End-State Driven Performance-Based Management of Pump-and-Treat (P&T) Remedies

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Outline

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  - Computational approaches
  - Pre-screening tool framework
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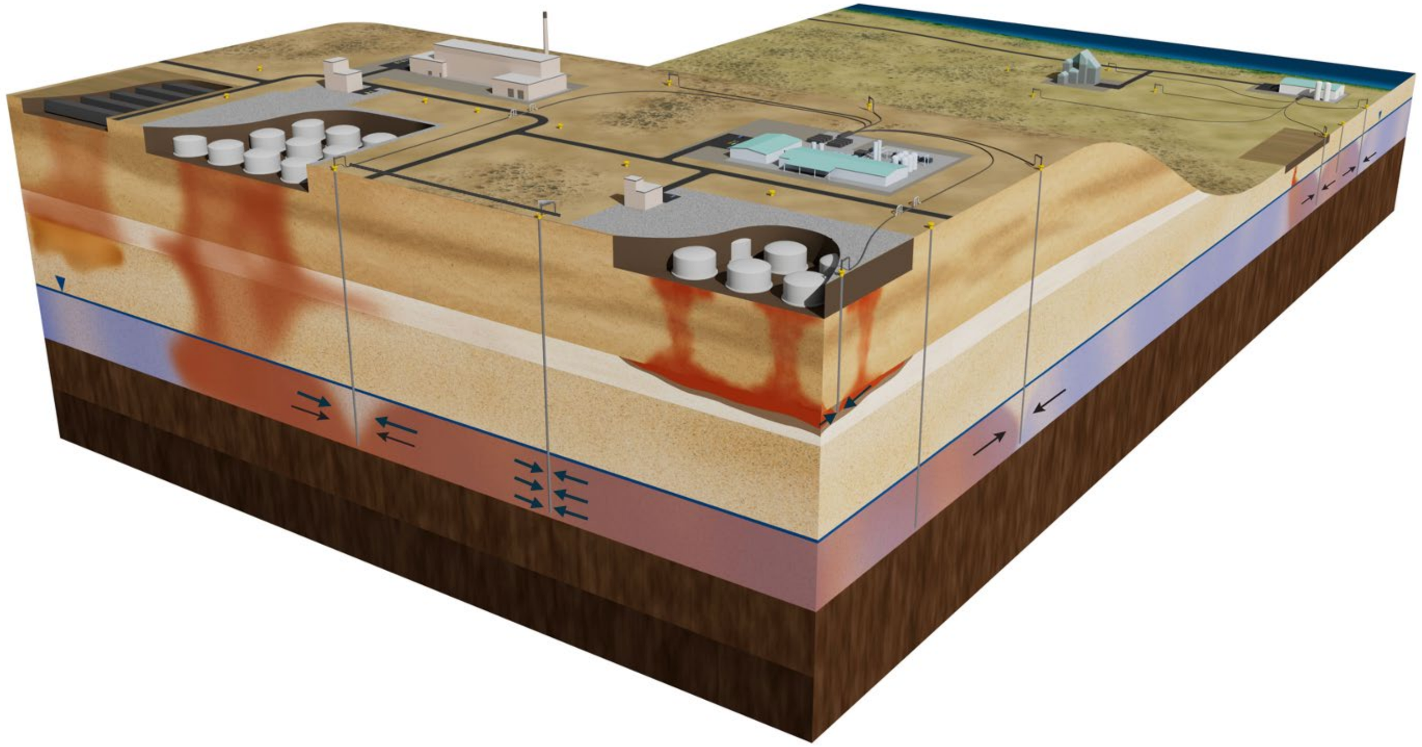
  - Hanford 200 West P&T
  - Scenario evaluation
- Part 3: Use of Deep-Learning Approaches
  - Well performance predictions
  - Increasing model efficiency

Part 1– Performance-Based Optimization of P&T



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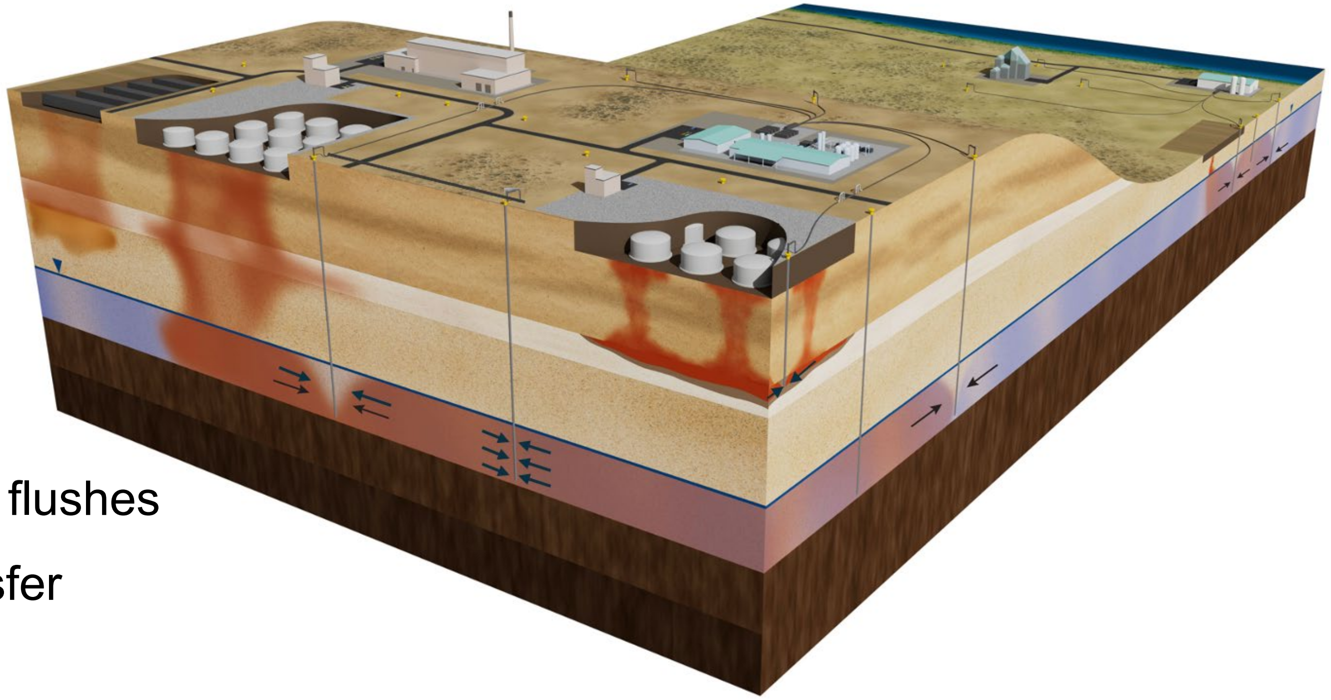
Pump-and-Treat (P&T) Systems

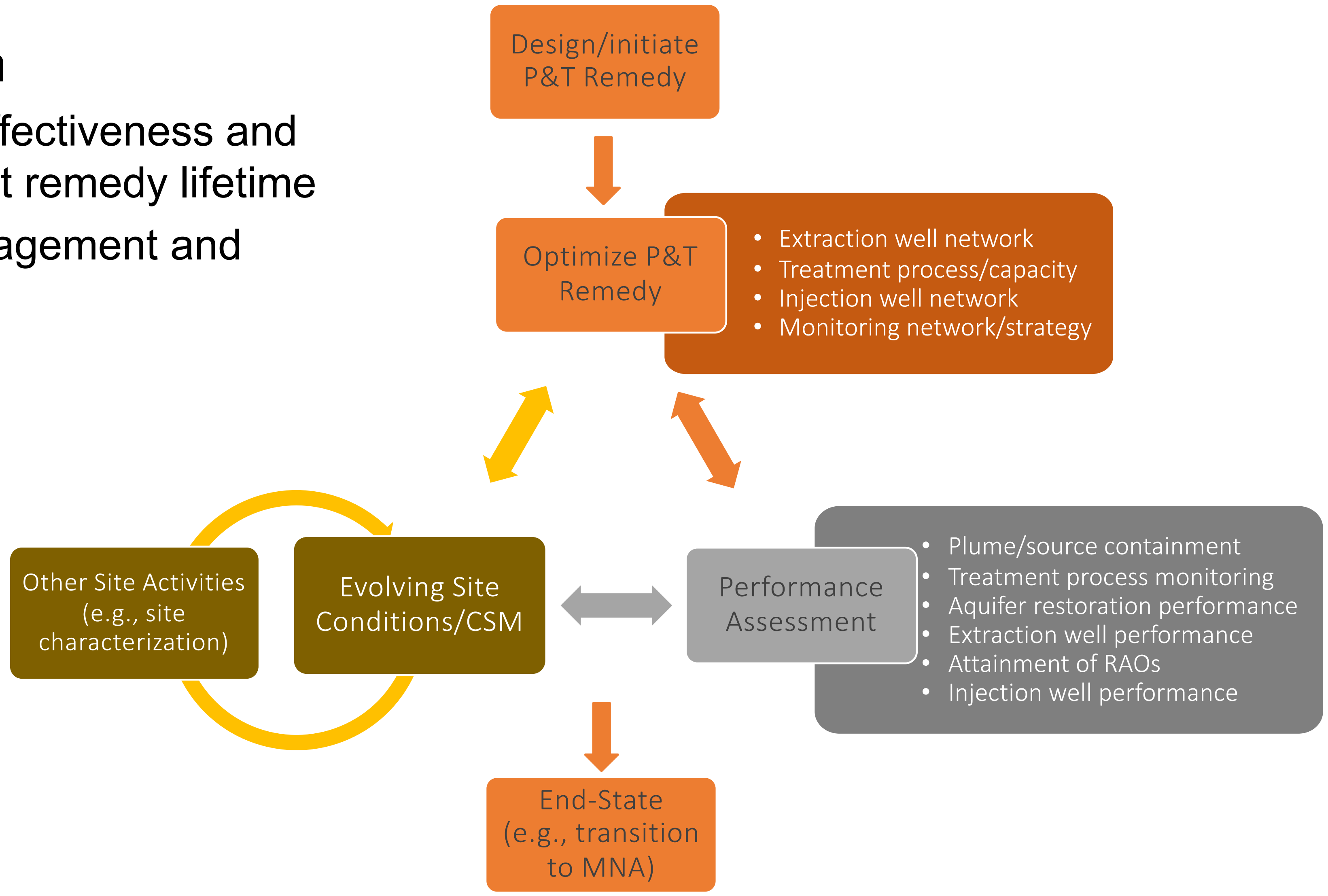
- Pump-and-treat (P&T) systems have been used for hydraulic containment and/or treatment of contaminated groundwater
  - A well network for groundwater extraction
  - Above-ground ex-situ treatment unit
  - Disposal system for the treated water
- Initial designs typically address large-scale containment and bulk treatment, and may not be an optimal design for mass removal and long-term effectiveness
  - Early goals focus on volumetric pumping
- Performance diminishes due to factors such as:
  - Heterogeneity
  - Large and dispersed plumes requiring multiple pore volume flushes
  - Presence of source zone and/or diffusion-limited mass transfer
  - Recalcitrant/competing contaminants

Pump-and-treat extraction well (adapted from PNNL-24741)

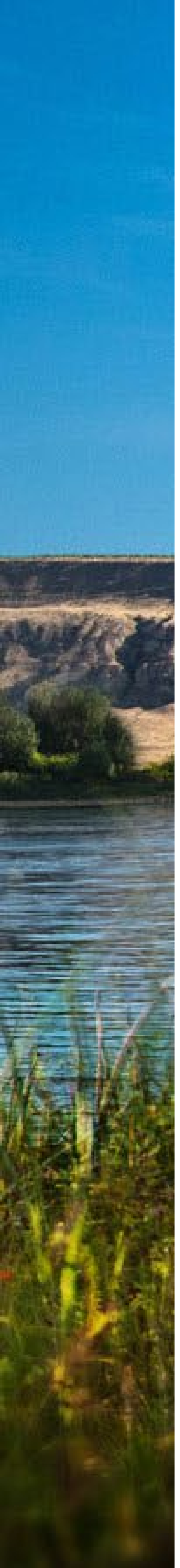


Performance-Based P&T Optimization

- Objective of periodic P&T optimization
  - Maintain/increase contaminant removal effectiveness and efficiency as much as possible throughout remedy lifetime
  - Well network and treatment capacity management and optimization
- Performance-based optimization approach relies on:
  - Continuous performance monitoring
  - Frequent updates to CSM based on the new data
  - Periodic evaluations of performance effectiveness and remedy lifetime
  - Computational optimization evaluations
    - Capacity & well network effectiveness



