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Development of a Numerical Transport Model to Support Groundwater Remedy Selection at a Former Uranium Mill Site

Keaton Belli, Chelsea Bokman, Jennifer Nyman, Liz Moran, and Ken Pill

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Site Background

- Ancestral land of the Ute and Timpanogos tribes
- 1956–1984: Uranium ore processing facility
- 16M tons of uranium mill tailings in unlined impoundment
- Primary COCs: ammonia and uranium
- Completion of tailings removal expected by 2029

Goals

DOE-EM overall goal: Receive Nuclear Regulatory Commission concurrence on a final groundwater remedy before tailings removal is complete

UMTRCA requires a **numerical groundwater model** to demonstrate a predicted remedy timeframe.

Analytical batch pore flushing model used to identify sensitivity parameters for remedy timeframe.

Greatest uncertainties in natural flushing timeframe:

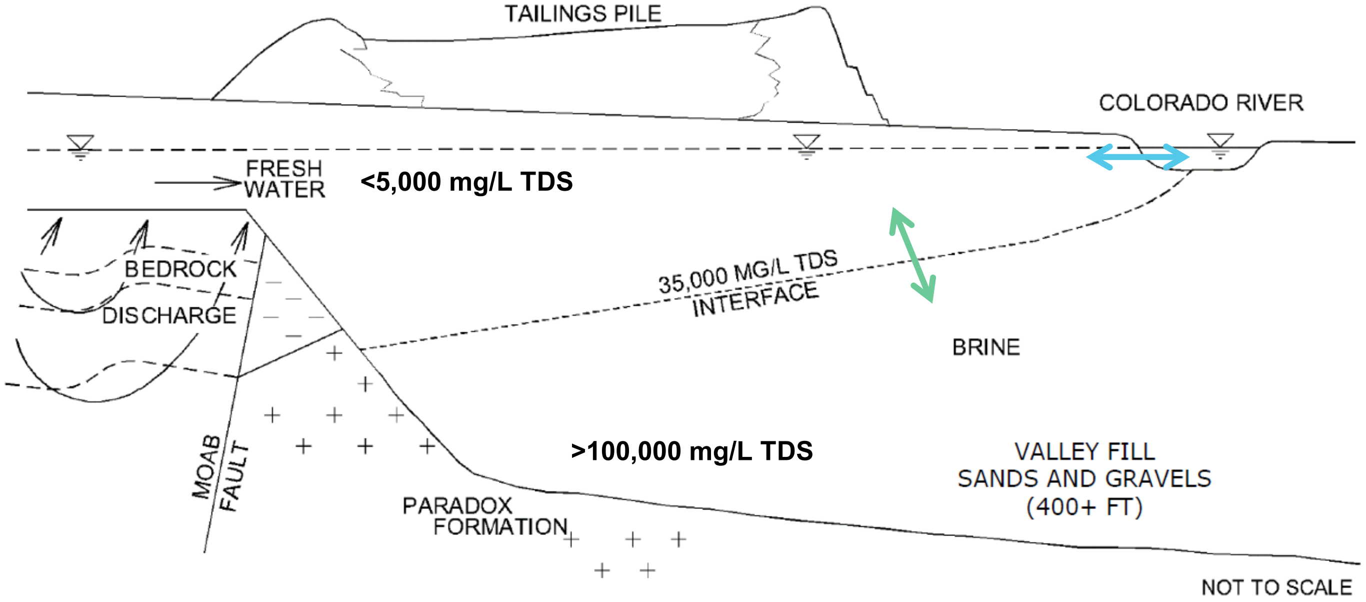
- Distribution coefficient (K_d) for uranium
- Flow rate through the groundwater plume
- Mass transfer of ammonia from brine zone

Objectives

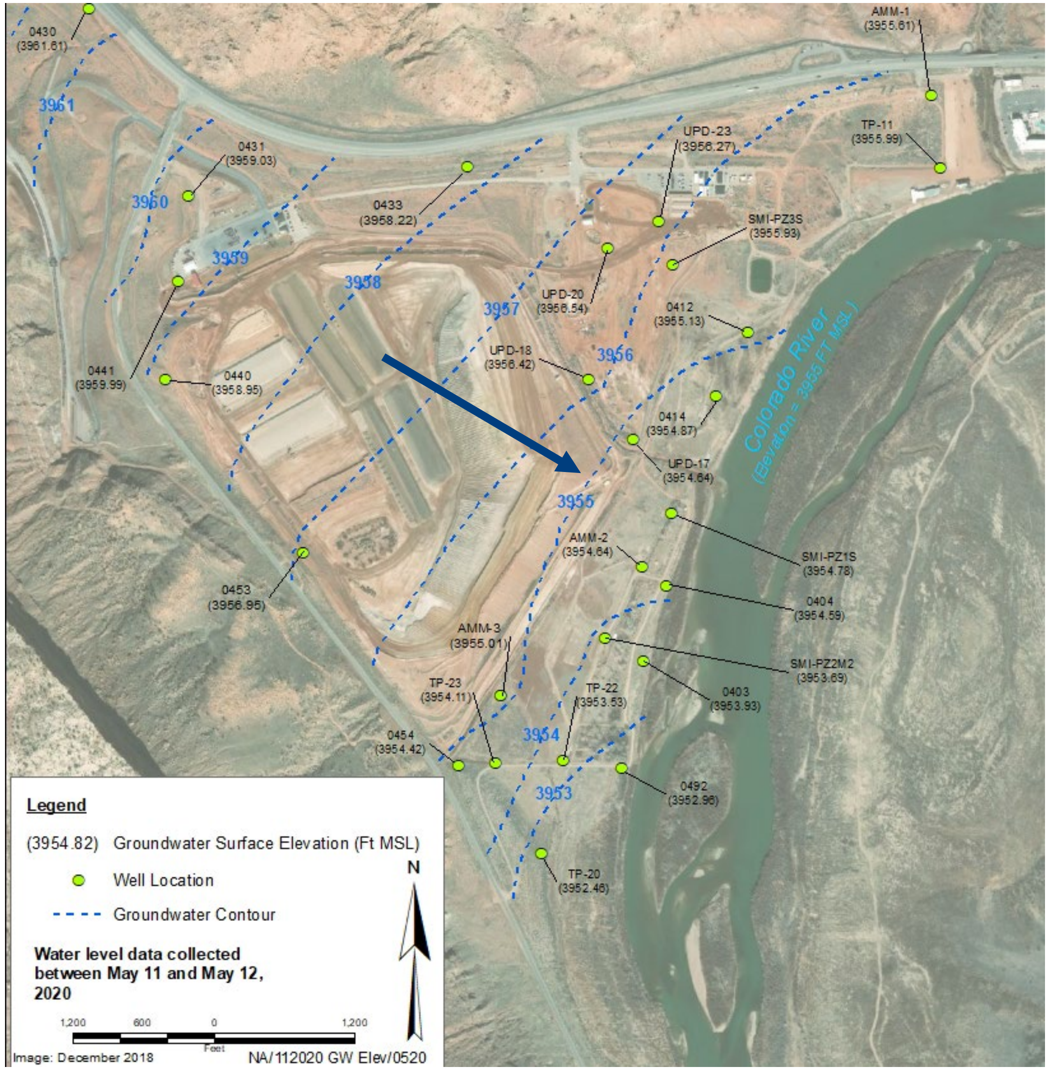
- Update CSM using data collected over the past 20 years
- Develop numerical groundwater flow and transport model based on updated CSM
- Evaluate sensitivity of remedial timeframe to key model parameters
- Develop predictive model scenarios to evaluate remedial timeframes of potential active remedies

