Pacific Northwest
NATIONAL LABORATORY

DEEP VADOSE ZONE PROGRAM @PNNL

Hanford Data Visualization and Analysis in SOCRATES to Support Remedy Performance Assessment and Optimization

November 2025

Christian Johnson
Senior Development Engineer

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-217555

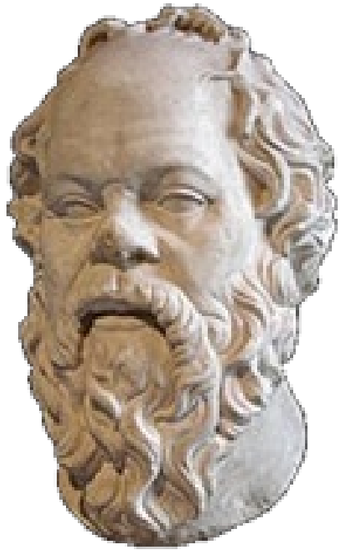
REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES at PNNL

Organized in cooperation with IAEA

RemPlex Global Summit
November 4–6, 2025

Overview

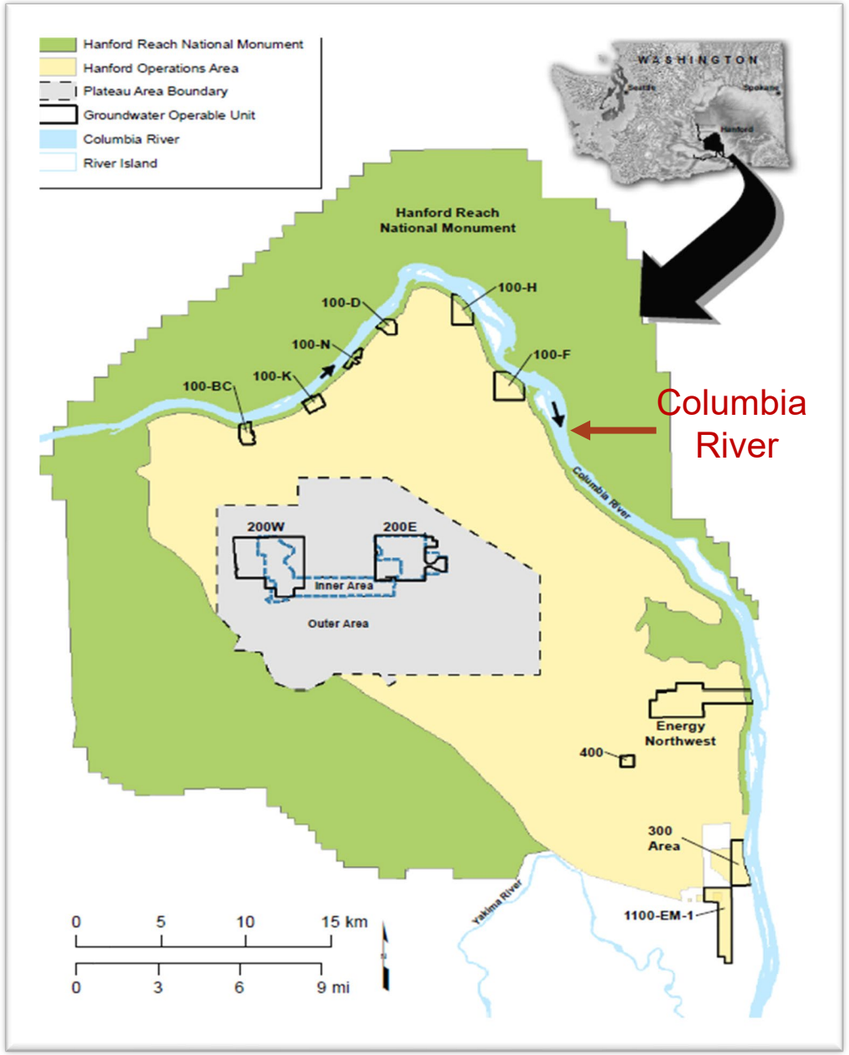
- Environmental management data
- Hanford Site Central Plateau groundwater remediation
- SOCRATES to support decision making
- HYPATIA for P&T remediation system data
- ORIGEN for data visualization & communication



Socrates, ancient Greek philosopher, c. 470 – 399 BC

U.S. Department of Energy Hanford Site

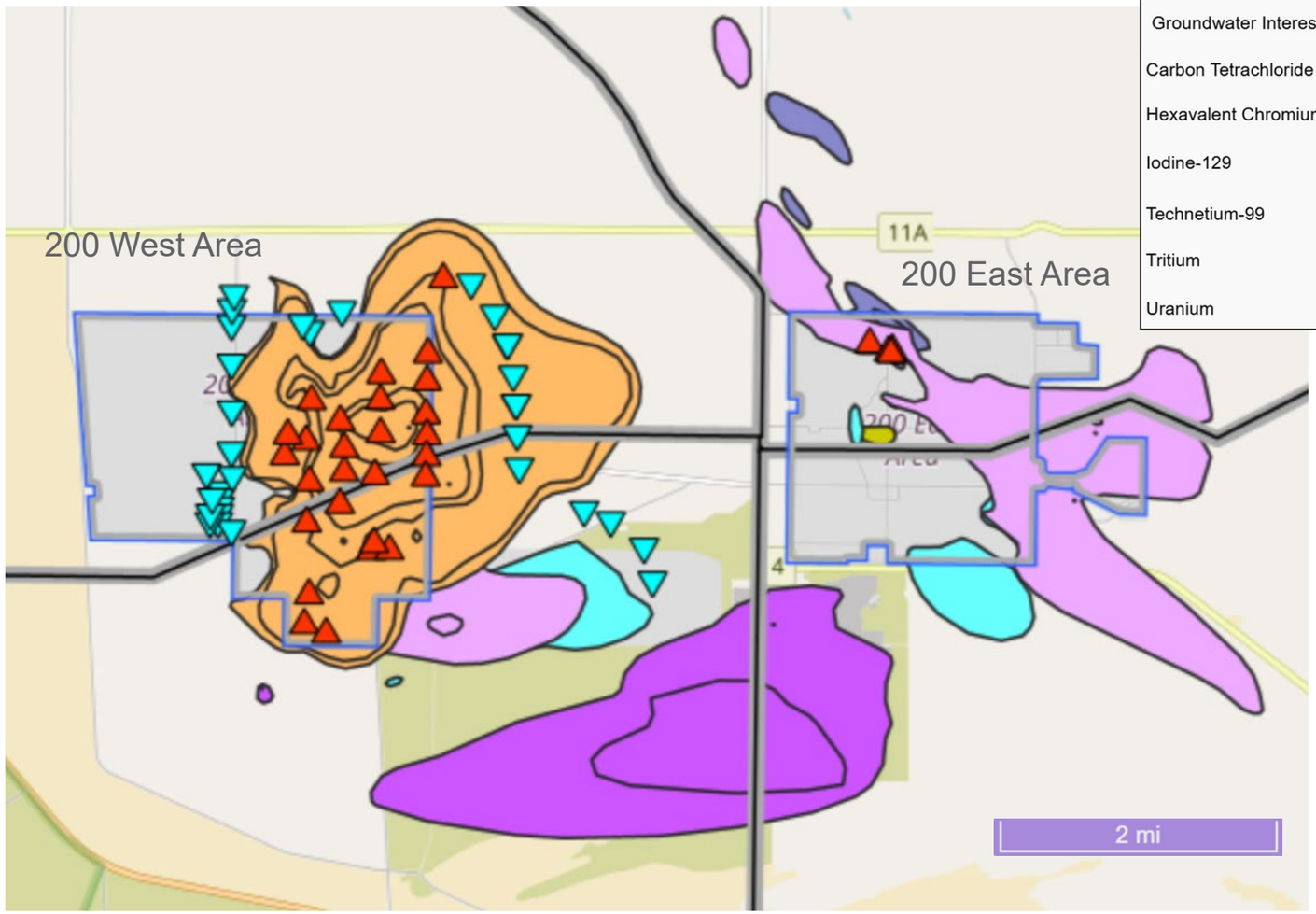
- Soil and groundwater contamination from historical practices as part of plutonium production
  - Radionuclide, organics, metals, and inorganics
  - Very complex site
- River Corridor
  - Reactor operations
- Central Plateau
  - Nuclear fuel reprocessing
  - Waste disposal and management



