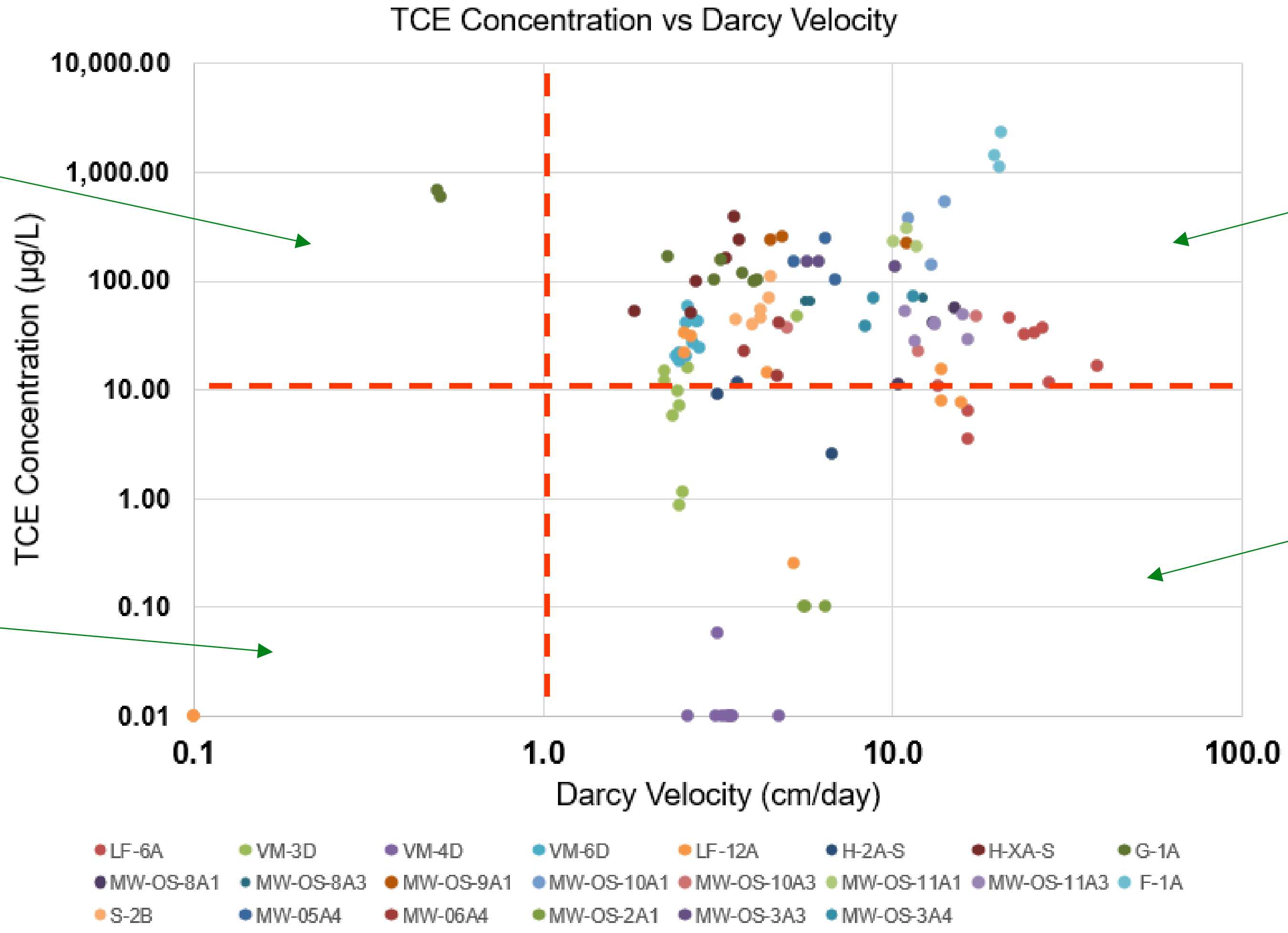


Site 1 Results

Site 1 PFM Box Diagram Results

High C, Low DV:
- **Mass Storage**
- **Matrix Diffusion Potential**
- **Challenging in situ Remediation**

