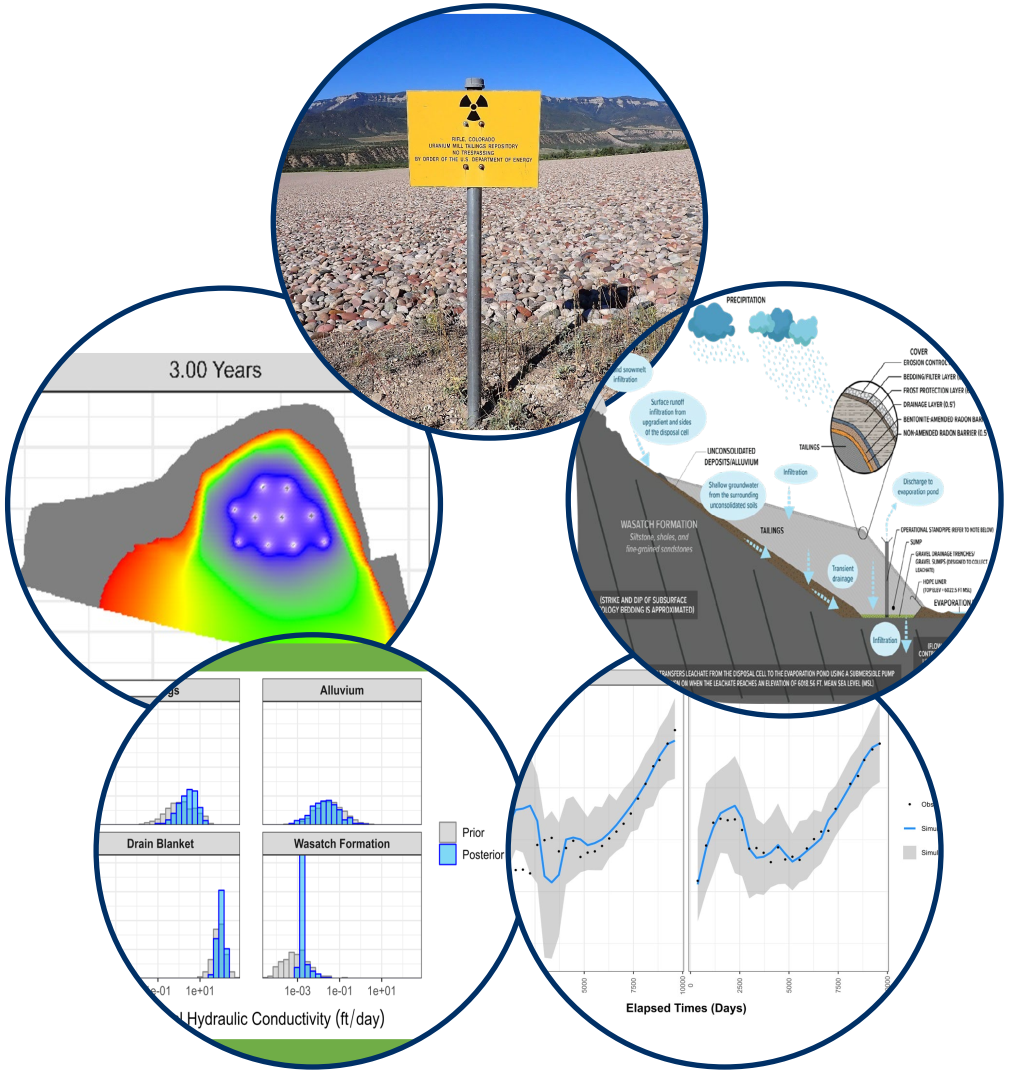
A Groundwater Modeling Case Study to Evaluate Dewatering at a Uranium Mill Tailings Disposal Site



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Rifle, Colorado, Disposal Site Dewatering

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Rifle, Colorado, Disposal Site Dewatering

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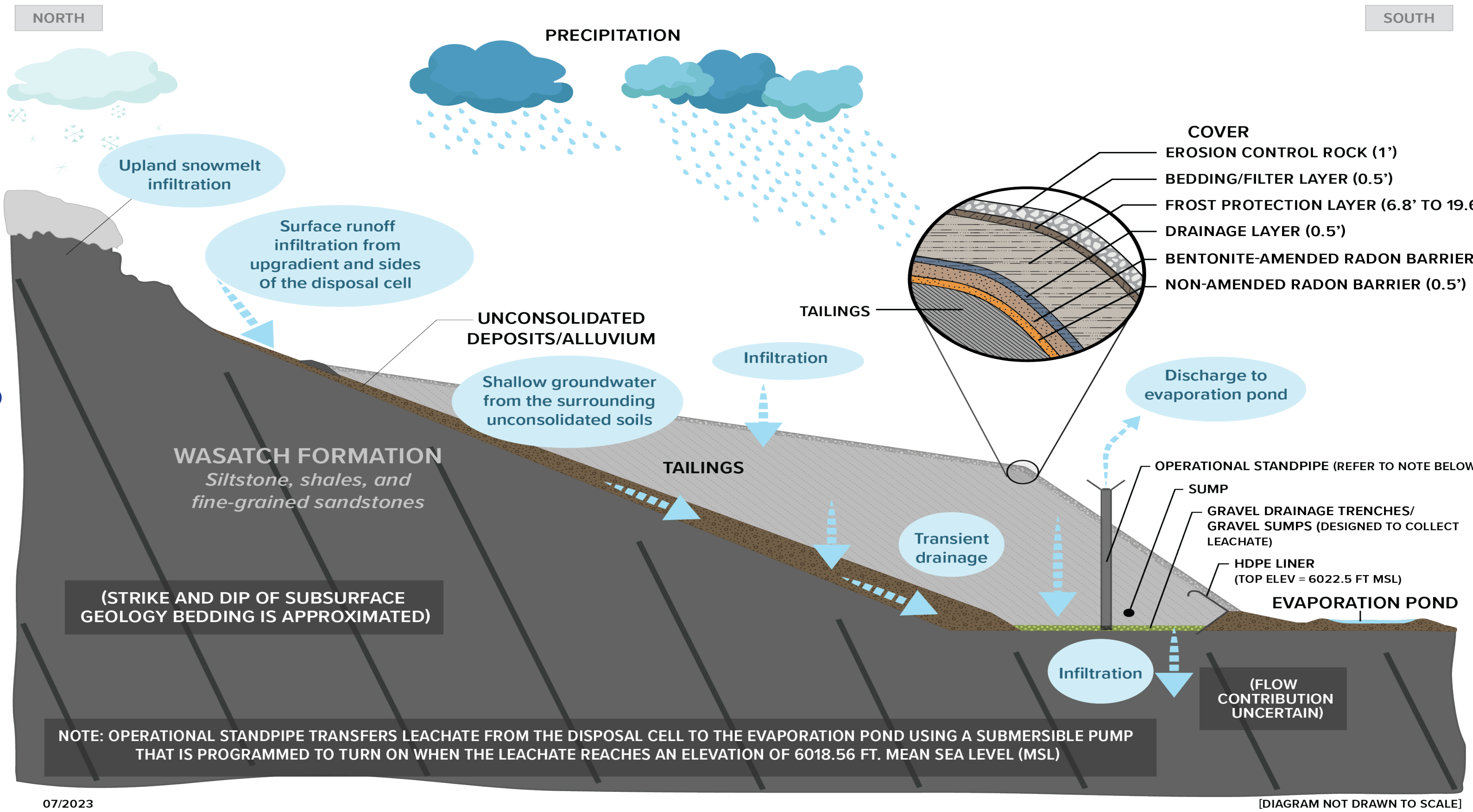
Rifle, Colorado, Disposal Site Dewatering *(continued)*