DEEP VADOSE ZONE PROGRAM @PNNL

Groundwater Contamination in the Central Plateau

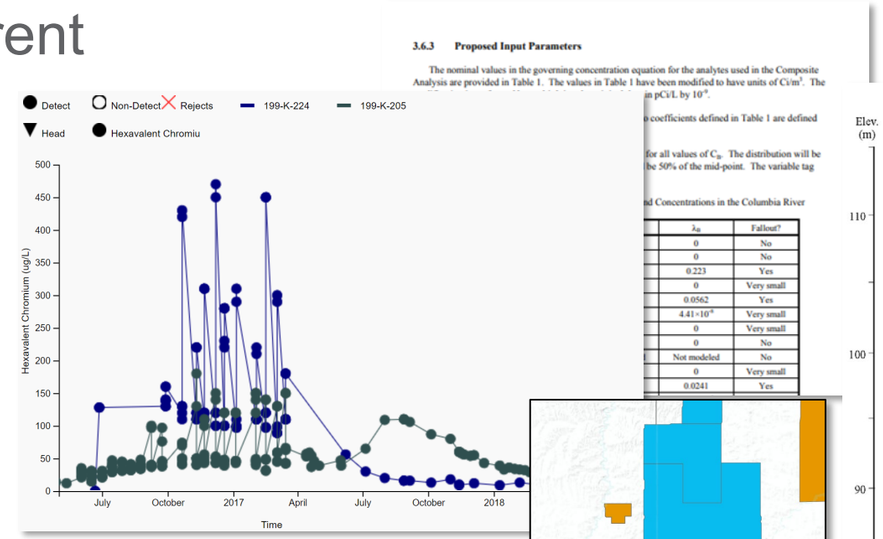
- Multiple groundwater contaminant plumes in the Central Plateau
  - See image (nitrate is not shown, but is widely distributed)
- Remedy
  - Pump-and-treat (P&T) active remediation
  - Followed by monitored natural attenuation

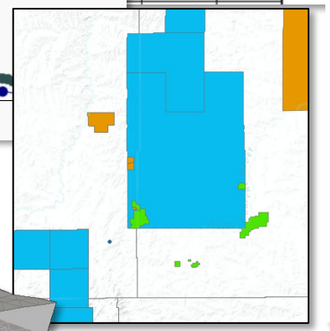


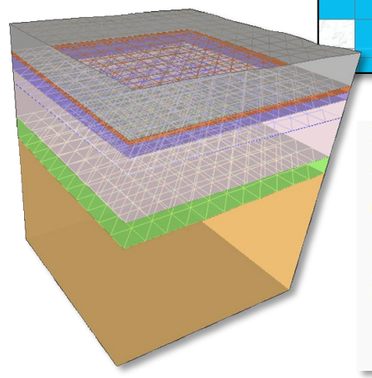
DEEP VADOSE ZONE PROGRAM @PNNL

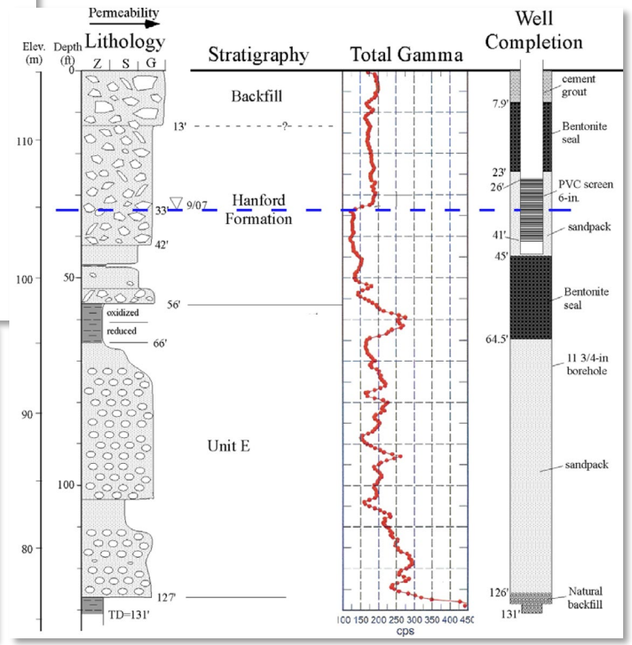
Lots of Hanford Environmental Data – Multiple Types/Sources

