Pacific Northwest NATIONAL LABORATORY

DEEP VADOSE ZONE PROGRAM @PNNL

Implementing Vertical Characterization and Focused Remediation in an Active Pump and Treat (P&T) Remedy: Examples from the Hanford Site

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Presented in *International Approaches to Discrete Aquifer Zone Characterization*

2025 RemPlex Summit

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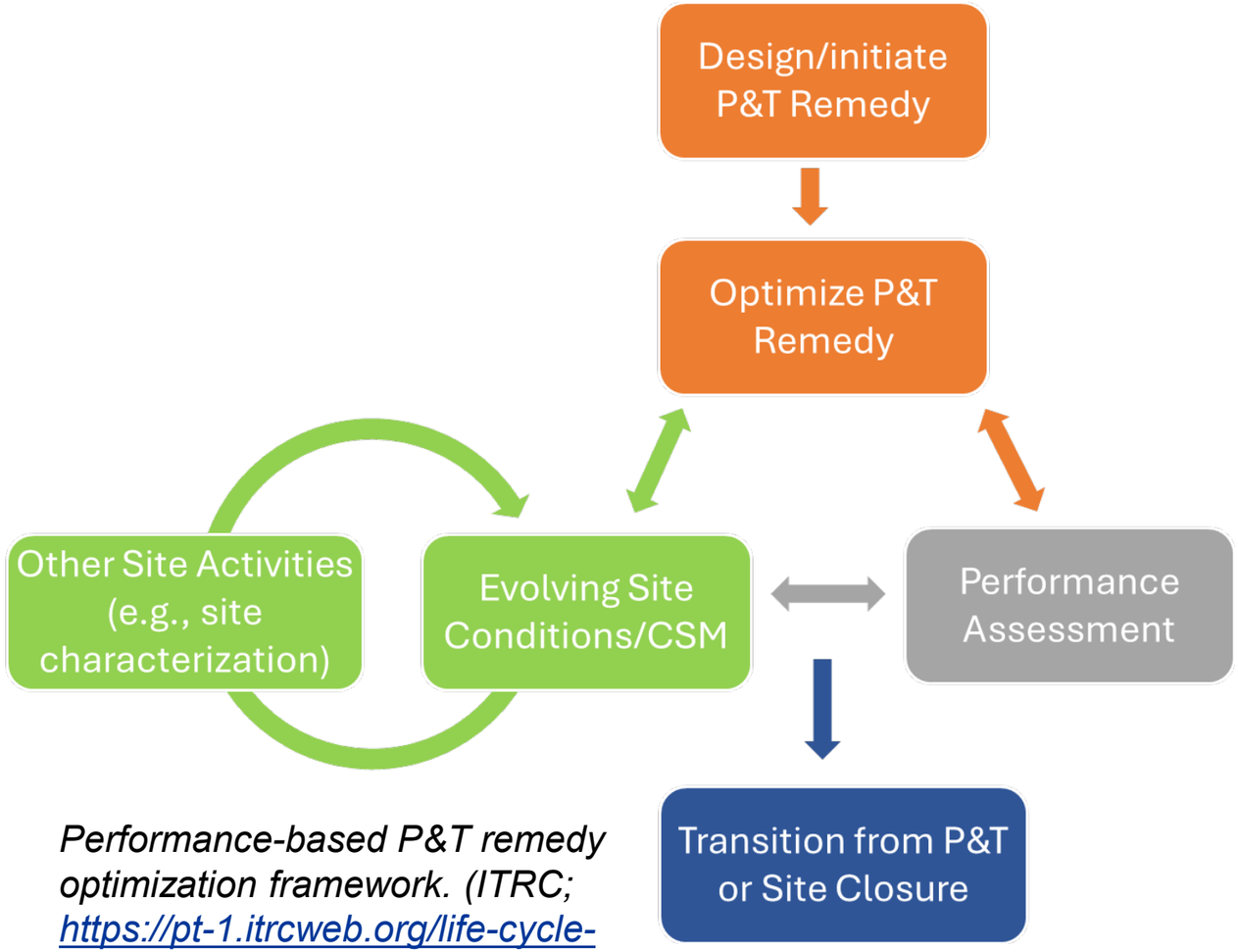
P&T Remedy Lifecycle Paradigm

- Characterization and monitoring are performed throughout the remedy lifecycle – not just the beginning
- Vertical characterization becomes increasingly important during optimization and closure transition
- Increased vertical characterization and optimization are priority objectives for Hanford's P&T remedy



Performance-based P&T remedy optimization framework. (ITRC; https://pt-1.itrcweb.org/life-cycle-optimization/)

Presentation Roadmap

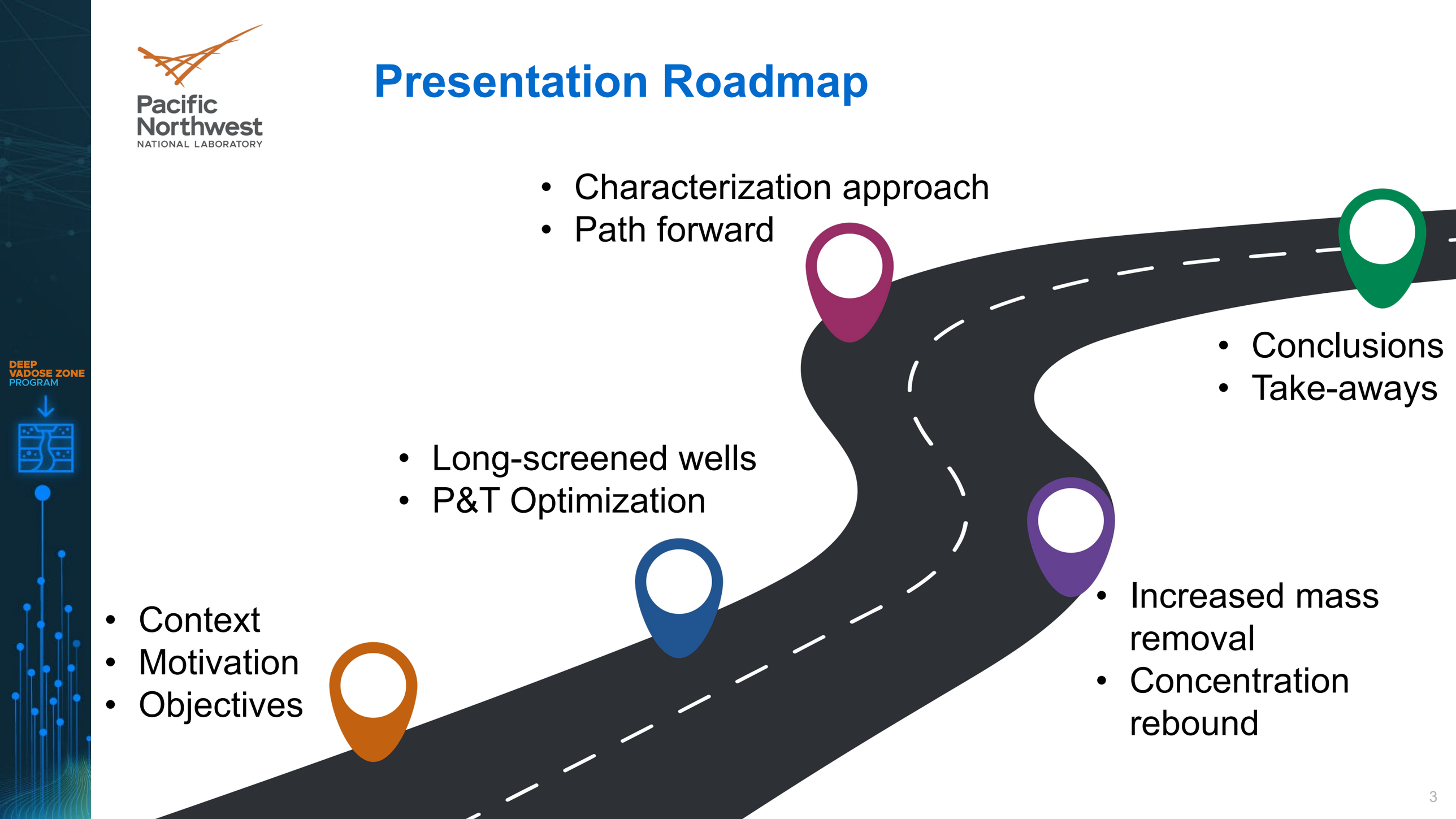
- Context
- Motivation
- Objectives

- Characterization approach
- Path forward

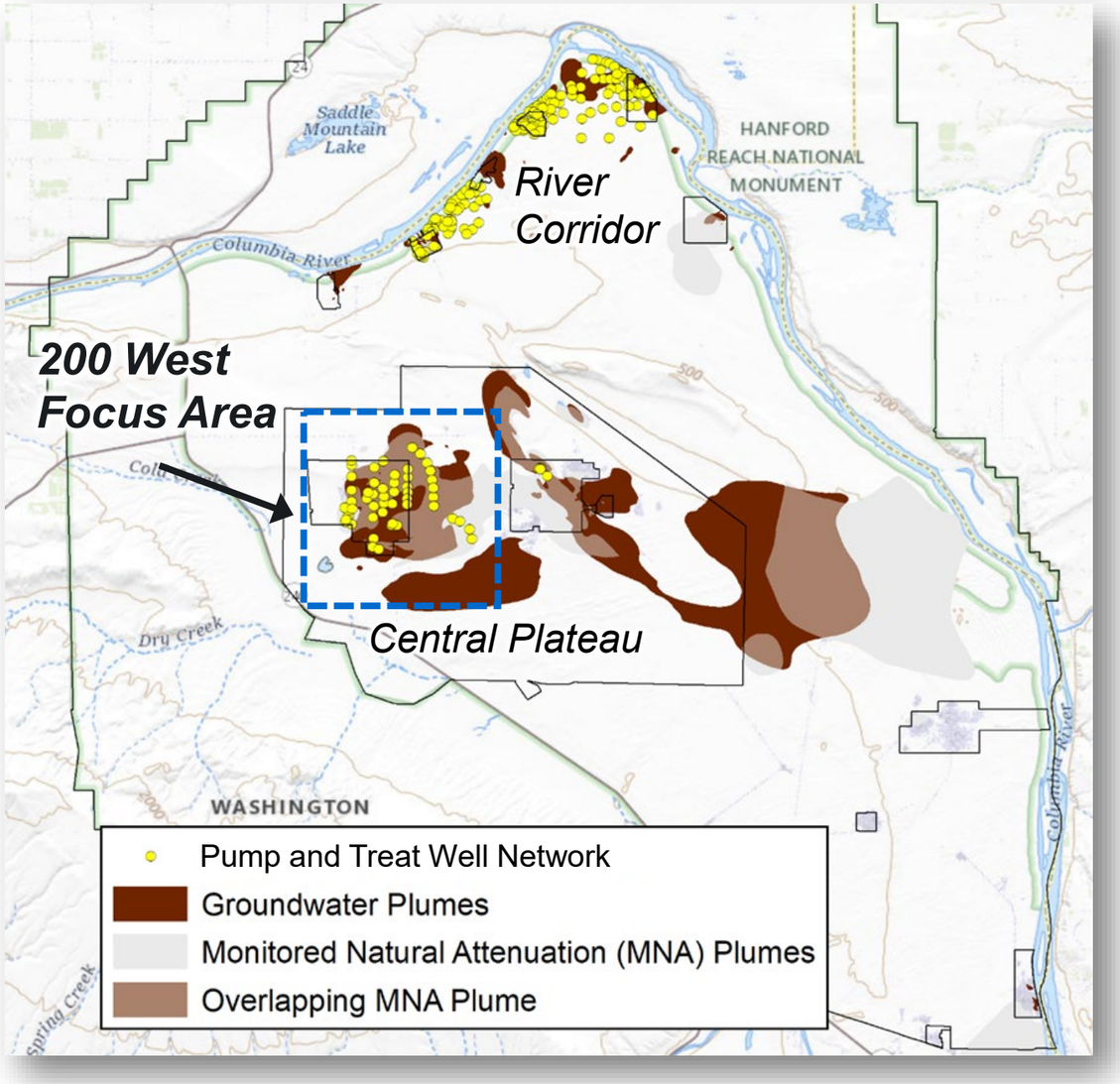
- Long-screened wells
- P&T Optimization