Key Site Features

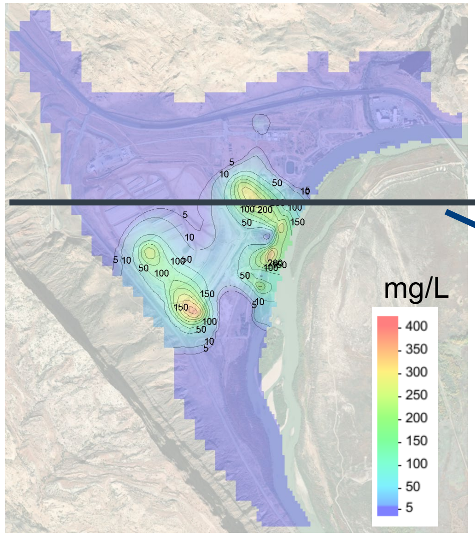
- Regulatory context
  - Limited use groundwater
  - Endangered species habitats
- Brine
  - Density-driven flow
- Groundwater-surface water interactions
  - Colorado River stage increases up to 20 feet during summer runoff
  - Flow direction reversal
- Biogeochemistry
  - Adsorption/cation exchange
  - Nitrification
  - Ionic strength effects
  - Redox conditions

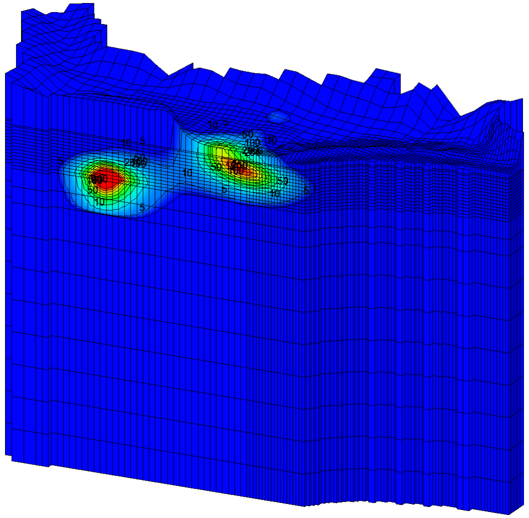


Groundwater Flow and Contaminant Distribution

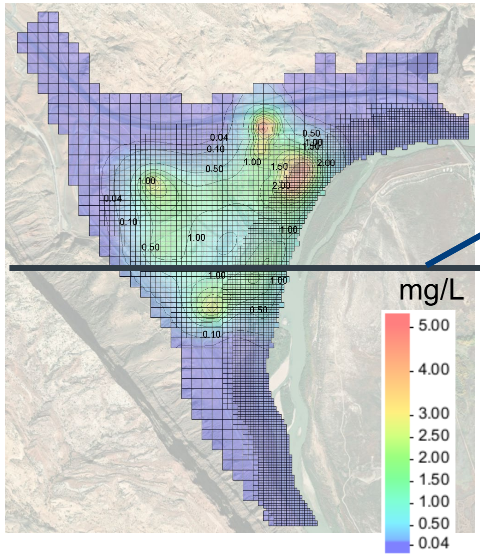


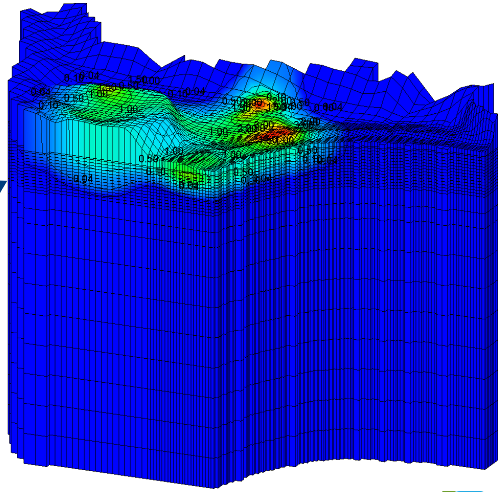
Ammonia





Uranium





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Previous Modeling Efforts

2003 FEFLOW Model

- Numerical model
- Steady-state flow based on river gaining condition
- No variable-density flow
- Transport of ammonium

2011/2015 MODFLOW, SEAWAT MODEL

- Numerical model
- Transient flow
- Variable-density flow
- Simulation period limited to one year due to limitation variable density flow assumptions
- No contaminant transport

2020 Batch Pore Flushing Model

- Analytical model
- Steady-state flow based on river gaining condition
- No variable-density flow
- Uniform concentrations
- Transport of ammonium and uranium

Improvements of the Current Model

Improvements

- Key biogeochemical processes
- Density-driven flow and mass flux from brine zone
- Groundwater-surface water interactions
- Transient calibration to 15 years of data with monthly timesteps