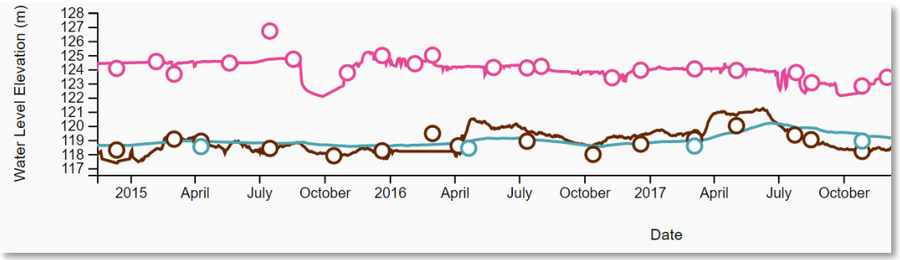
- Data inherently comes in different forms and formats
  - Electronic tabulated data
  - Information from reports
  - Well log or geophysical data
  - Sensor data
  - Spatial data
  - Data/model in 3 dimensions
  - Satellite/remote sensing
- Multiple agencies may control data
  - Overlapping "authoritative" data sources
  - Data access varies across organizations and time (e.g., with changes in contractors)









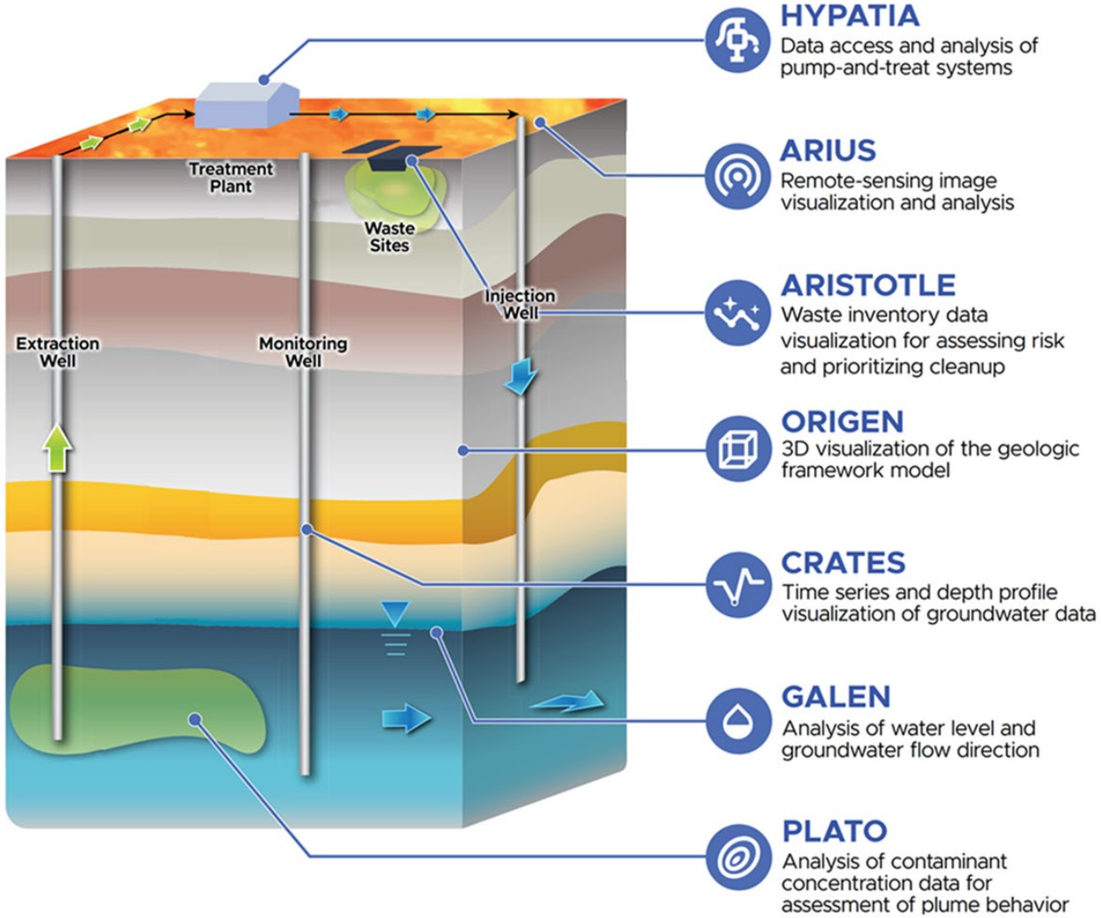


DEEP VADOSE ZONE PROGRAM @PNNL

SOCRATES

Suite Of Comprehensive Rapid Analysis Tools for Environmental Sites

- Web application to access, visualize, and analyze environmental data
  - Multiple modules for specific data/analyses
  - Supports environmental decision-making
  - Implemented on Amazon Web Services for robust performance, ease of maintenance, & user control
- Consistent, reproducible, and rapid analytics
- Based on standard statistical methods and EPA / USGS guidance
- Developed under a QA program compliant with the American Society of Mechanical Engineers NQA-1 standard



MARINuS
Custom mapping to support reporting and communication

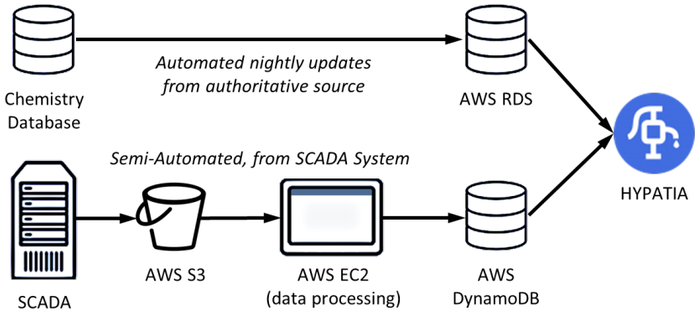
EUCLID
Custom plots to support reporting and communication

DEEP VADOSE ZONE PROGRAM @PNNL

EPA = U.S. Environmental Protection Agency
USGS = U.S. Geological Survey
QA = quality assurance

