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DEEP VADOSE ZONE PROGRAM @PNNL

Vertical Characterization of Flow and Contaminant Concentration in New Hanford Extraction Wells

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2025 RemPlex Summit

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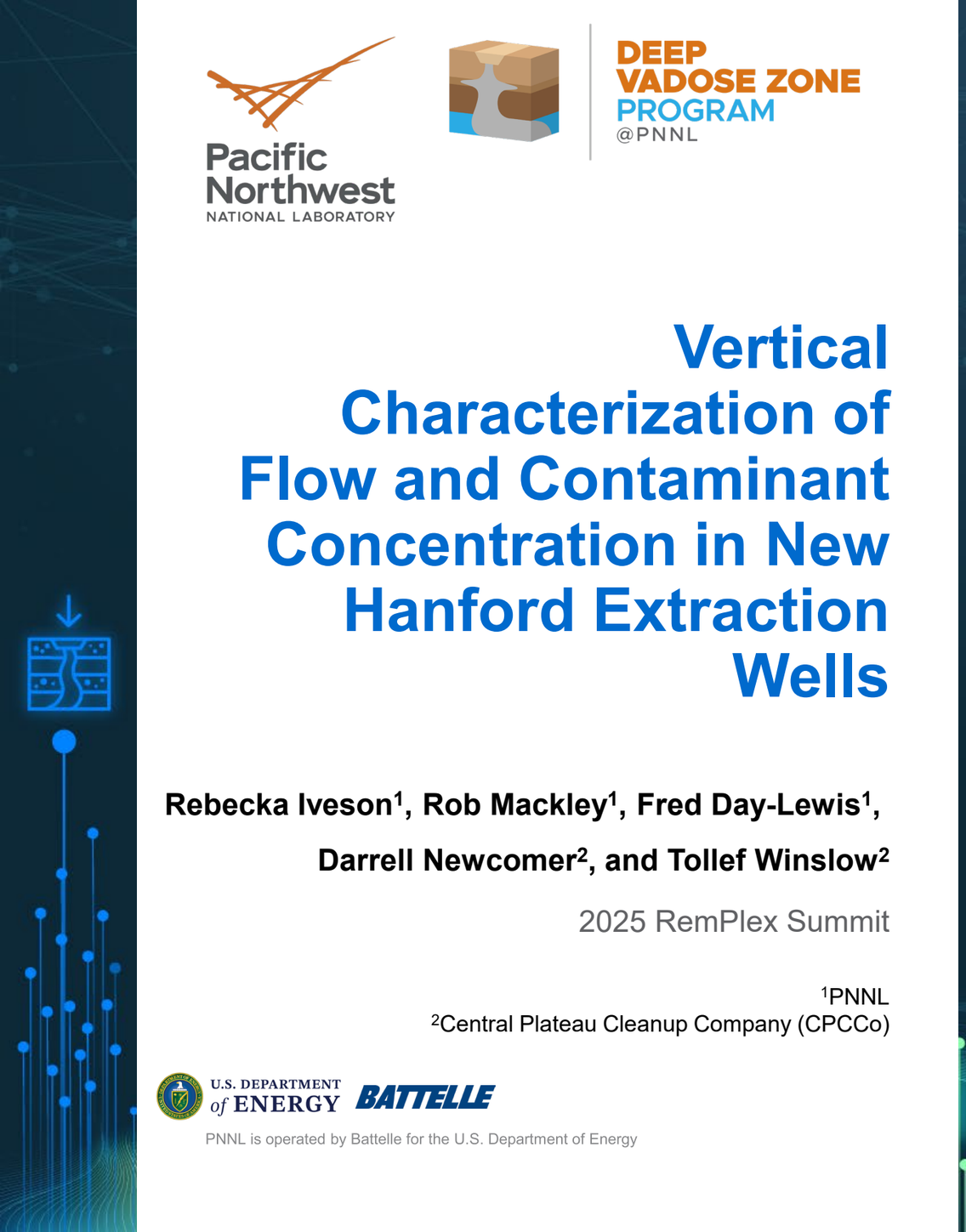
[2]Central Plateau Cleanup Company (CPCCo)



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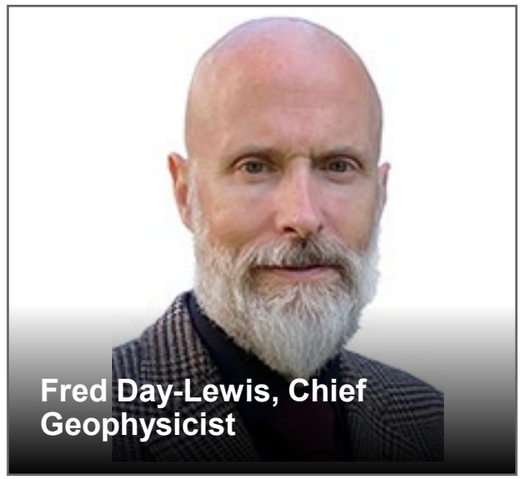
DVZ Research Team

From Top Left Clockwise: Rebecka Iveson, Jack Flannigan (MSIPP intern/UArizona), Daniel Petroski, Zoe Vincent, Elliz McClelland (photography by Andrea Starr | Pacific Northwest National Laboratory)

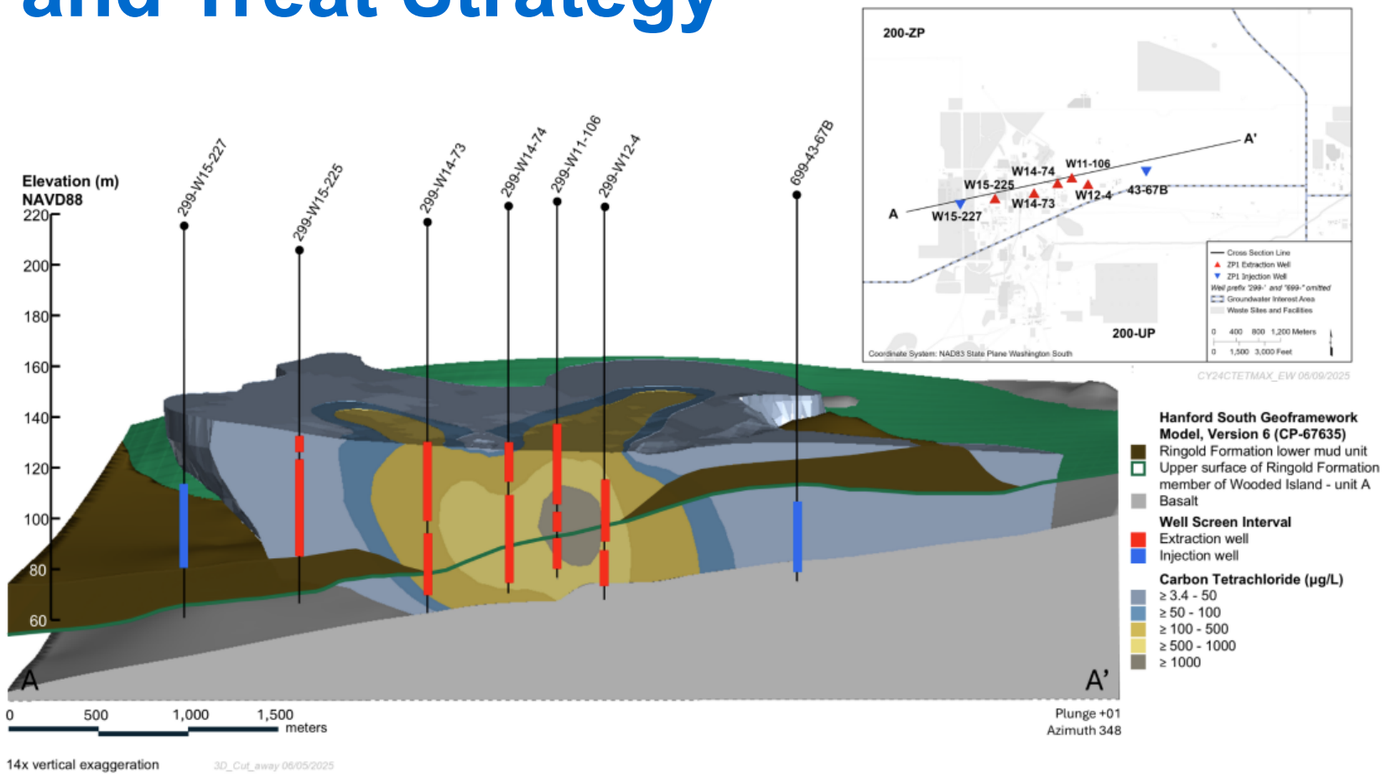
Rob Mackley, Hydrogeologist and Project Manager, DVZ



Fred Day-Lewis, Chief Geophysicist

Hanford's Pump and Treat Strategy

- Primary remediation method for groundwater
  - Over 400 wells, including long-screened wells that span multiple aquifer layers, aiming to remediate and monitor extensive plume areas
  - Reinject treated water for added hydraulic control
- Layered, sedimentary aquifer system
  - Lateral and vertical variation in plume concentrations
  - Preferential flow paths (known and unknown)