CSM = Conceptual Site Model
RAO = Remedial Action Objective



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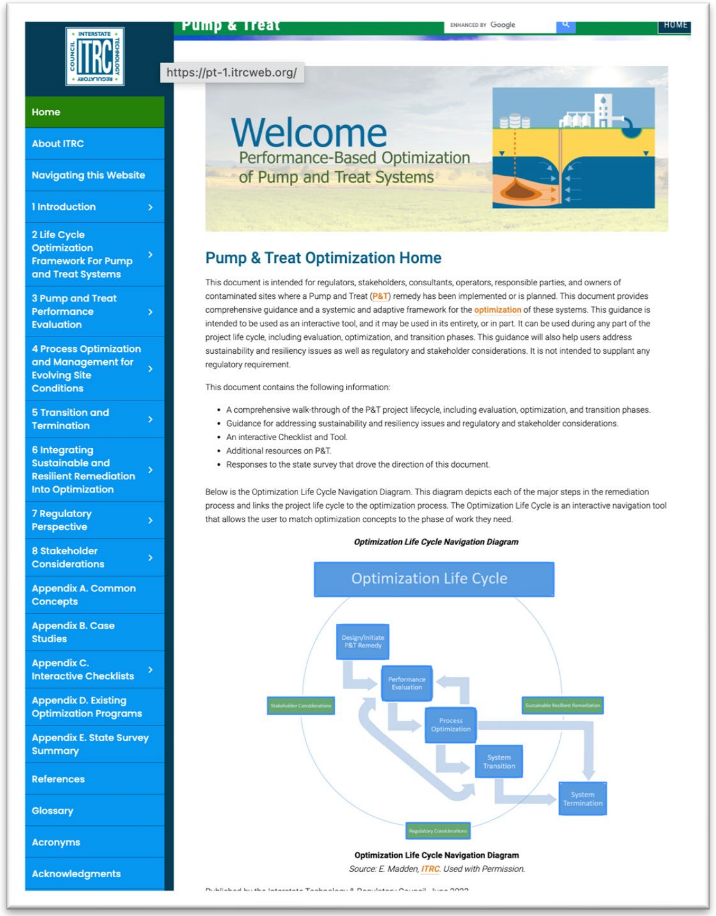
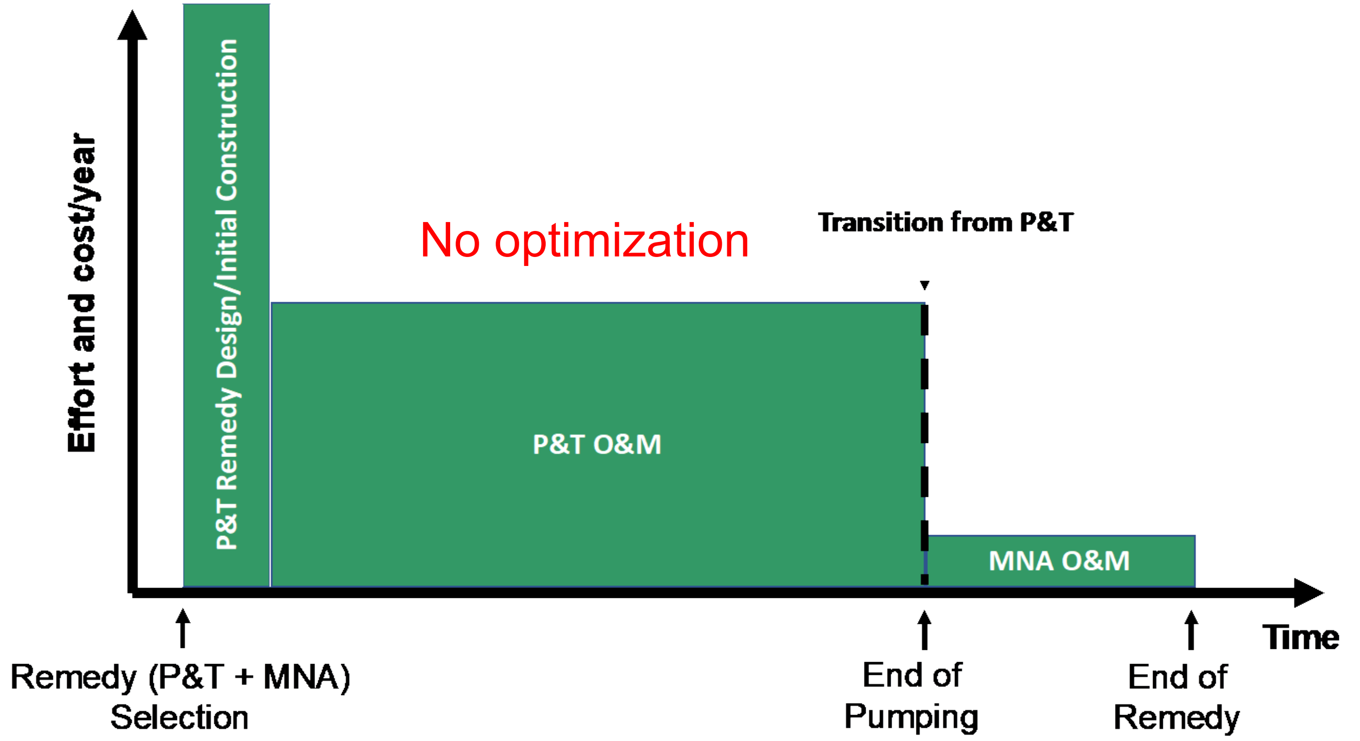
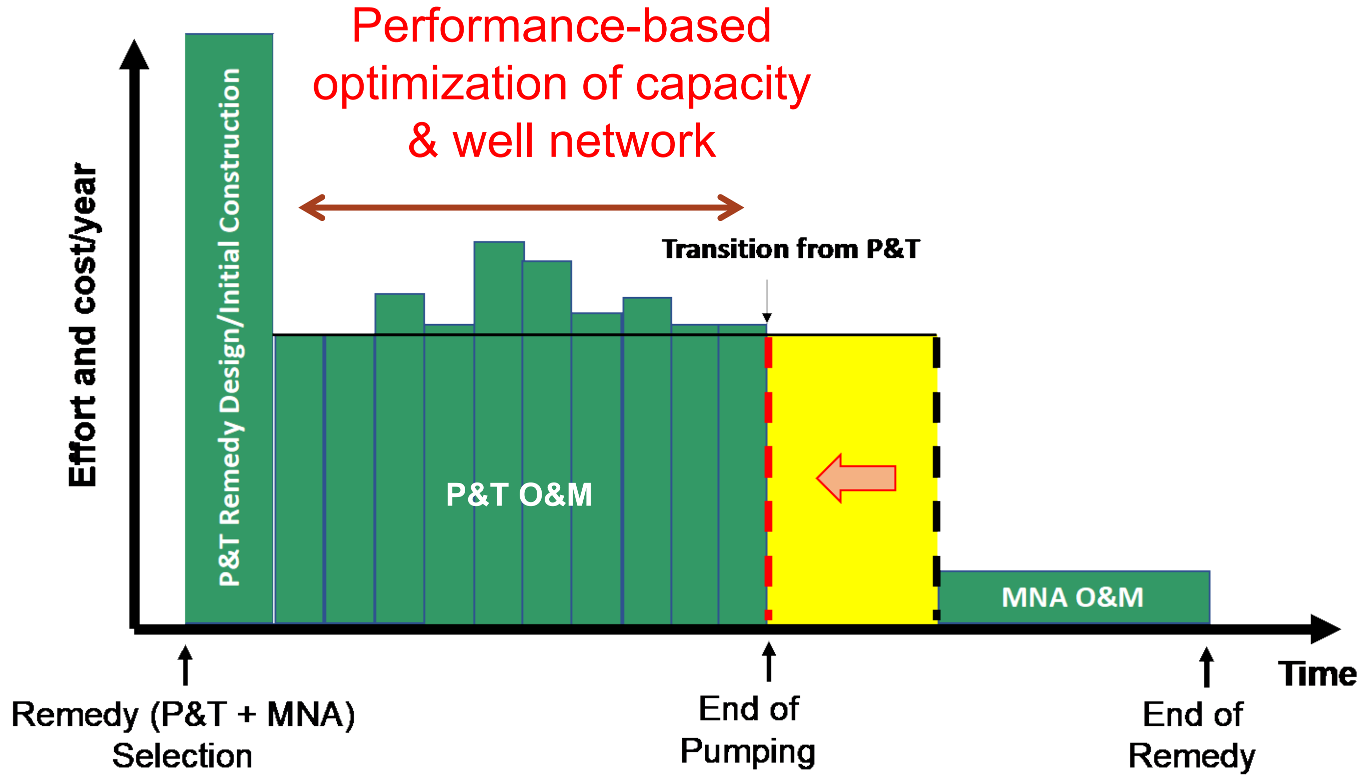
ITRC Guidance

- Interstate Technology Regulatory Council (ITRC)
- New performance-based P&T optimization guidance published in 2023



Adopted from the guidance





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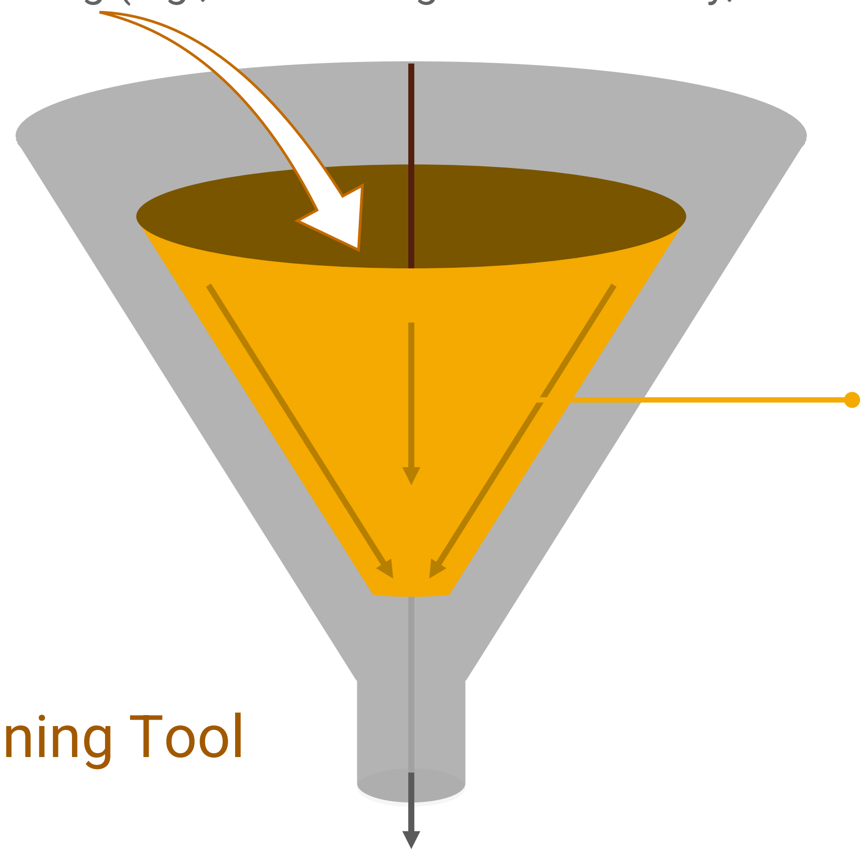
https://pt-1.itrcweb.org/

Computational Optimization and Pre-screening

- Formal optimization evaluations require:
  - Flow & transport (F&T) model of P&T system, coupled with optimization algorithms to run thousands of simulations
  - Resource intensive!
- Pre-screening (i.e., scoping) framework
  - Supports scenario evaluation to feed into decision tools
  - Reduced computational burden



- Comparative assessment of scenarios
- Narrower set of potentially successful optimization approaches
- Uncertainty evaluation