Data Sources

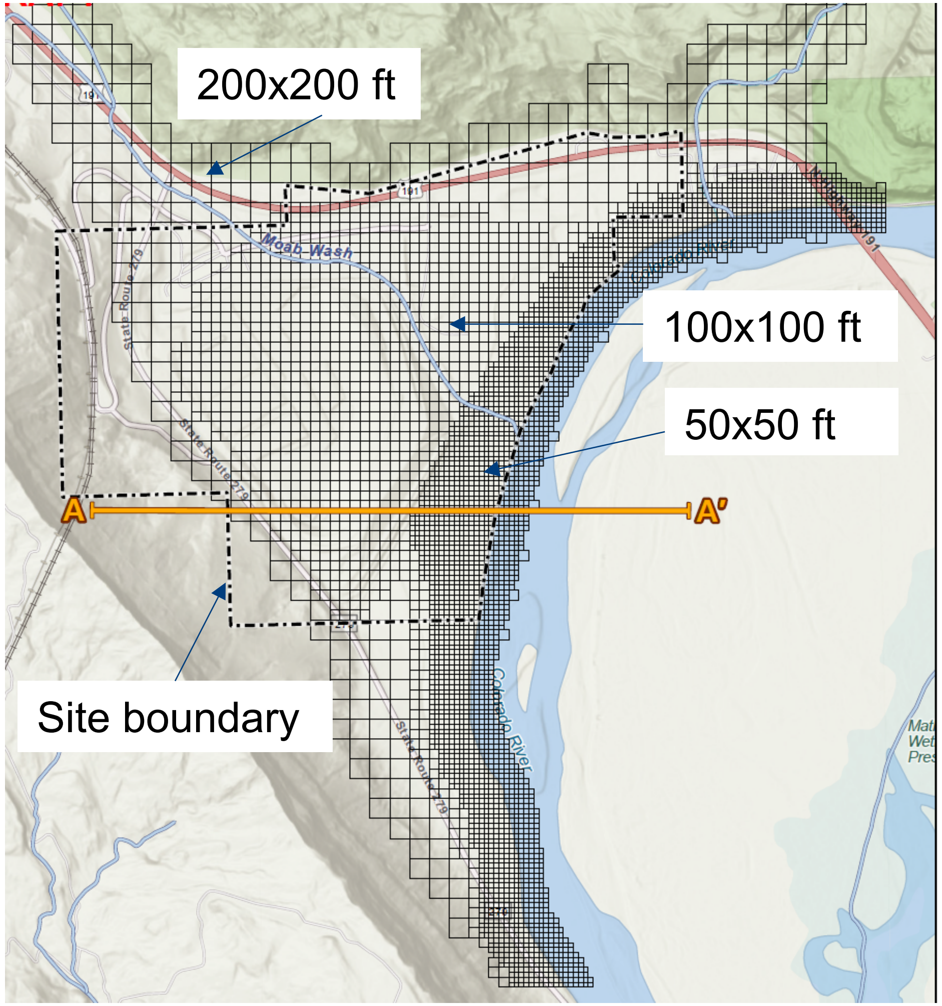
- Column flushing studies
- Sequential solid-phase extractions
- Nitrification batch reactors
- Soil gas survey (SRNL)
- Electrical resistivity tomography (PNNL)
- Boat-towed river survey (PNNL)

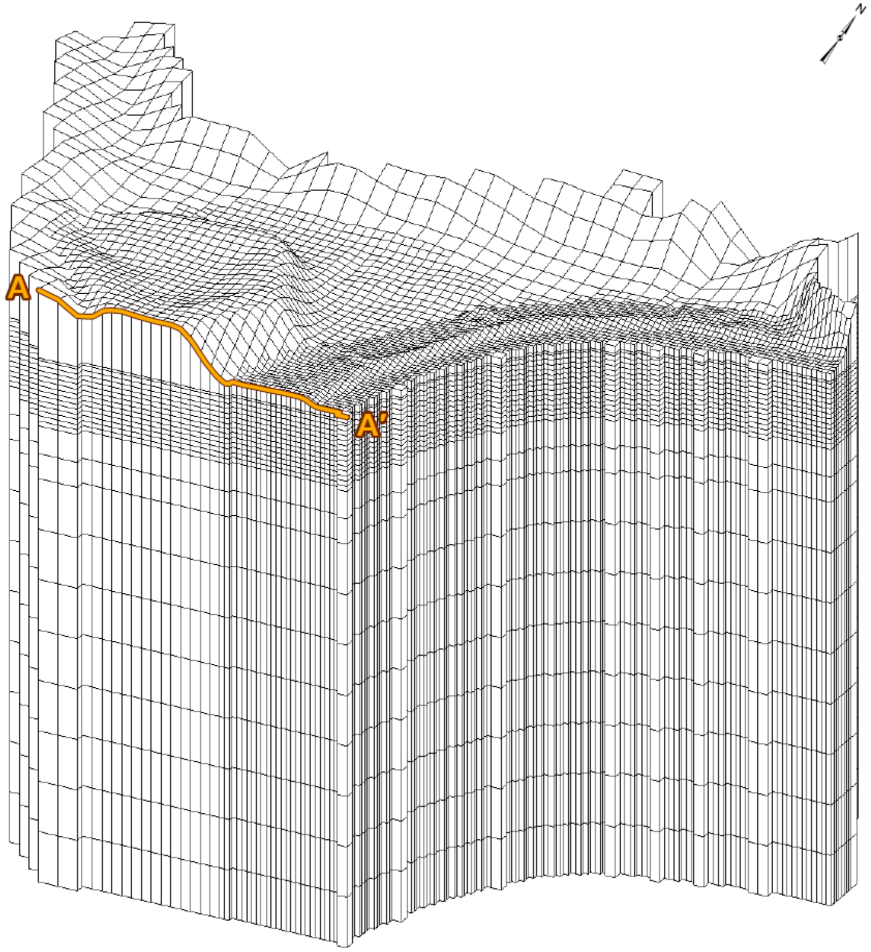
Pacific Northwest NATIONAL LABORATORY

SRNL® SAVANNAH RIVER NATIONAL LABORATORY

Model Domain

- Model domain across the entire site
- 25 layers
- Top of layer 1 = ground surface
- Model grid sizes vary to increase computational efficiency