Rifle, Colorado, Disposal Site Dewatering

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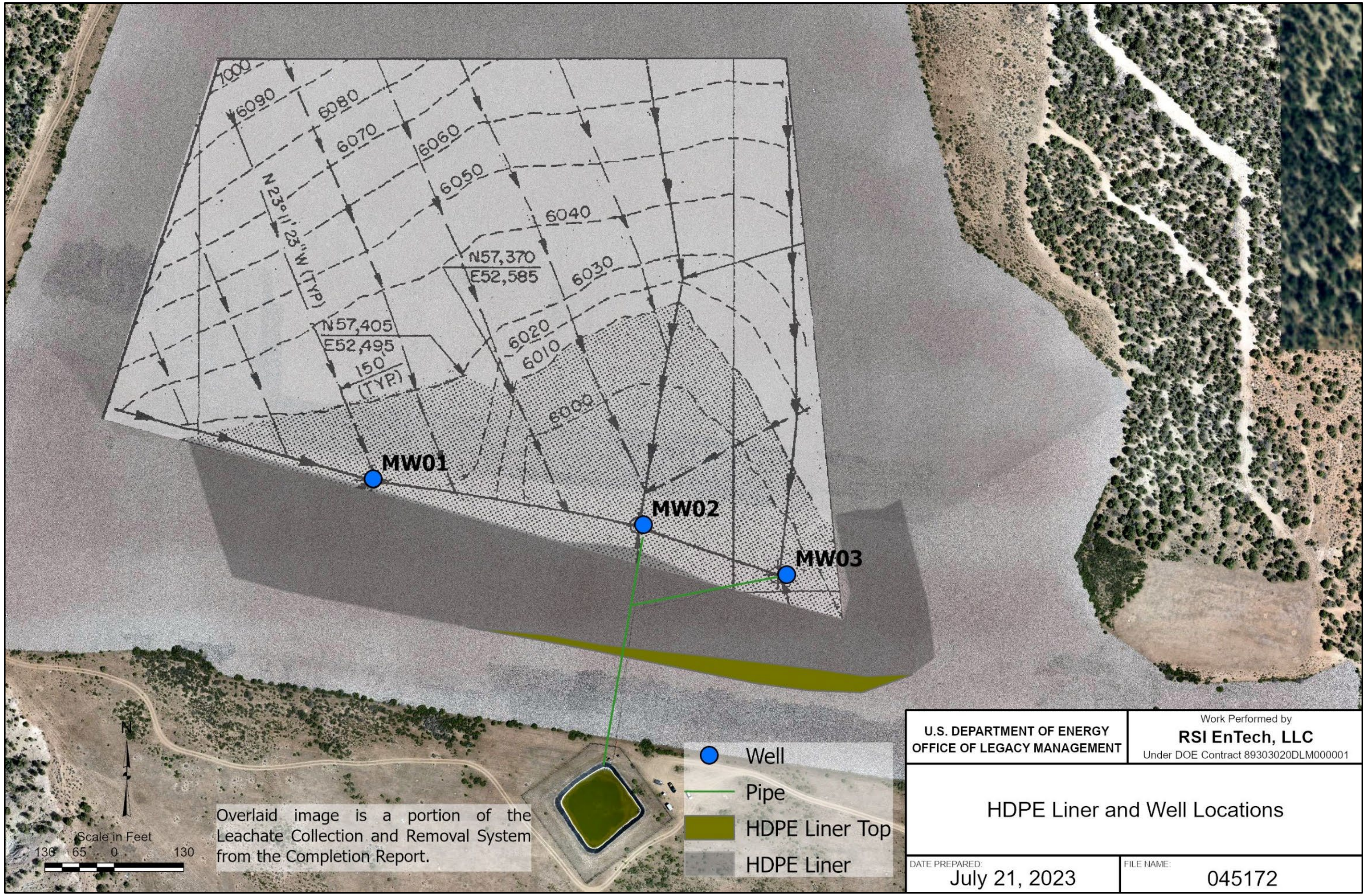
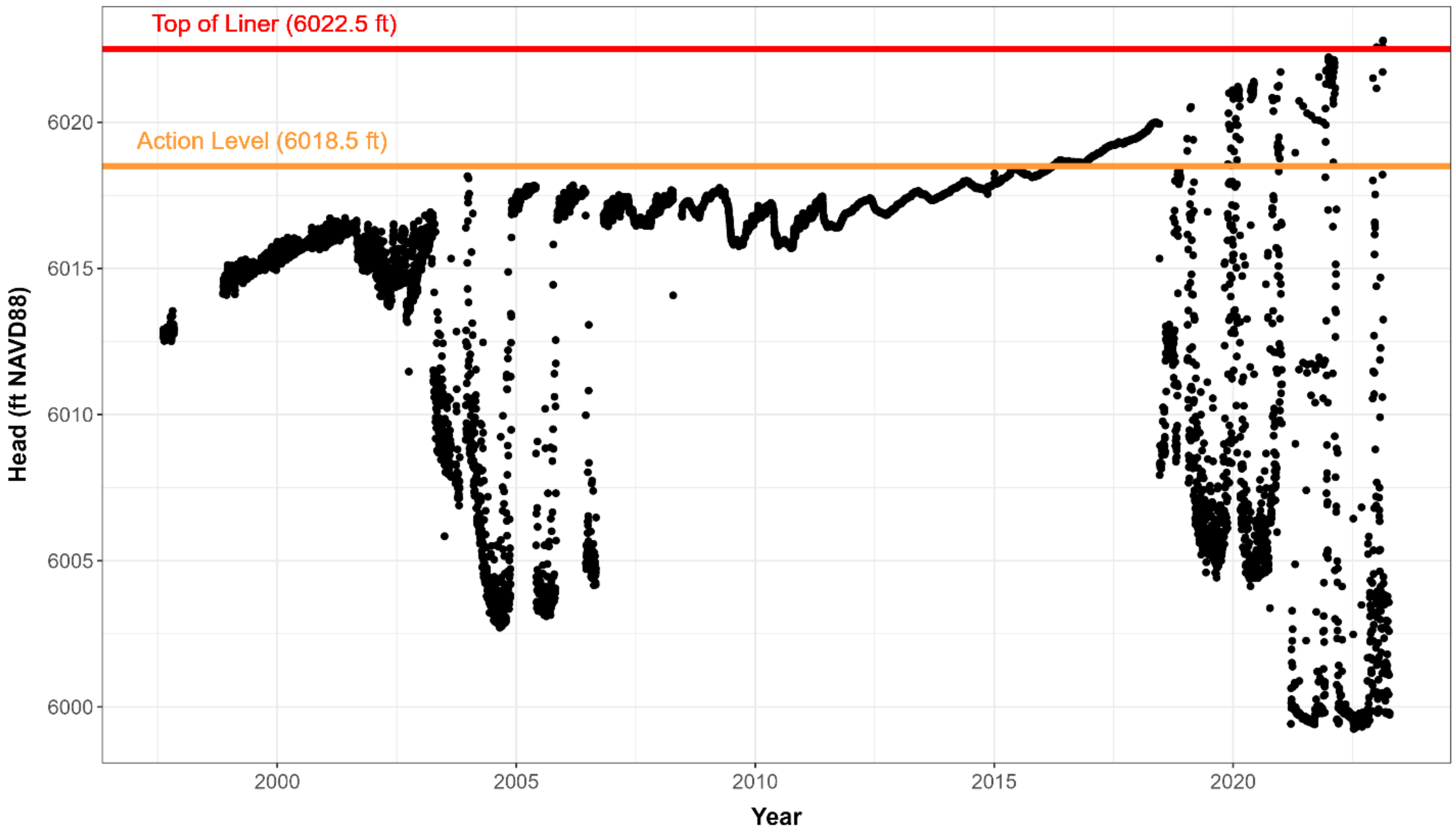