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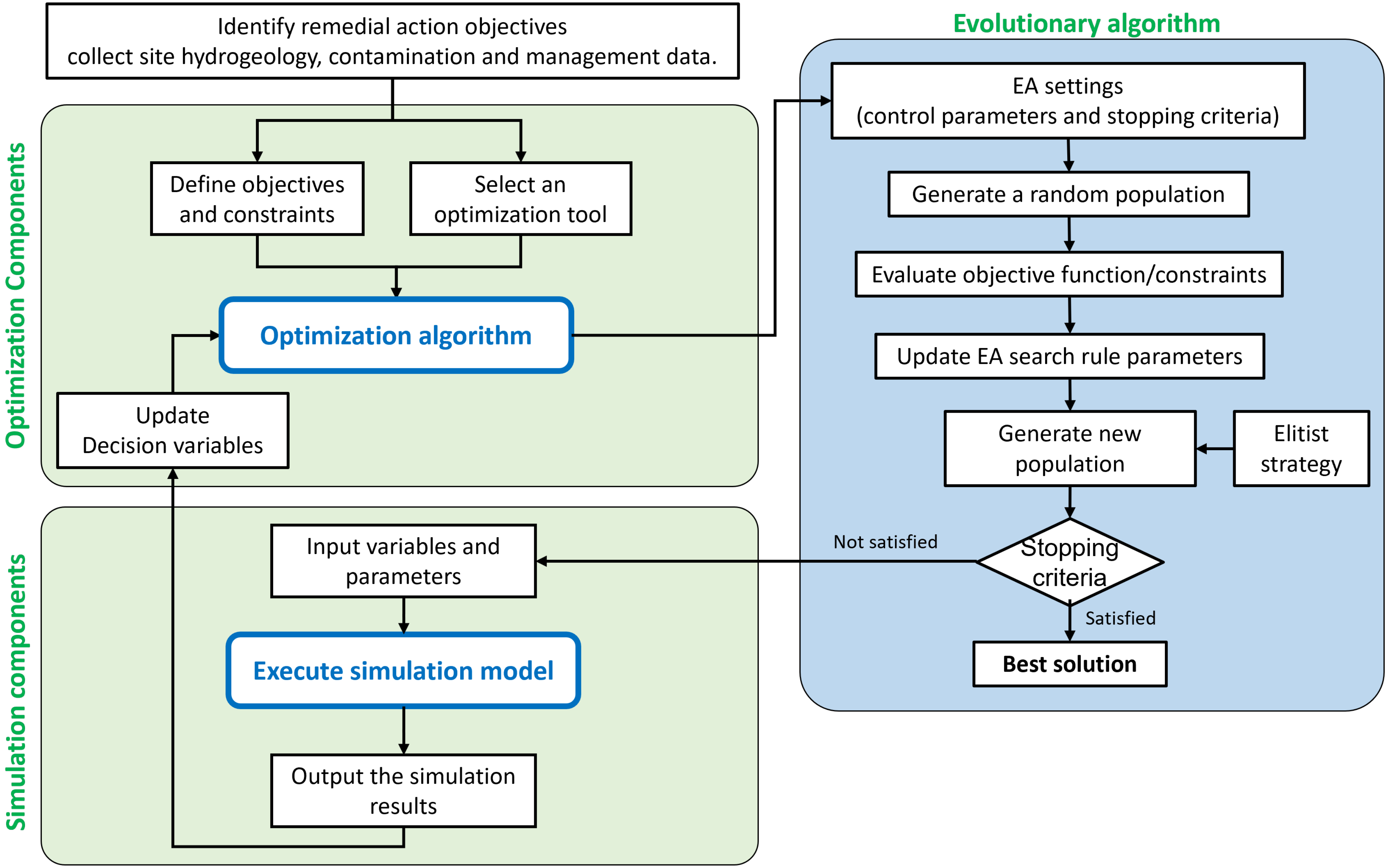
Pre-screening Tool Framework

Formal optimization parameters

Reduced complexity fate and transport model



Stochastic approach for solving both single-objective and multi-objective problems

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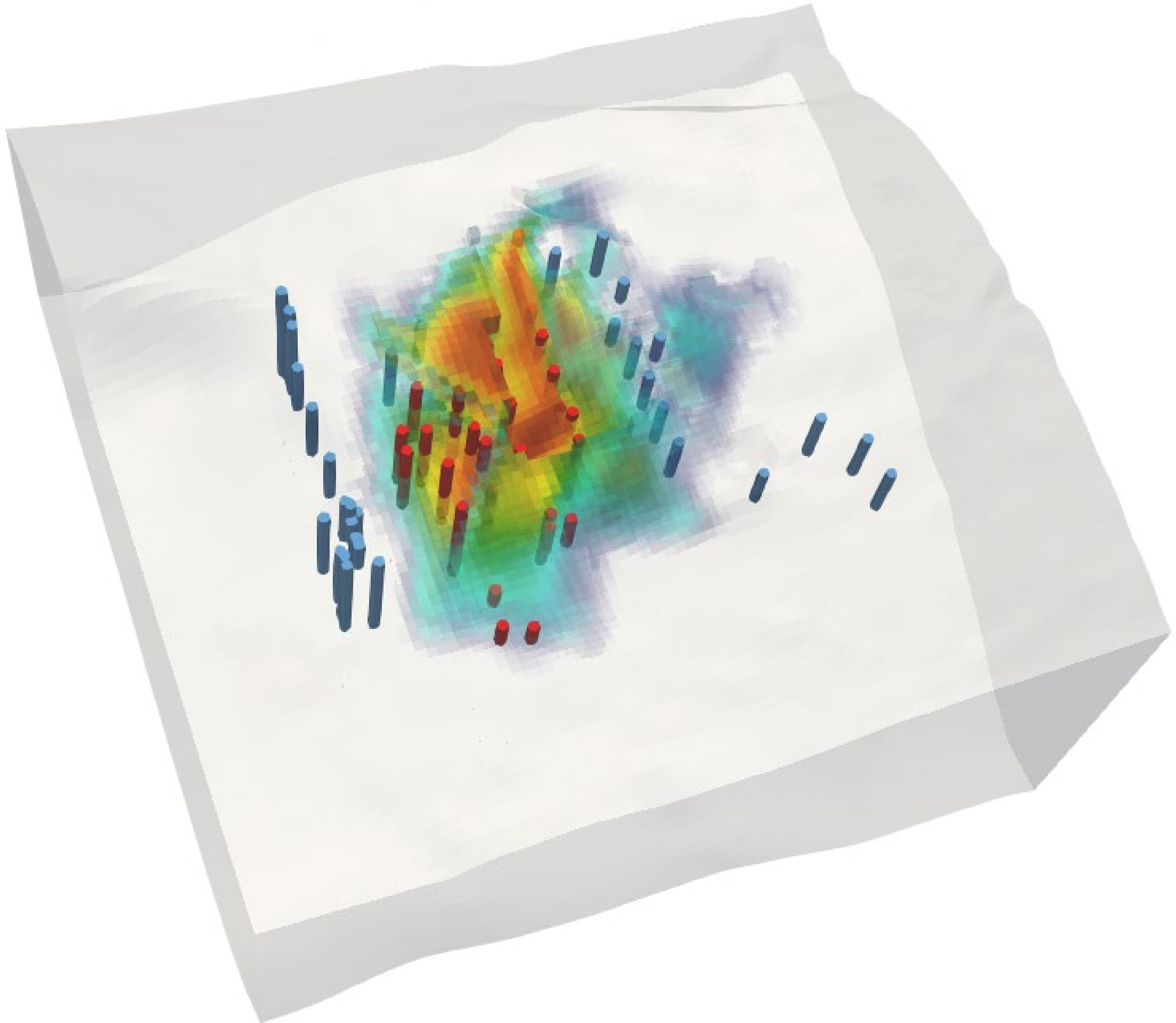
Part 2 – Pre-Screening Tool Demonstration



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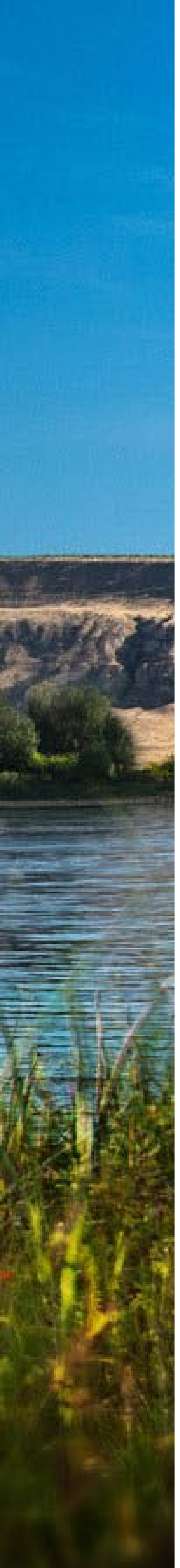

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Hanford 200 West P&T

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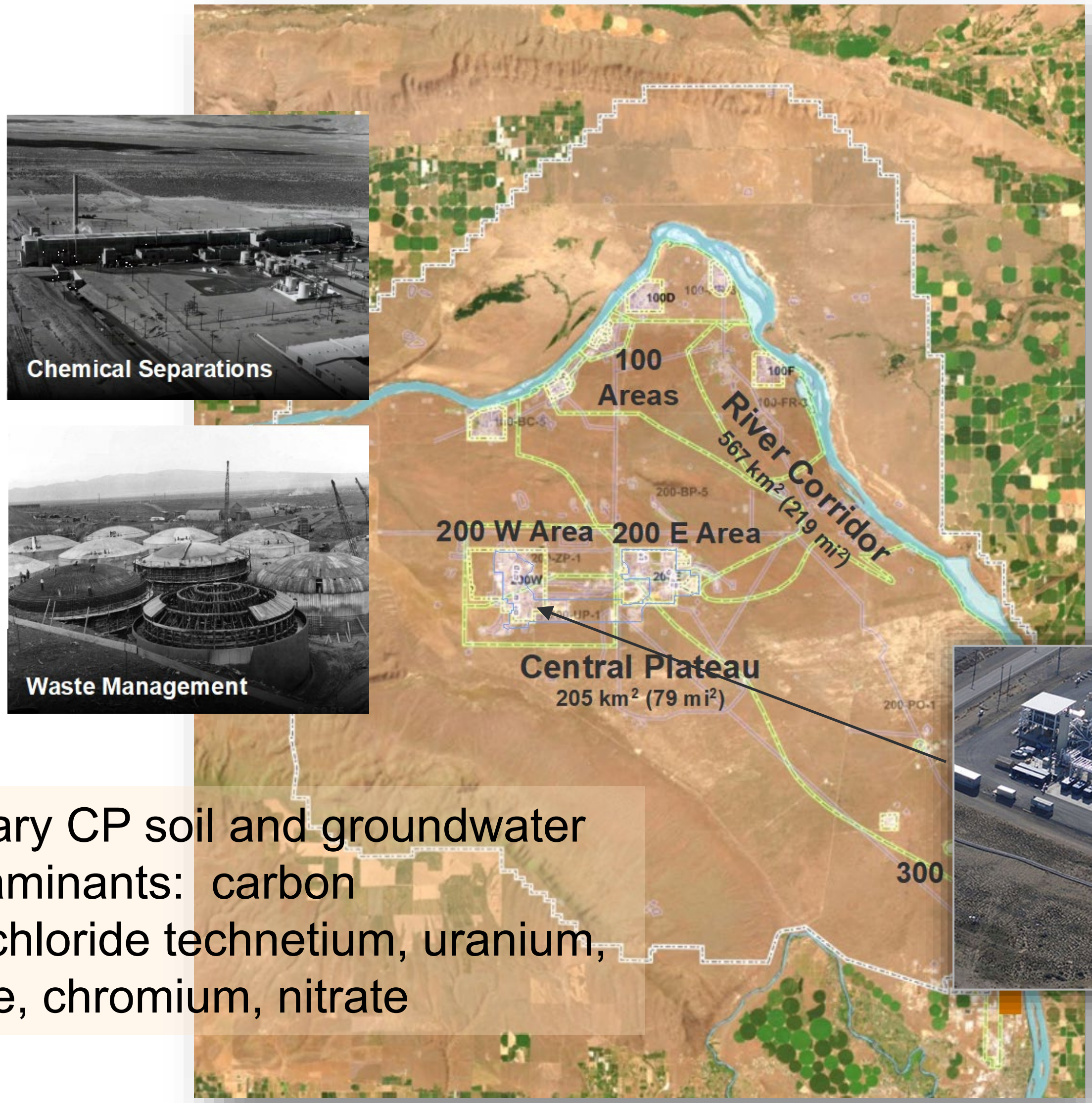
- Historical plutonium production for the Manhattan Project
- Operating since 2012 in the Central Plateau (CP) of the Hanford Site
  - Will be pumping for 25 years per 200-ZP-1 operable unit Record of Decision
- Addressing groundwater plumes:
  - Carbon tetrachloride (CTET)
  - Technetium
  - Uranium
  - Chromium
  - Nitrate*
- Current treatment capacity is 2500 gpm
  - 38 existing extraction wells
  - 30 existing injection wells