- Increased mass removal
- Concentration rebound

- Conclusions
- Take-aways



P&T Remedies at Hanford

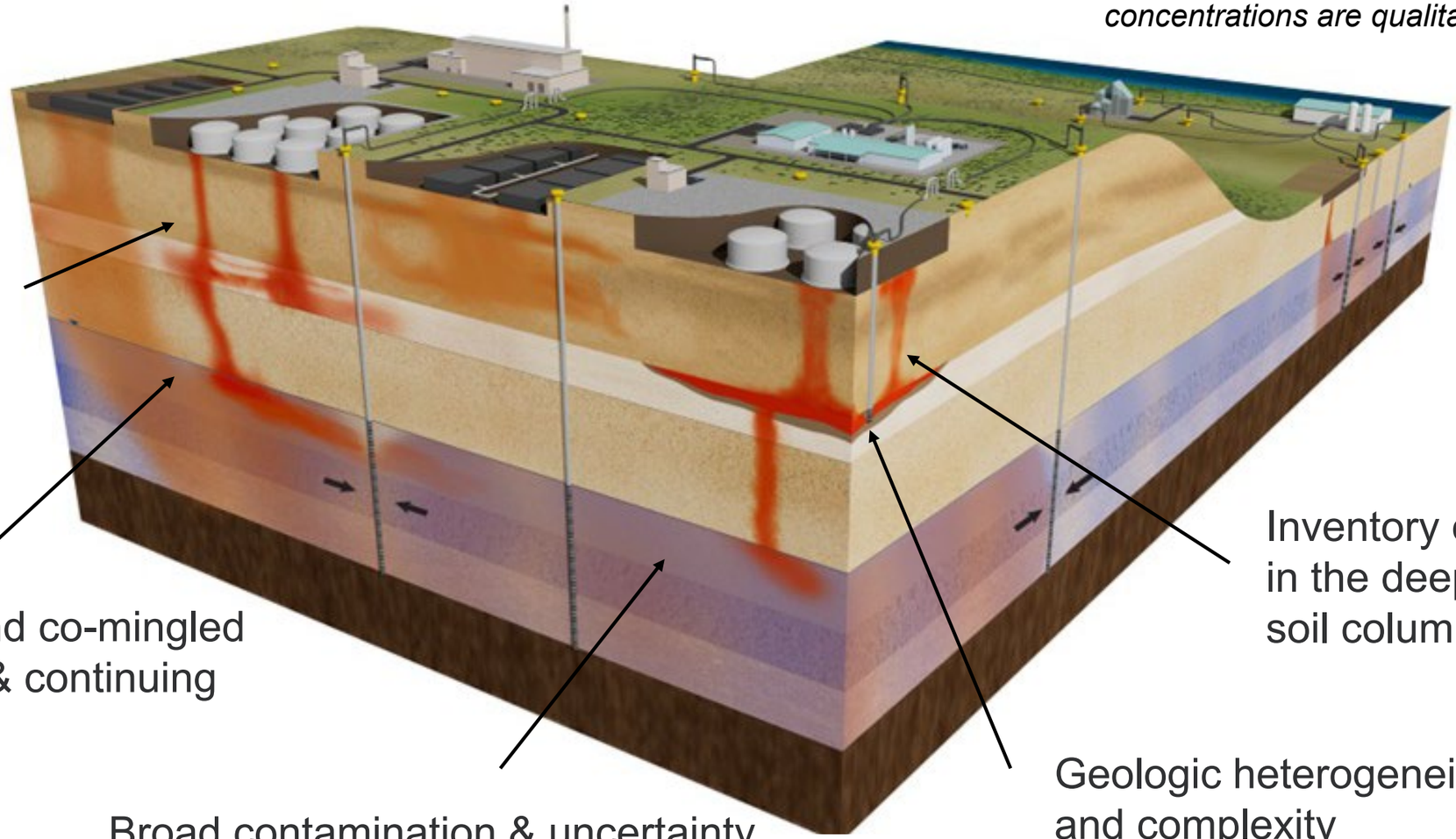


Hanford Site Groundwater P&T Wells. (DOE, 2024)

- Five P&Ts along the River Corridor
  - Since the 1990's
- 200 West P&T facility
  - Since 2012

Conceptual Site Model for 200 West P&T

Conceptual site model (CSM) of Hanford groundwater remediation (plume extent and concentrations are qualitative depictions)



Complicated contaminant behavior

Recalcitrant and co-mingled contaminants & continuing sources

Broad contamination & uncertainty with the amount and distribution

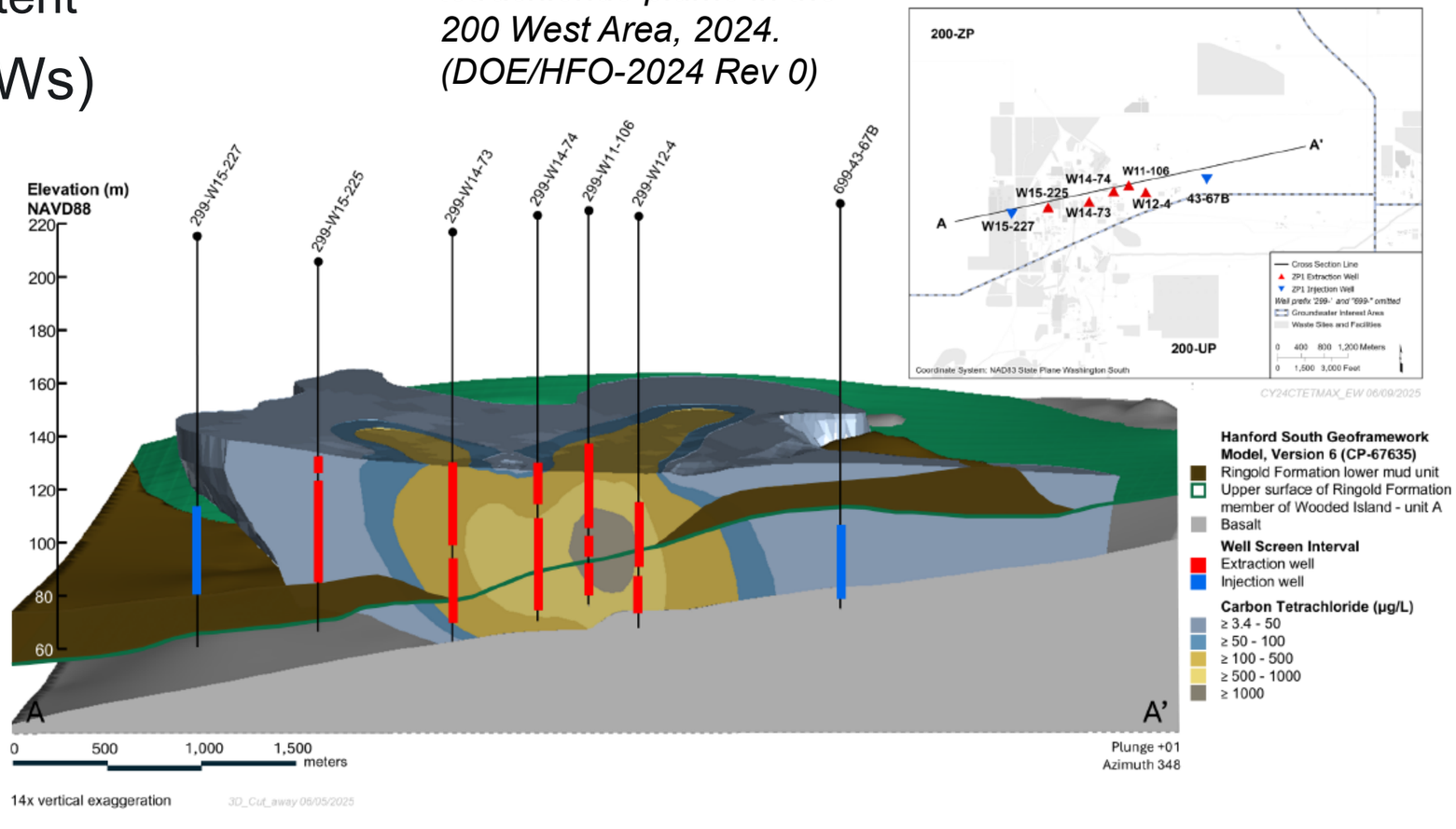
Geologic heterogeneity and complexity

Inventory of contaminants in the deep vadose zone soil column

Phases of 200 West P&T Optimization

- Initial remedy optimization objectives
  - Volumetric removal
  - Hydraulic capture
  - Decrease plume areal extent
- Long-screened wells (LSWs)
  - Dual-purpose designs
  - 50-200 feet of screen
  - Single pumped concentration
  - Expect to have higher removal in permeable zones

Three-dimensional carbon tetrachloride plume in the 200 West Area, 2024. (DOE/HFO-2024 Rev 0)

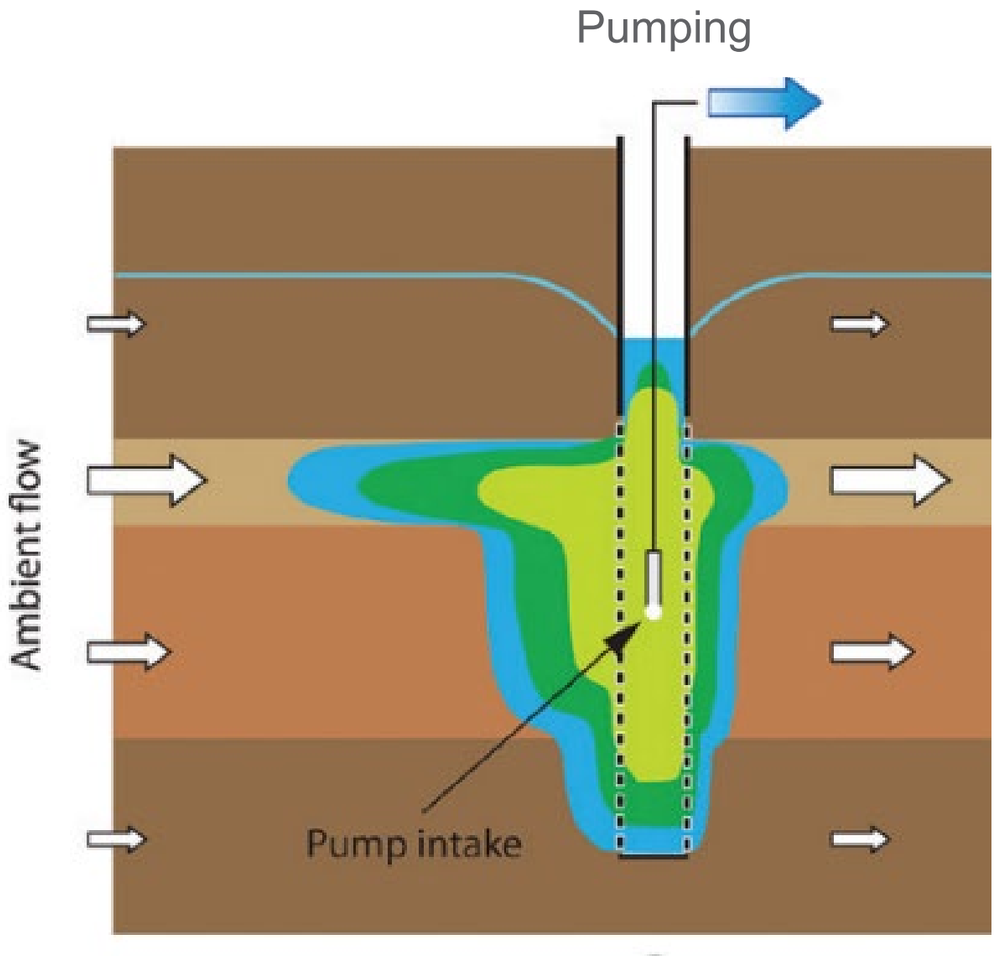


Phases of 200 West P&T Optimization

- Next phases of optimization
  - Mass removal in high-concentration zones
  - Balancing facility capacity
- Identify the high-concentration zones
  - Existing long-screened wells
  - Multi-level completions
- Focused extraction
  - Retrofit existing LSWs
  - New discrete-zone wells