Need for Dewatering

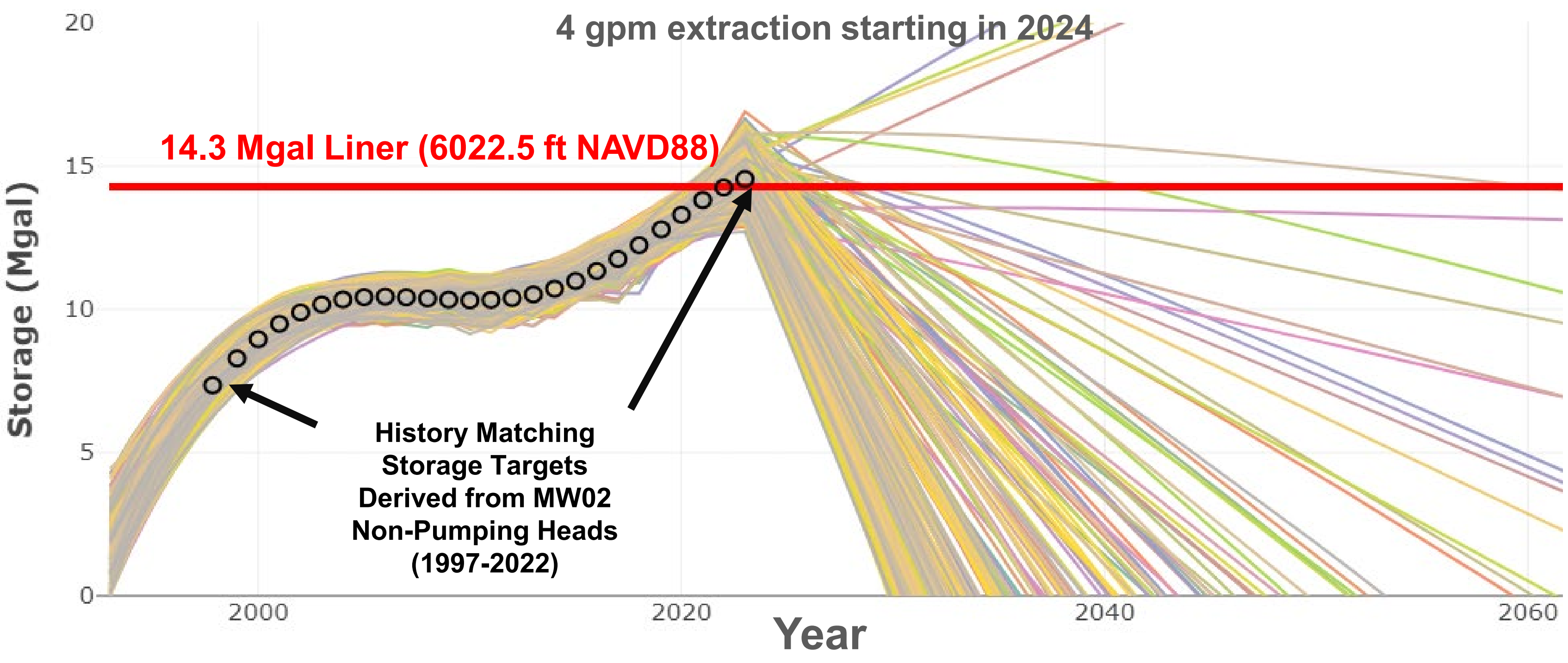
- Leachate pore fluids have accumulated at the toe of the cell and have reached the top elevation of the HDPE liner system.
- MW03 could operate at 3.0 gpm in 2009, but now MW02 and MW03 can only sustain a combined 0.5 gpm. Redevelopment is not likely to be sufficient.

Ensemble Approach

- Data available for model configuration and calibration are limited.
- An ensemble of calibrated models can be created to provide a range of outcomes and their probability for a given dewatering design with an inherent analysis of calibration parameter uncertainty.

Stochastic Water Balance Model

$$Storage\ (t) = V(Cover\ Recharge) + V(Initial\ Tailings\ Fluids) - V(Pumping) - V(Transient\ Drainage)$$

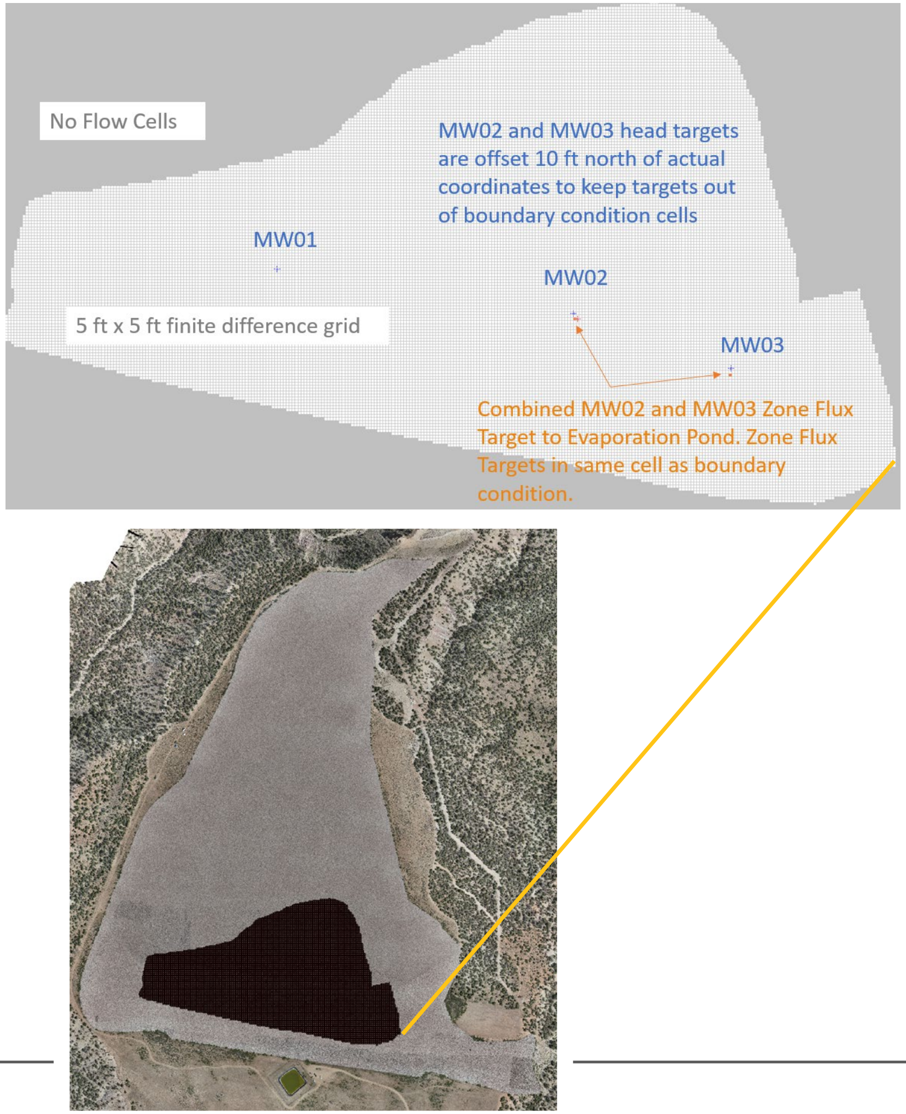


1 Million Realizations
Randomly sampled a value for each parameter 1 million times and then calculated storage yearly.

Filtered Realizations with History Matching
Following rejection sampling, 235 parameter combinations were able to reproduce target storage values. Provides estimates for recharge through the cover, initial tailings fluid migration, and discharge into bedrock.