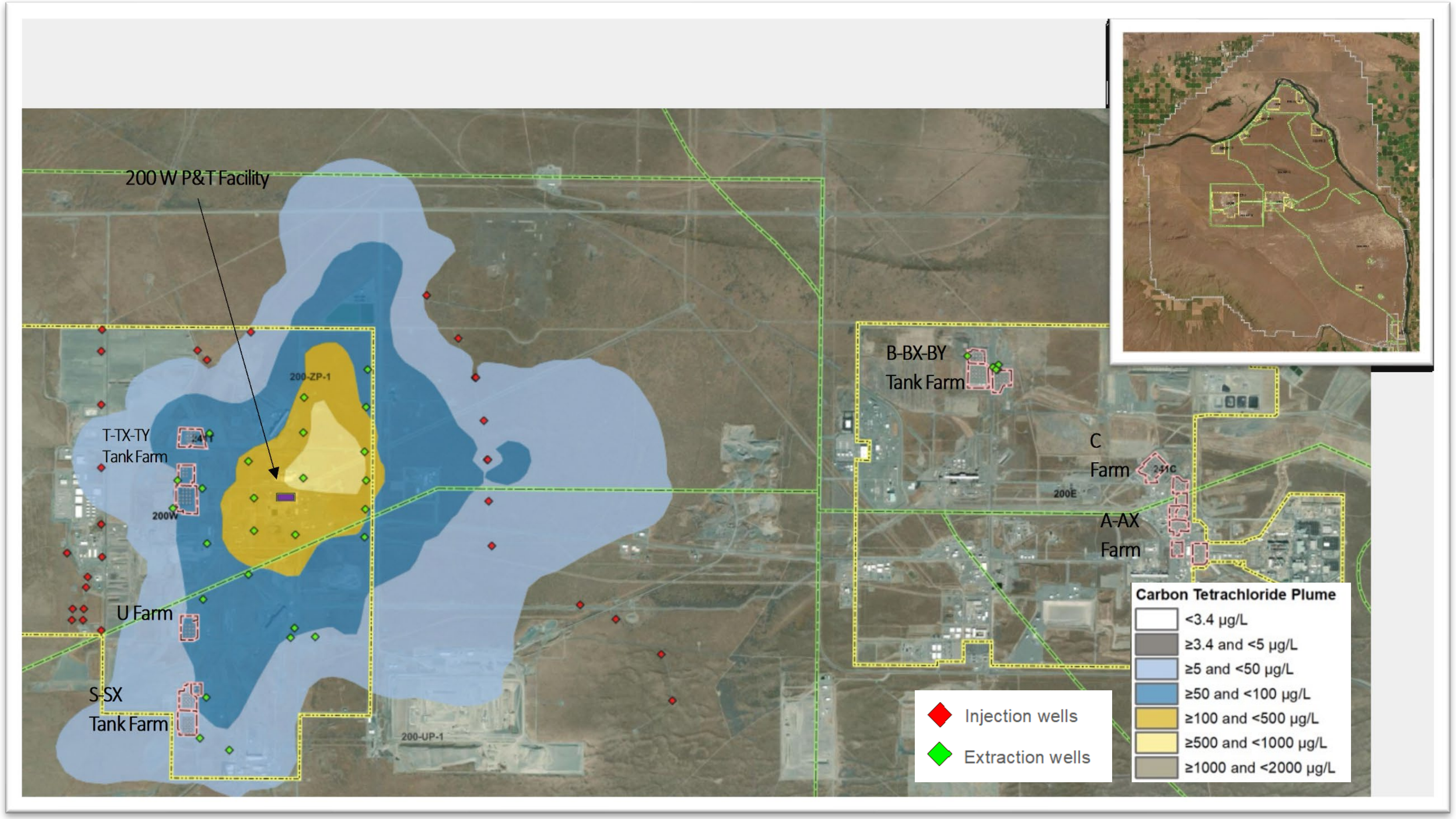
Primary CP soil and groundwater contaminants: carbon tetrachloride technetium, uranium, iodine, chromium, nitrate

U.S. DOE Hanford 200 West Groundwater Pump-and-Treat Facility (https://www.usa.skanska.com/what-we-deliver/projects/57299/)

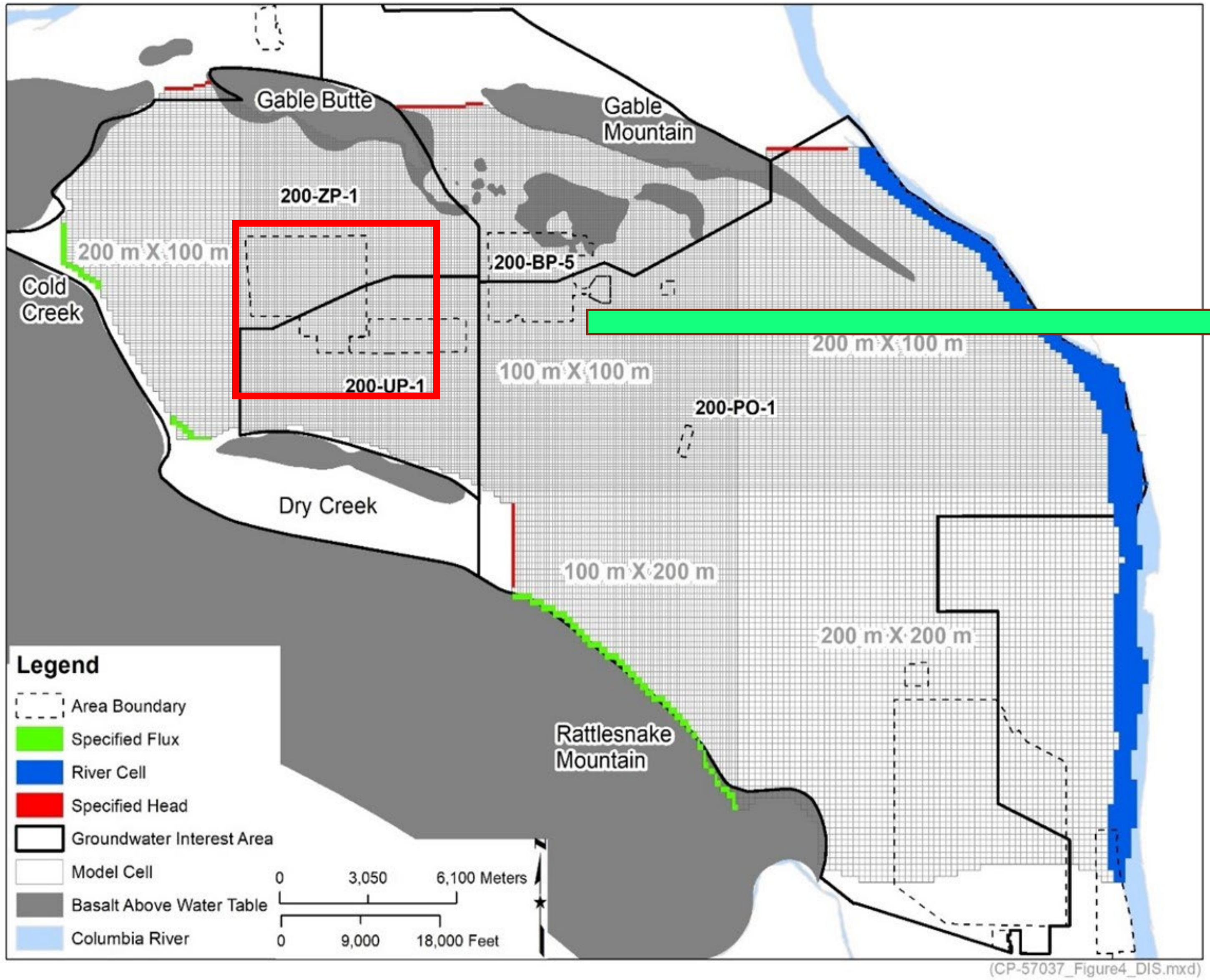
* Nitrate treatment is currently suspended under an optimization study

200 West P&T: Optimization Study

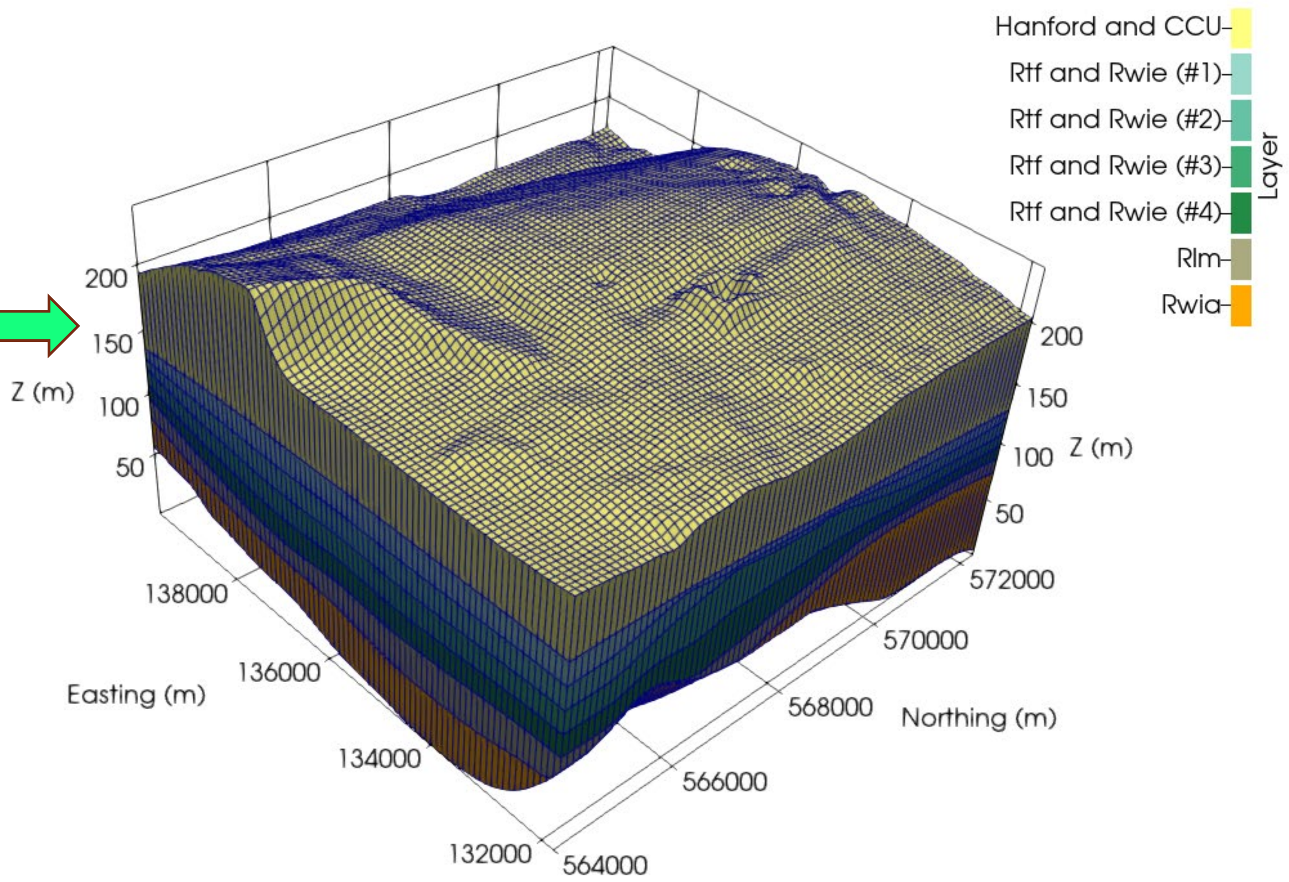
- Large carbon tetrachloride plume in the 200-ZP-1 Operable Unit (OU)
  - Slower CTET degradation rate
  - More contaminant mass in the aquifer
  - Diminishing performance at some wells
- 200-ZP-1 OU Optimization Study Plan to evaluate
  - Increasing carbon tetrachloride removal and treatment
  - Evaluating the transition to monitored natural attenuation (MNA) for nitrate, consistent with RAOs