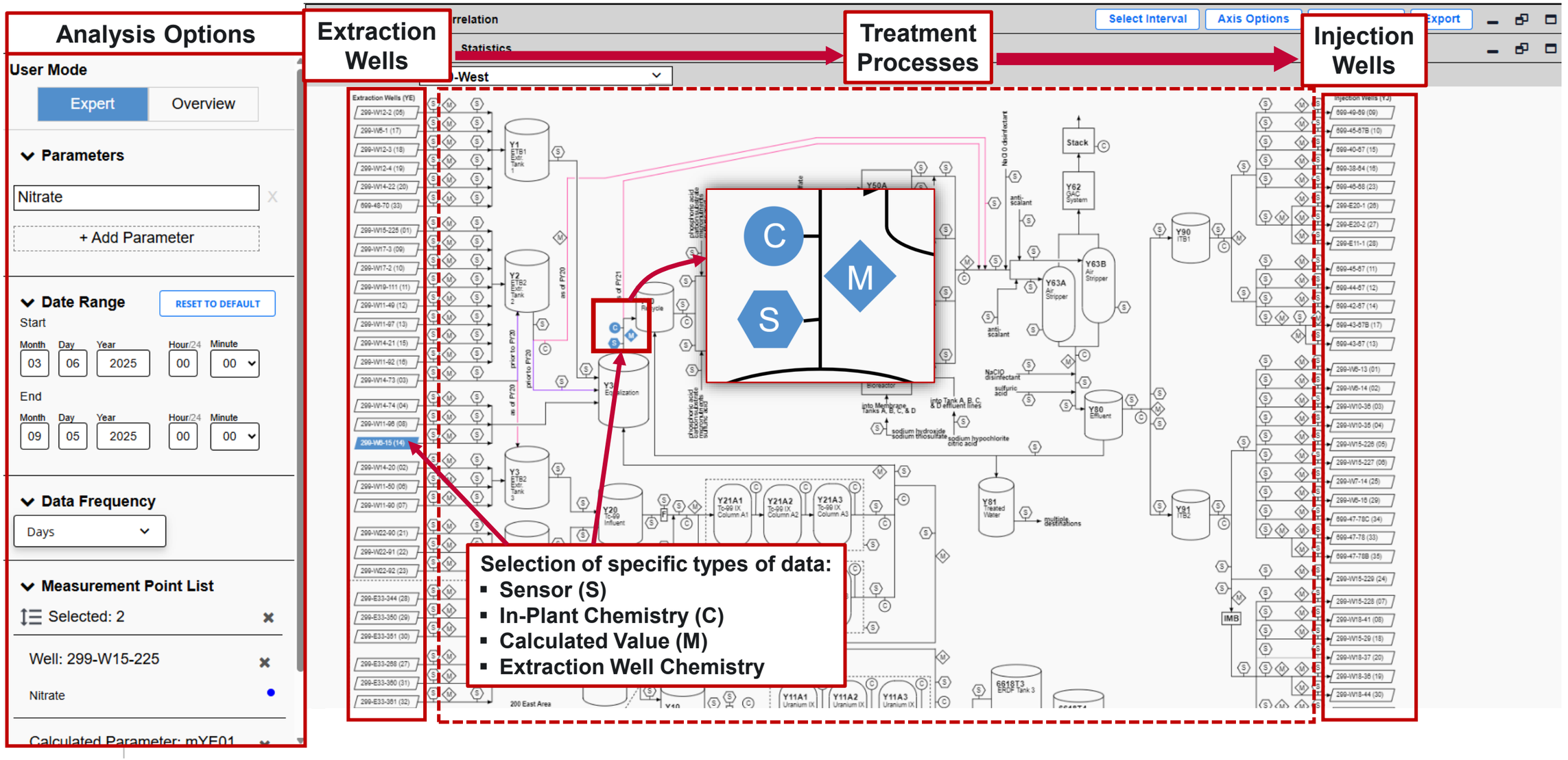
HYPATIA – HYdraulic Pump-And-Treat Information Analytics

- Access to pump-and-treat (P&T) system data
  - Sensors (flow, pressure, etc.)
  - Chemistry (multiple parameters)
    - ✓ Extraction wells and in-plant locations
- Analysis of P&T data
  - Aggregation, smoothing, sum/diff.
  - Mass flow rate, injectivity metric
- Remedy performance assessment
  - Unit operations or overall system
  - Extraction well performance
  - Injection wells
  - Maintenance
- Future planning