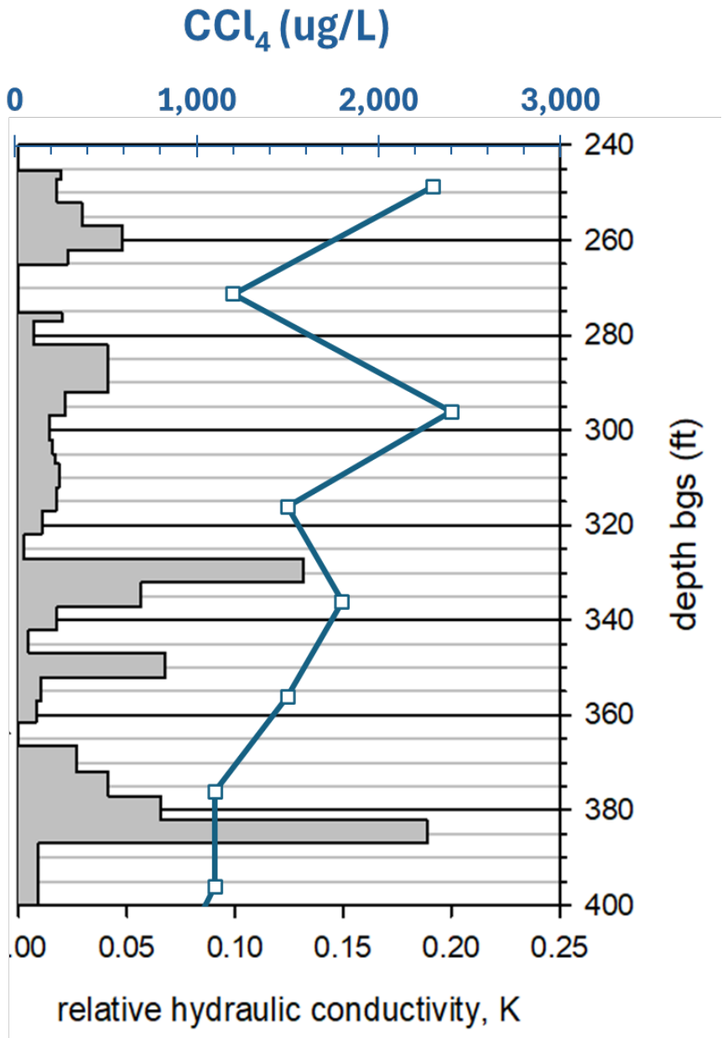
Challenge of Extraction in a Long-Screened Well (LSW)

- Layered alluvial sediments
  - Open-framework gravels
  - Gravels with fines in the matrix
  - Sands
  - Silts
- Pumped concentrations are dominated by higher-K zones
- Preferential extraction and sweeping of pore space in higher-K zones
- Mass remains in lower-K zones
- Implications for transition to closure



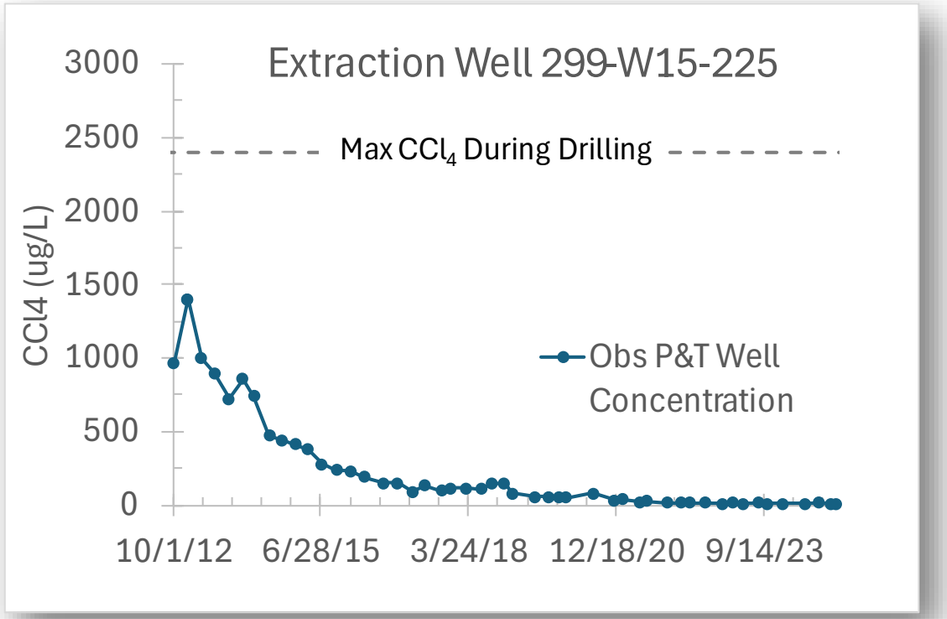
Origin and mixture of pumped groundwater in multi-layered aquifer. (McMillan et al. 2015)

Challenge of Extraction in a Long-Screened Well (LSW)



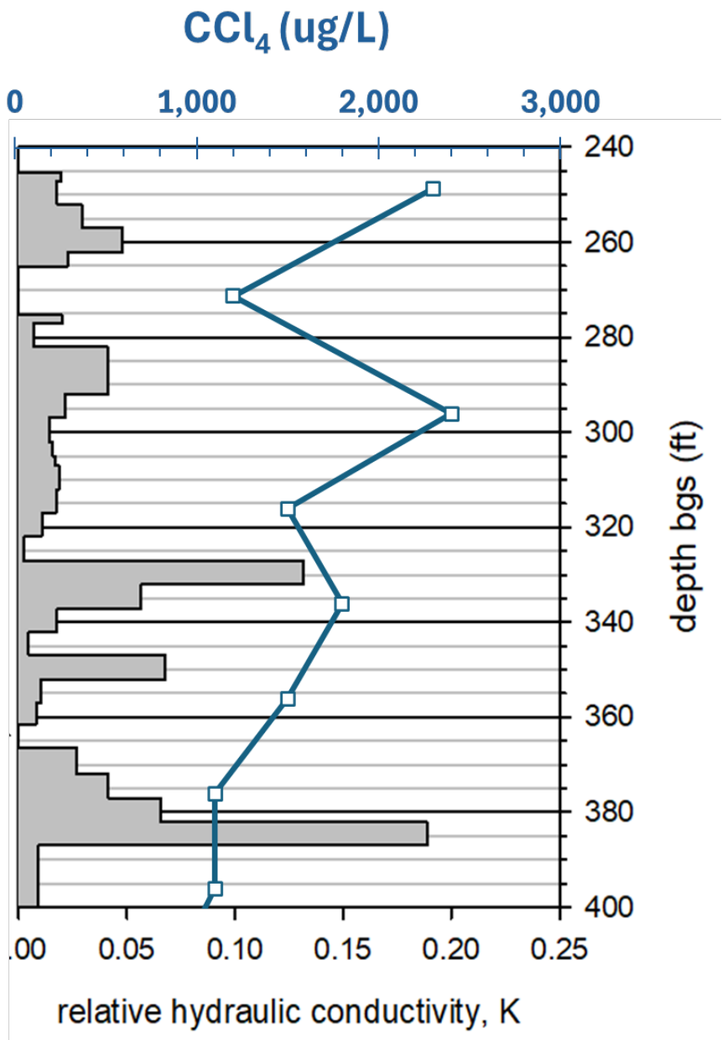
Hydraulic conductivity (K) from electromagnetic borehole flowmeter (EBF) survey and CCl_4 concentrations during drilling. (PNNL-18732)

- CCl_4 extraction well 299-W15-225
  - Full-screened (145 ft)
- Samples during drilling
  - Higher CCl_4 in upper part of aquifer
  - Max of 2,400 µg/L

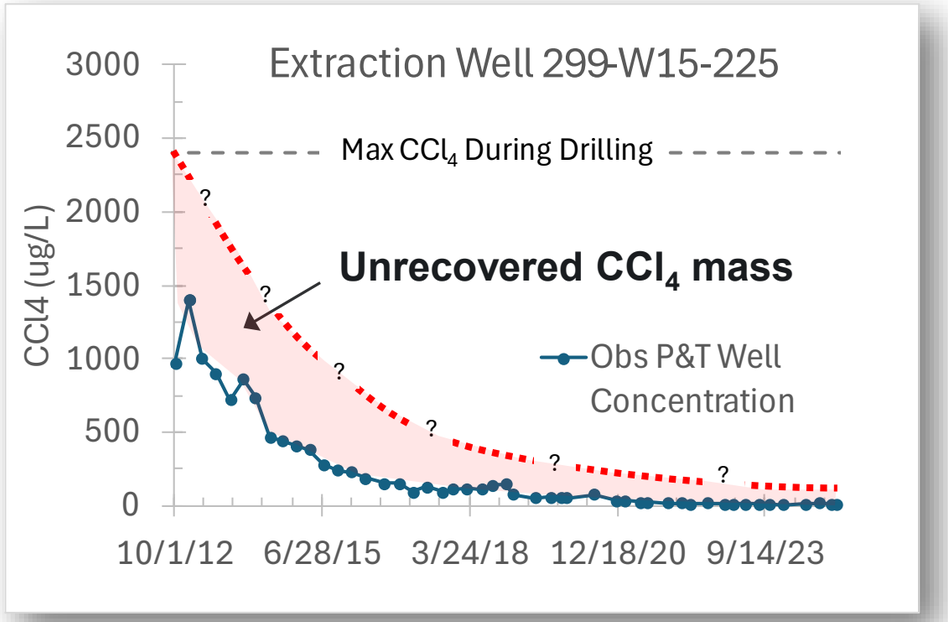


CCl_4 concentrations available through the Environmental Dashboard Application (https://ehs.chprc.rl.gov/eda).

Challenge of Extraction in a Long-Screened Well (LSW)



- LSWs likely contribute to unrecoverable CCl_4 mass
- Dilution from higher-K zones
- Flow-weighted concentrations during pumping
- Can we get more mass?