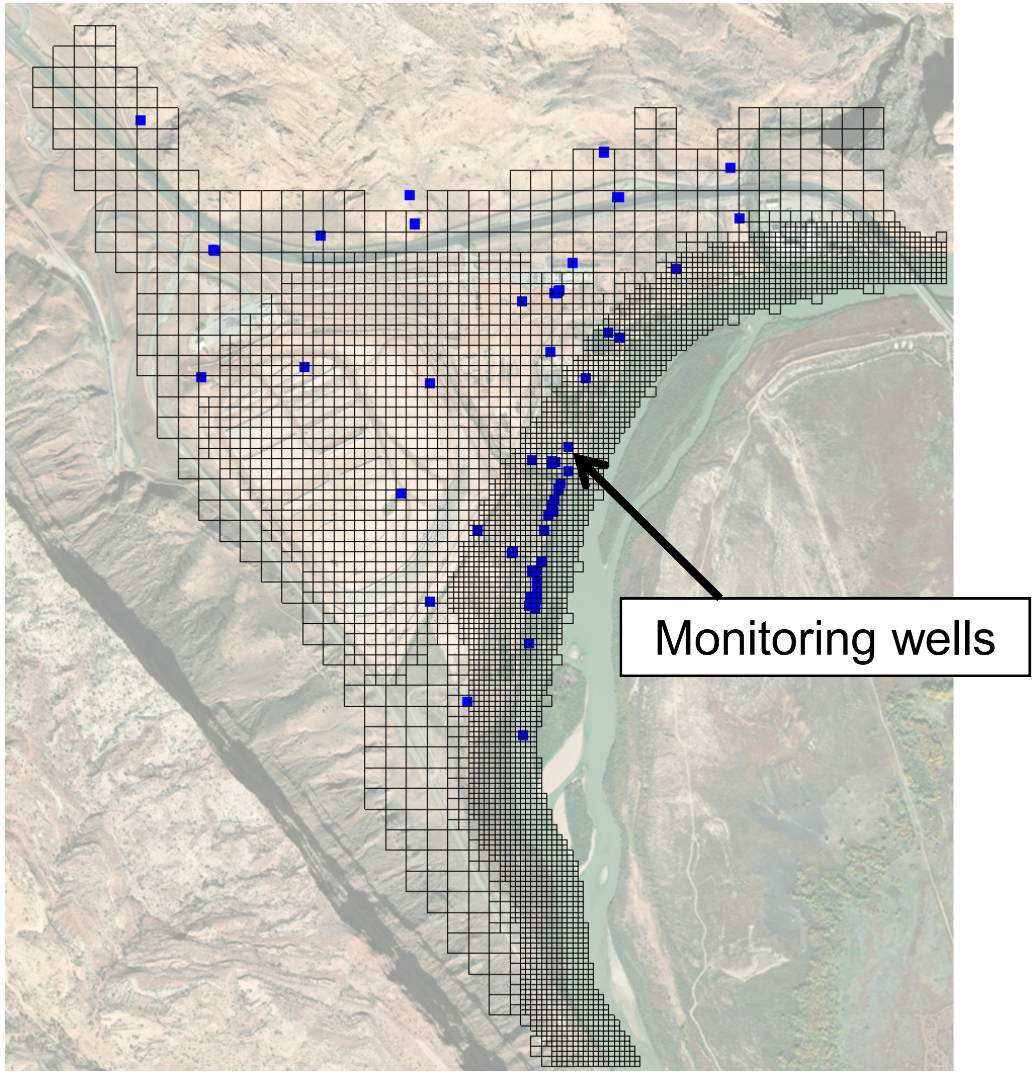
Calibration Dataset

Quantitative Calibration

- Groundwater elevation at 66 monitoring wells from 2010–2024

Qualitative Calibration

- TDS distribution
- Ammonia and uranium concentrations 2010–2024
- Water budget targets
- ERT data from PNNL
- Boat-towed EM data from PNNL