Forecasting
Forecasted changes in storage with additional pumping scenarios for the 235 parameter combinations. Provides estimated additional dewatering rate.

Modeling Objective and Approach



Objective

Calibrate an ensemble of groundwater flow models through history matching and simulate additional extraction to evaluate:

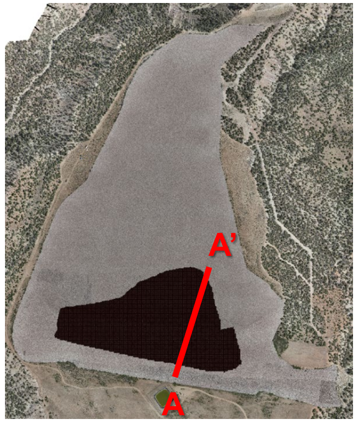
- The feasibility and probability of meeting dewatering needs given the low permeability of tailings, limited spatial/temporal data distribution, and associated uncertainty.
- Potential for success with partially and fully penetrating extraction well scenarios.

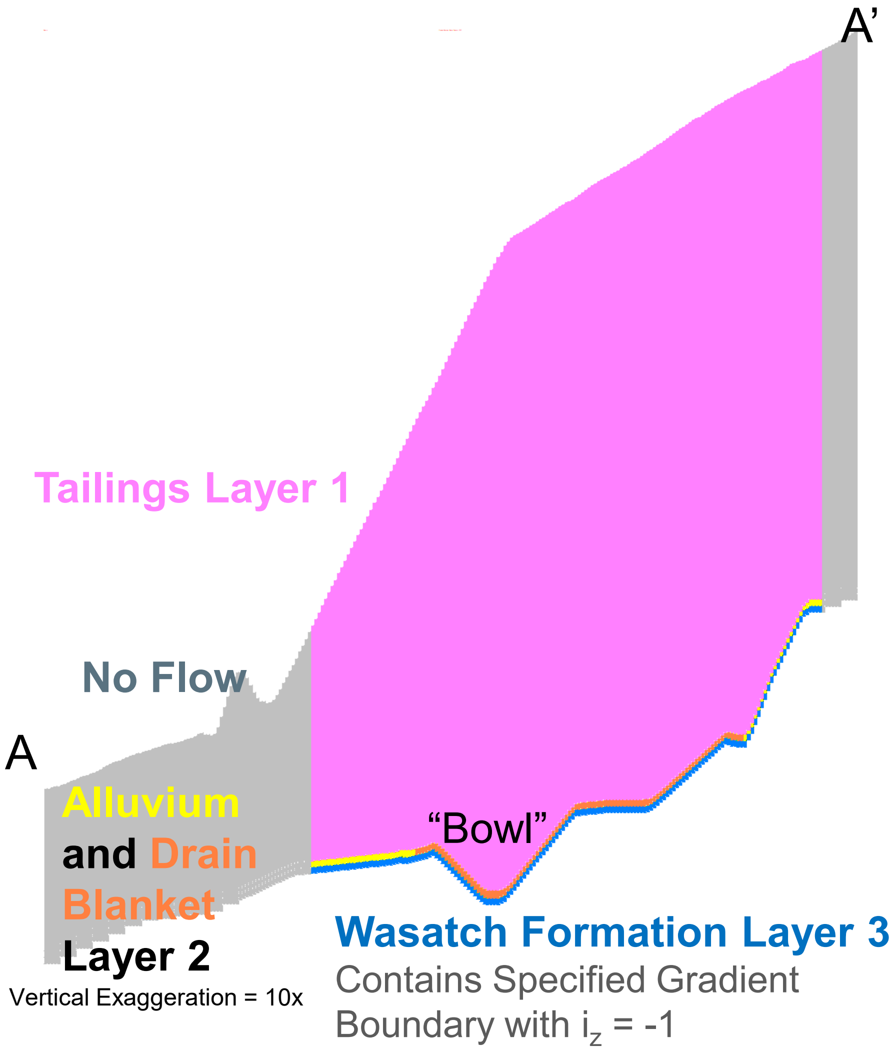
Approach

MODFLOW-USG and PESTPP-IES

- 5x5-foot grid over three layers with 96,000 cells and 53 transient stress periods (1996-2024); active domain focuses on bowl area adjacent to the HDPE liner.
- Establish prior distribution for each calibration parameter with a covariance matrix (range, mean, sill variance contribution, and standard deviation).
- Incorporate calibration targets (groundwater elevations, head censor targets (MW01), total flux to the evaporation pond, and discharge into the Wasatch Formation); incorporate observation noise into the ensemble (σ^{-1}).
- Initial ensemble of 600 members; final ensemble of 223 members following calibration.
- Configure for predictive simulations.
- Pre- and postprocessing using Groundwater Vistas along with pyEMU and FloPy utilities.

Boundary Conditions and Calibration Parameters





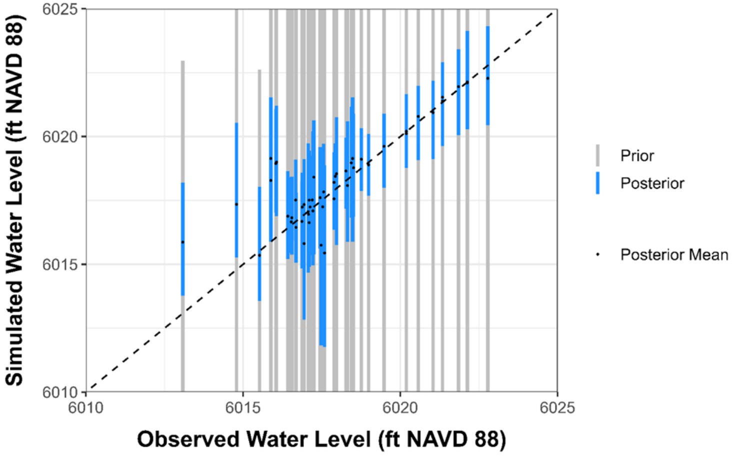
Boundary Conditions

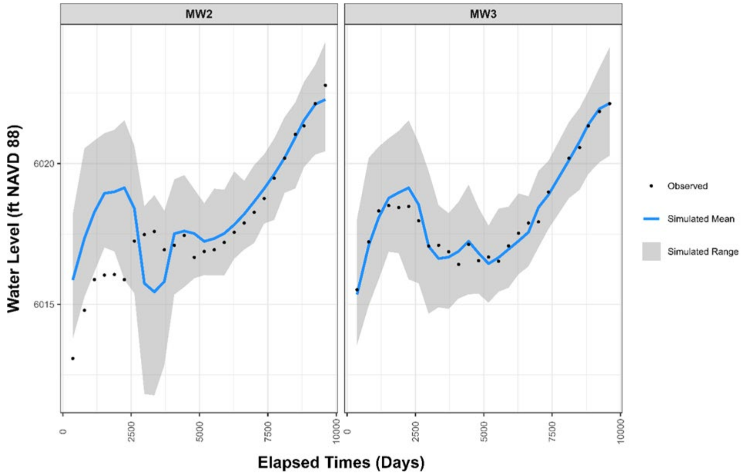
- **Specified Gradient Boundary** — discharge into bedrock.
- **Recharge Package** — combined estimated rate of infiltration through the cover and draining of initial tailings fluids.
- **Drain Package** for MW02 and MW03 — head is known, but individual flows are not.
- **No Flow** — representing HDPE liner to the south.