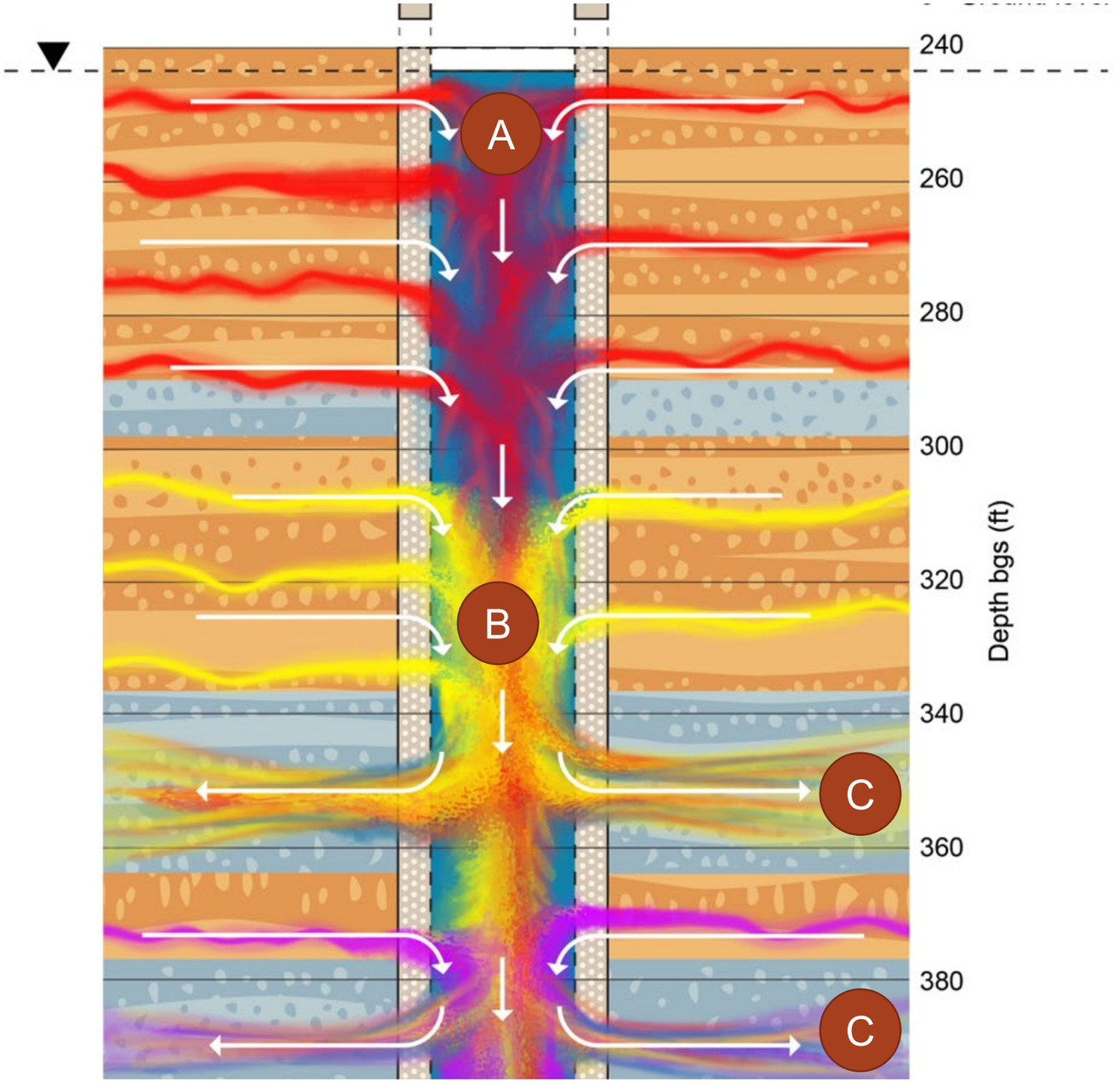
Three-dimensional carbon tetrachloride plume, 2024. (CPCCo, 2025)

Key Components of Remediation Strategies:

1. Monitor performance
2. Optimize contaminant removal or containment
3. Assess and adjust continuously

Challenges of Long-Screened Wells

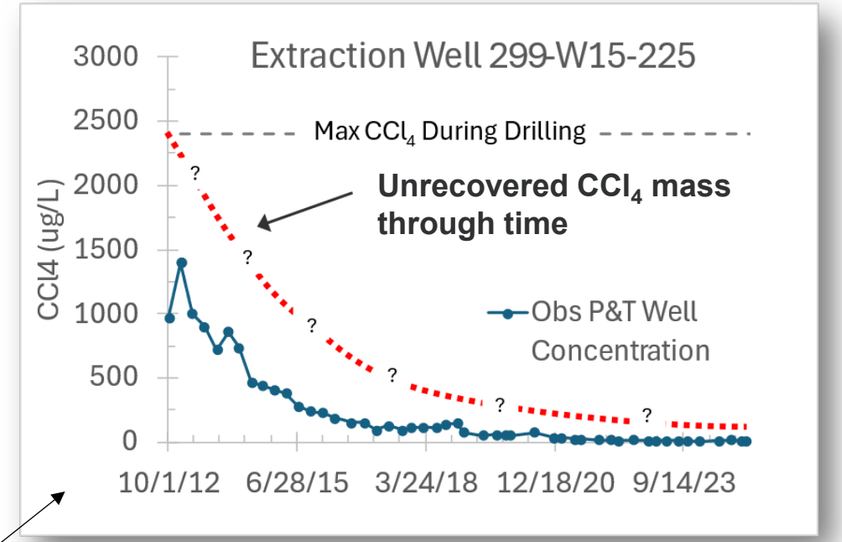
- Low-flow, no purge, other passive sampling methods are representative of vertically redistributed groundwater
  - May not “see” mass in zones of outflow under ambient conditions
- Well acts a conduit for flow
- Pump intake depth does not control where groundwater inflow occurs
- Higher-rate pumped samples will ‘produce’ GW from zones of high hydraulic conductivity (introduces bias)



Possible flow patterns and contaminant mixing in a well

Problem Statement

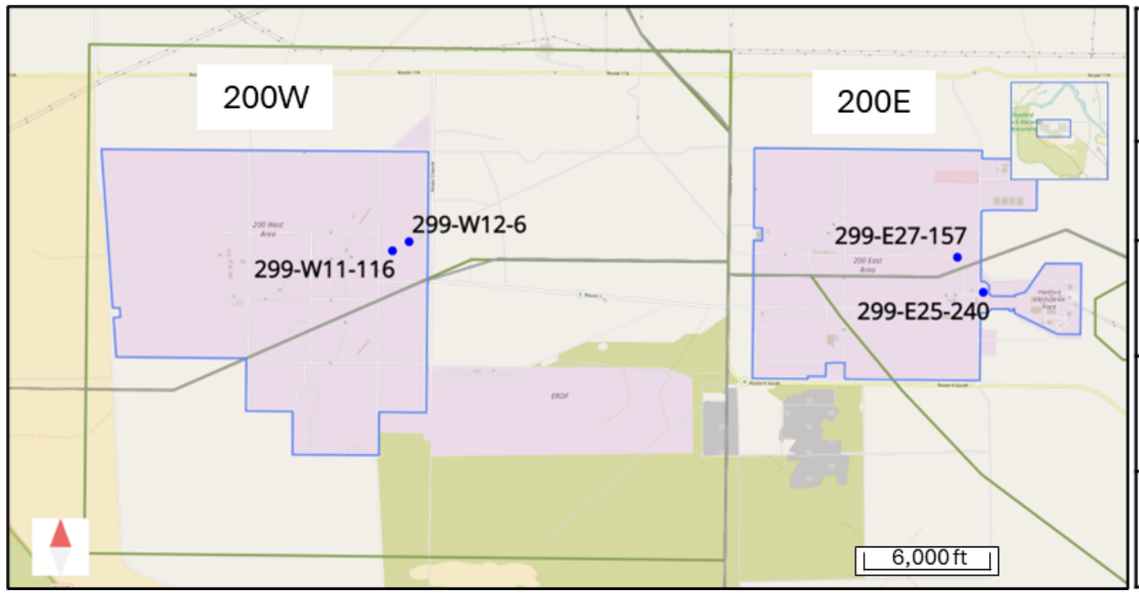
- Challenges in monitoring the Pump-and-Treat (P&T) system:
  - Complex aquifer-well interactions
  - Vertical flow dynamics leading to dilution effects
  - Obscured high-concentration zones within low-permeability layers
- **Leads to**: Impact on remedy design and remediation objectives



Mass removal in a Hanford long-screened extraction well (299-W15-225).