Reduced Complexity Model Setup



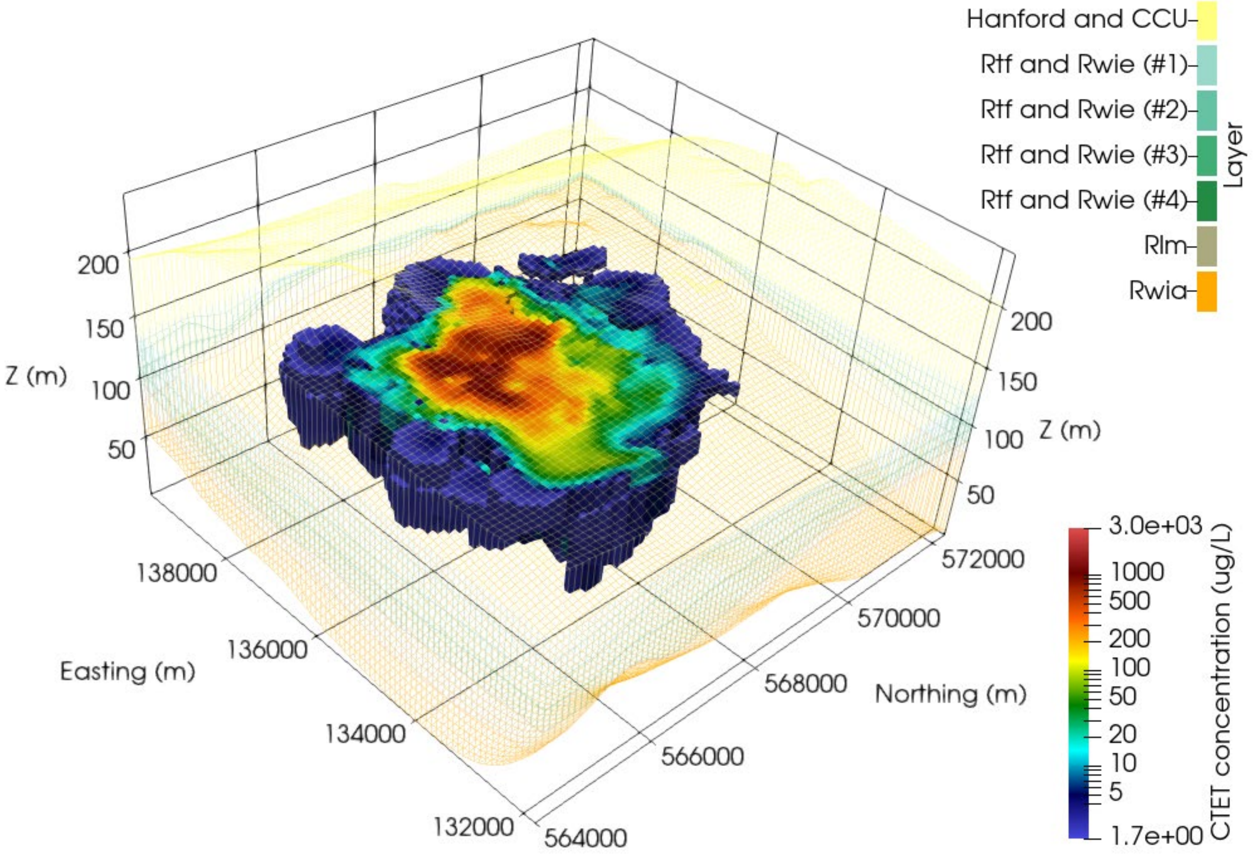
Plateau to River (P2R) Version 8.3 Model Extent and Groundwater Flow Boundary Conditions (source: ECF-HANFORD-22-0114-REV.0)



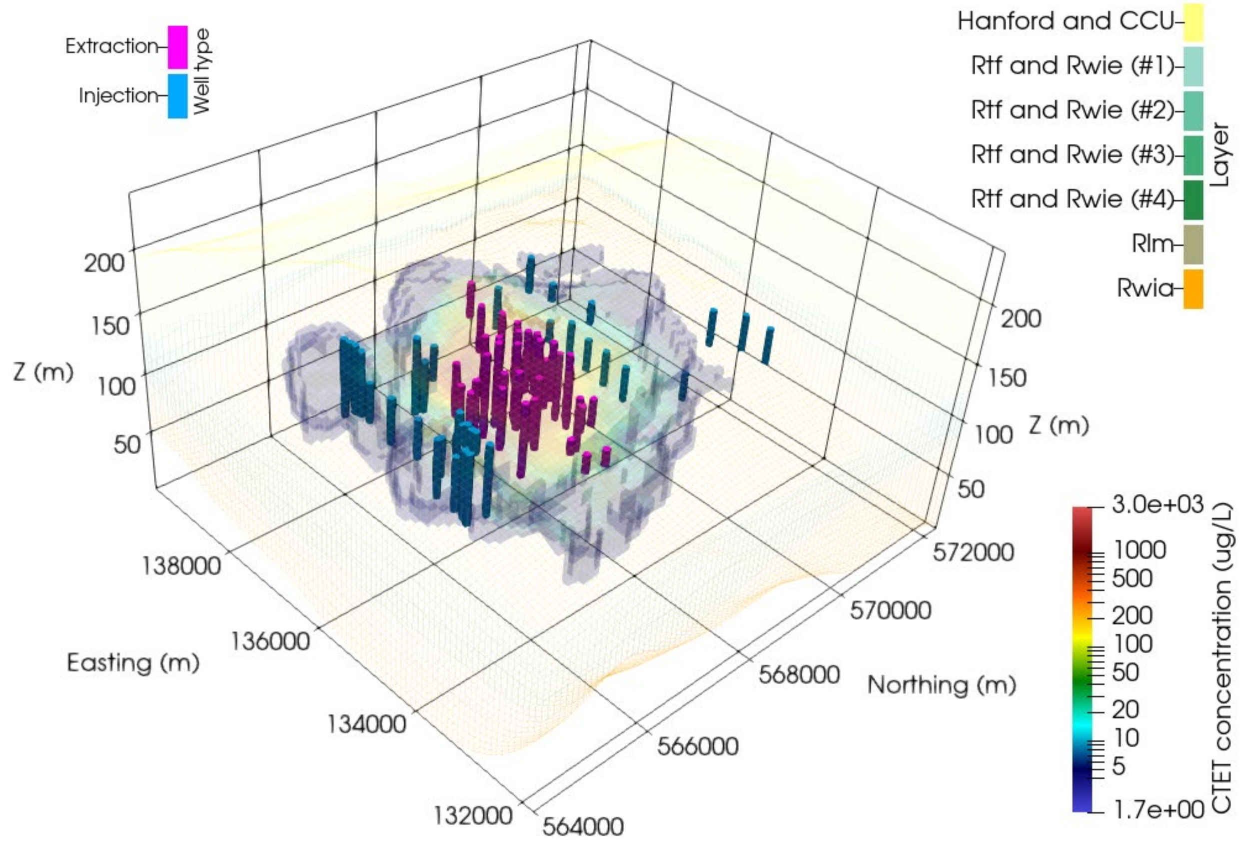
Reduced Complexity Model Domain
(eSTOMP model domain)

Reduced Complexity Model Setup

- Initial CTET plume (2015)

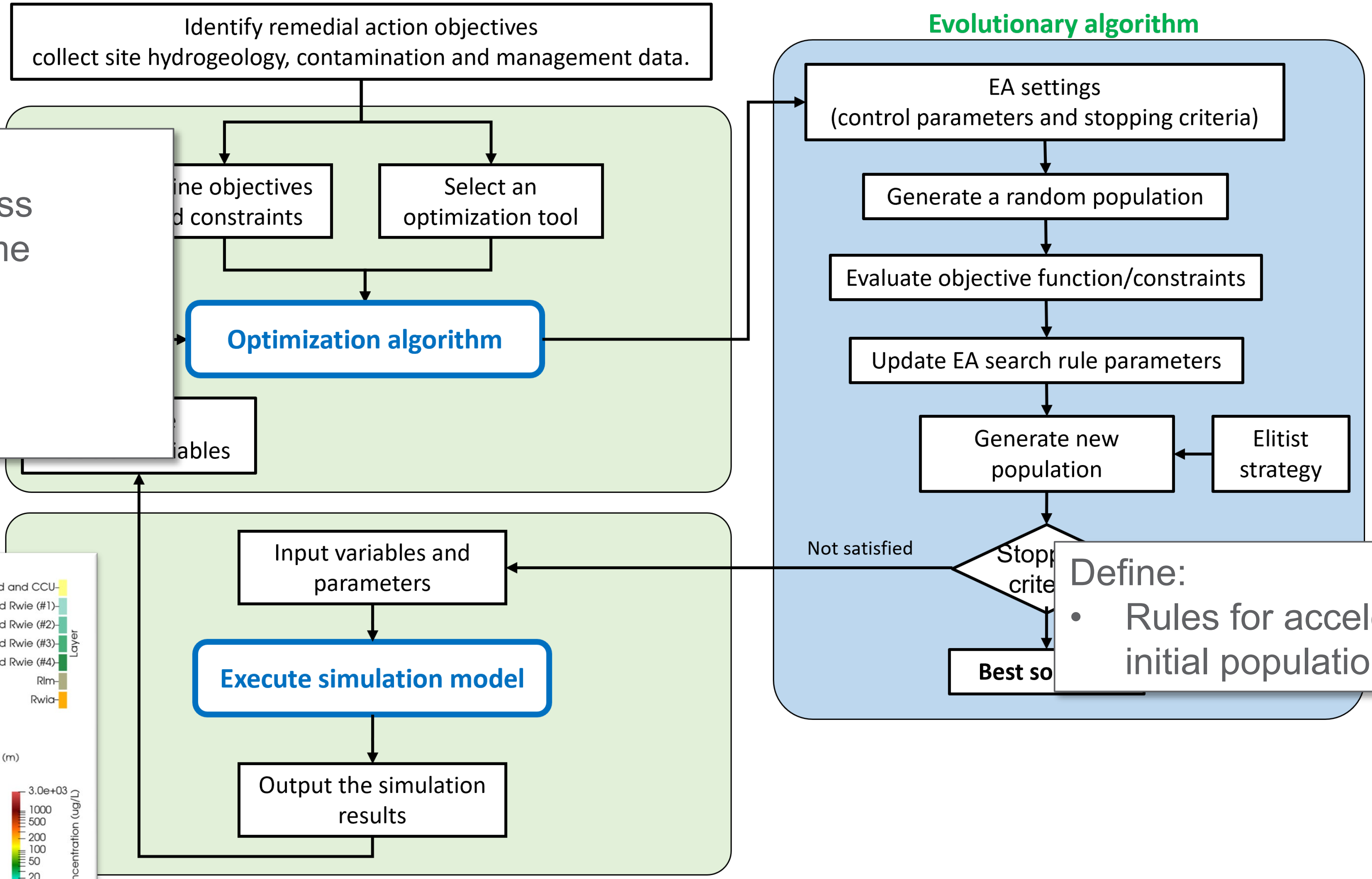


- Existing extraction and injection wells

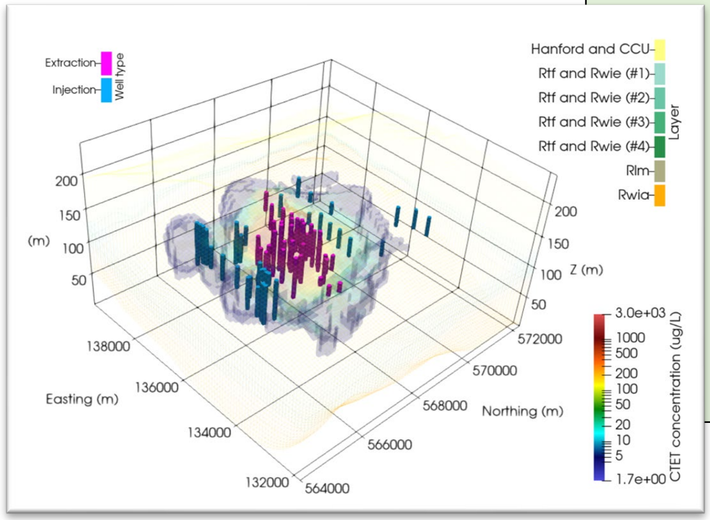


Pre-Screening Tool Optimization Setup

Define:
- Optimization goal (e.g., mass recovery, pumping timeframe minimization, etc.)
- Constraints
  - Treatment capacity
  - Well installation rules