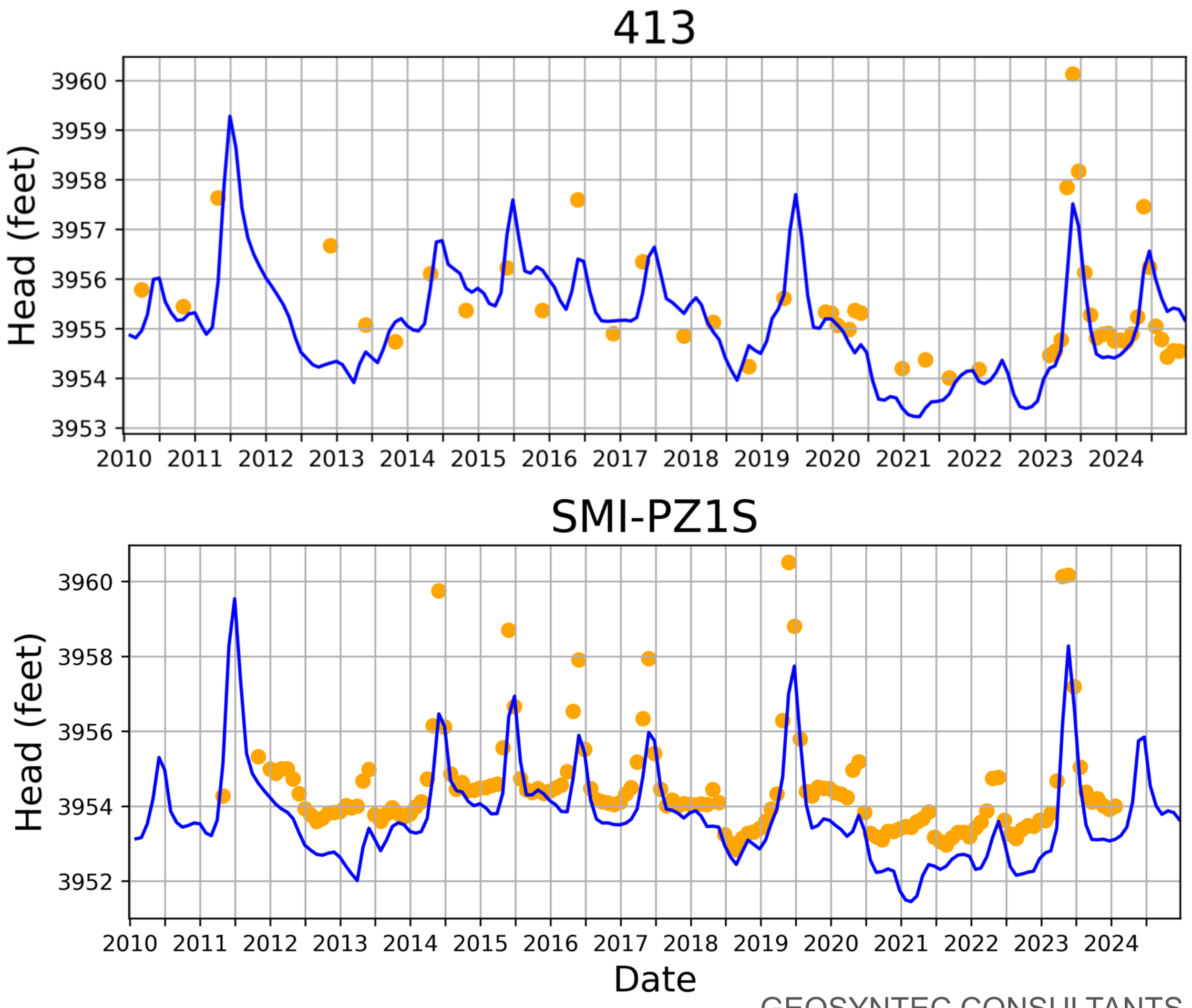


Flow Model Calibration Results

- Successful calibration
- Overall
  - RMSE = 2.3 ft
  - %RMSE = 12.9%

Calibrated flow model captures major hydrograph features

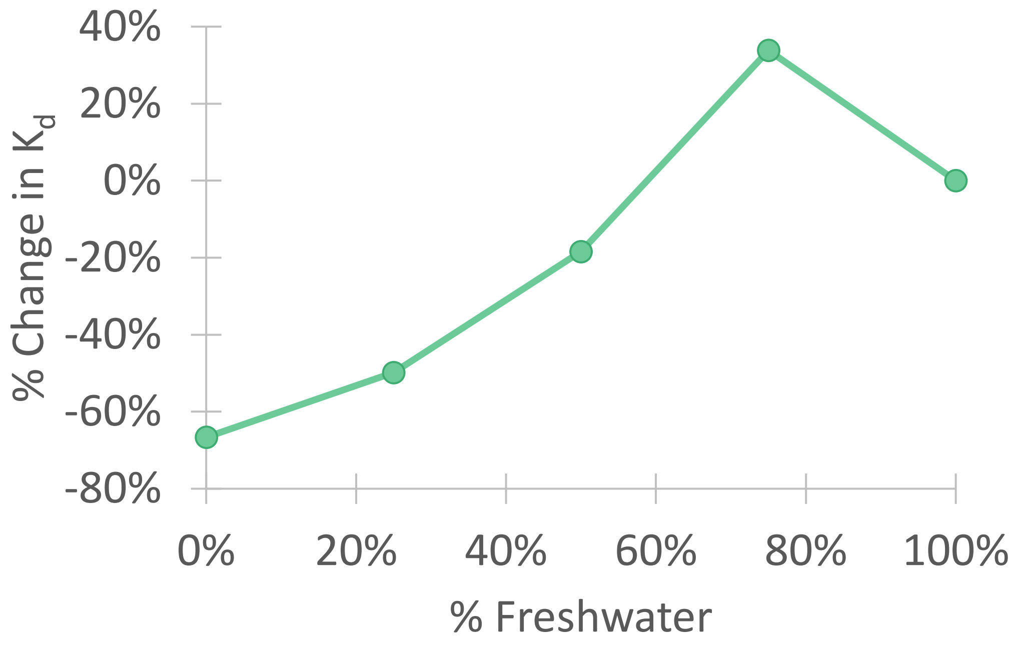
Simulated and Observed Hydrographs



Observed
Simulated

Biogeochemistry – Uranium Adsorption

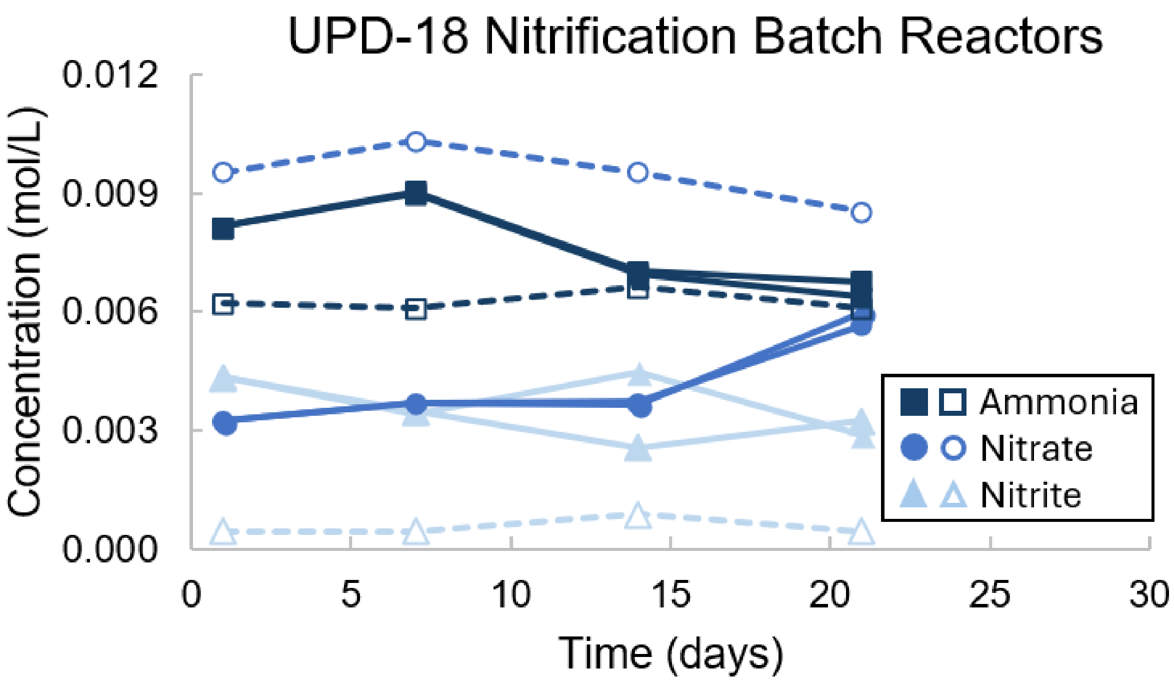
- Effects of groundwater composition evaluated in Geochemists Workbench
- Non-linear change in K_d across freshwater-brine interface
  - K_d expected to fluctuate <±30%
- Constant K_d throughout model domain
  - Uranium: 1 L/kg
  - Ammonia: 0.5 L/kg
  - Values consistent with historical and recent column tests, batch isotherms, and literature