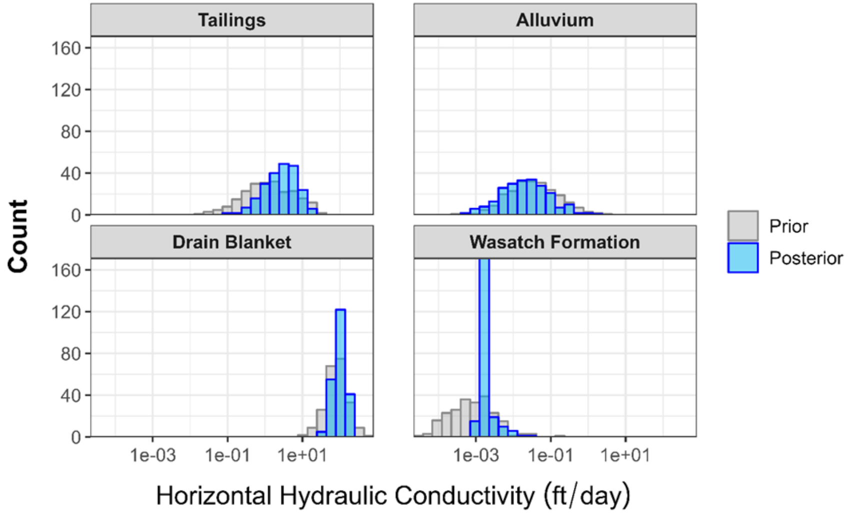
Calibration Parameters

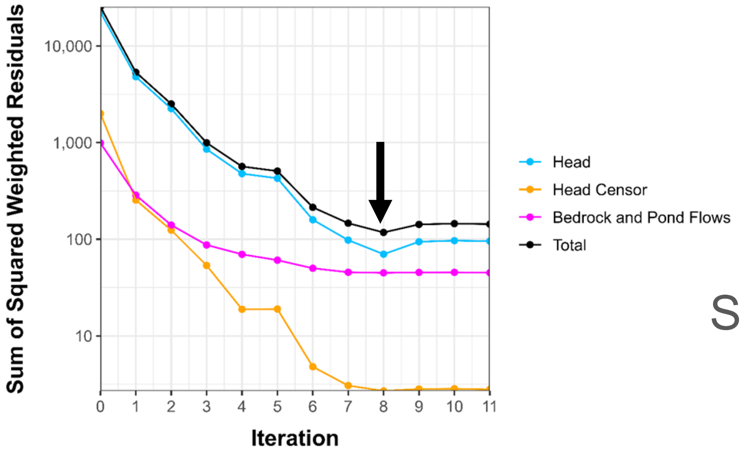
- Hydraulic conductivity and anisotropy.
- Recharge multipliers.
- Specific storage.
- Specific yield.
- Temporal drain conductance.

Calibration Results Examples



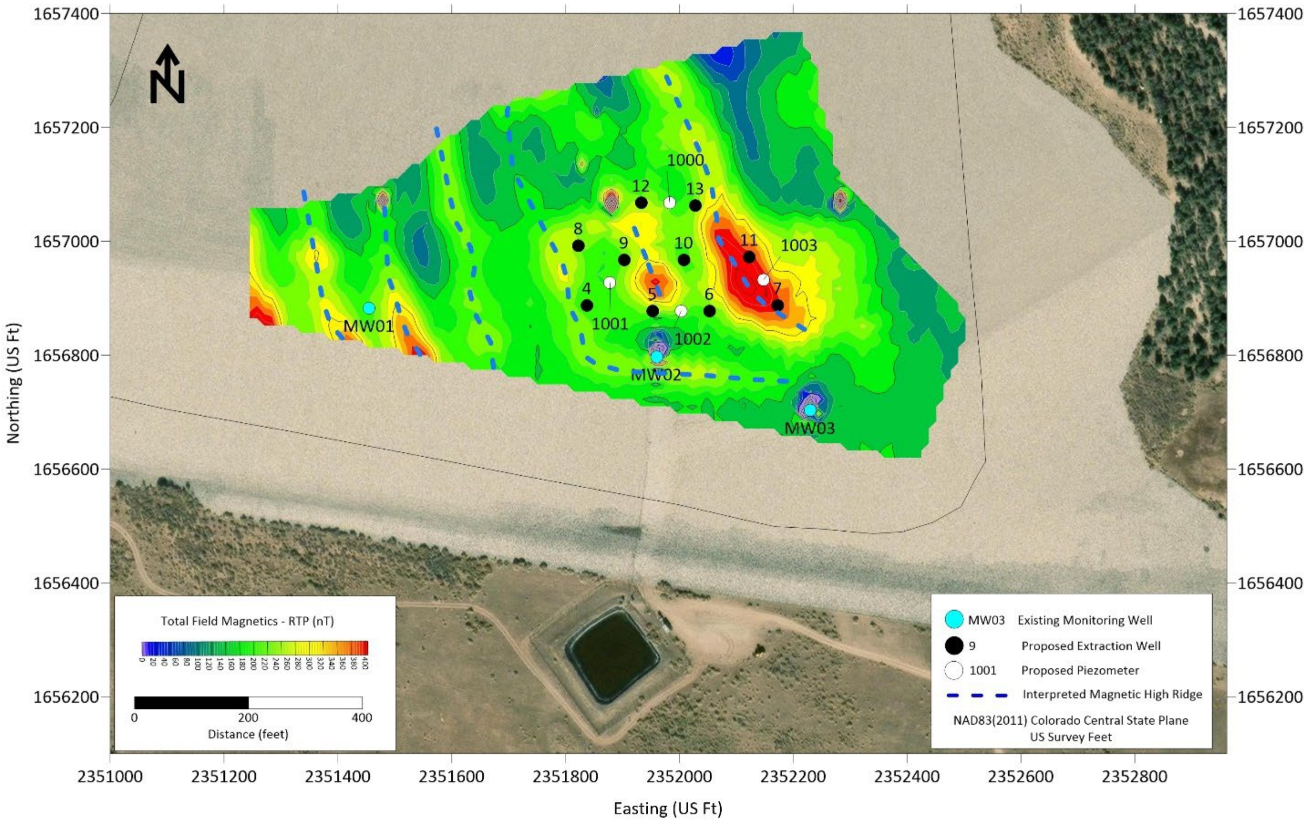






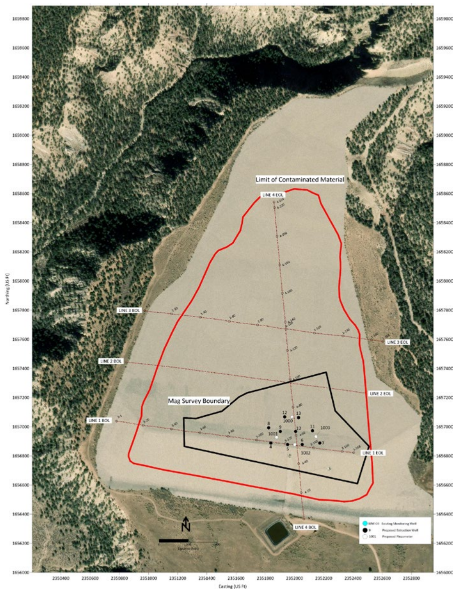
Similar plots further exemplify calibration performance with other target types as well as prior and posterior parameter distributions for the ensemble.