Low C, Low DV:
- **Do Not Target for Remediation**



High C, High DV:
- **Plume Migration Risk**
- **Target for Remediation**

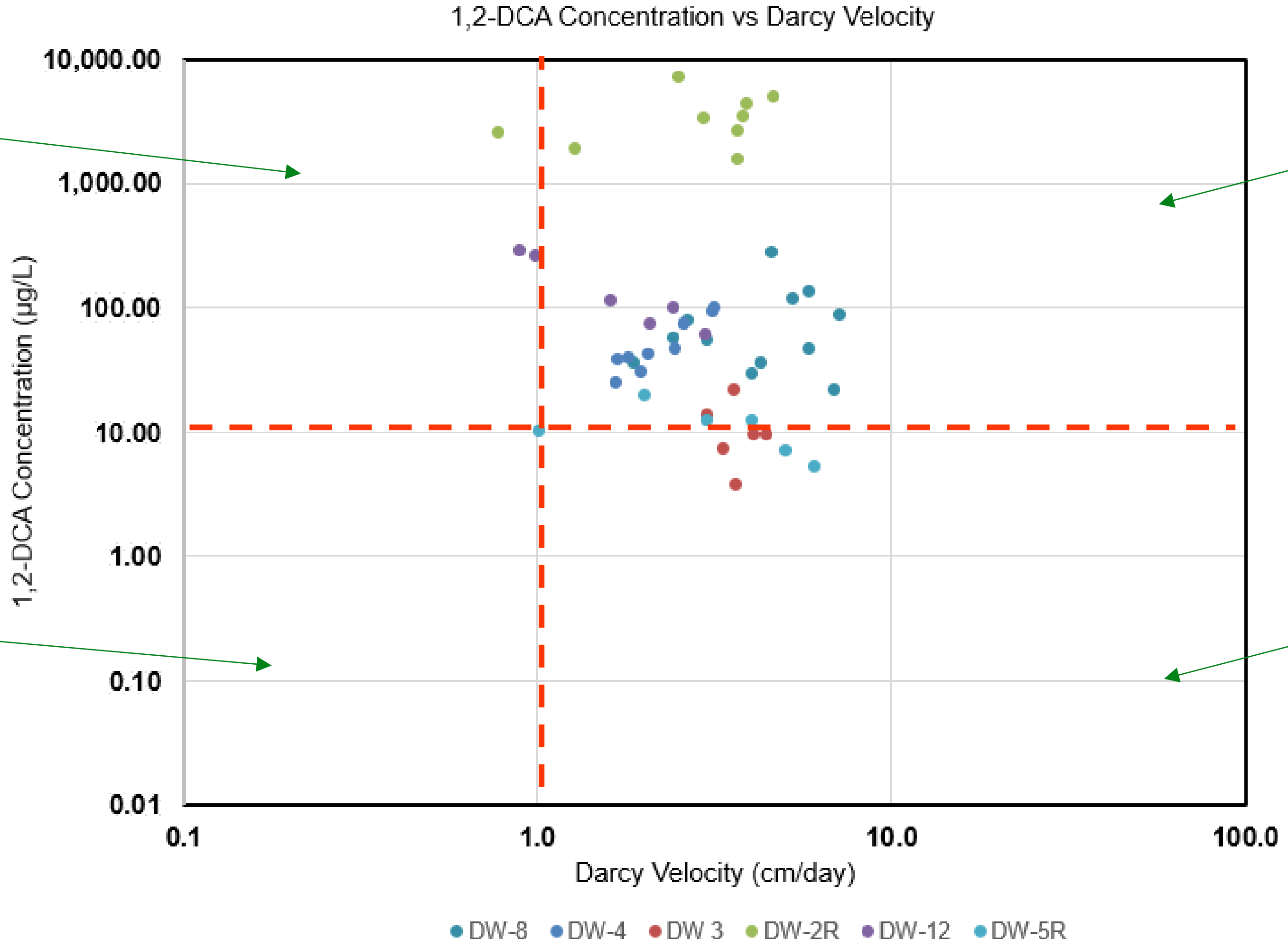
Low C, High DV:
- **Low Remediation Priority**

Site 2 Results

Site 2 PFM Box Diagram Results

High C, Low DV:
- **Mass Storage**
- **Matrix Diffusion Potential**
- **Challenging in situ Remediation**