Define:
- Rules for accelerating initial populations



Optimization: Scenario Setup for Comparative Evaluation

Current Time 2024 — 2026 — End of Pumping 2038

Scenarios

Baseline

No Optimization (static well network)
P&T Capacity (gpm)
3400

Scenario-1

Well Network Optimization
P&T Capacity (gpm)
3400

Scenario-2

Well Network Optimization	
P&T Capacity (gpm)	
3400	4500

End-state Performance Criteria:
Baseline 95th percentile concentration level in 2038

Opt. Goal #1	Opt. Goal #2
Minimize active cleanup timeframe	Maximize total CTET mass recovery

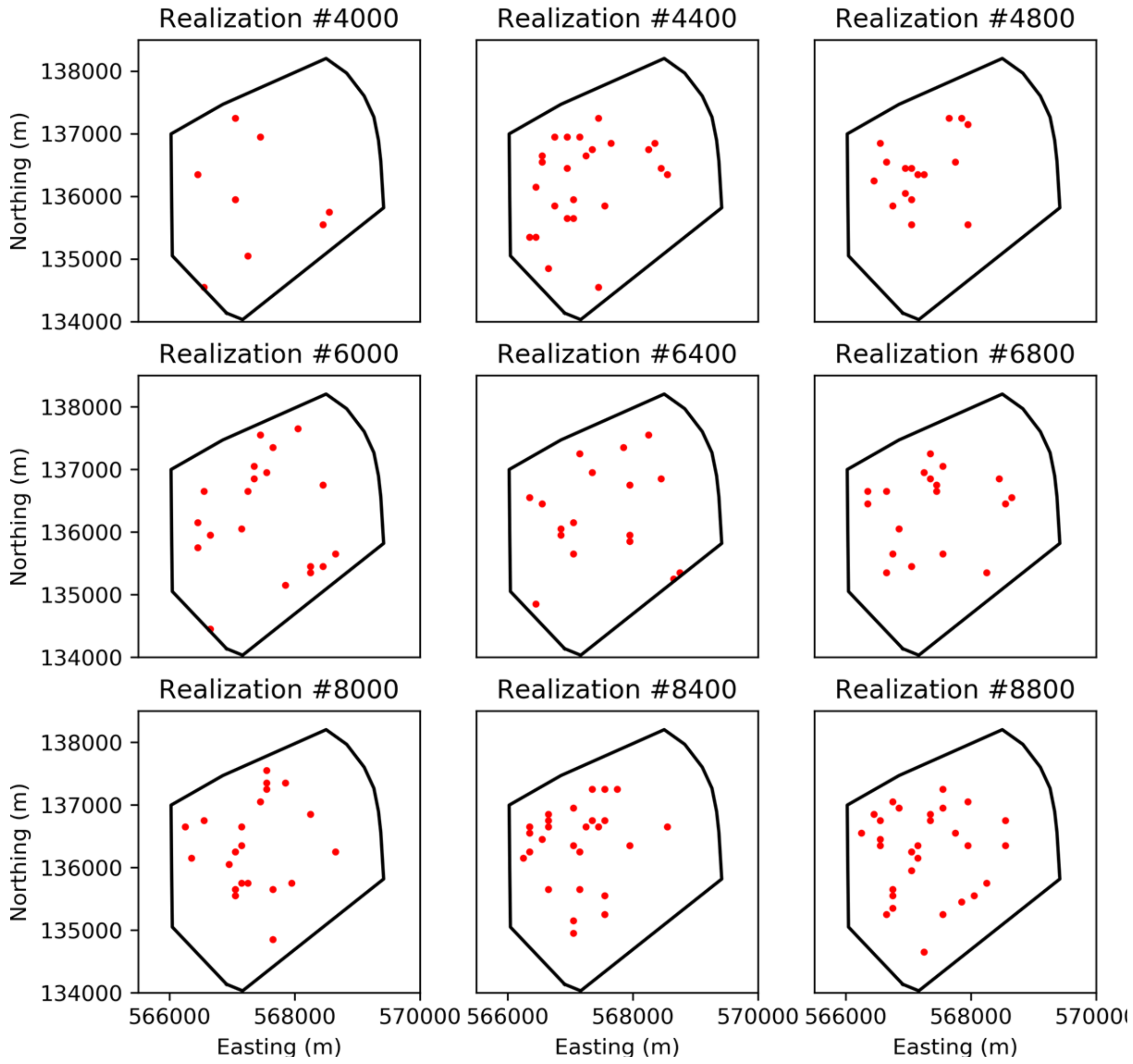
Optimization Constraints: Well Installation

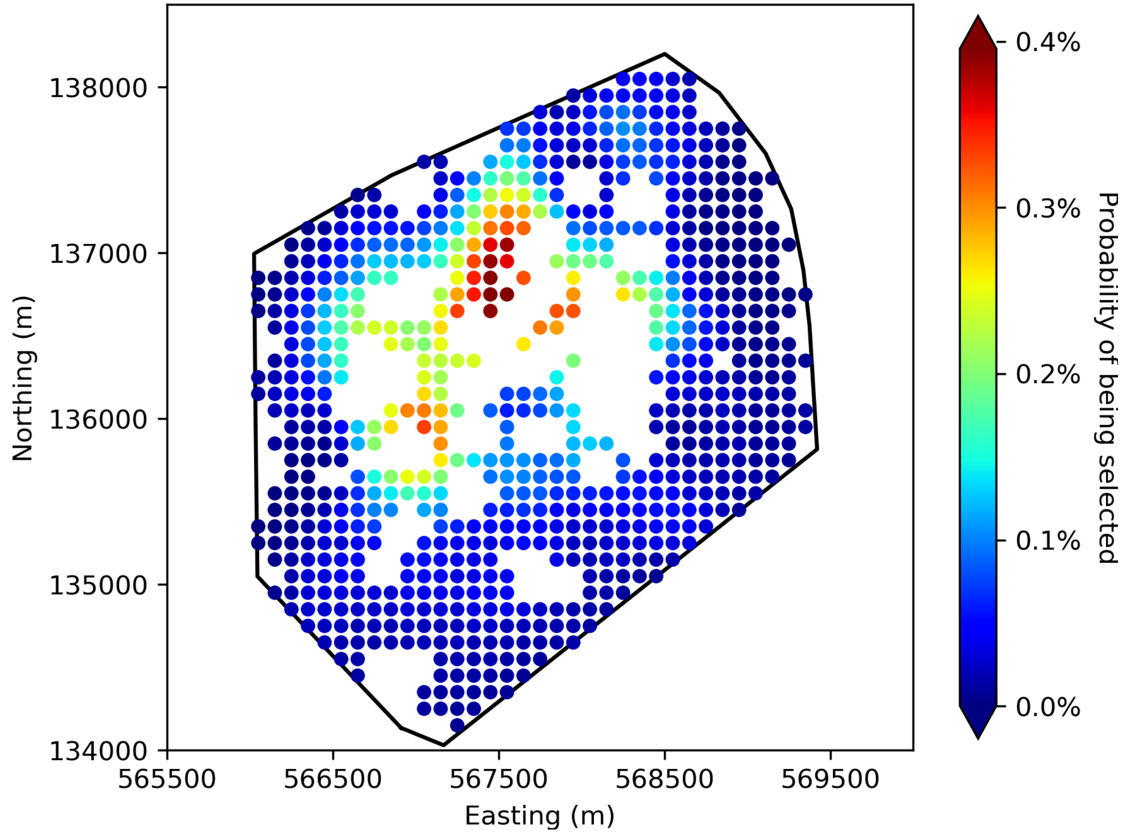
- Parameterization rules:
  - **Rule 1**: One-to-one well replacement with a maximum number of active wells (based on the total capacity of the treatment plant)
  - **Rule 2**: Each well only has one operation period
  - **Rule 3**: Each well has a fixed pumping rate
  - **Rule 4**: When a new well replaces an old well, the new well inherits the pumping rates of the old one

Example Realizations from the Evolutionary Algorithm

Optimization Setup: Well Locations

- Concentration-weighted sampling to create the initial population for the optimization simulation

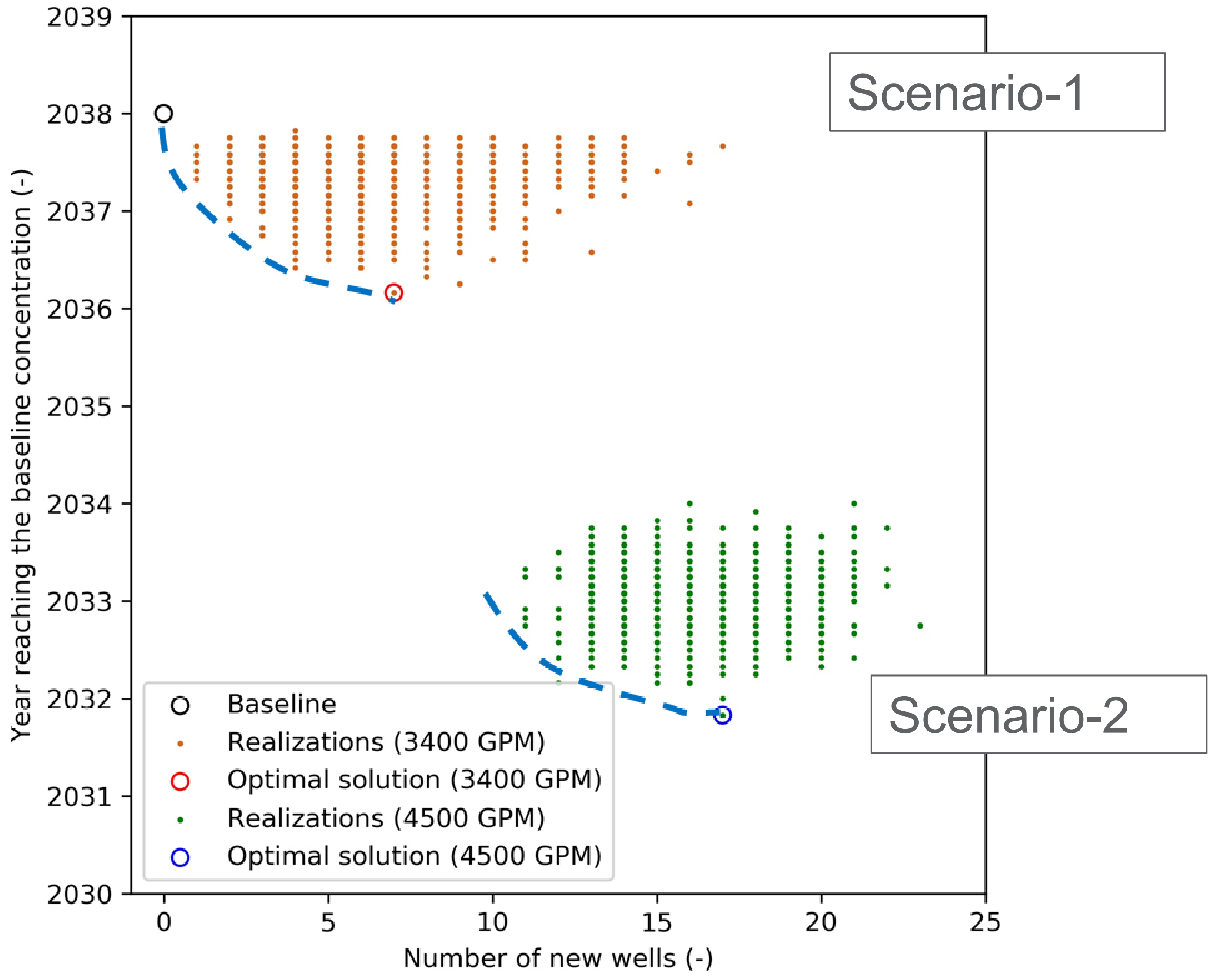




- High concentration locations are more likely to be chosen for installing new wells in initial realizations