- **A Way Forward:** Measuring intraborehole flow and estimating the depth-varying contaminant concentrations in the surrounding aquifer
  - Hanford Case Study

Study Location: New Extraction Wells at Hanford



Well ID	OU	COC
299-W12-6 (D0473)	ZP-1	CCl_4, TCE
299-W11-116 (D0474)	ZP-1	CCl_4, TCE
299-E27-157 (D0118)	BP-5	Tc-99
299-E25-240 (D0119)	PO-1	Tc-99

PNNL custom built field hydraulic testing trailer

200 West P&T Facility

Extraction Well

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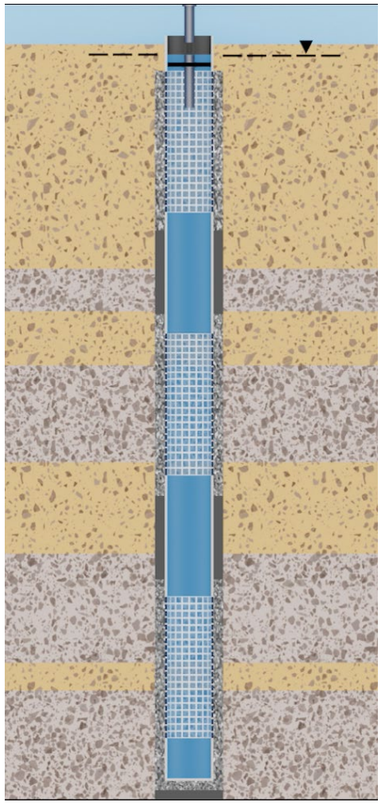
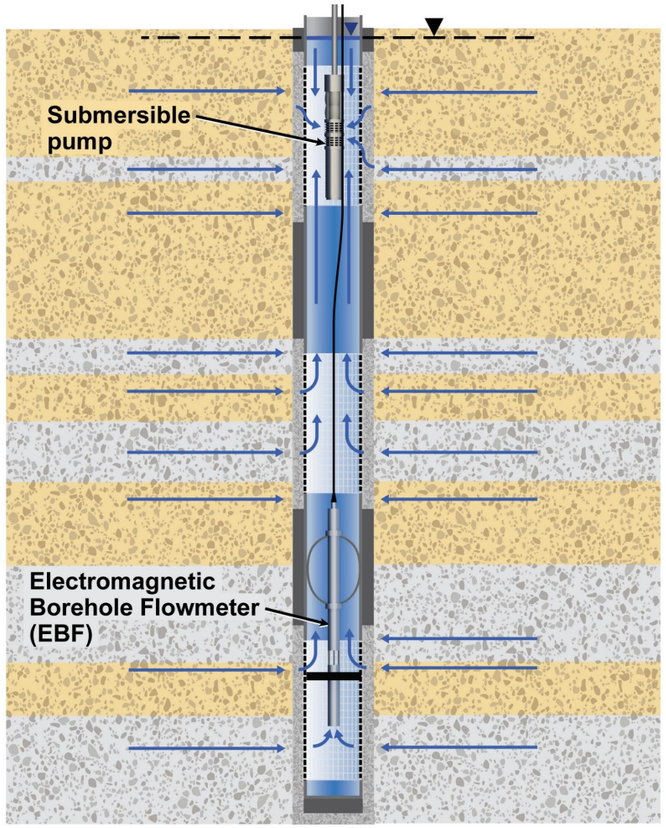
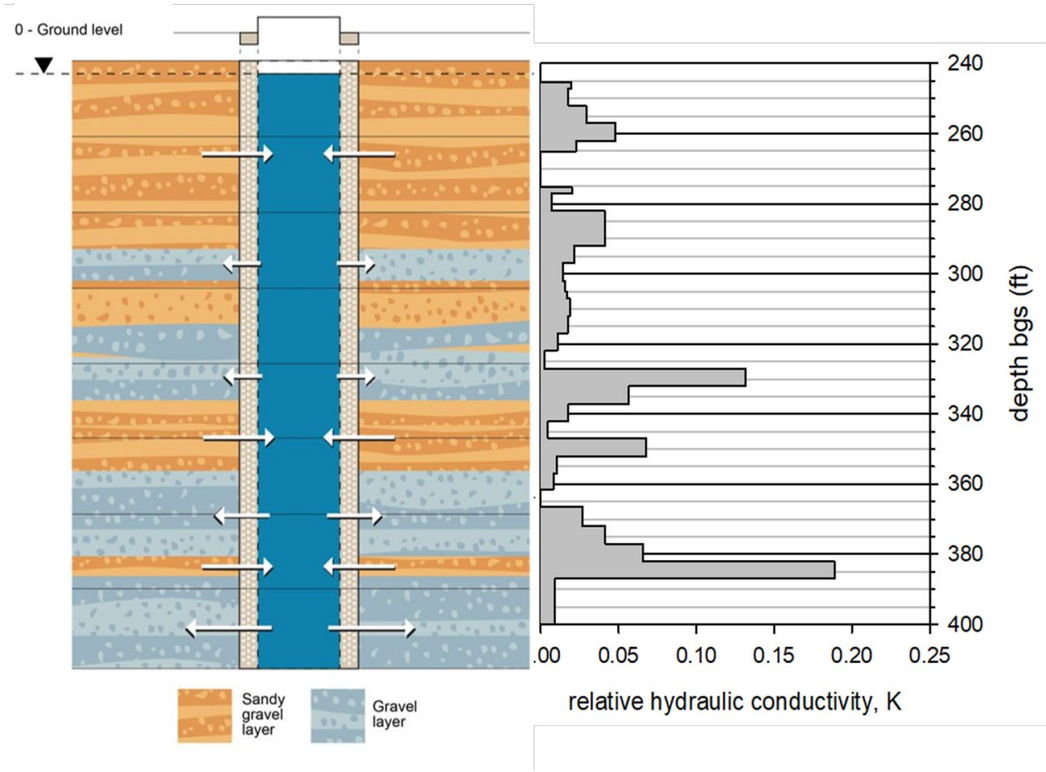
Integrating Characterization Methods – Electromagnetic Borehole Flowmeter (EBF)



EBF Survey – Ambient Conditions

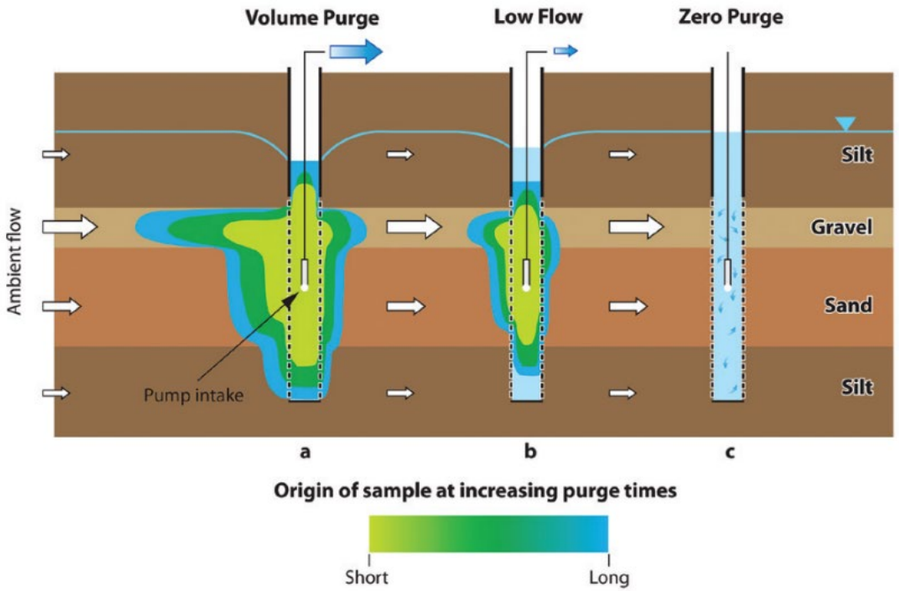


EBF Survey – Dynamic Conditions

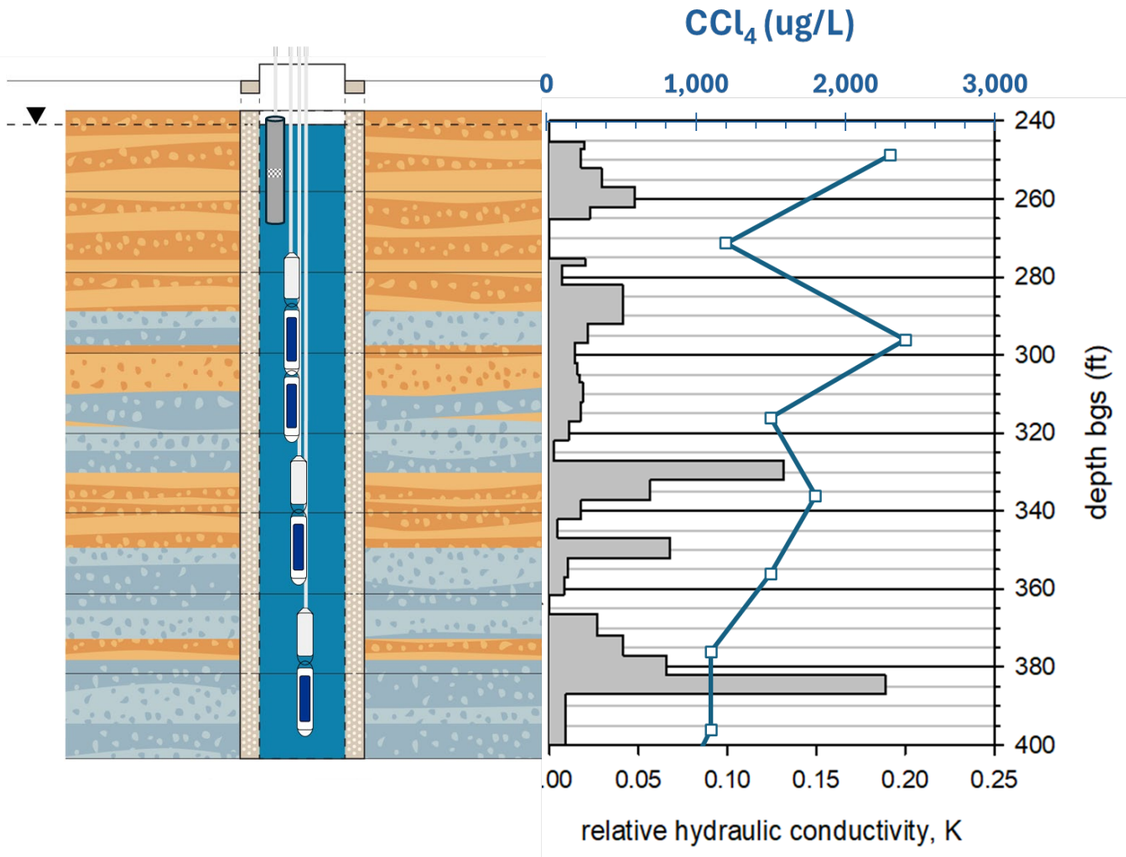


Relative hydraulic conductivity in Hanford well derived from the net vertical flow profile (recreated from Spane and Newcomer, 2009).