Parameter	Freshwater	Brine	Effect on K_d
pH	7.63	6.49	↓pH ↑K_d
Alkalinity (mg/L as CaCO3)	172	358	↓Alk ↑K_d
TDS (mg/L)	1,000	83,100	↑TDS ↓K_d

Biogeochemistry – Nitrification

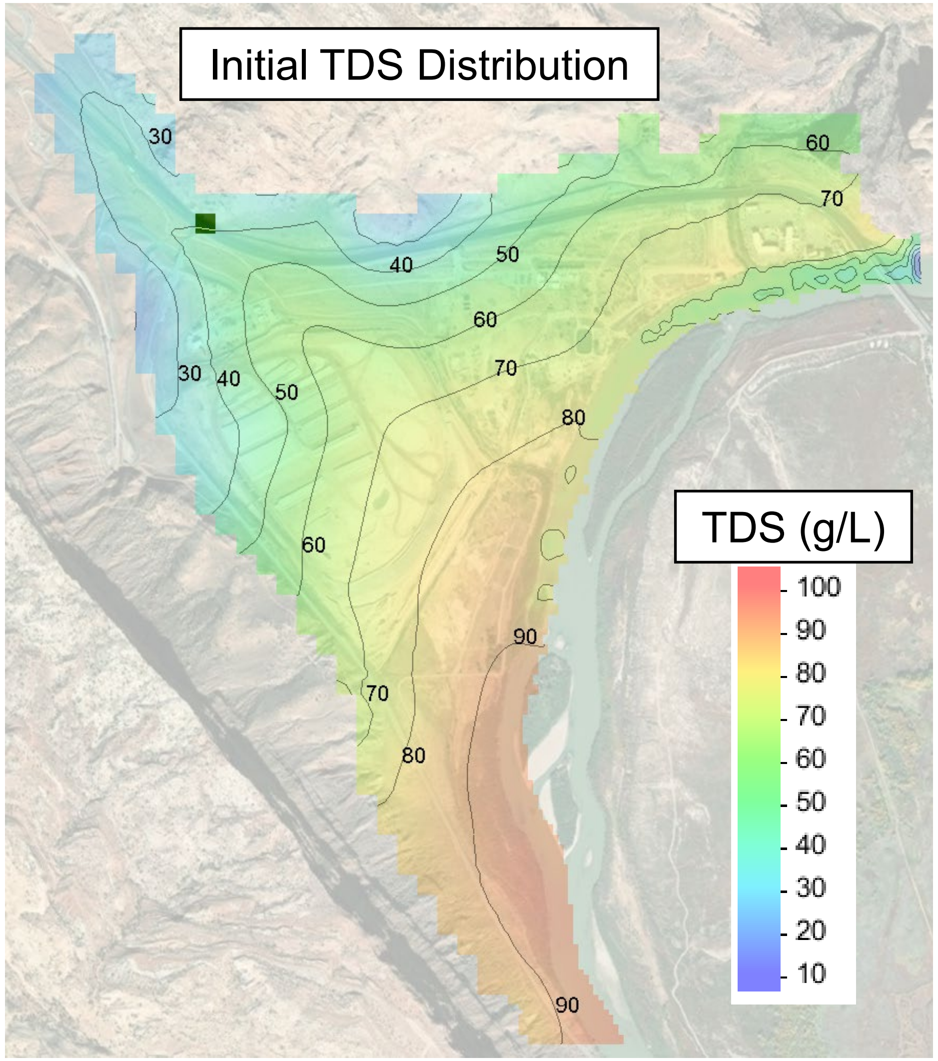
- Batch reactors to assess nitrification
  - Aerated site groundwater for 21 days
- Degree of nitrification may vary across the plume
- First order decay applied across entire site in upper aquifer layers
  - 1.8×10^{-4} day^{-1}



Solid lines = live reactors
Dashed lines = heat-killed control reactors

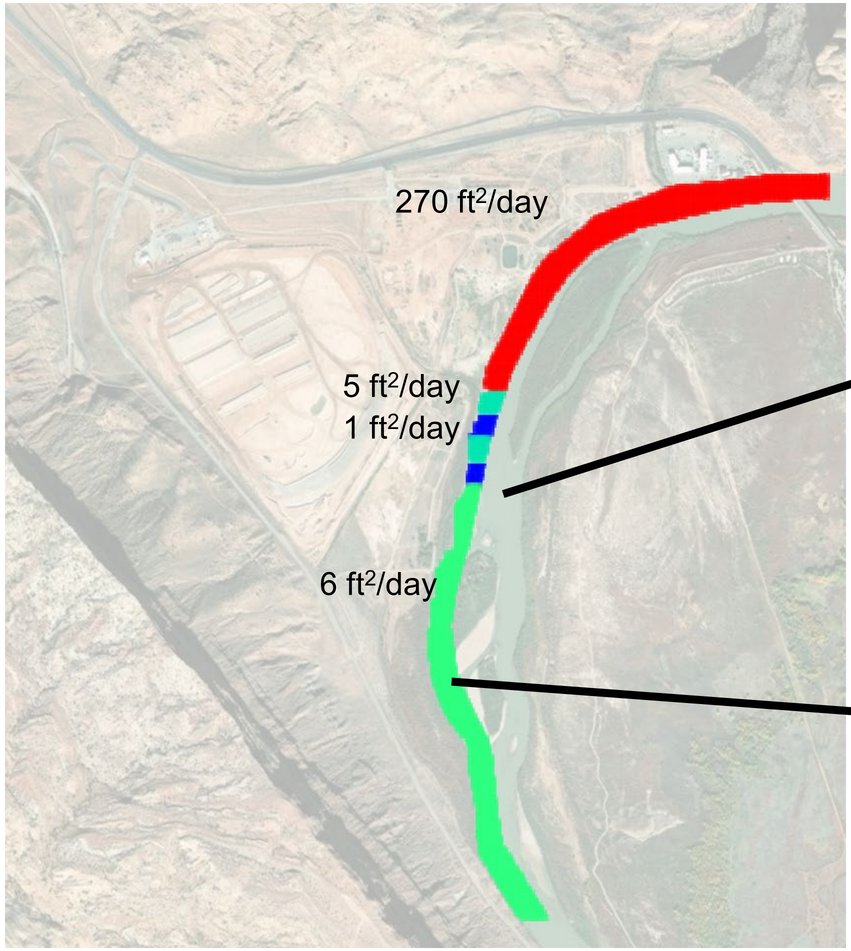
Density-Driven Flow

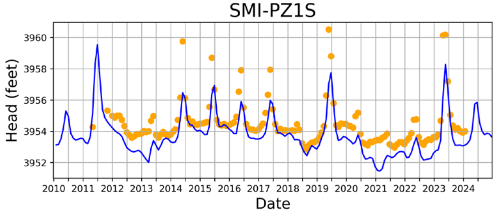
- High TDS, higher relative density, slower flow and transport
  - → Longer predicted natural flushing time
- Simulation of mass flux from deep ammonia plume
  - → Longer predicted natural flushing time
- Constant source at bottom layer of model
- Initial TDS distribution generated from pseudo-steady state model
  - → Physics-driven distribution instead of interpolated data