Results for Goal #1 (Minimizing active pumping timeframe)

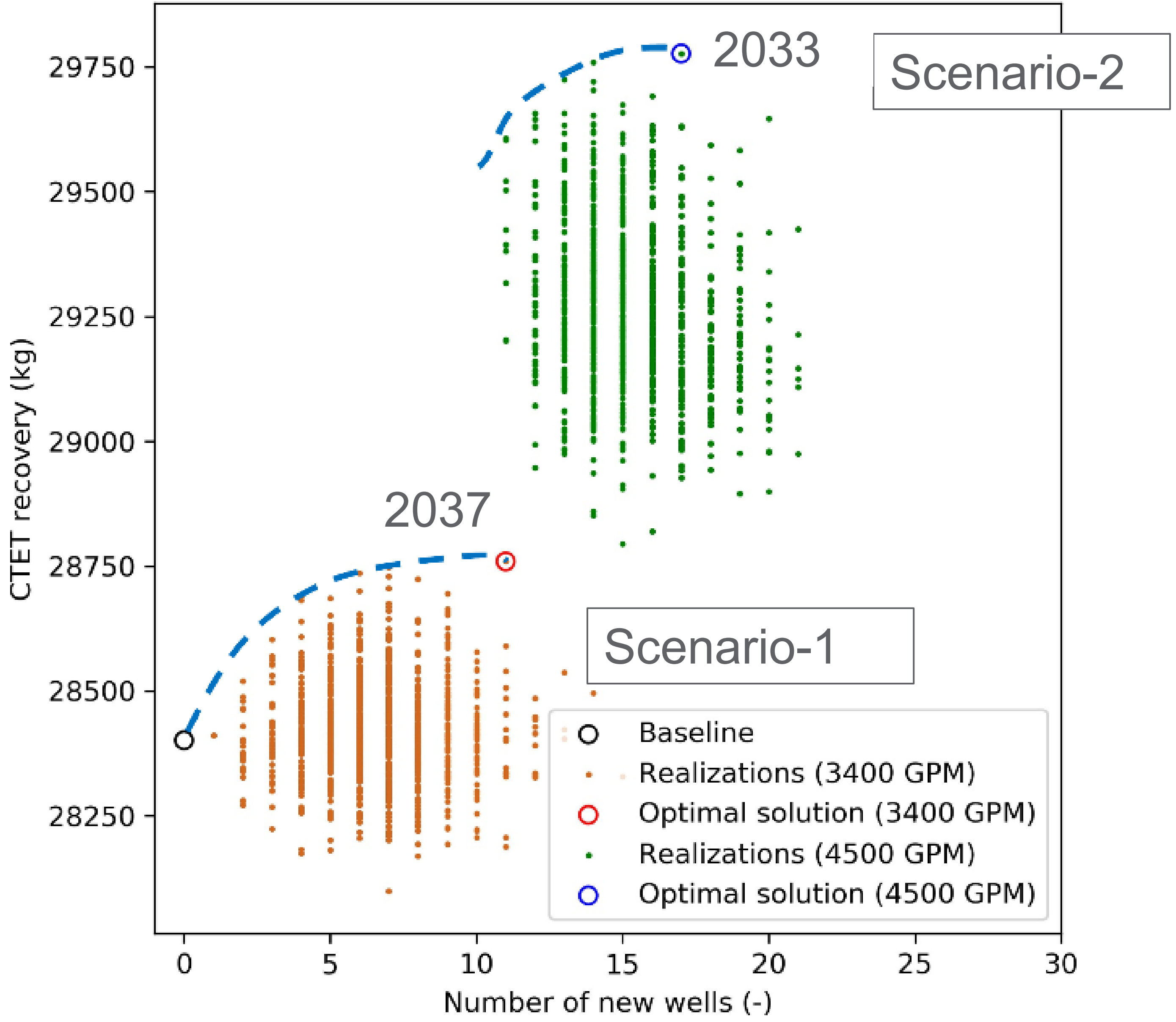
- Scenario-1 with well network optimization only (i.e., constant P&T capacity at 3400 gpm) achieves ~ 8% reductions in active remediation timeframe
  - Total of 7 new wells are added to the network
  - Achieves the same 95th percentile concentration level as the baseline with 2 fewer years of pumping
- Scenario-2 with well network optimization and increasing P&T capacity is found to have relatively more reduction in remedy lifetime, ~24%
  - Total of 17 new wells added to the network
  - Achieves the same 95th percentile concentration level as the baseline with 6 fewer years of pumping



Relation between # new wells added versus pumping timeframe

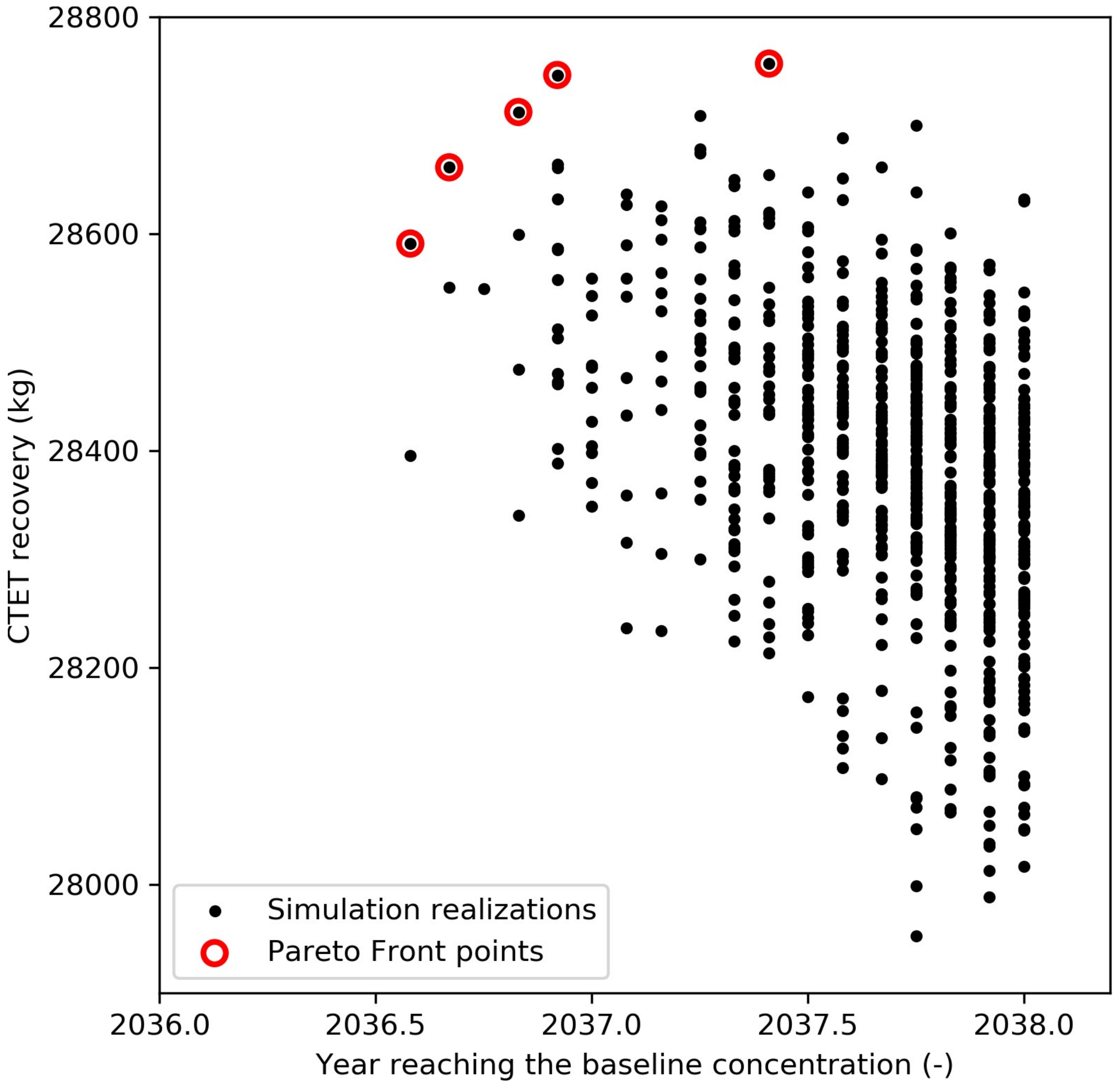
Results for Goal #2 (Maximizing CTET Mass Recovery)

- Scenario-1 provides about ~ 4% reduction in pumping timeframe
  - A total of 11 wells added to the network
  - Achieves the same 95th percentile concentration level as the baseline with 1 year less pumping
- Scenario-2 provides about ~20% reduction in pumping timeframe
  - A total of 13 wells added to the network
  - Achieves the same 95th percentile concentration level as the baseline with 5 fewer years of pumping



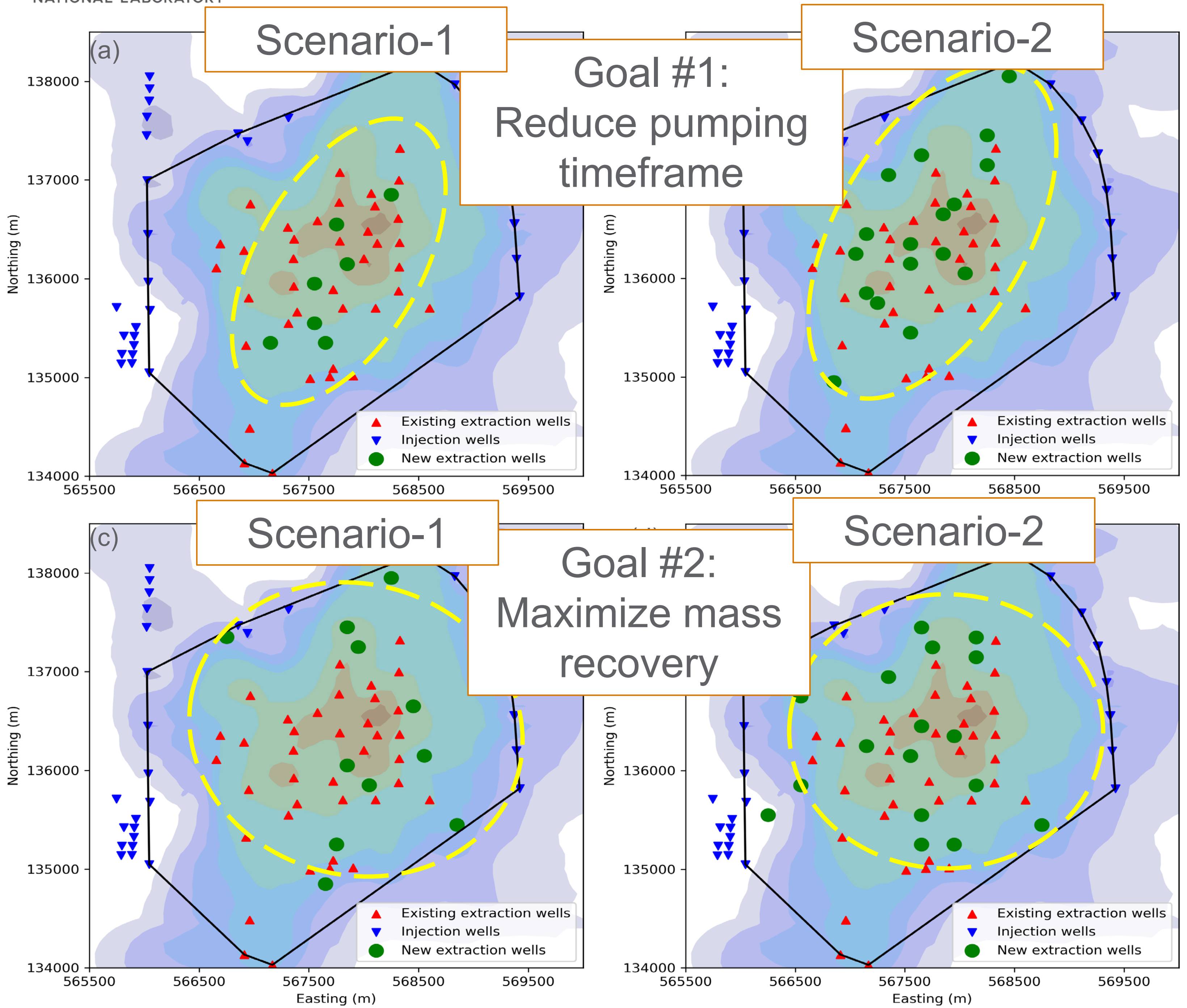
Relation between simulated total CTET mass recovery and the number of new wells added