Integrating Characterization Methods – Snap Samplers



Schematic of the impacts of different sampling techniques on sample origin (McMillan et al. 2015).

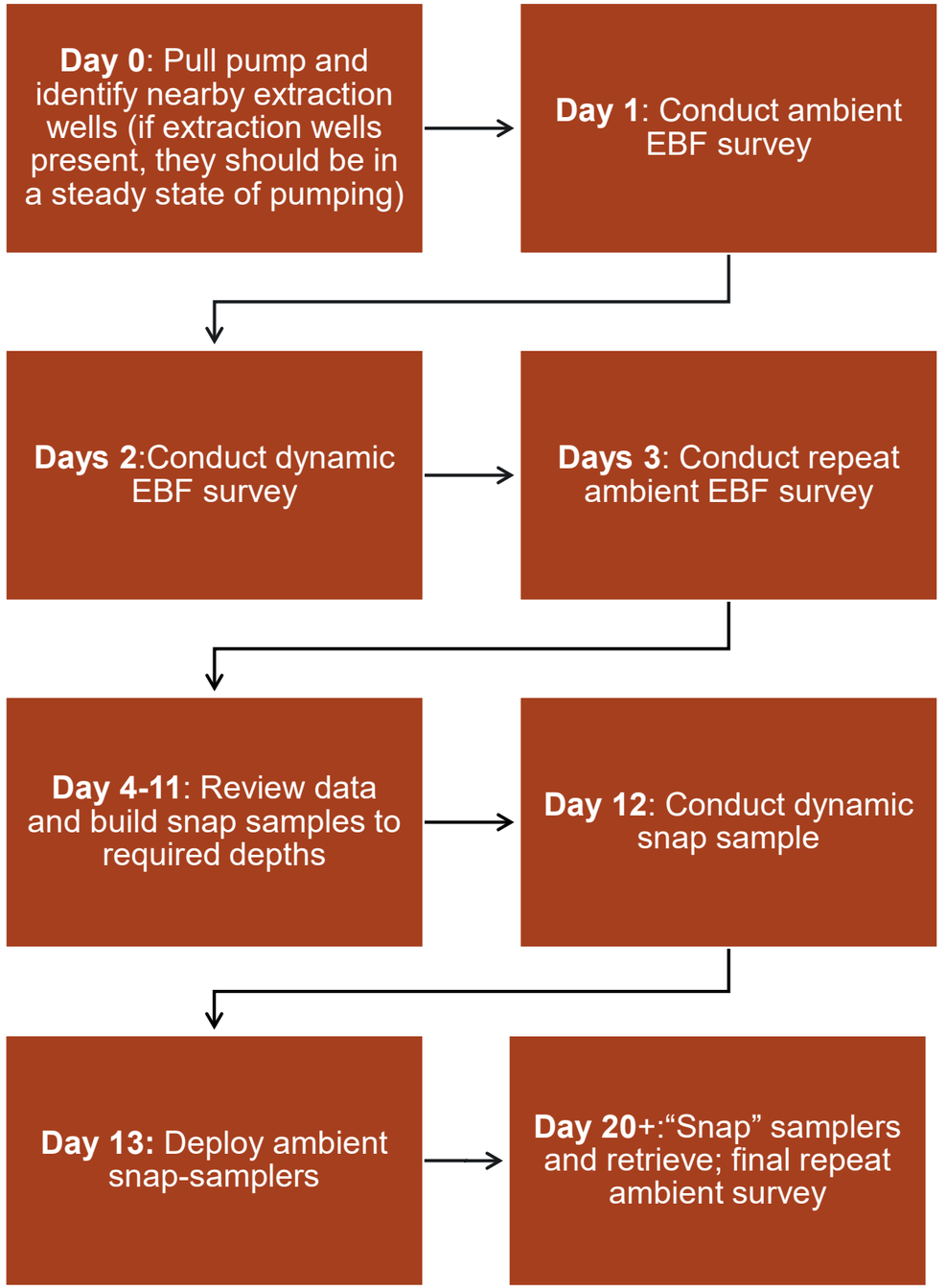


Snap Samples Deployed in Well – Dynamic Conditions

Relative hydraulic conductivity in Hanford well derived from the net vertical flow profile (recreated from Spane and Newcomer, 2009).

Field Schedule

- Vertical Flow Measurements
  - Ambient flow profiles
  - Dynamic flow
  - Combined → normalized hydraulic conductivity (K)
- Concentration Measurements
  - Depth-discrete groundwater sampling under ambient and dynamic conditions
    - Dynamic snap samplers = inflow zones during pumping; identify intervals that may contribute more contaminant mass during extraction

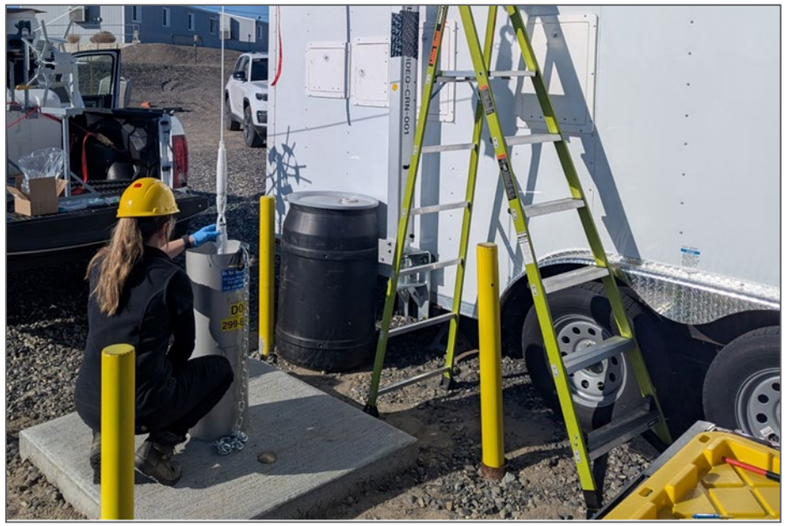


Typical schedule of flow profiling and sampling.

Onsite at Hanford





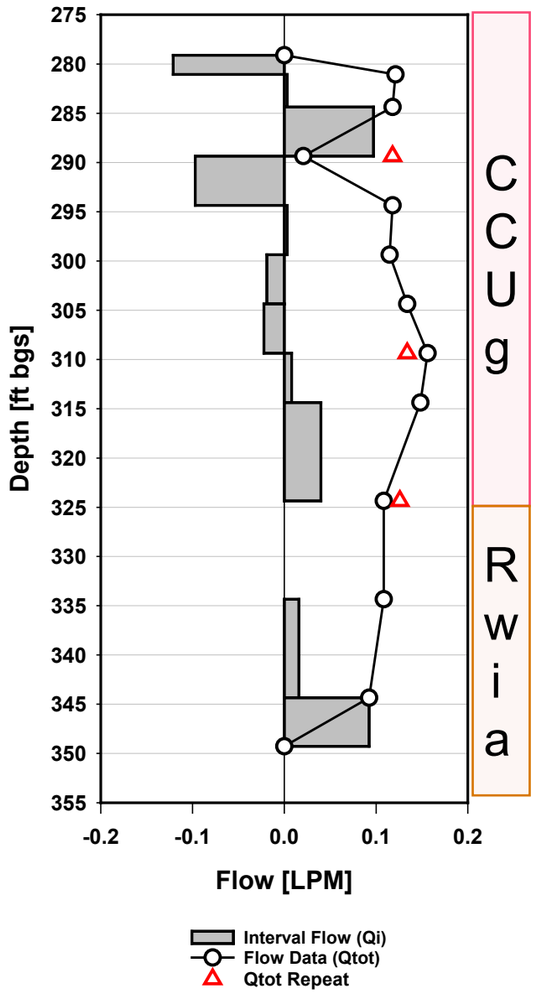
Upper row – deploying the EBF; Lower row from left – submersible groundwater pump deployment, in-situ water quality monitoring, snap sampler deployment (photography by Andrea Starr)