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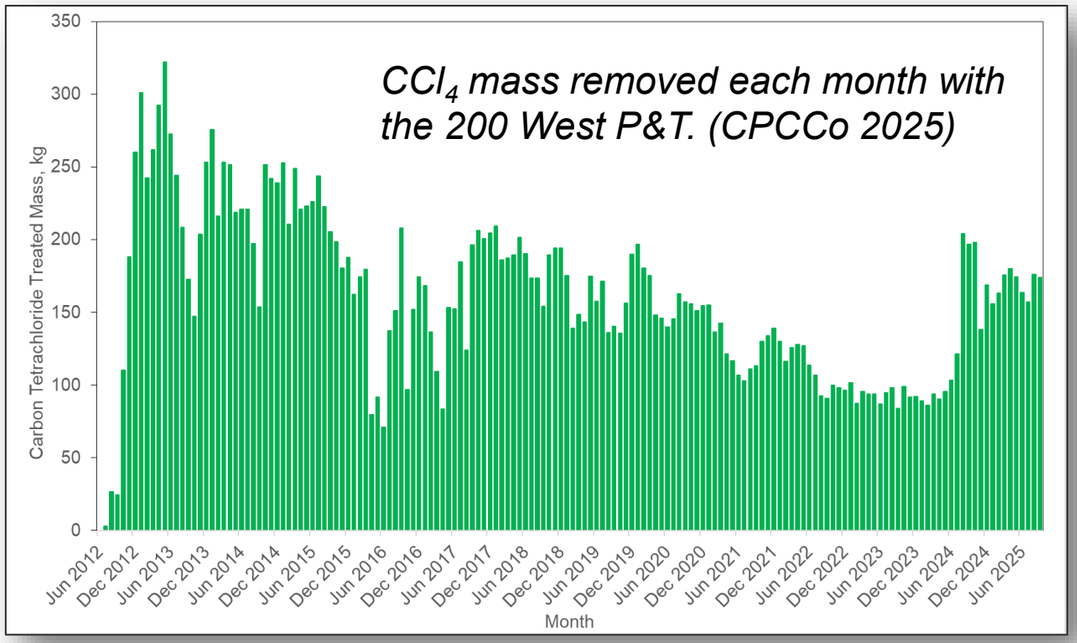
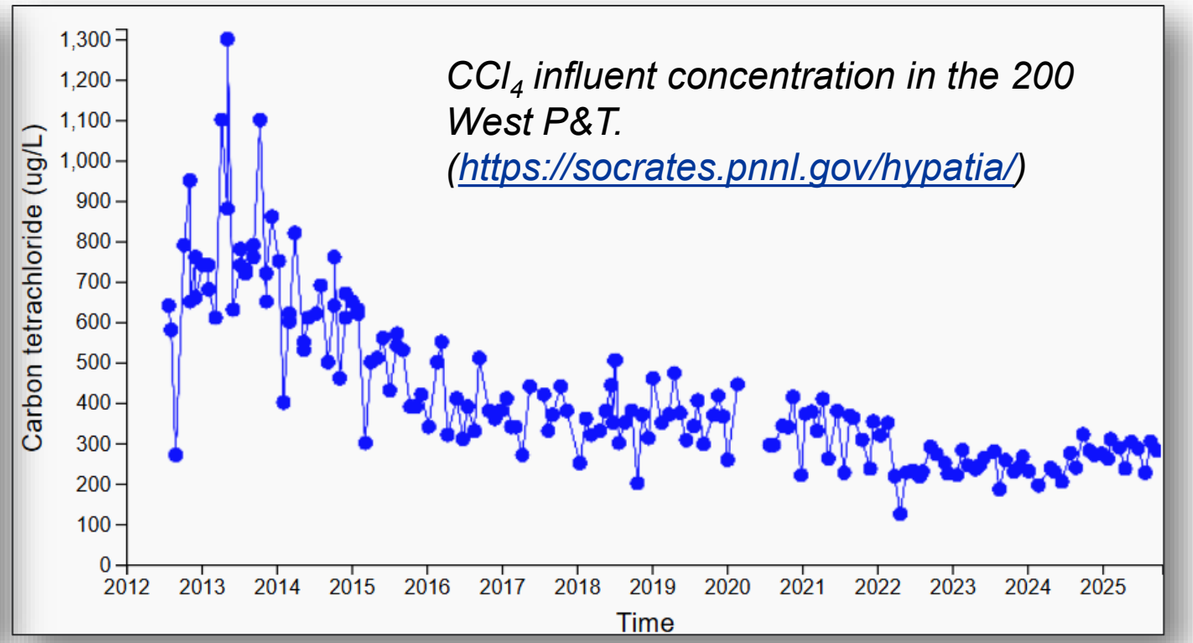
200 West P&T Remedy Performance

- First decade (2012 – 2022)
  - Decreasing mass removal and influent concentration – typical of a P&T remedy
- Recent remedy optimization activities
  - Influent concentrations have remained stable since 2022
  - Additional wells added – increased mass removal since 2024

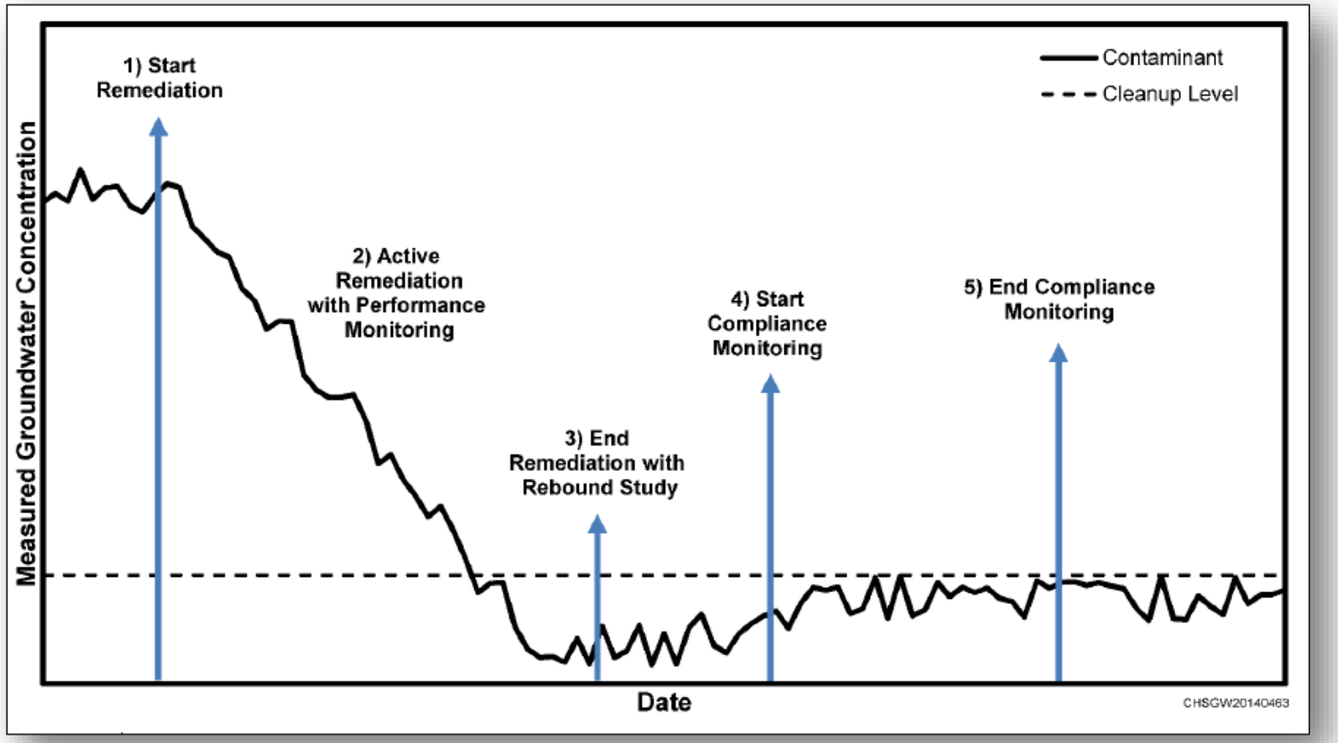


CCl_4 mass removed each month with the 200 West P&T. (CPCCo 2025)



CCl_4 influent concentration in the 200 West P&T. (https://socrates.pnnl.gov/hypatia/)

Challenge of Transitioning from the P&T Remedy

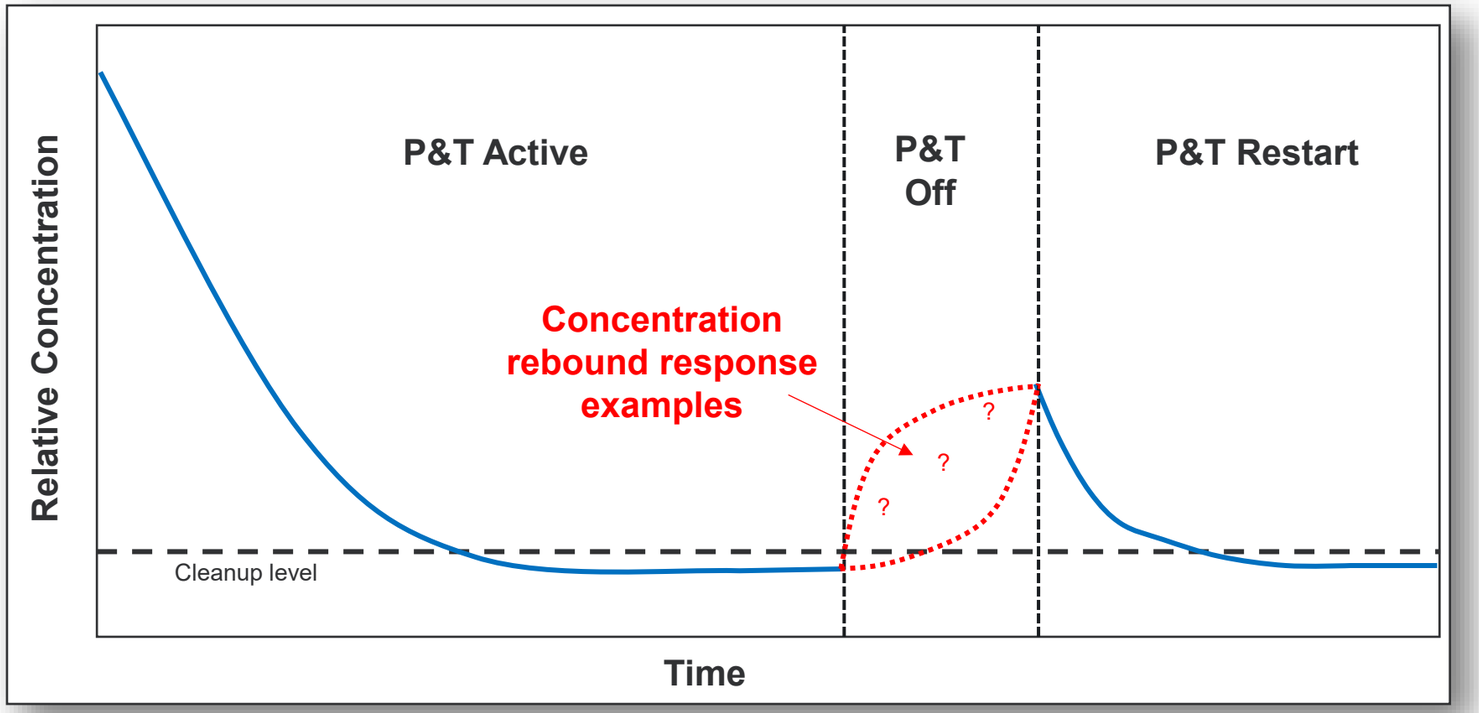


Conceptualization of contaminant concentrations during the P&T remedy lifecycle with no rebound. (DOE/RL-2021-23, Rev 0)

- Numerous guidance documents and strategies for performance assessments
- Rebound studies have been initiated in the 100-Area for P&T of Cr(VI) with success
  - Transitioning to compliance in areas
- 200 Area has thicker aquifer and more heterogeneity

Challenge of Transitioning from the P&T Remedy

- Increasing concentrations following shutdown
- Rebound response due to multiple reasons
  - Re-saturation of source
  - Back diffusion
  - Different sampling methods
  - Well hydraulics
- Vertical characterization key to accurately interpreting rebound and next steps



Conceptualization of contaminant concentrations during the P&T remedy lifecycle with rebound.