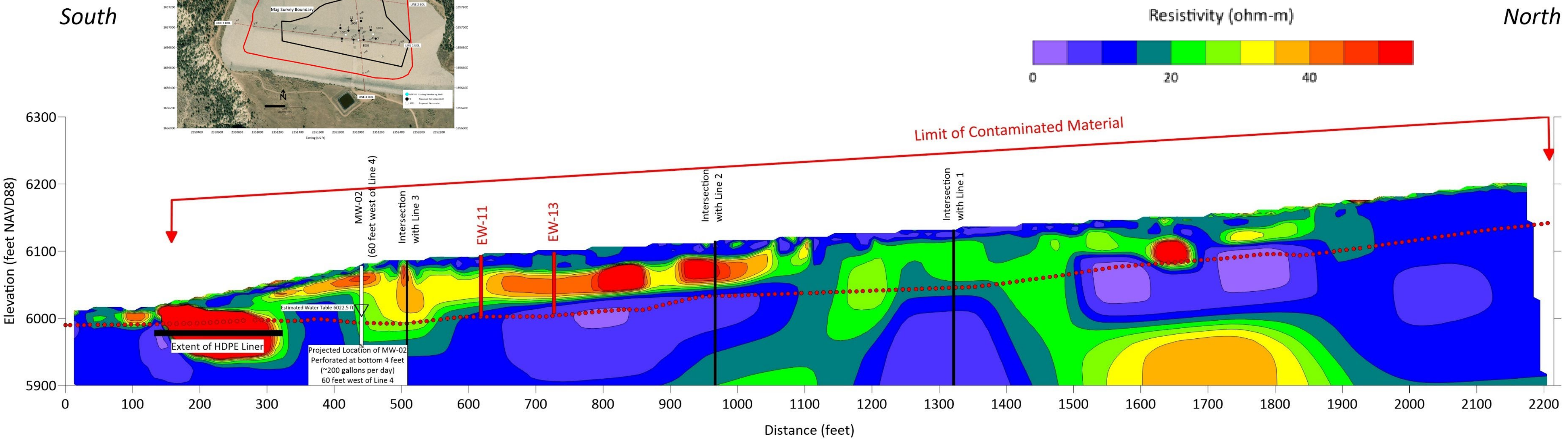
Preparing for Predictive Simulations



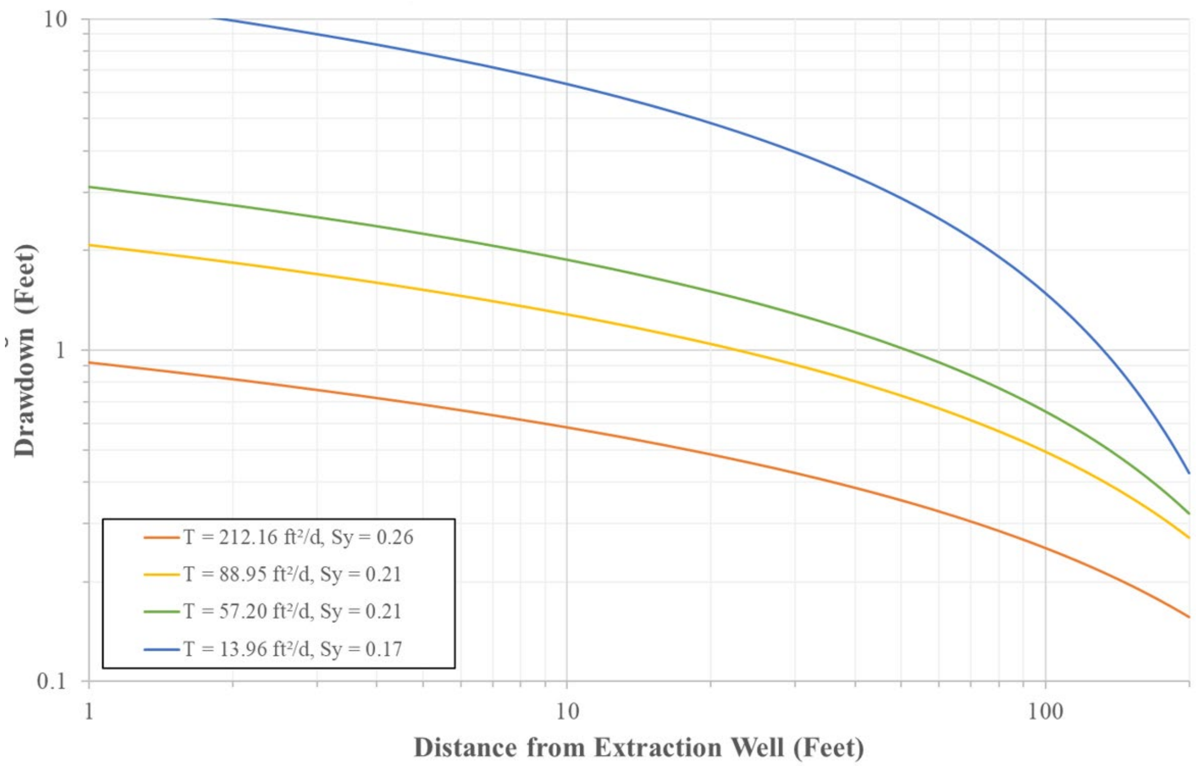
Milling debris (wood, concrete, masonry, steel) was placed in piles 2-3 feet high in the lower portions of the tailings embankment with approximately 100-foot spacings.

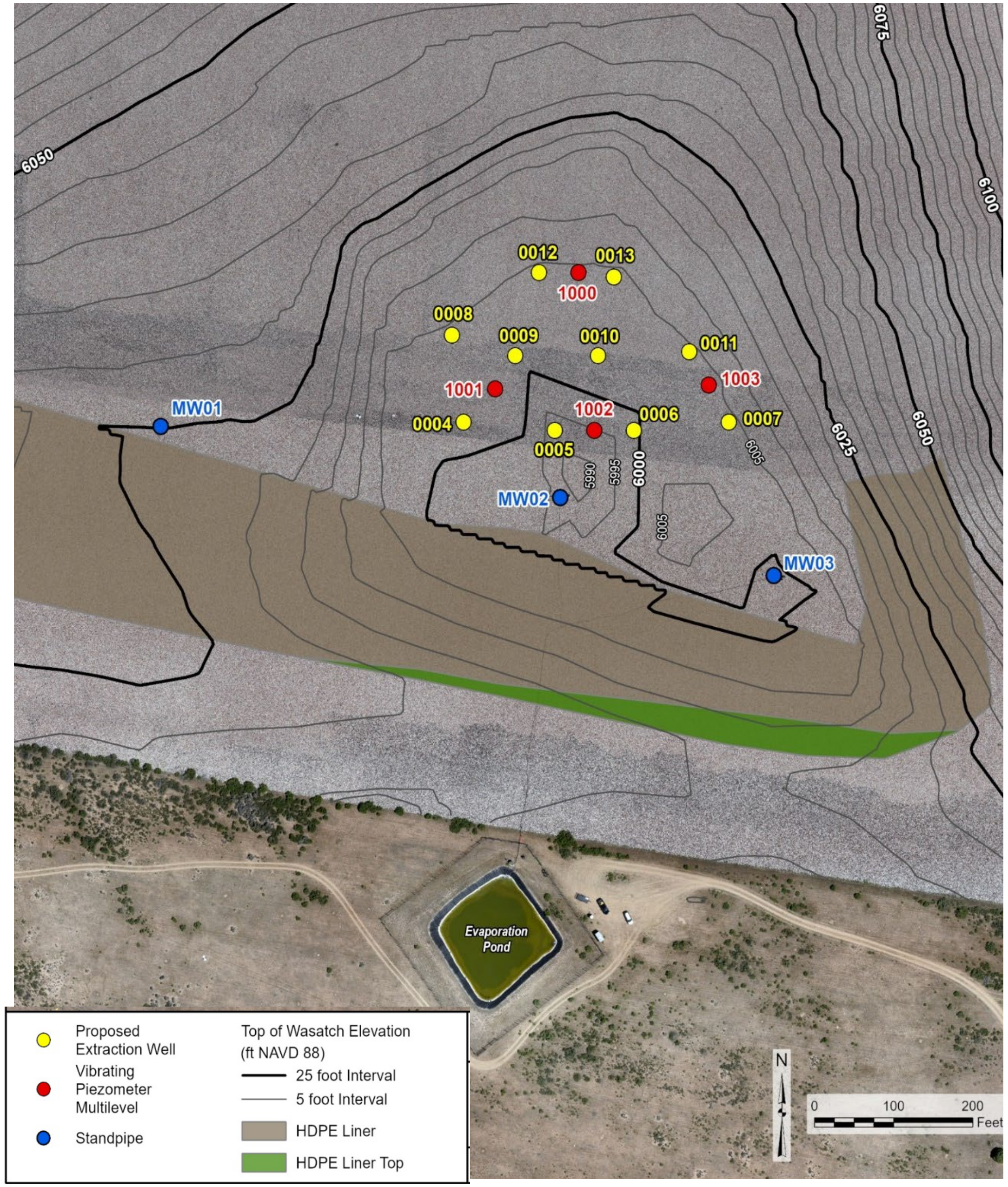
Preparing for Predictive Simulations *(continued)*