Key Findings – 200 East Area Wells

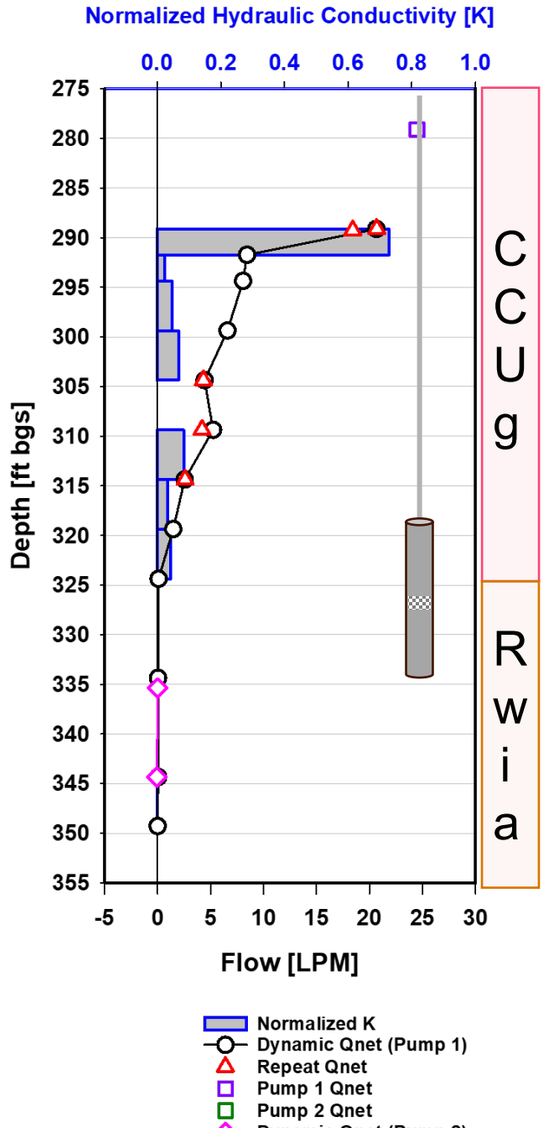
CCUg: weakly-compacted sandy gravels

Rwia: sand/silt/clay dominated with some gravels

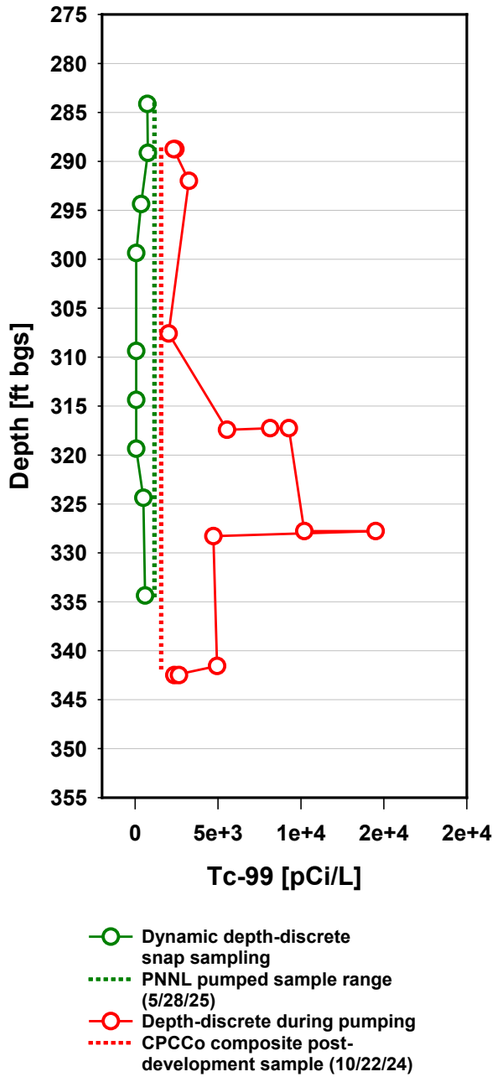
Ambient EBF



Dynamic EBF



Tc-99 Profile



Key Findings – 200 East Area Wells

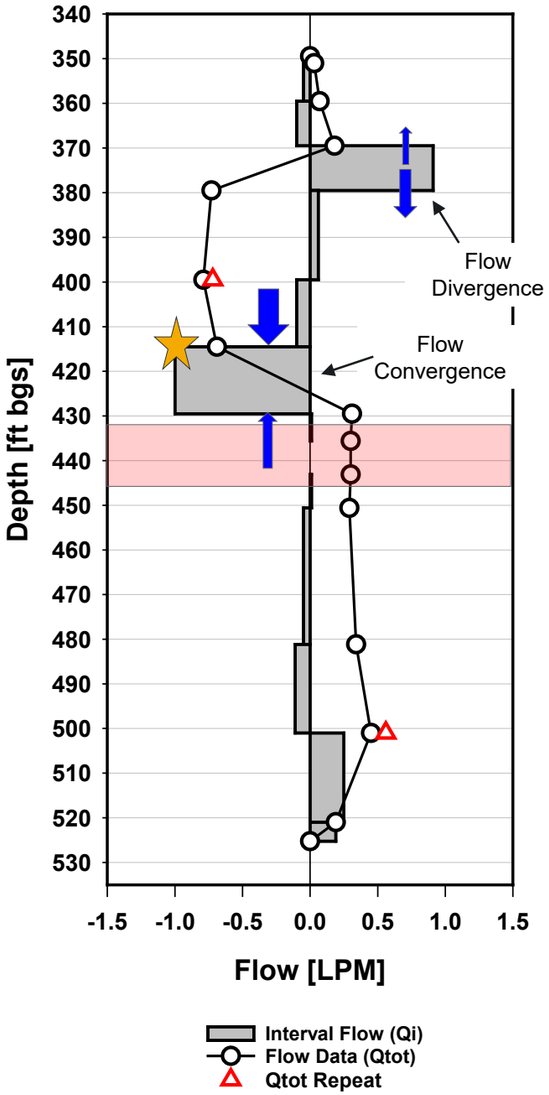
- **Well & Aquifer Hydraulics:**
  - Low vertical gradients limit contaminant redistribution under ambient conditions (**minimal intraborehole flow**)
  - **Upper CCUg Zone**: Highest K; dominant source of pumped groundwater flow
  - **Lower Rwia Zone**: Negligible flow, contributing little to extraction
- **Tc-99 Concentration Trends:**
  - **Ambient Sampling**: Minimal variation in Tc-99 concentrations due to low flows, lack of strong inflow zones at high concentration intervals, ambient flow redistribution of contaminants
  - **Pumped Sampling**: Tc-99 concentrations primarily originate from permeable CCUg (not captured from lower Rwia)
- **Evaluations and Challenges:**
  - Potential **bypass flow** through filter pack and formation, and unequal mixing impacts the accuracy of sample concentration profiles
  - **Next Step**: Ongoing testing to refine aquifer characterization and account for dynamic wellbore effects

Key Findings – 200 West Area Wells

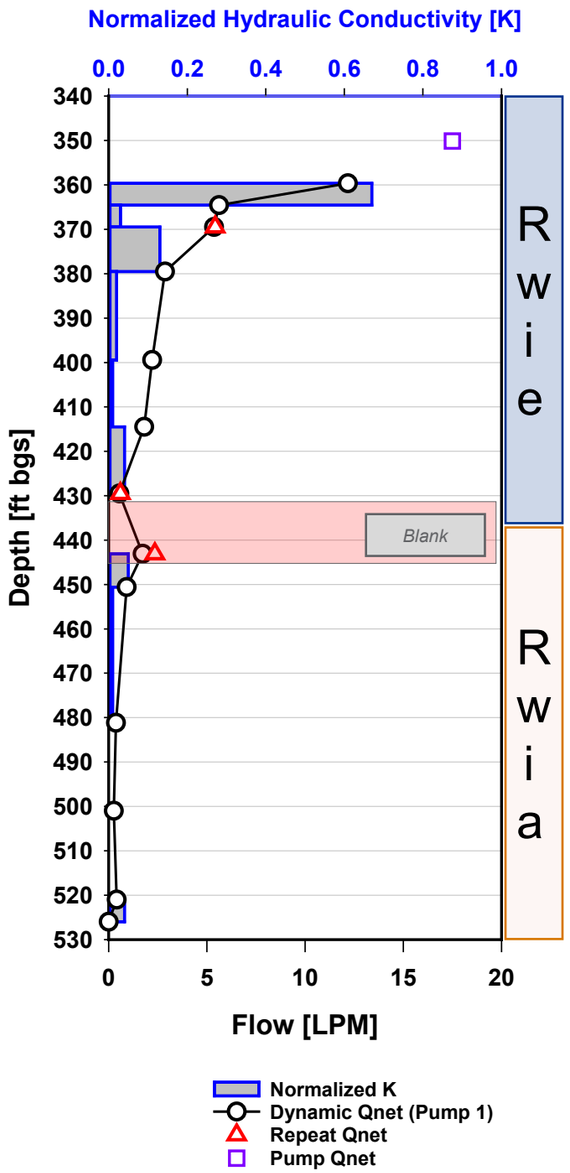
Rwie: Moderate to strongly cemented sandy gravel