Path Forward for Vertical Characterization and Optimization

U.S. DEPARTMENT of ENERGY **Hanford Field Office (DOE-HFO)**

Evaluate and Demonstrate

- Vertical characterization methods
- Discrete-zone monitoring and extraction wells

Implement Vertical Optimization

- Mass removal in high-concentration zones
- Improved remedial outcomes

2023 → DEEP VADOSE ZONE PROGRAM @PNNL → CPCCo Central Plateau Cleanup Company → **2028+**

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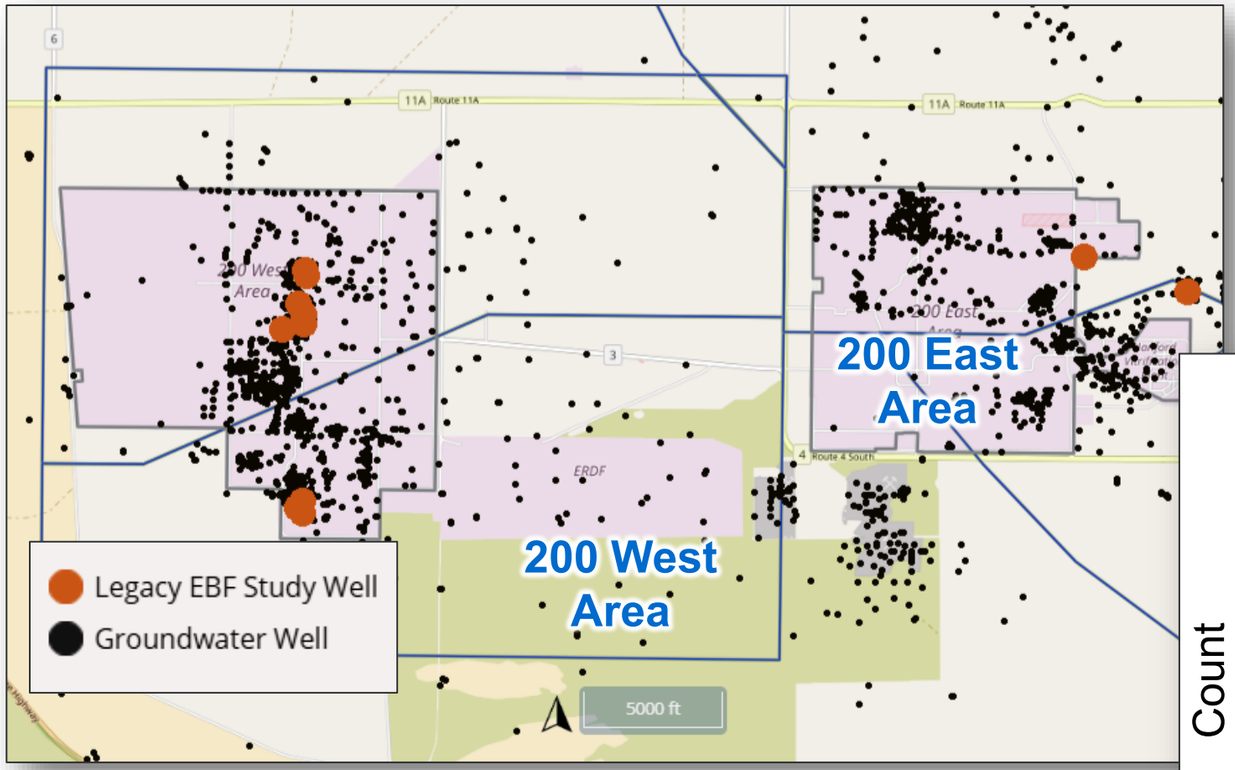
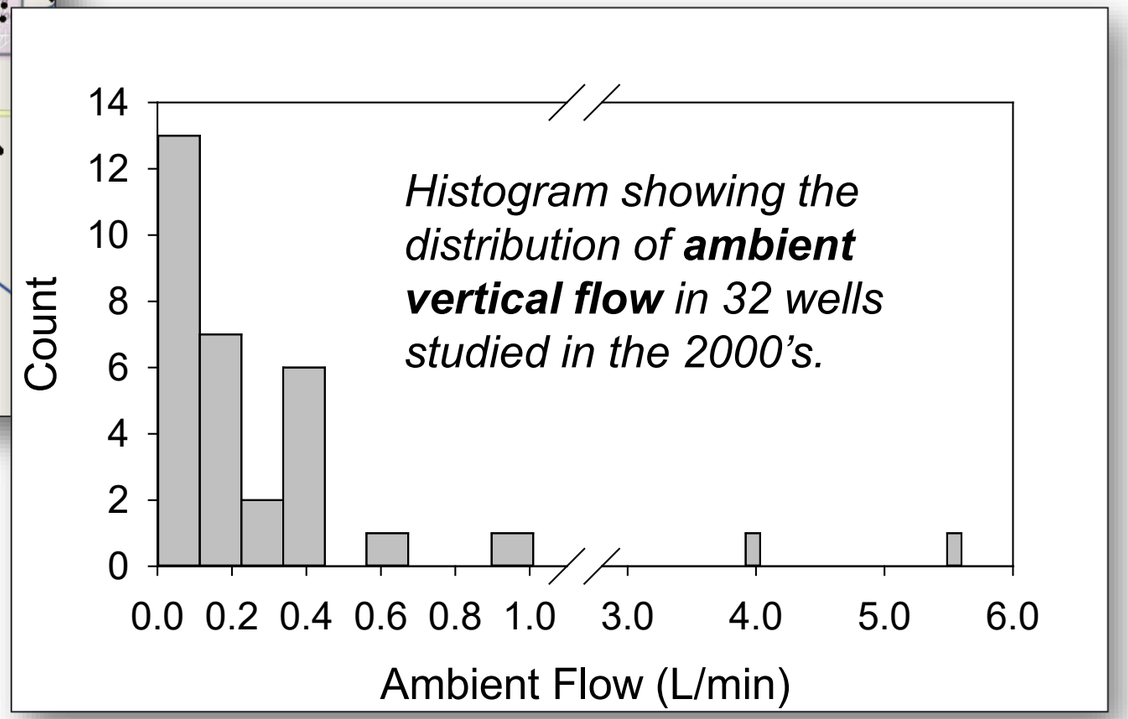
Focus for remaining slides

Early Vertical Characterization

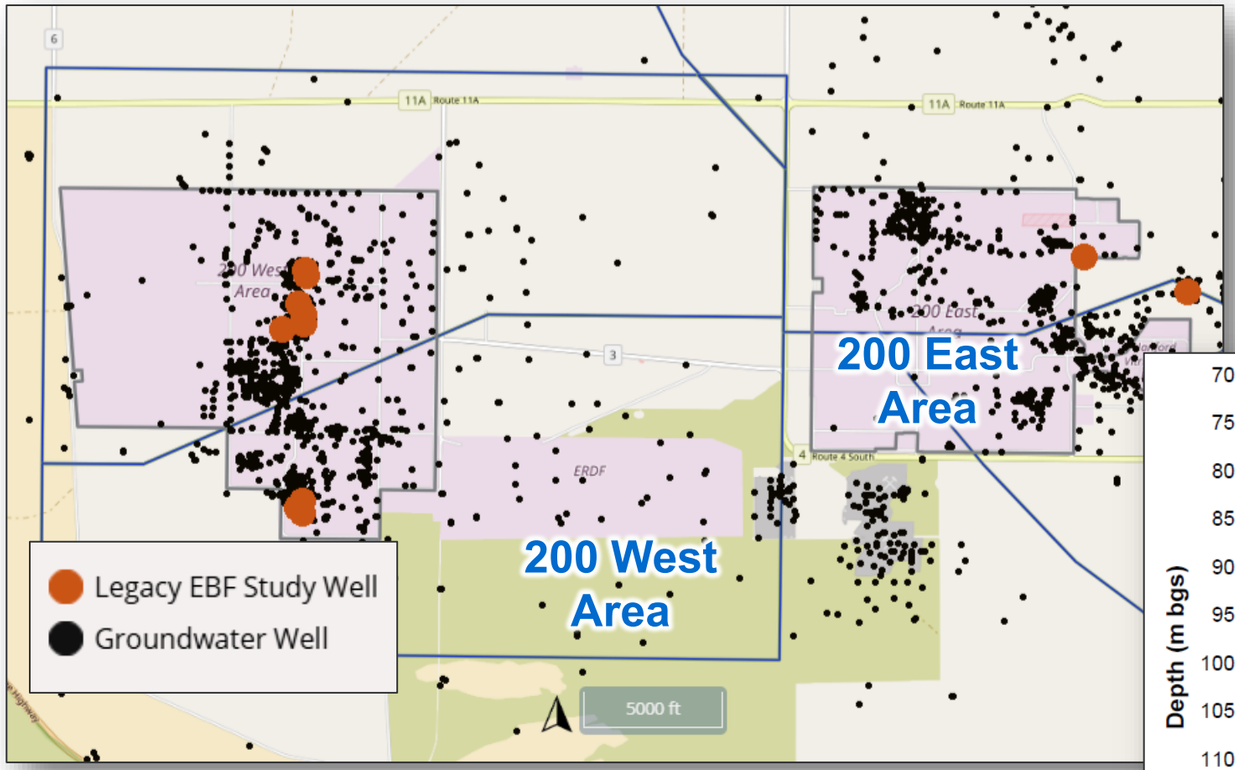


Locations of legacy EBF study wells among the broad network of Hanford groundwater wells.

- Legacy EBF and single-well tracer tests
  - 30+ wells in the early to late 2000's
  - PNNL studies (Spane, Newcomer, and Vermeul)