DEEP VADOSE ZONE PROGRAM @PNNL

HYPATIA Interactions

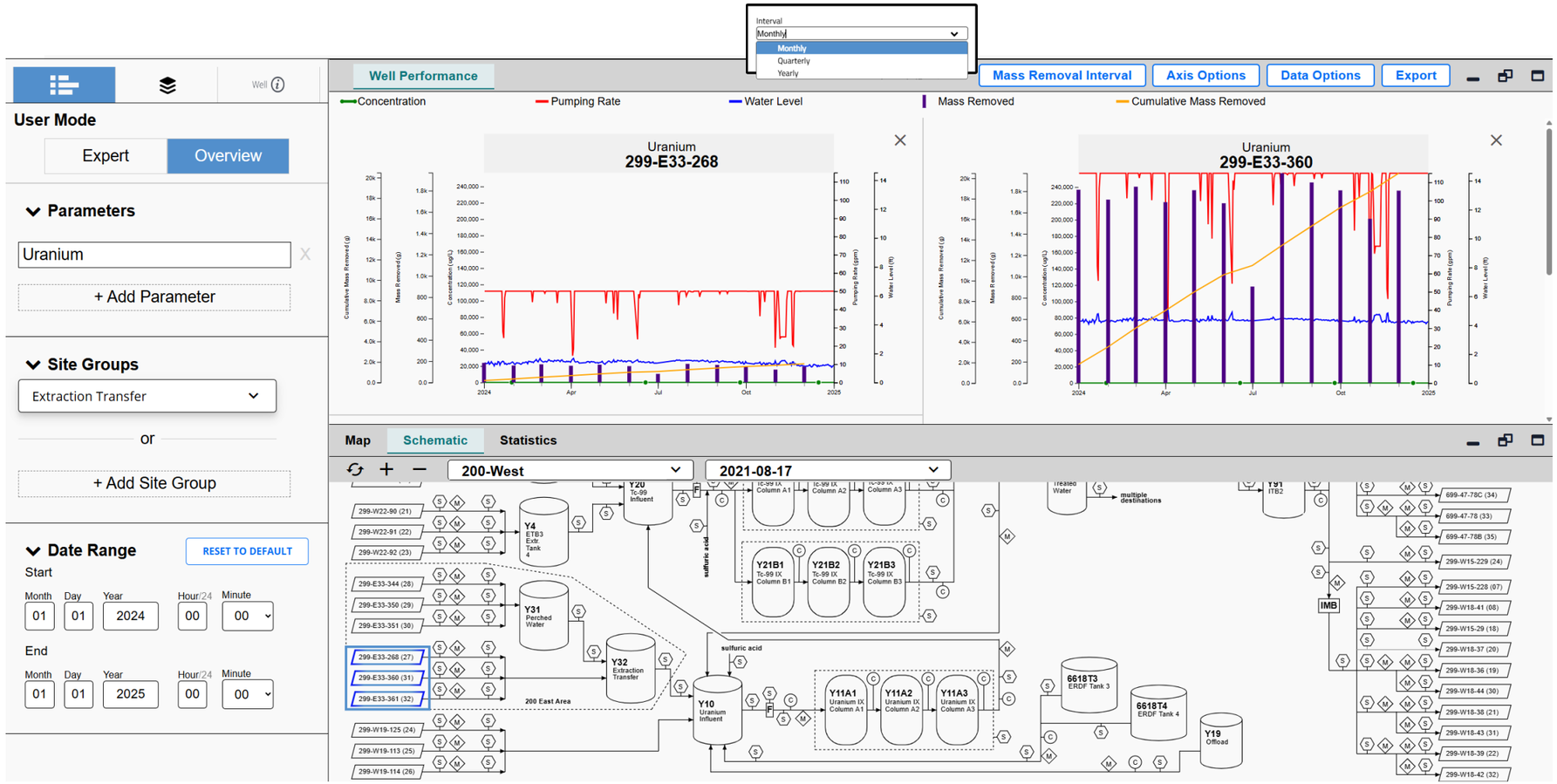


HYPATIA Data Analysis and Statistics

Meas. Point	Parameter/Type	Units	Average	Std. Dev.	Median	Max.	Min.	Count	Area
sY30: FIT_Y30	Flow Rate	gpm	1842	430.9	1845	2392	1115	153	406026130
sY30: TIT_Y30	Temperature	°F	69.22	2.119	70.06	72.08	63.06	153	10590
cY30	Nitrate	ug/L	133500	19243	140500	152000	104000	6	17373660
299-W6-15	Nitrate	ug/L	397000	1414.2	397000	398000	396000	2	42130800
mY30	Nitrate Mass Flow Rate	g/d	1224410	211776	1208130	1860810	704963	153	187290290

HYPATIA – Well Performance Overview

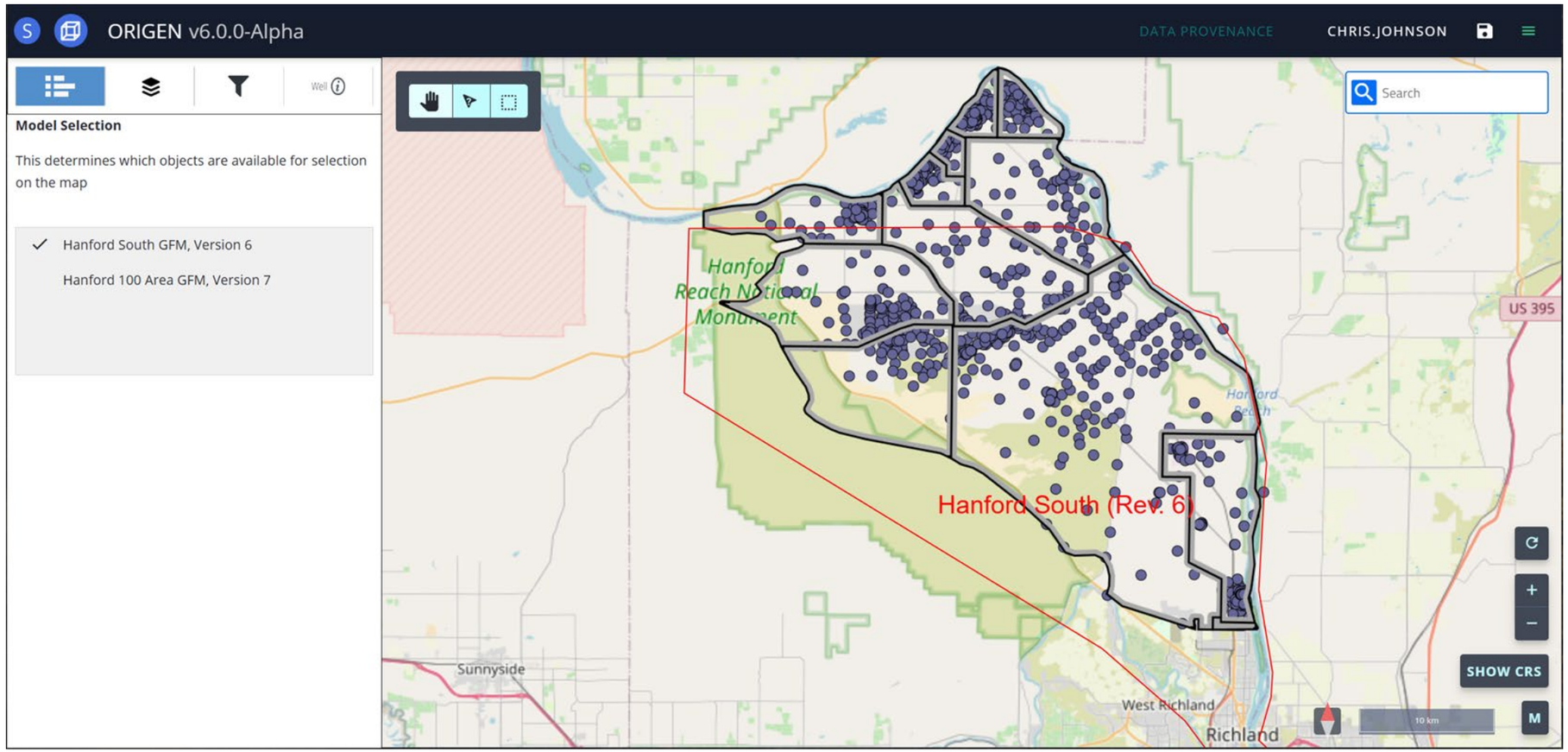
- Well performance for selected contaminant, group of wells, and date range
- Panel of plots
  - Normalized scales
  - Easy comparison
- Key datasets are plotted
  - Flow rate
  - Water Level
  - Concentration
  - Mass removed
    - ✓ Monthly, quarterly, yearly



Meas. Point	Parameter/Type	Units	Average	Std. Dev.	Median	Max.	Min.	Count	Area
299-E33-360	Concentration (Uranium)	ug/L	97.85	3.569	97.60	105.0	93.70	8	32330
299-E33-361	Concentration (Uranium)	ug/L	14.30	0.6899	14.35	15.00	13.10	6	4599
299-E33-268	Mass Removed (Uranium)	g	152.1	27.71	157.7	183.8	80.26	12	50550
299-E33-360	Mass Removed (Uranium)	g	1707	274.9	1807	1969	905.7	12	568890
299-E33-361	Mass Removed (Uranium)	g	0.02101	0.03422	0	0.09842	0	12	5.683