Rwia: sand/silt/clay dominated with some gravels

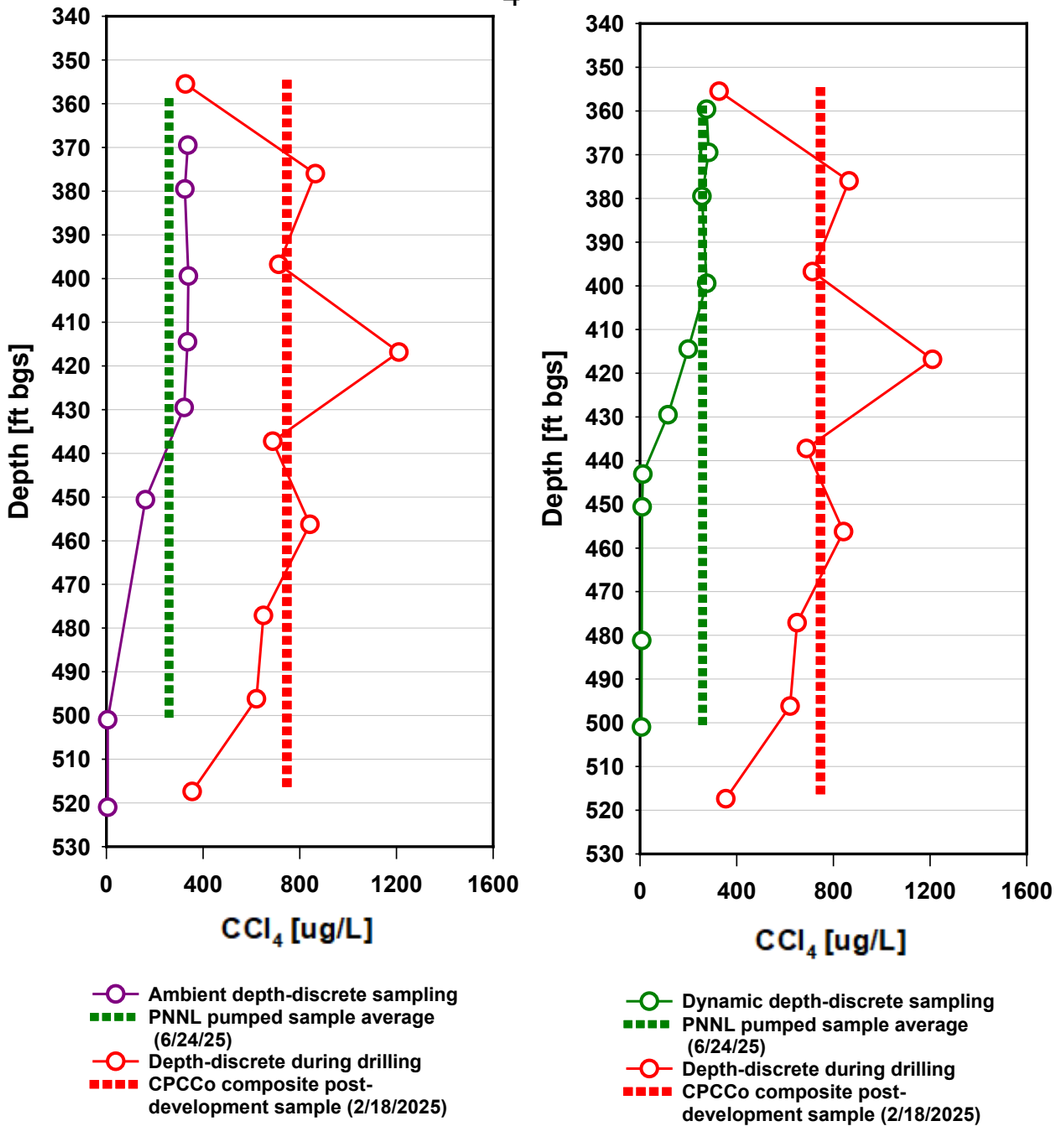
Ambient EBF



Dynamic EBF

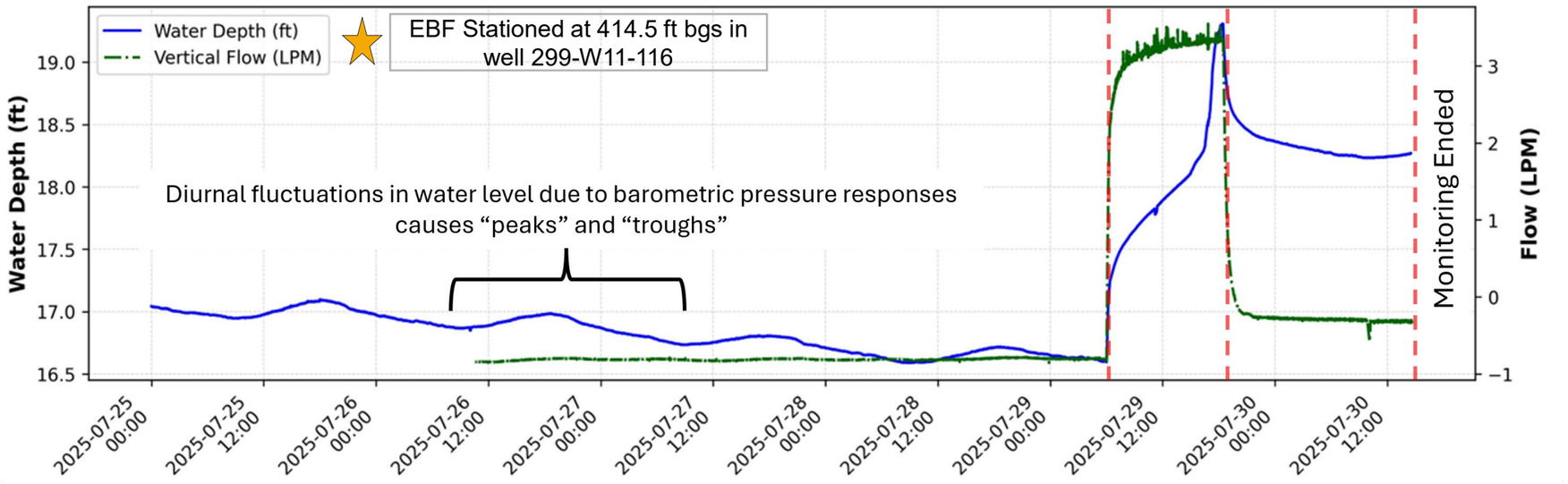


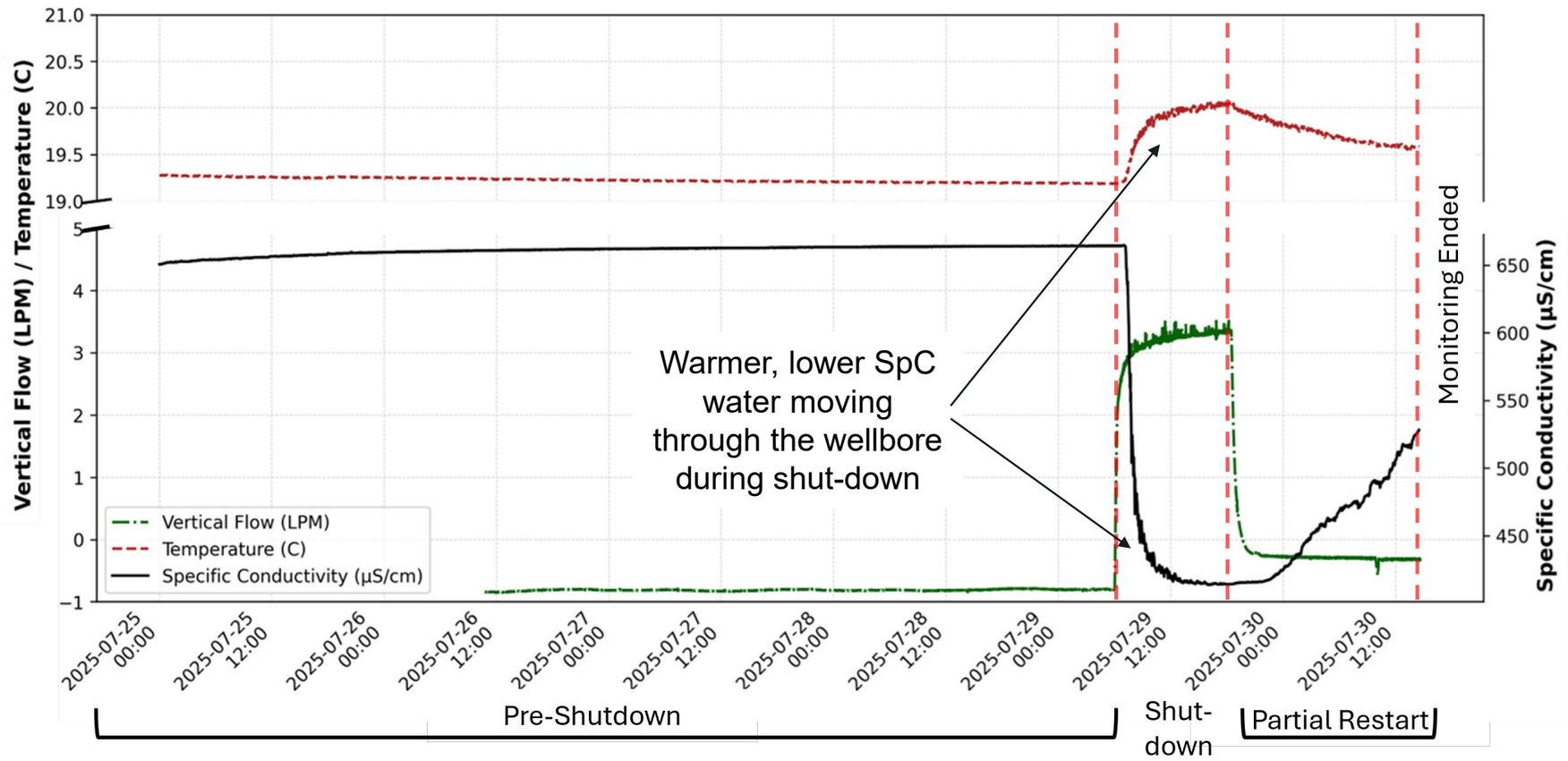
CCl_4 Profile



Transient Monitoring During P&T Shutdown

- Vertical flow and water level monitoring at one depth
- Shutdown period = ~ 12 hrs





Key Findings – 200 West Area Wells

- **Well & Aquifer Hydraulics:**
  - **Strong vertical hydraulic gradients** drive significant **intraborehole flow** and contaminant redistribution
  - Groundwater primarily drawn from **Rwie** → Moderately high K; minimal contribution from **Rwia**
  - **Localized Influences**: K and nearby pumping primarily affect flow patterns.
  - **P&T Operations**: Large-scale pumping results in flow reversals, revealing aquifer lateral/vertical heterogeneities
- **CCl_4 Concentration Trends:**
  - Higher concentrations **during drilling vs snap samples** → Masking effects of outflow zones
    - Low-concentration inflows in upper and lower screened intervals diluting depth-discrete concentrations
  - Pumped groundwater originates from **Rwie**, leaving contaminants in **Rwia** untreated
- **Evaluations and Challenges:**
  - Zonal isolation to target lower aquifer zones will be hindered by filter pack bypass