Early Vertical Characterization



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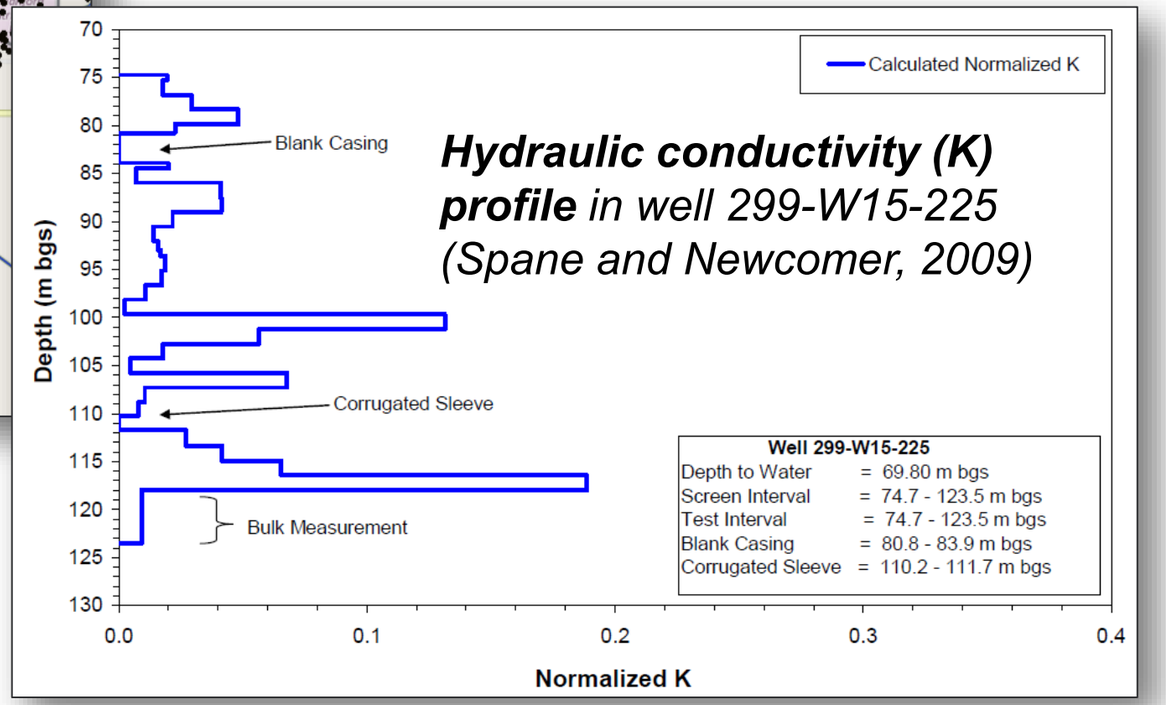
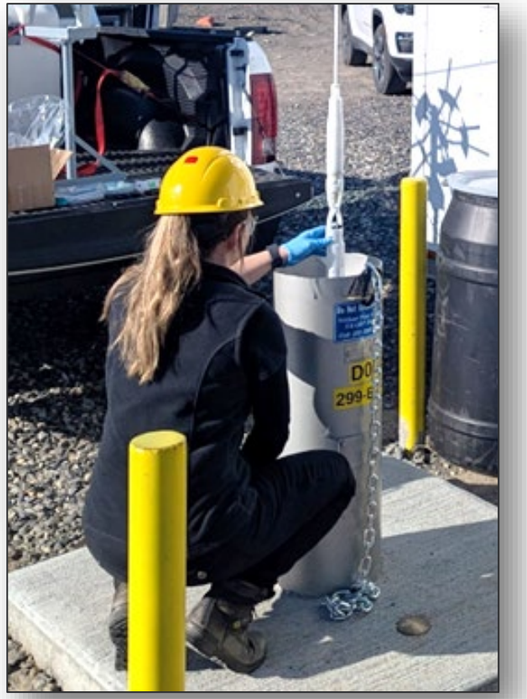


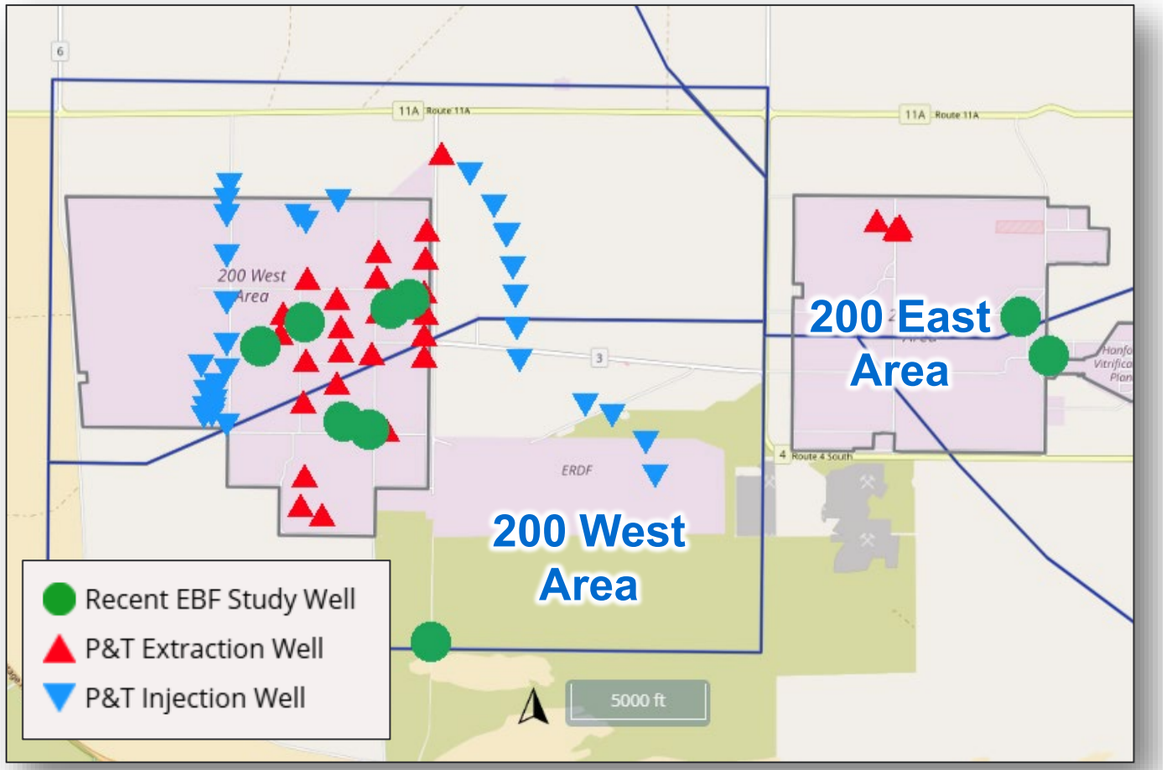
***Hydraulic conductivity (K) profile** in well 299-W15-225 (Spane and Newcomer, 2009)*

Recent Vertical Characterization

- Vertical contaminant and hydraulic characterization (2024 – ongoing)
  - Inflow/outflow zones
  - Vertical flow and mixing
  - Well vs aquifer concentration with depth
  - Snap Samplers

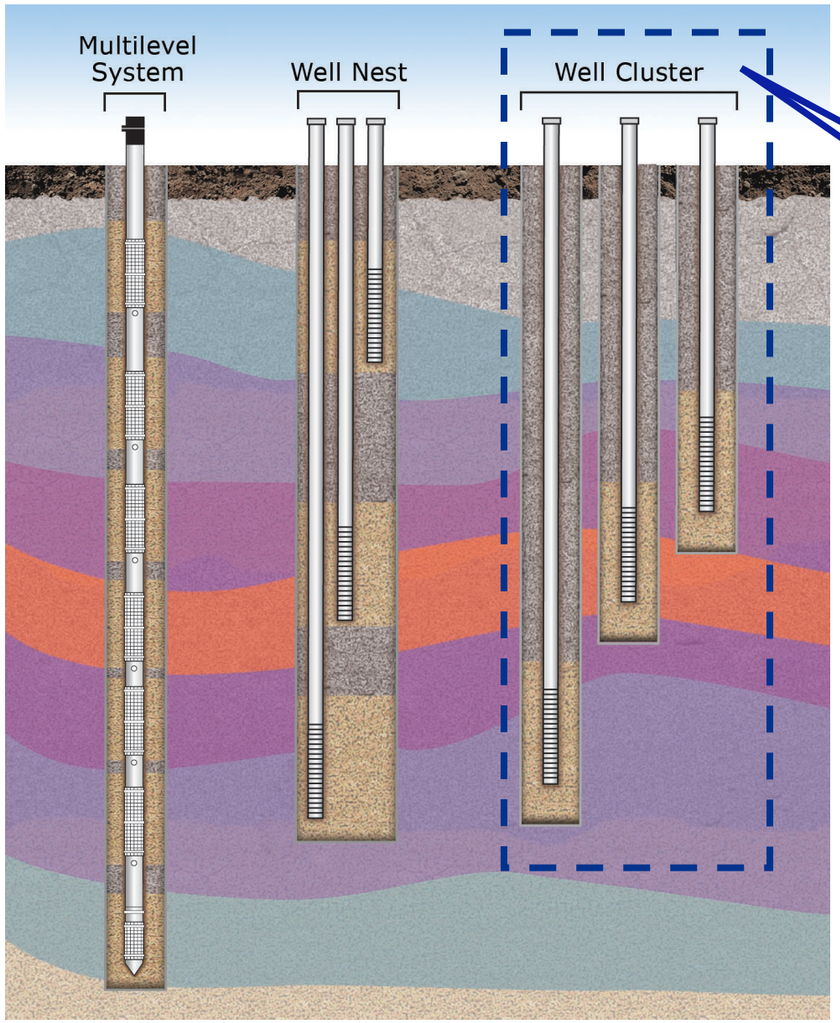


PNNL field characterization activities in 2025 involving EBF and Snap Samplers.



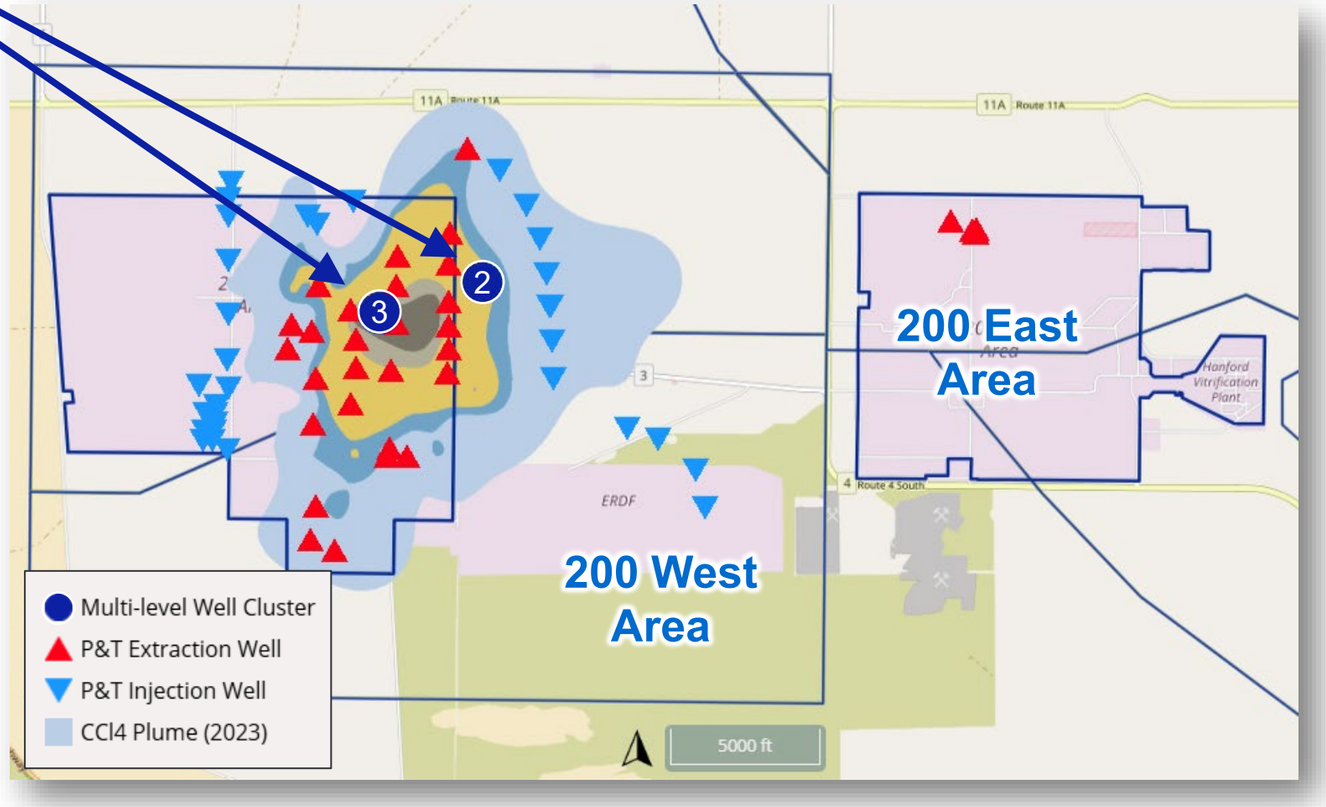
Locations of 10 wells included in ongoing vertical characterization with EBF (2024 – ongoing) in relation to the network of P&T extraction and injection wells in the 200 West and East Areas.