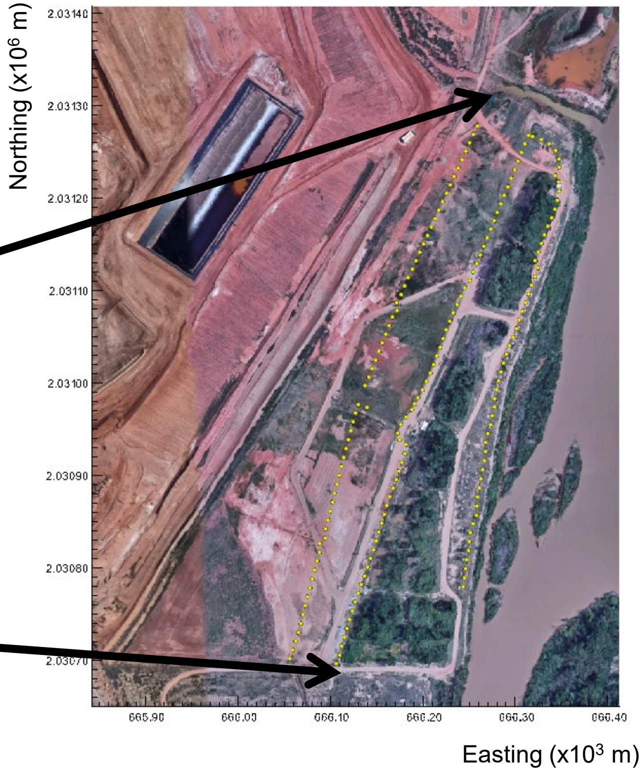


GW-SW Interaction – Riverbed Conductance

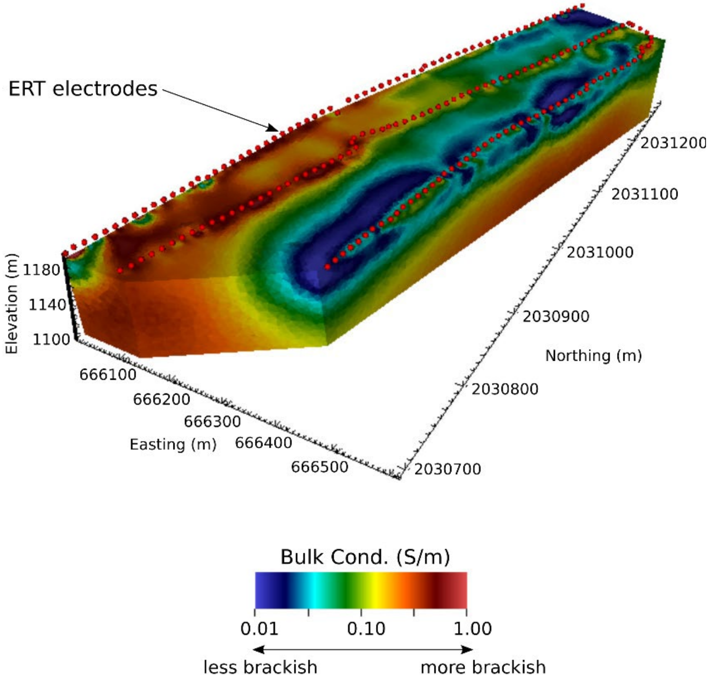
Calibrated river conductance to transient heads







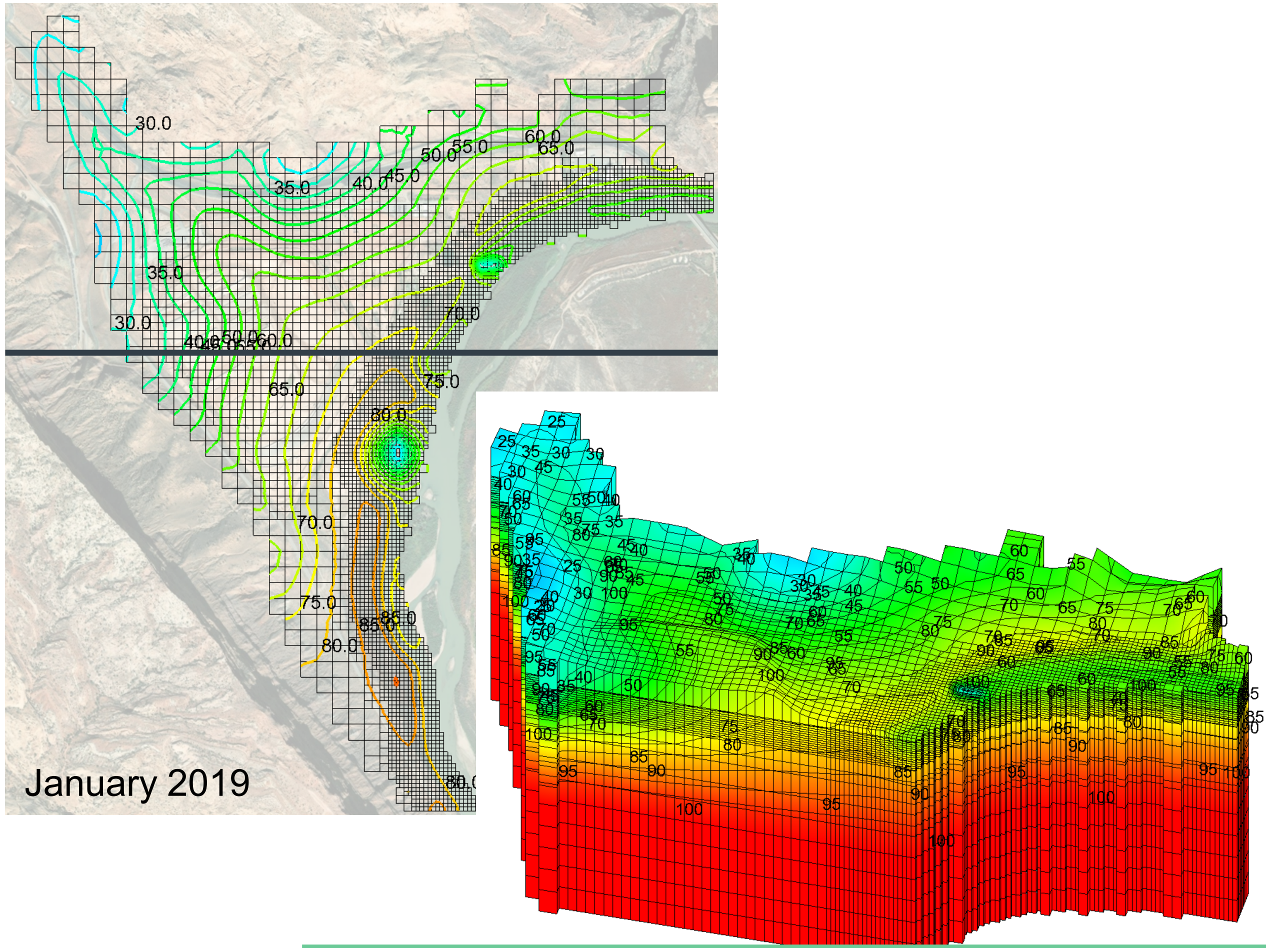
Calibrated river conductance qualitatively agrees with the ERT and boat-towed EM data