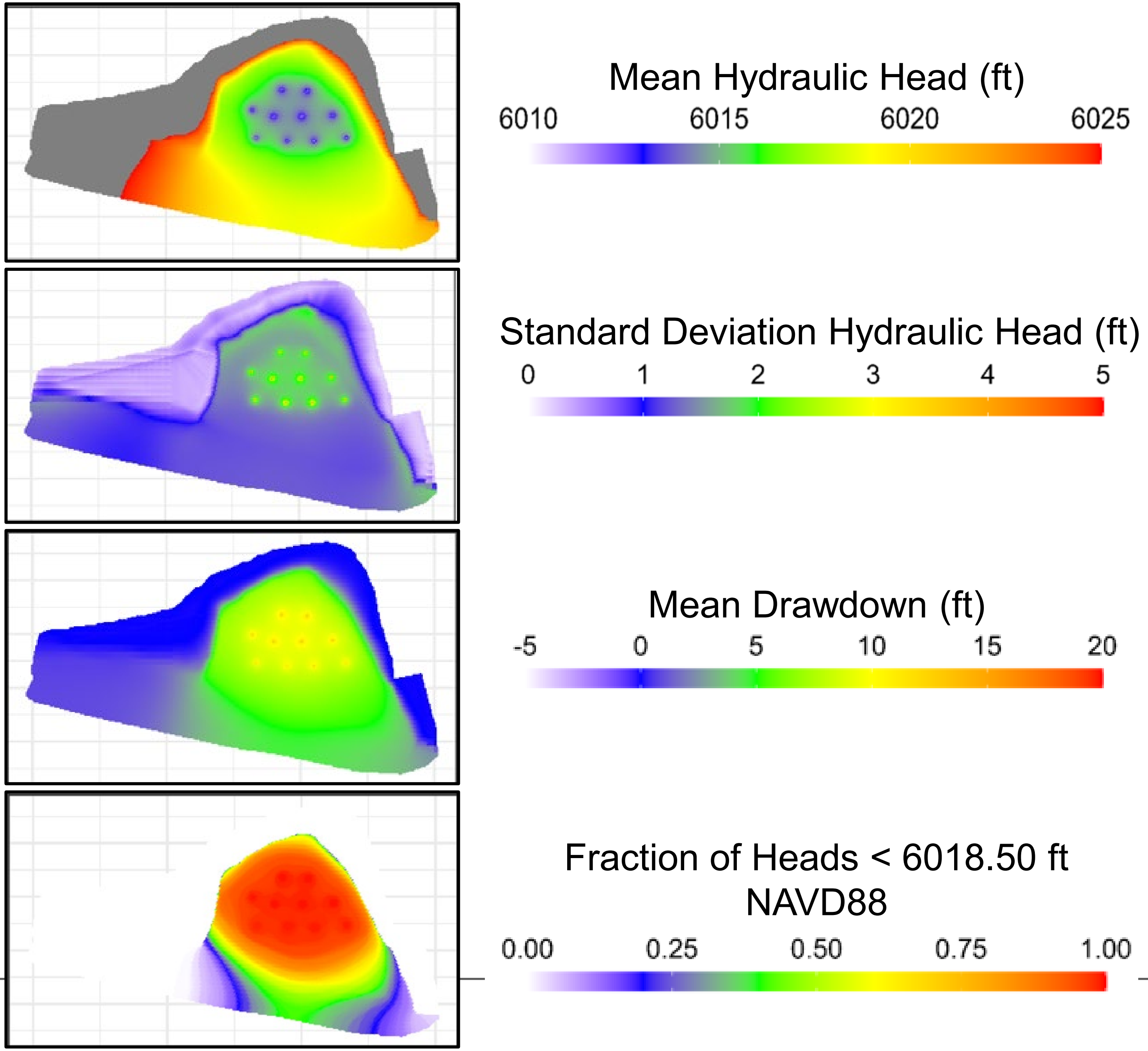




Predictive Simulations



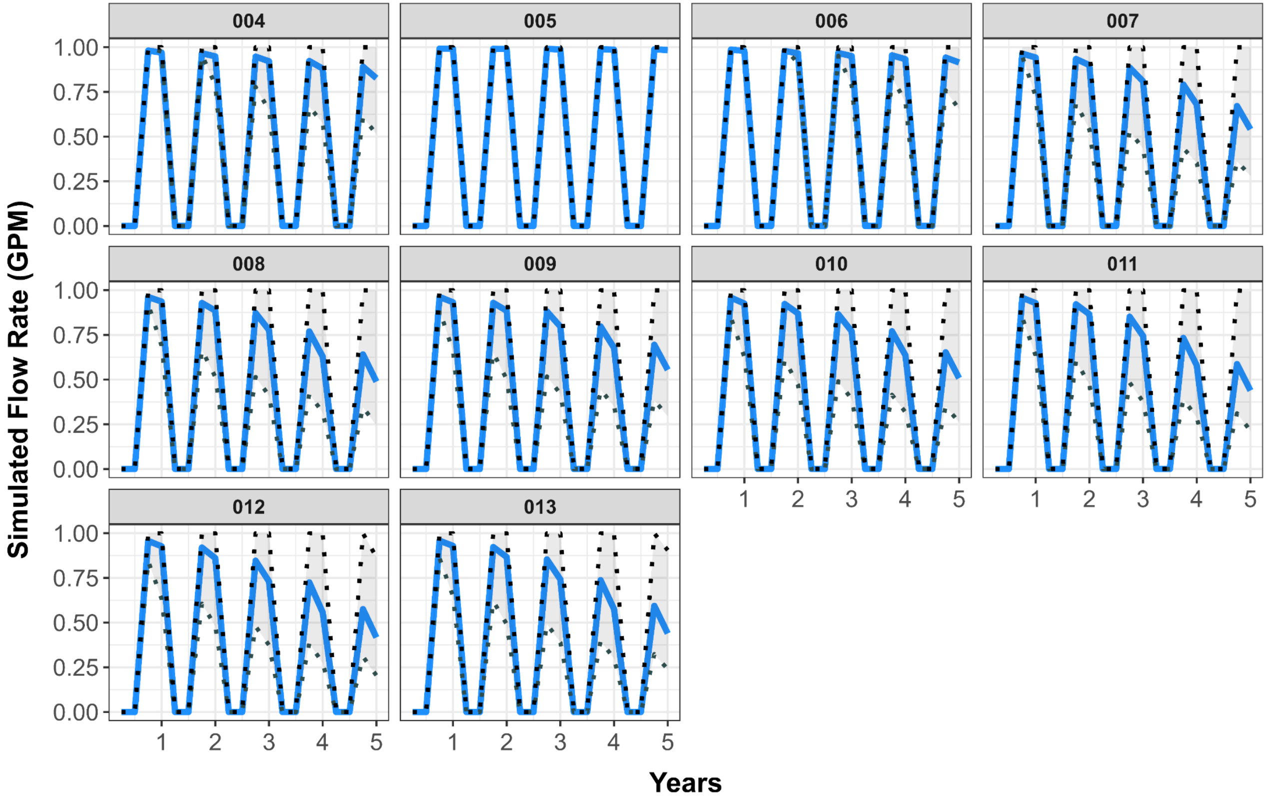




223 Member Ensemble Spatial Results

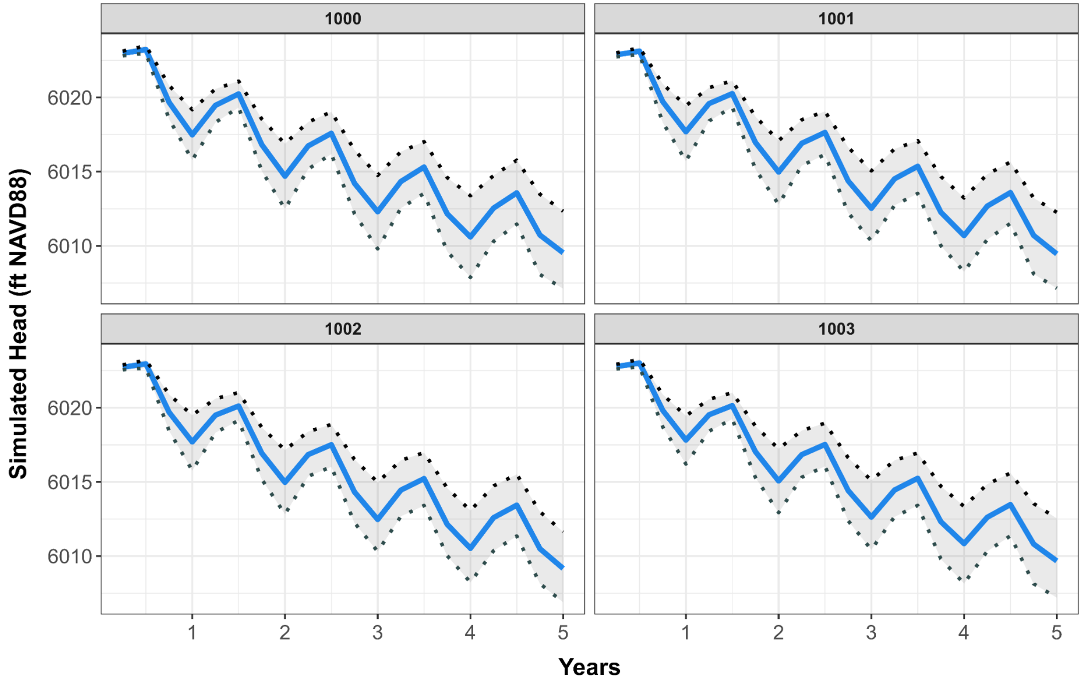
After 2 Years of Dewatering

223 Member Ensemble Temporal Results



10th-90th Percentile Range
Ensemble Mean

Forecast Piezometer Heads



223 Member Ensemble Temporal Results

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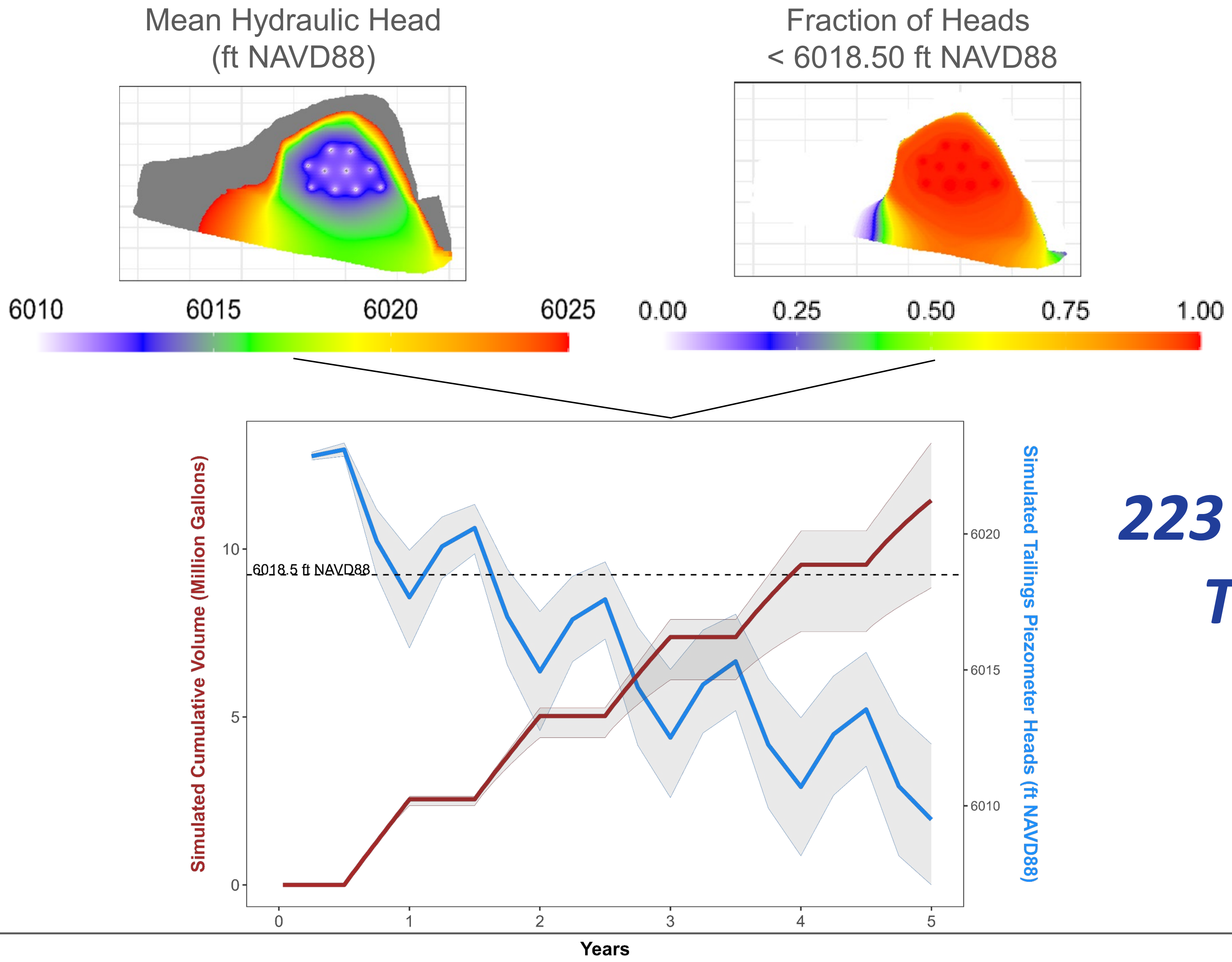

Drilling, Installation, and Construction

Drilling, Installation, and Construction

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Conclusions

- Predictive modeling using an ensemble approach has significant advantages for evaluating design alternatives over a single, deterministic model, especially where data available for calibration is spatially limited.
- Model calibration and uncertainty analysis completed simultaneously. Variability in model forecasts provides a measure of reliability.
- Since every member of the posterior ensemble provides an acceptable fit of the calibration data, the ensemble can be used to provide a range of predictions for a given design, providing decision makers, SMEs, and regulators with a more robust means for design selection and recommendation.
- Example shown where a calibrated ensemble probabilistically forecast the performance of a dewatering system design within a uranium mill tailings disposal cell.