Recent Vertical Characterization



Comparison of discrete-zone well completion options. (https://solinst.com)

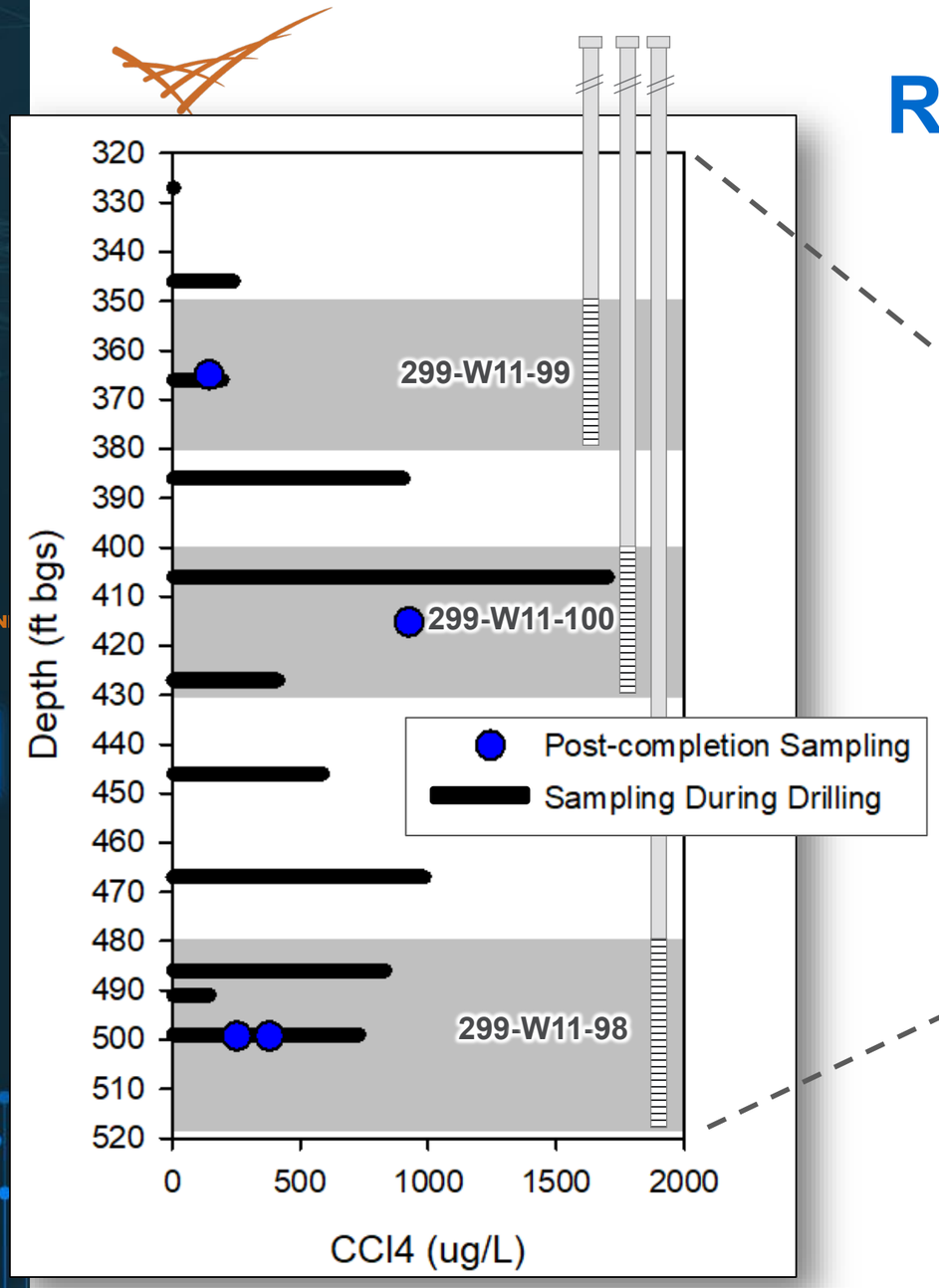
- Well clusters installed in 2024 for multi-level monitoring of CCl_4



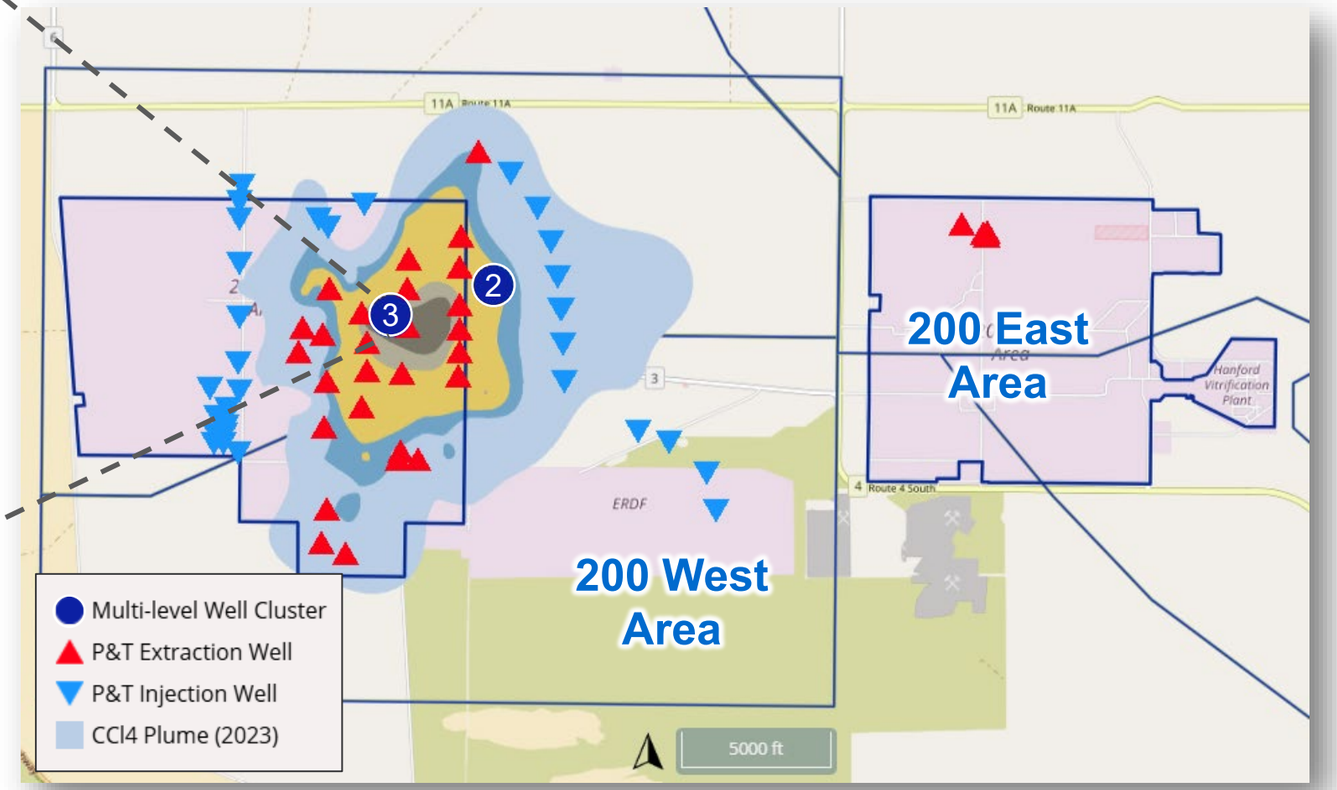
Locations of recently-constructed well clusters to monitor CCl_4 concentrations vertically within the aquifer (number of wells in each cluster noted).

Recent Vertical Characterization

- Three-well cluster in center of CCl_4 plume
- Highest concentrations in middle portion of the aquifer



CCl_4 concentrations with depth in a three-well cluster. (https://socrates.pnnl.gov)



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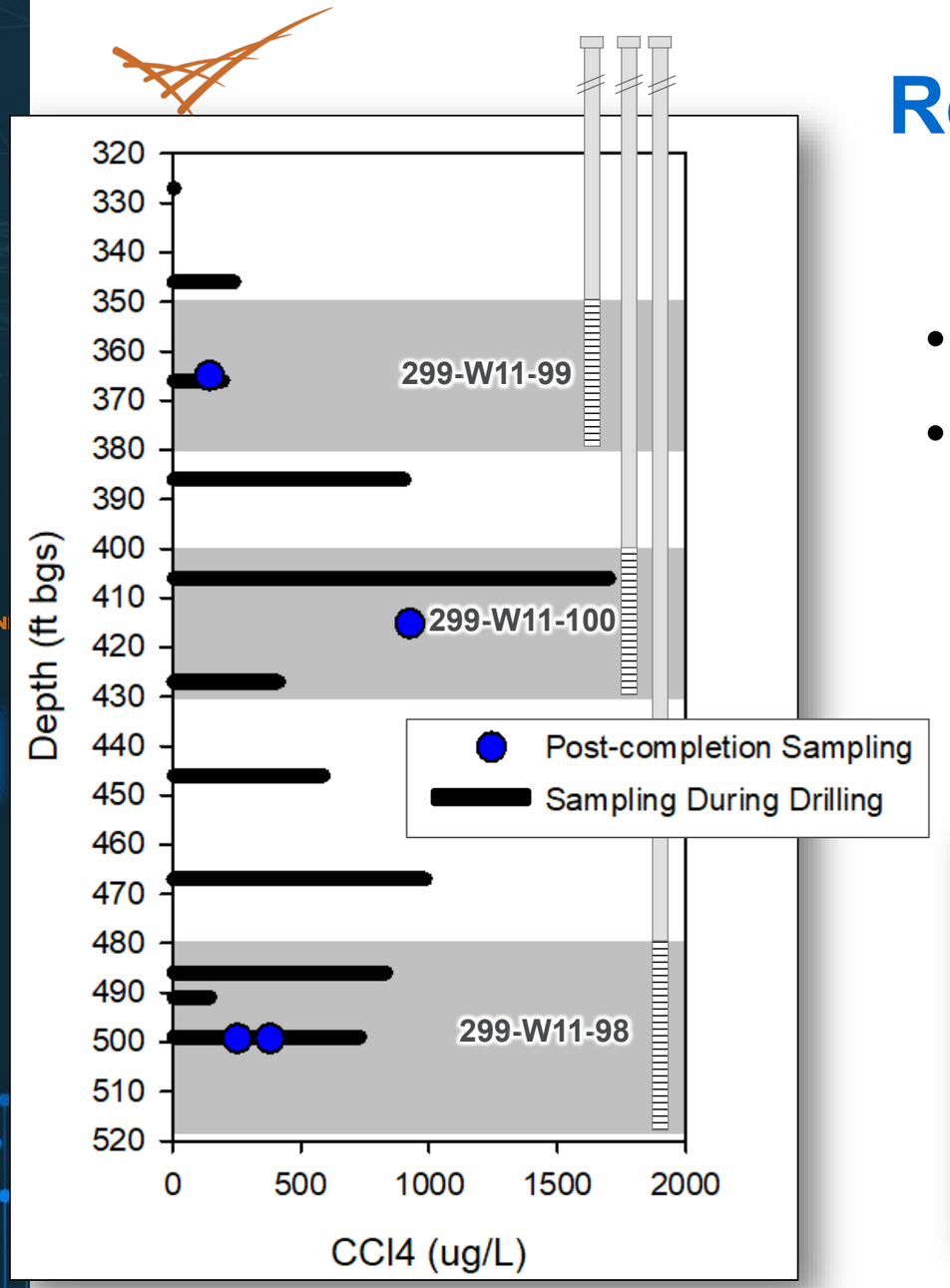
Recent Vertical Characterization