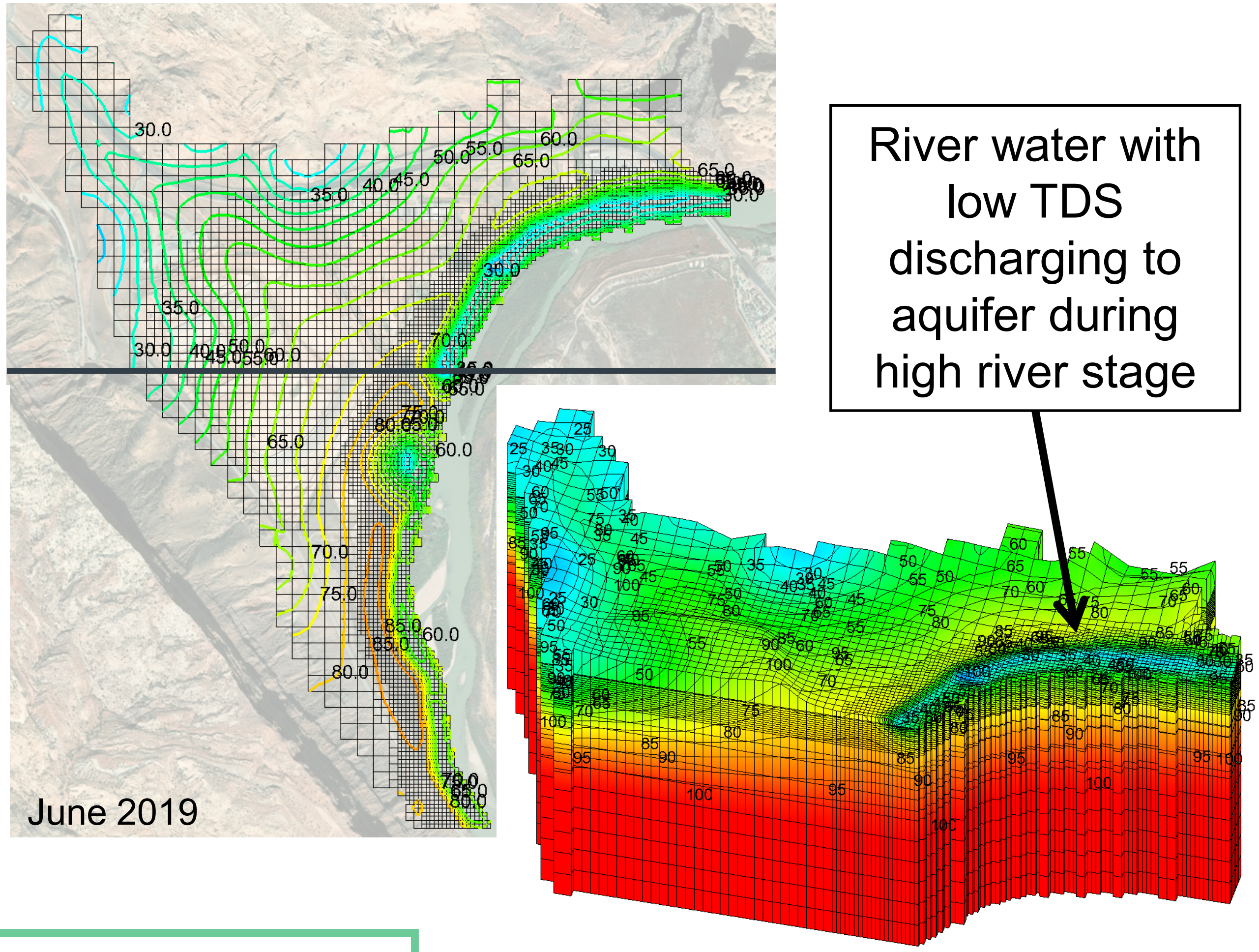
ERT data provided by team led by Tim Johnson (PNNL)
Boat-towed EM data provided by team led by Frederick Day-Lewis (PNNL)

GW-SW Interaction – TDS

Low River Stage



High River Stage



River water with low TDS discharging to aquifer during high river stage

Seasonal transition between gaining and losing conditions increases natural flushing remedial timeframe

Conclusions and Next Steps

- Numerical model decreases uncertainties identified in previous models and addresses complex hydrology and biogeochemistry
- Groundwater-surface water interactions have a larger impact on the remedial timeframe than previously expected
  - Seasonal river transitions from gaining to losing and inclusion of mass flux from ammonia in deep brine
- Next steps:
  - Predictive scenarios to evaluate remedial timeframes of active remedies
  - Sensitivity testing of key model parameters

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