Ongoing Evaluations: Concentration Analyses

- Estimate concentration of contaminant in the aquifer using flow and depth-discrete sample data

Method 1: Simple mass balance

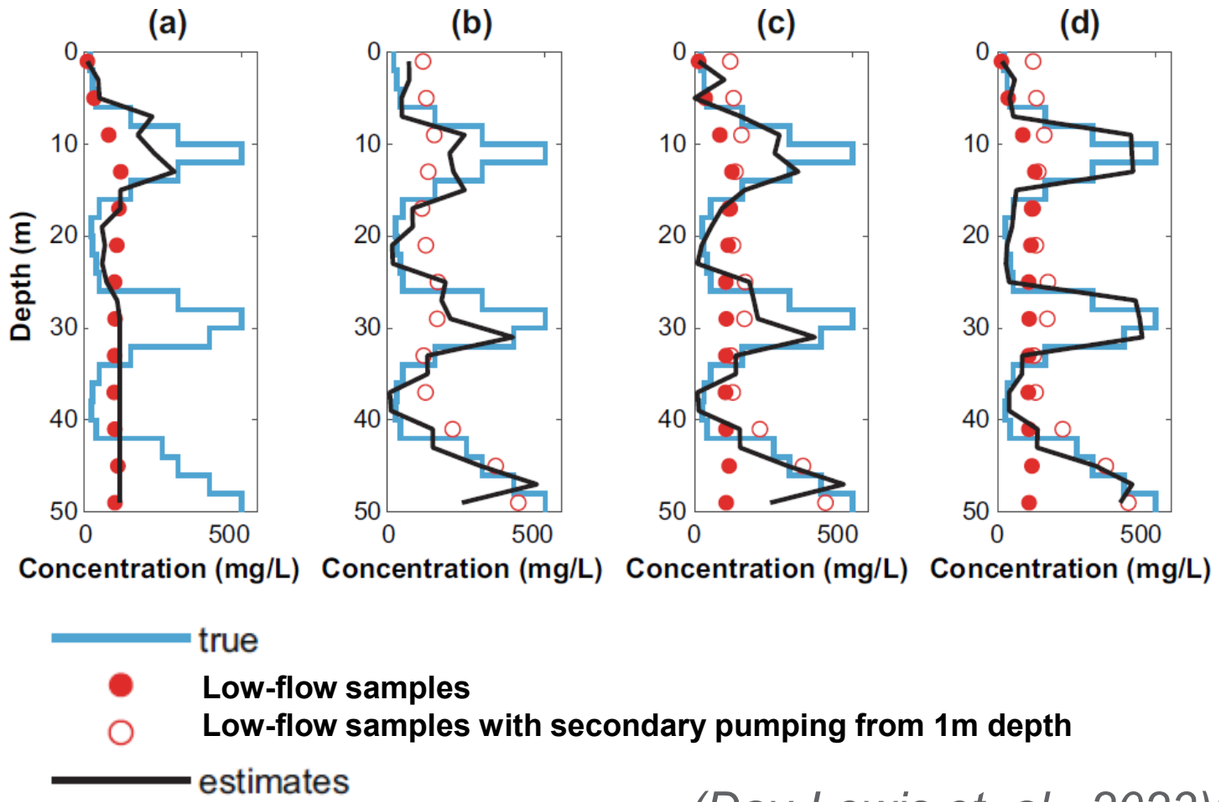
$$c_i = \frac{Q_{tot+1}C_{tot+1} - Q_{tot}C_{tot}}{Q_i}$$

Where:

- C_i is the concentration in groundwater entering the well over the i^{th} interval
- Q_{tot} is the measured vertical flow at a depth in the well
- C_{tot} is the measured concentration at a depth in the well
- Q_i is the difference in EBF flow at the top and bottom of the i^{th} interval under dynamic conditions

(Flach, 2002)

Method 2: Inversion model



(Day-Lewis et. al., 2023)

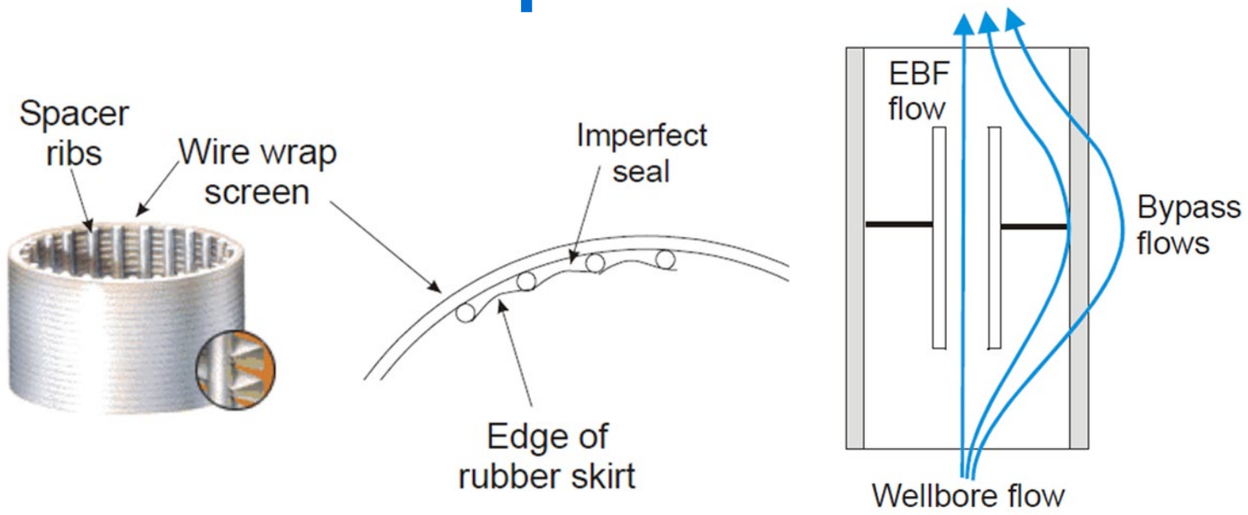
Next Steps and Remediation Implications

Next Steps

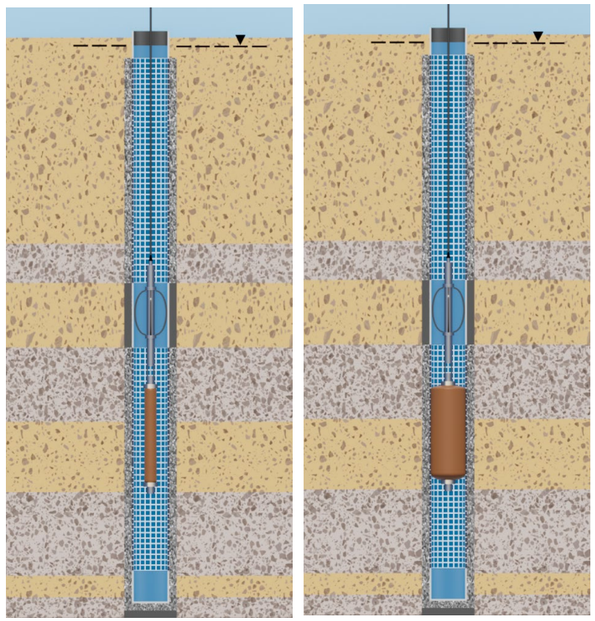
- Bypass reduction estimation
- Aquifer parameter estimation (T, far field heads)

Remediation Implications

- Zonal isolation in existing extraction wells
- New discrete zone-wells
- Temporal EBF monitoring during opportunistic P&T shutdown events yield valuable characterization



Above: Bypass phenomenon in wells with wire-wrapped screens (from Flach, 2002)



Left: Prototype packer combined with an EBF to reduce bypass

Acknowledgments

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- Thank you to our amazing team of field and safety specialists from PNNL and CCPCo!