High C, High DV:
- **Plume Migration Risk**
- **Target for Remediation**



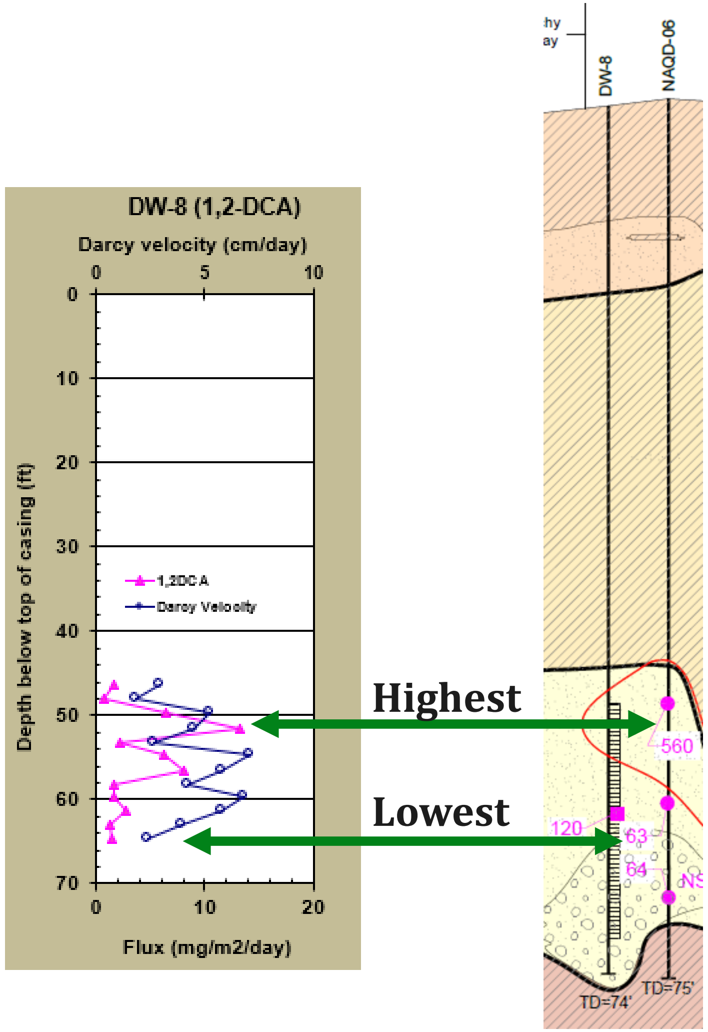
Low C, Low DV:
- **Do Not Target for Remediation**

Low C, High DV:
- **Low Remediation Priority**

Site 2 Results

PFM Results Correlation with Grab Groundwater Results

- 1,2-DCA mass flux results in well DW-8 closely matched 1,2-DCA concentrations in a grab groundwater sample collected 20 feet away.
  - ✓ Confirmed the upper portion of the aquifer should be targeted for remediation rather than the lower.
  - ✓ PFM results provided more resolution and insight than grab-groundwater samples or well sample



Conclusions and Lessons Learned

Lessons Learned

- PFM Installation in larger wells (e.g. 4-inch, 6-inch) is possible, but more expensive and challenging than 2-inch wells.
- The PFM testing program should be designed to meet your project objectives
  - E.g. shutdown extraction wells to test ambient groundwater flow conditions
- Previous bioremediation can affect PFM results (tracer consumption by microbes). Discuss with PFM manufacturer first.
- Consider redeveloping older wells and running a camera survey to improve data quality and avoid PFMs getting jammed.
- PFM materials/analytical costs are $3-5K per 2-inch well, depending on number of samples and analysis.
- A small amount of GAC from the unsampled PFMs requires disposal. Include waste disposal in scope and budget.
- Our regulators were supportive of collecting PFM data to enhance the CSM and expedite site cleanup. Appropriate time should be allocated educating stakeholders about different technologies to optimize its application.

Conclusions

- Challenging sites with large legacy well networks and long well screens can be leveraged to gain new CSM insights using PFMs
- Mass flux data measured using PFMs provides a more complete understanding of plume dynamics than groundwater concentration data alone.
- PFM Applications:
  - Repeatable pre- and –post remediation testing
  - Enhance understanding at wells with missing or poor quality well logs
  - Rapidly identify in situ remediation priorities and challenges
    - Based data from these two sites, VOC concentrations of ~10 ug/L and darcy velocity of ~1 cm/day may be used to guide remediation

Thank you

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Special Thanks to Jay Cho at EnviroFlux for patiently answering my questions!

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