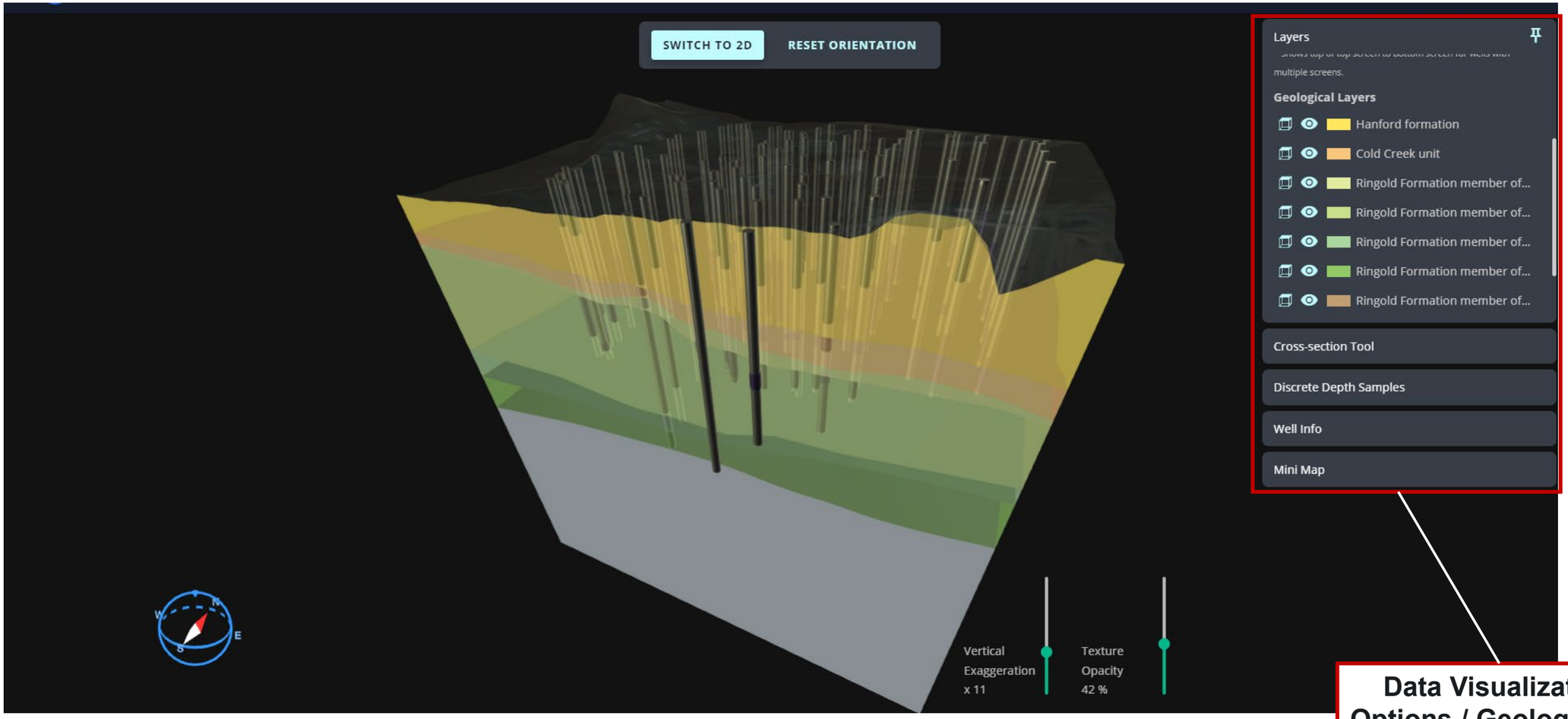
ORIGEN – Online Retrieval Interface for GEologic iNformation

- Interactive 3D visualization of selected area
  - Hydrogeological units / geology
  - Well locations, depths
  - Cross sections
  - Soil sample data
  - Plume data



DEEP VADOSE ZONE PROGRAM @PNNL

ORIGEN 3D View of Geology and Wells

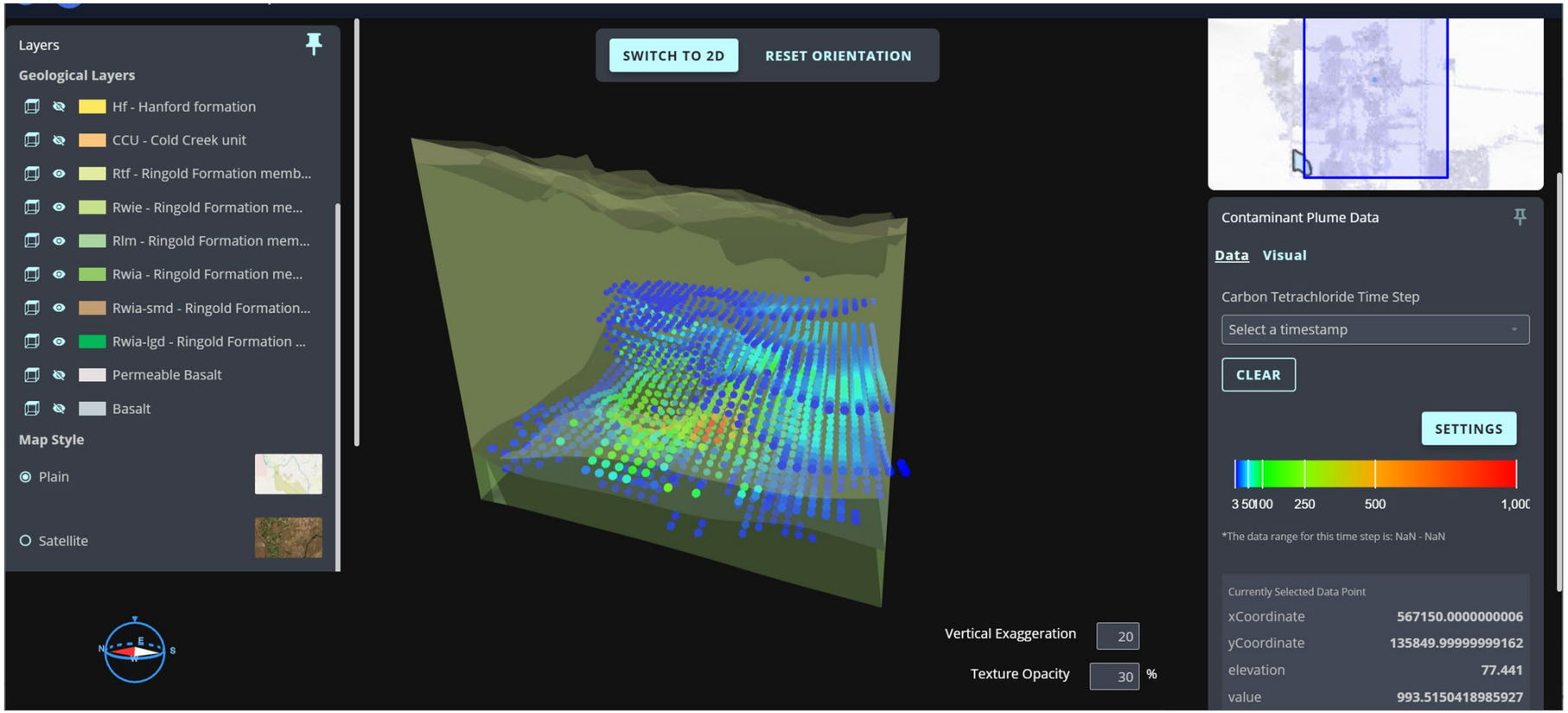


Data Visualization Options / Geologic and Well Info / Tools (cross-section, etc.)