References

Day-Lewis, F. D., Mackley, R. D., & Thompson, J. (2023). Interpreting concentrations sampled in long-screened wells with borehole flow: An inverse modeling approach. Groundwater. https://doi.org/10.1111/gwat.13300

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McMillan, L. A., Rivett, M. O., Tellam, J. H., & Dumble, P. (2015). Groundwater quality sampling at contaminated sites: The long and the short of it. IET Water/Wastewater, March/April 2015, 50–51. Retrieved from https://www.envirotech-online.com

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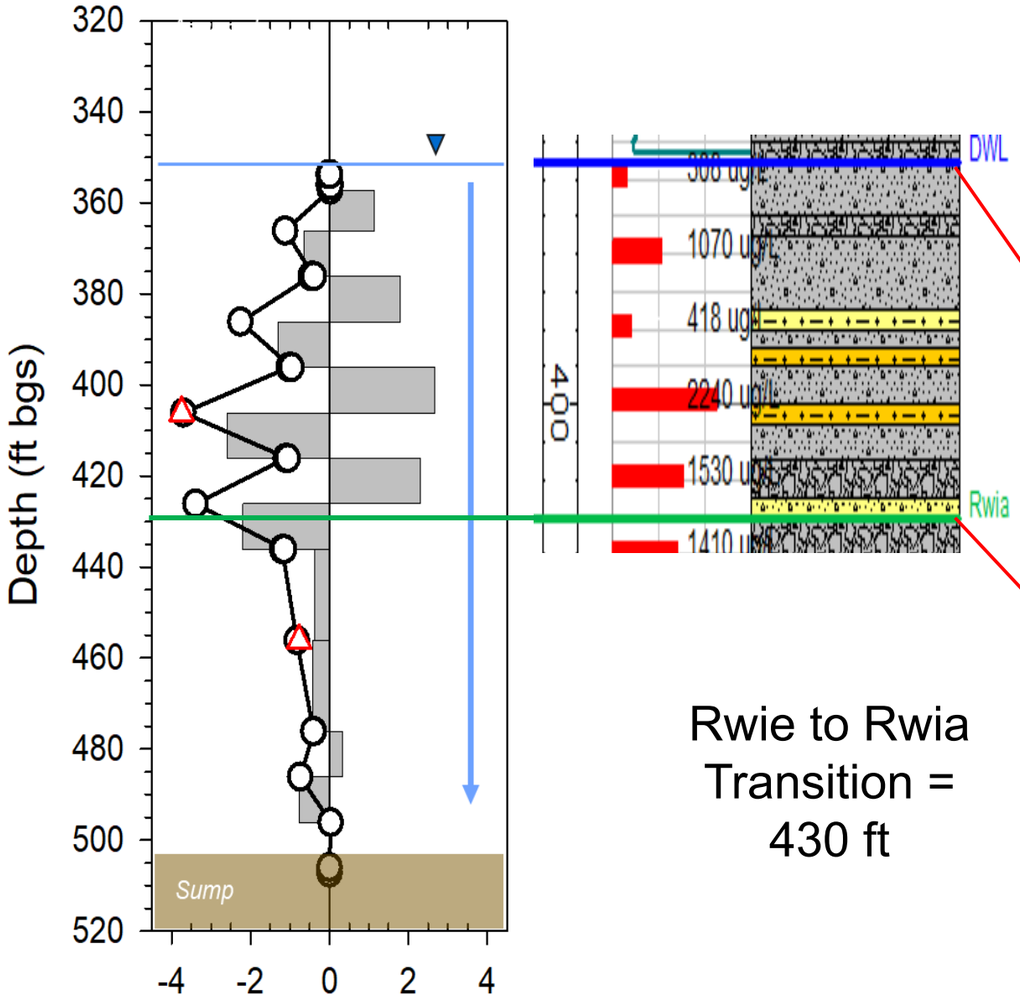
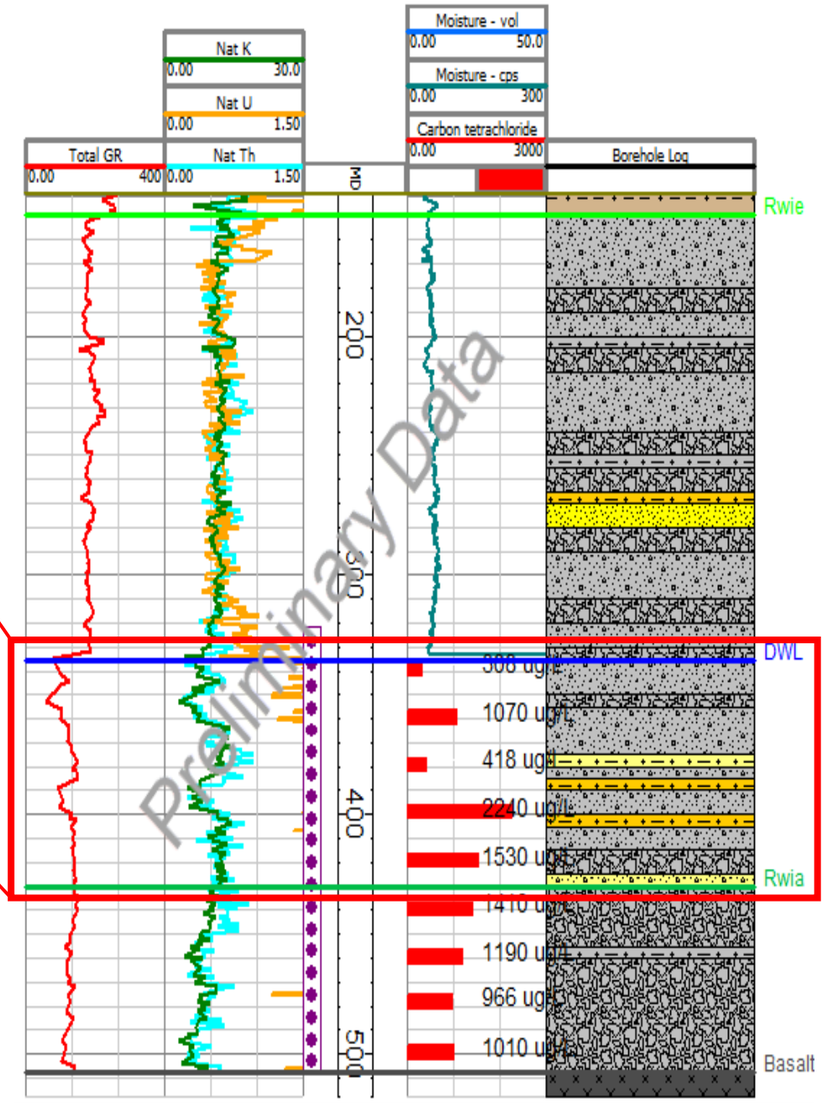
Thank you

Ambient EBF Survey Results for Well 299-W12-6 (D0473)

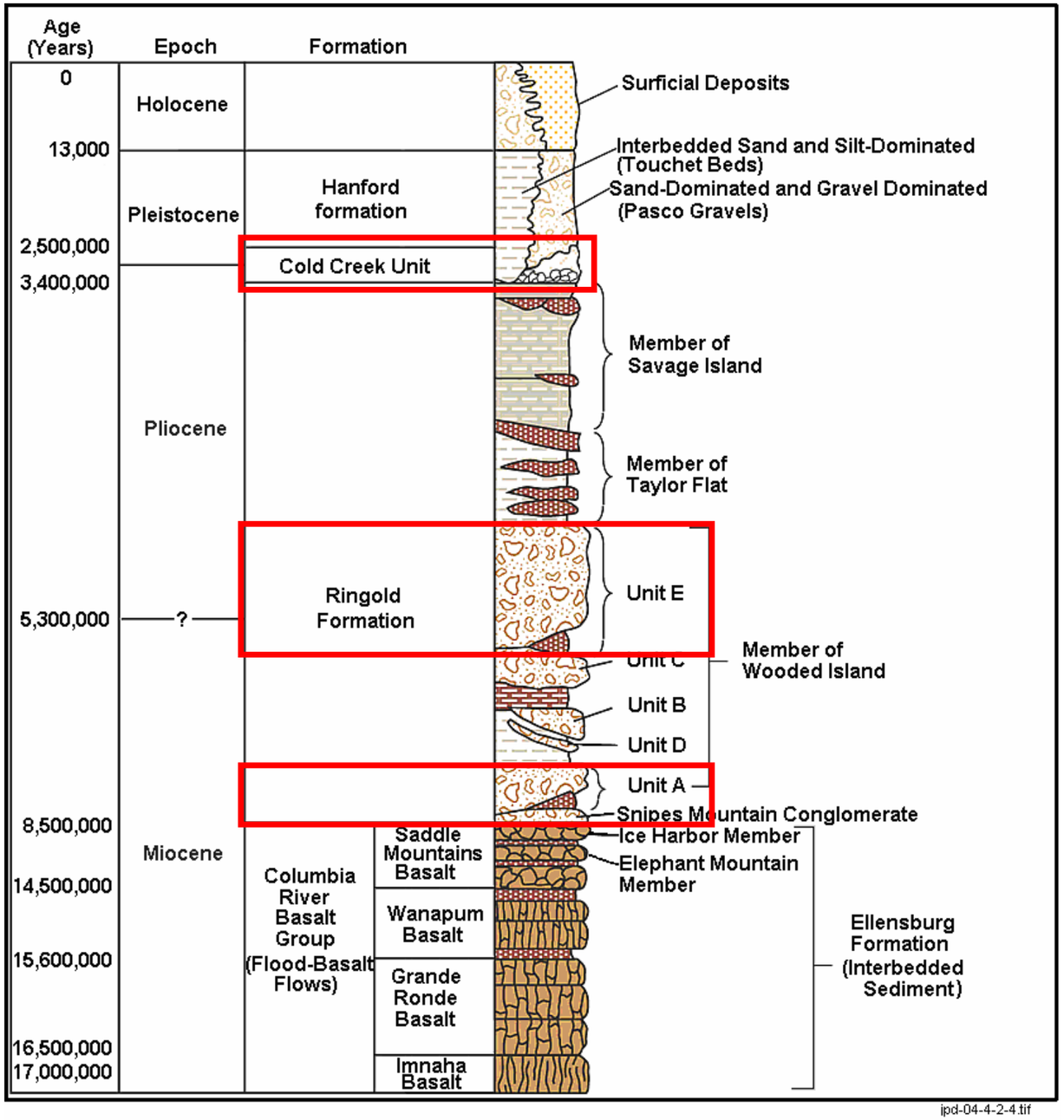


Rwie to Rwia Transition = 430 ft



Preliminary Results – Do not distribute

Hanford Stratigraphy



Generalized Hanford stratigraphy, 200 East Area (Reidel and Fecht, 2002)