- Consistent with CSM
- Improved representativeness of the higher-concentration zones compared to nearby LSWs



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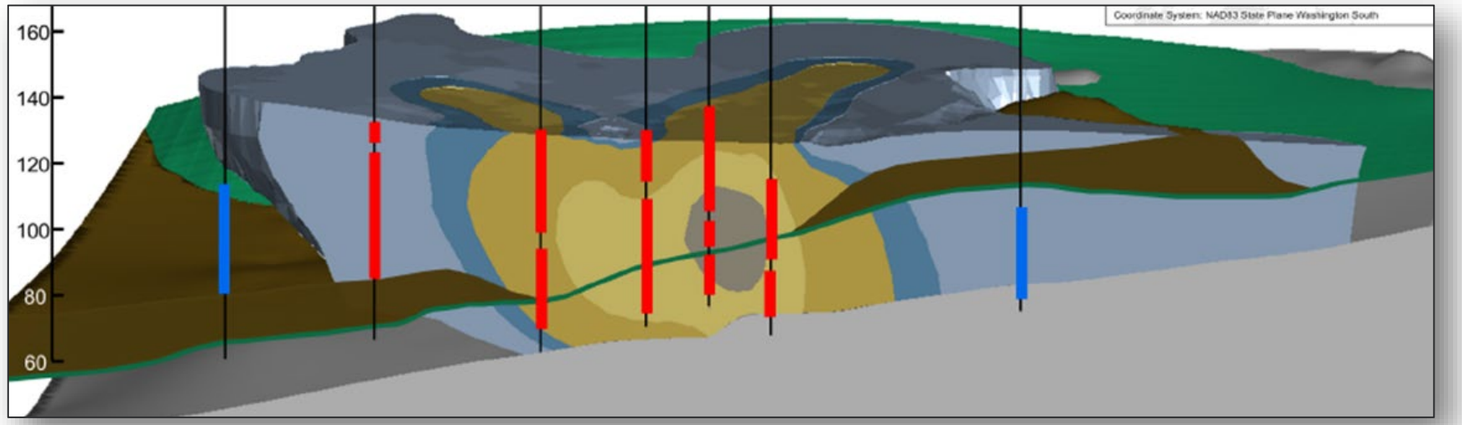
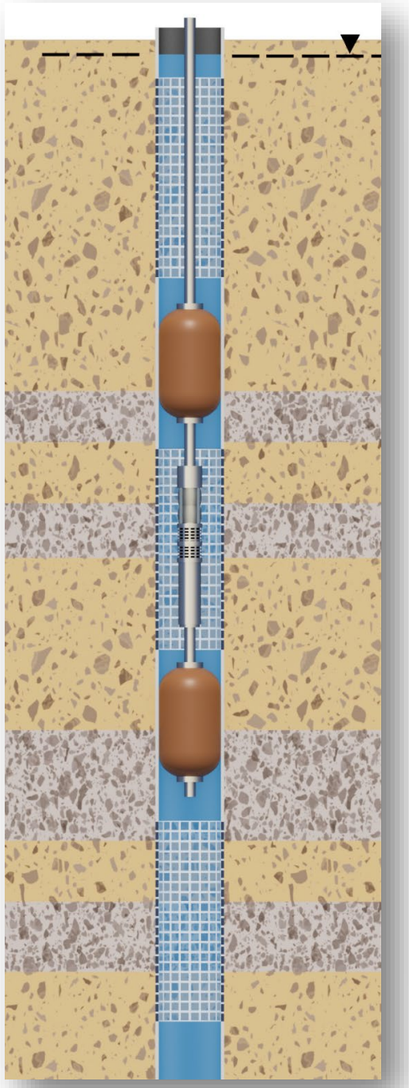


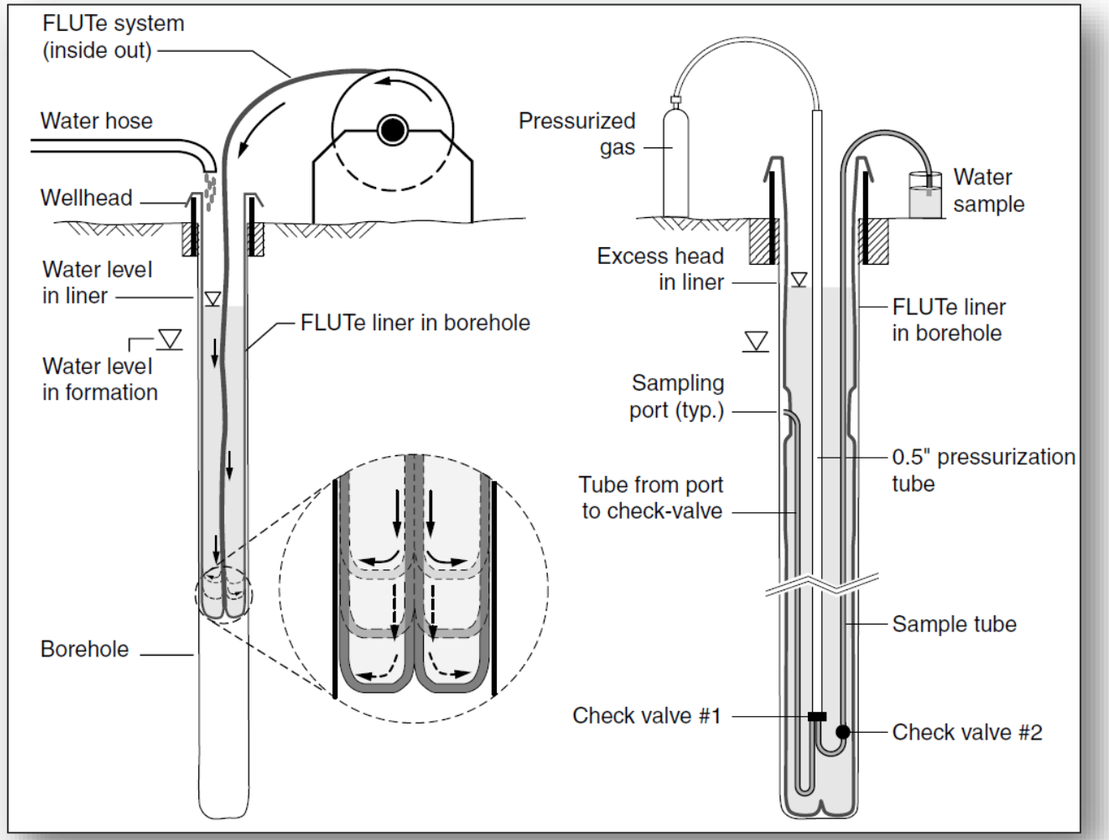
Three-dimensional carbon tetrachloride plume in the 200 West Area, 2024. (DOE/HFO-2024 Rev 0)

Ongoing Vertical Characterization

- Retrofitting existing LSWs
- Focused monitoring or pumping in discrete zones
- 2026 field demonstration
  - Straddle-packer pumping
  - Multi-port FLUTe liner installation



Straddle-packer pumping within a depth-discrete interval.



Schematic showing a single-port water Flute system. (Einarson 2006)

Challenges and Opportunities

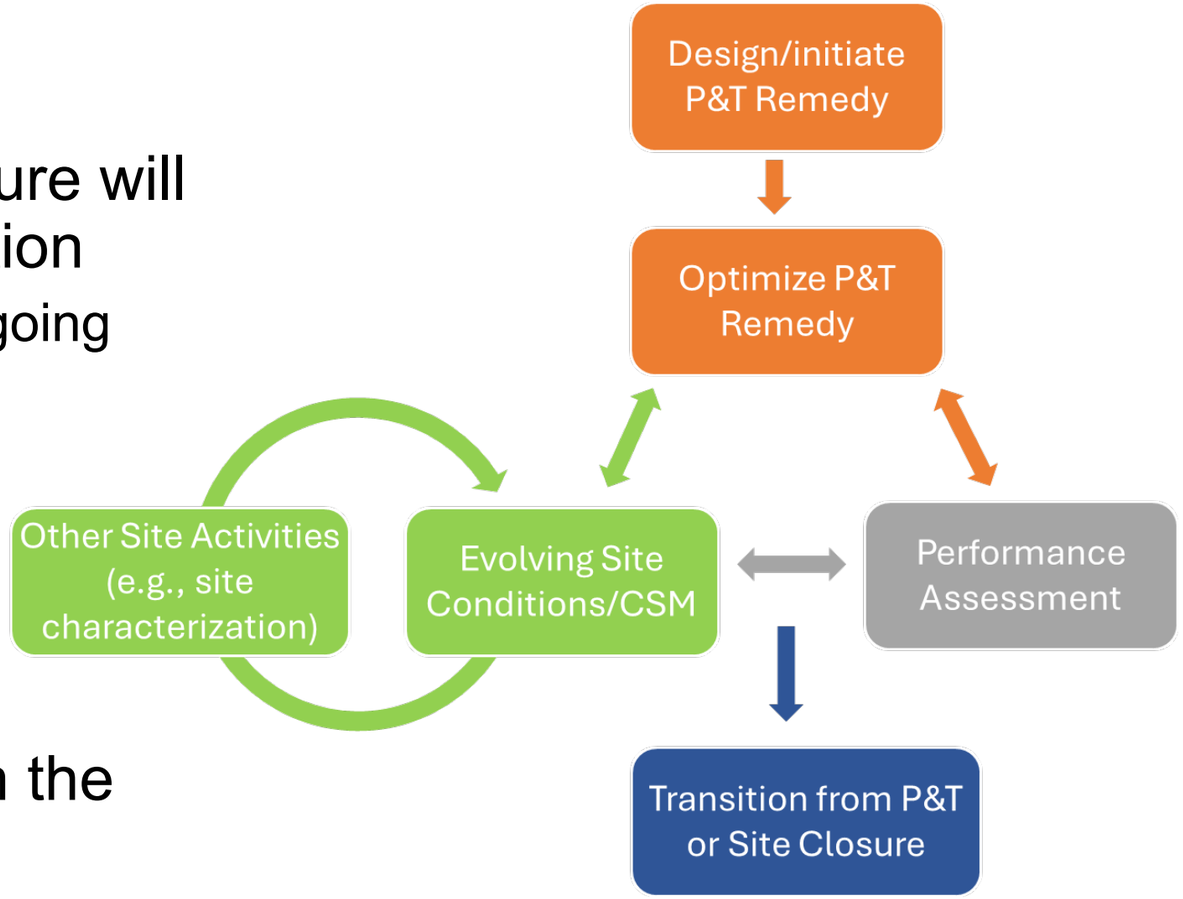
- Active P&T remedy
  - Hydraulic interference
  - Disruption to operations impacts volumetric and mass removal goals
  - High cost of operation and maintenance = less for characterization
- Controlled radiological area
  - Special training and access requirements
  - Added costs
- Implementation takes time

- Extensive water-level monitoring network
- Decades of data
- Shutdown-restart events provide analyzable responses
- Onsite expertise and equipment

- Seeing is believing
- Collaboration with stakeholders and contractors

Conclusions – Getting to Closure

- P&T optimization and transition to closure will require additional vertical characterization
  - Progress and results from recent and ongoing activities are encouraging
- Basis for improvements
  - Multi-level well completions
  - Retrofitting LSWs
  - Discrete-zone extraction wells
- Outcomes focused on mass removal in the most impactful way
  - Decreasing cleanup timeframe and costs



Performance-based P&T remedy optimization framework. (ITRC; https://pt-1.itrcweb.org/life-cycle-optimization/)