ORIGEN – Numerical Model
3D Carbon Tetrachloride Plume Data

- Visualize 3D scatter data for carbon tetrachloride (CT) plumes
  - P2R simulation results at years:
    - ✓ 2016, 2029, 2040, 2066, 2115, 2137

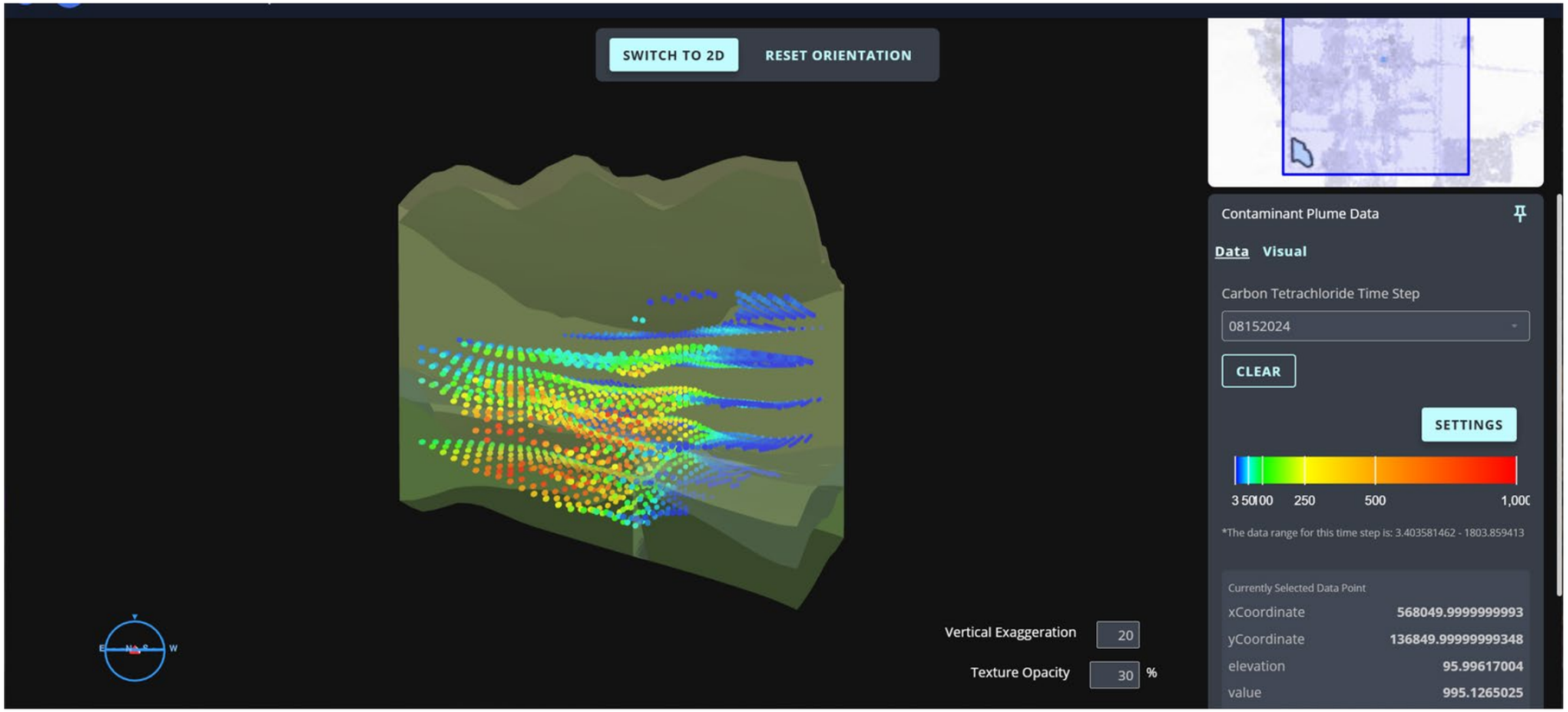
P2R = Numerical flow & transport model covering Central Plateau east/south to the Columbia River



DEEP VADOSE ZONE PROGRAM @PNNL

ORIGEN – Interpolated 3D Carbon Tetrachloride Plume Data

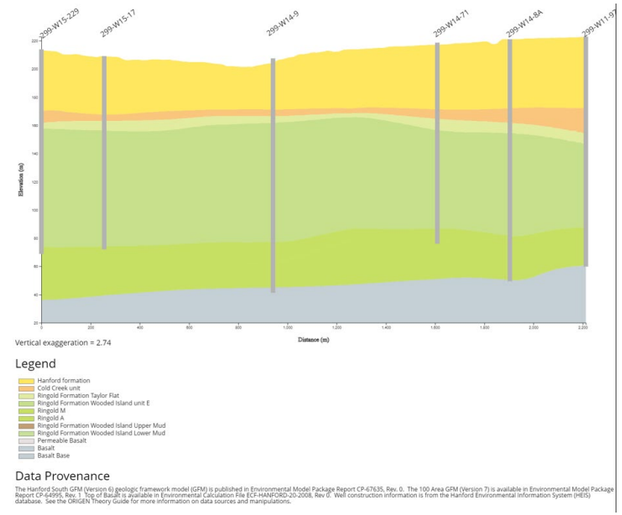
- Visualize 3D scatter data for carbon tetrachloride (CT) plumes
  - 2023 Interpolated 3D plume

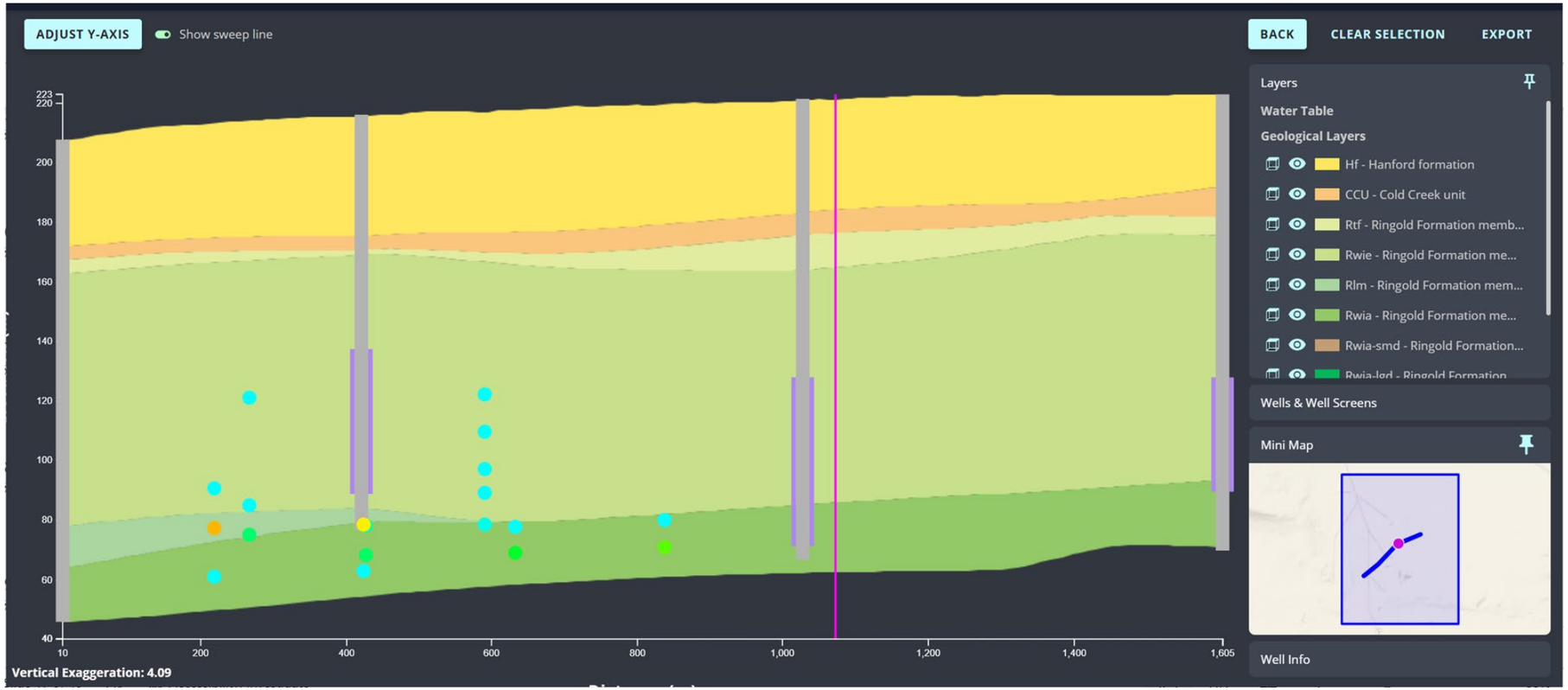


DEEP VADOSE ZONE PROGRAM @PNNL

ORIGEN – Cross Sections

- Geologic cross sections
- Wells in the cross section
  - Well screens
- Carbon tetrachloride plume data in cross section

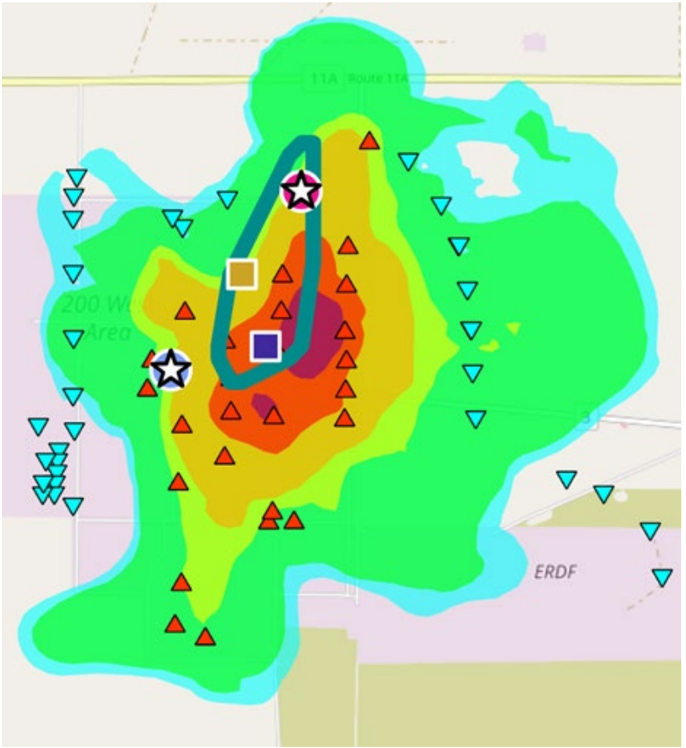




DEEP VADOSE ZONE PROGRAM @PNNL

Using HYPATIA and ORIGEN Information with Machine Learning and Optimization Approaches

- Machine learning (deep learning) to determine optimum well locations and pumping scheme
- Machine learning based on
  - Well performance data
  - Plume distribution data
  - Geology data
  - Numerical model simulations
- Objectives for optimizing mass removal, decreasing remediation time, etc.



Conceptual rendering of how AI might recommend optimal extraction well locations

Acknowledgements

- Team contributors:
  - Christian Johnson, Delphine Appriou, Jennifer Fanning, Jesus Fernandez, Frank Lopez Jr., Hung Luu, Ashton Kirol, Angelica Vargas, Reem Osman, Sophie Baur, Ross Cao, Tycko Franklin, and Patrick Royer

- Funding for this work was provided by the U.S. Department of Energy Hanford Field Office under the Deep Vadose Zone – Applied Field Research Initiative.

Pacific Northwest NATIONAL LABORATORY

DEEP VADOSE ZONE PROGRAM @PNNL

Thank You

https://www.pnnl.gov/projects/socrates

https://socrates.pnnl.gov
(for non-Hanford guests, CRATES only)

Contact:

Christian Johnson
cd.johnson@pnnl.gov

socrates@pnnl.gov

REMPLEX
CENTER FOR THE REMEDIATION OF COMPLEX SITES
@PNNL

remplex@pnnl.gov
https://www.pnnl.gov/projects/remplex