Optimization Outcome: Pareto Front Analysis for Scenario1



- The Pareto front plot provides the relationship between the two competing objectives:
  1. The time taken to reach the baseline CTET concentration; and
  2. The efficiency of CTET mass recovery
- Pareto front points: improvement in one objective will cause degradation in the other ("non-dominant" solutions)
- The curvature in the Pareto front indicates the rate at which these trade-offs change

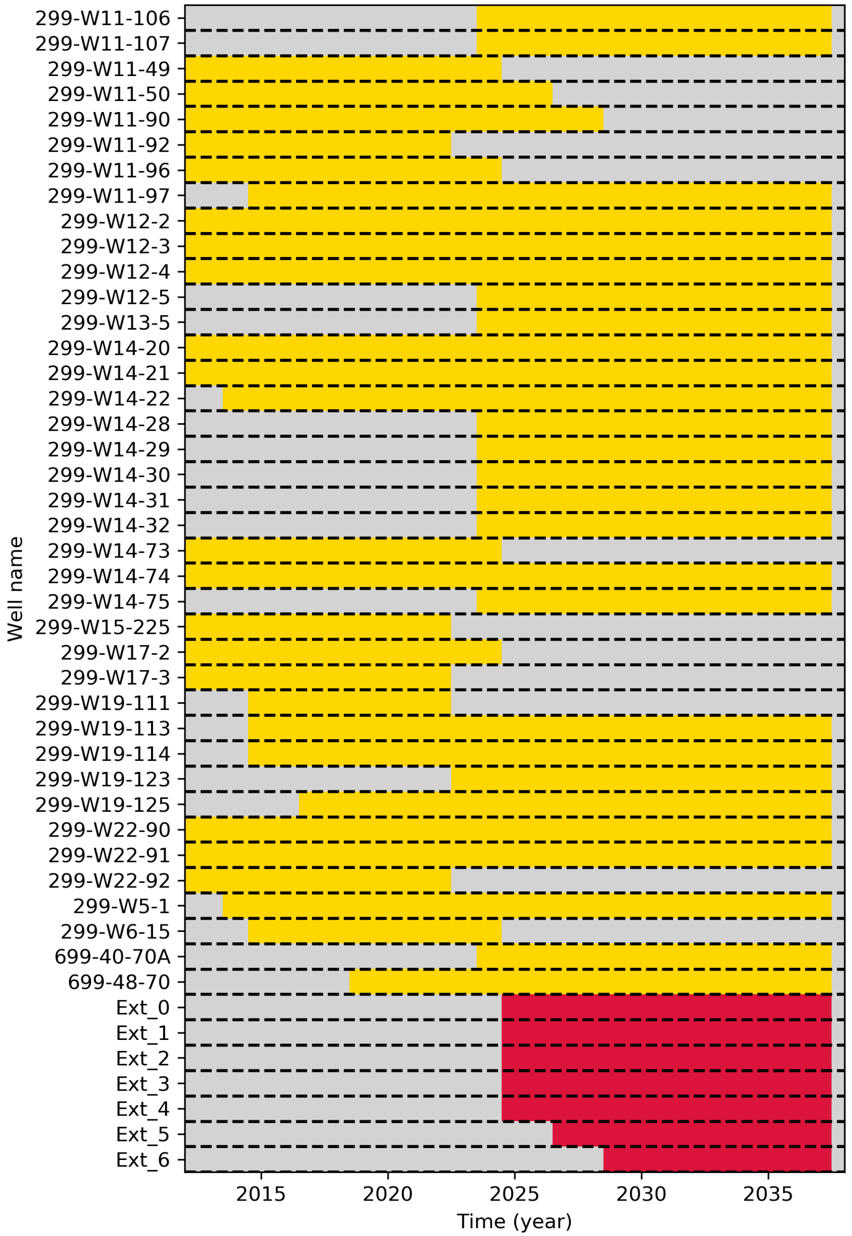
Optimization Results: New Well Locations

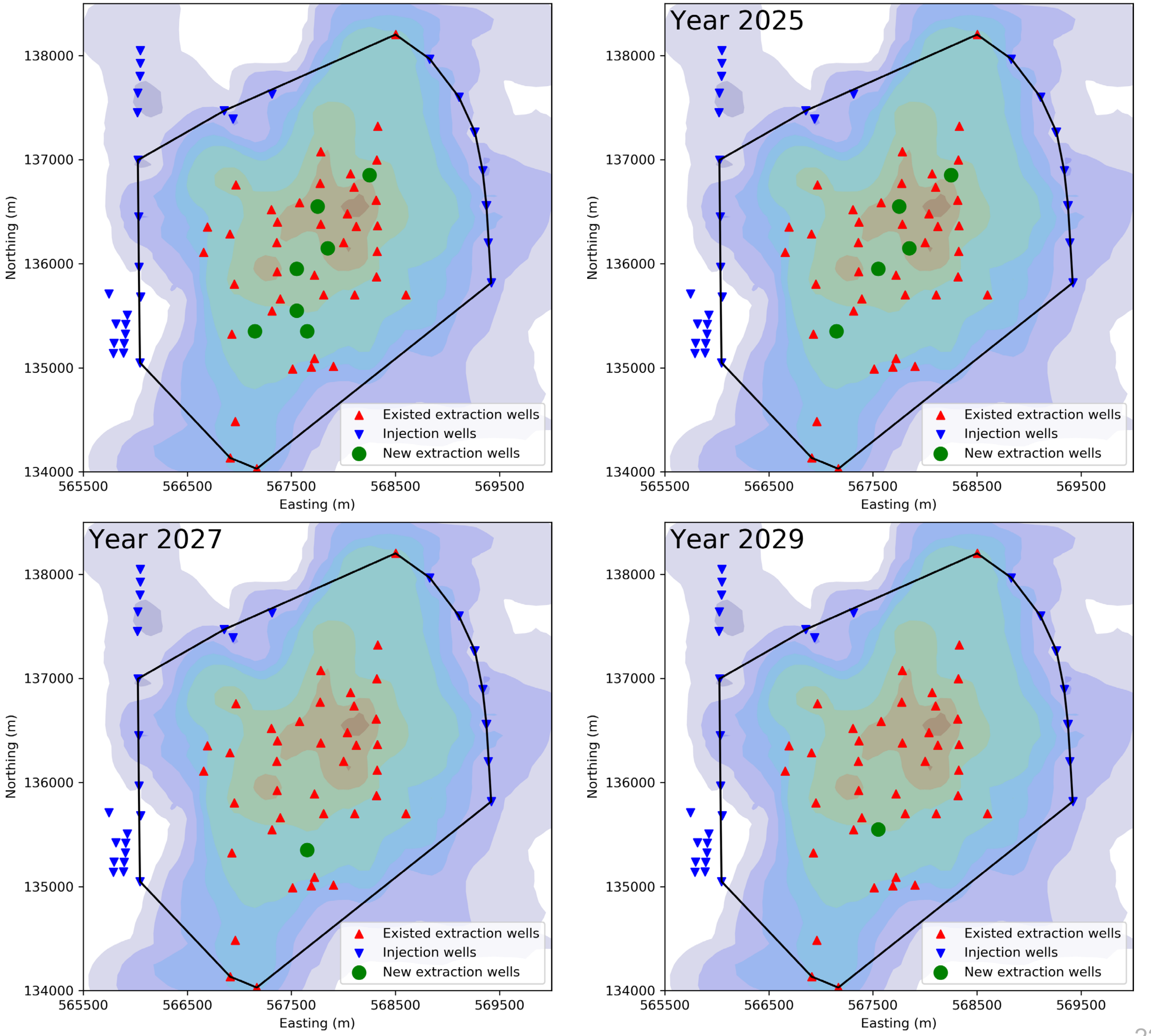


- Different optimization objectives result in varying strategies for selecting new well sites.
- To minimize cleanup time, wells are placed in high-contamination zones to lower the concentrations
- To maximize mass recovery, wells are spread out for thorough coverage, especially as concentrations decrease

Scenario1: Optimal Solution at 3400 GPM

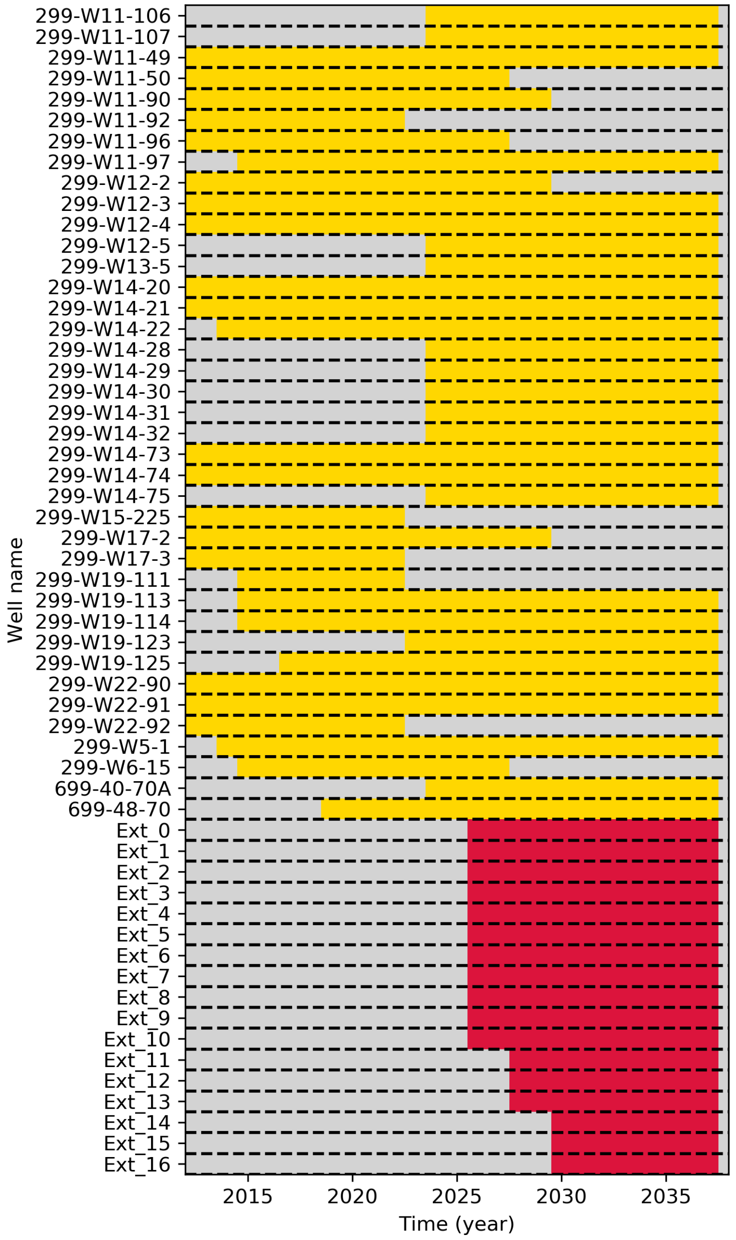
- Installation schedule and new well locations

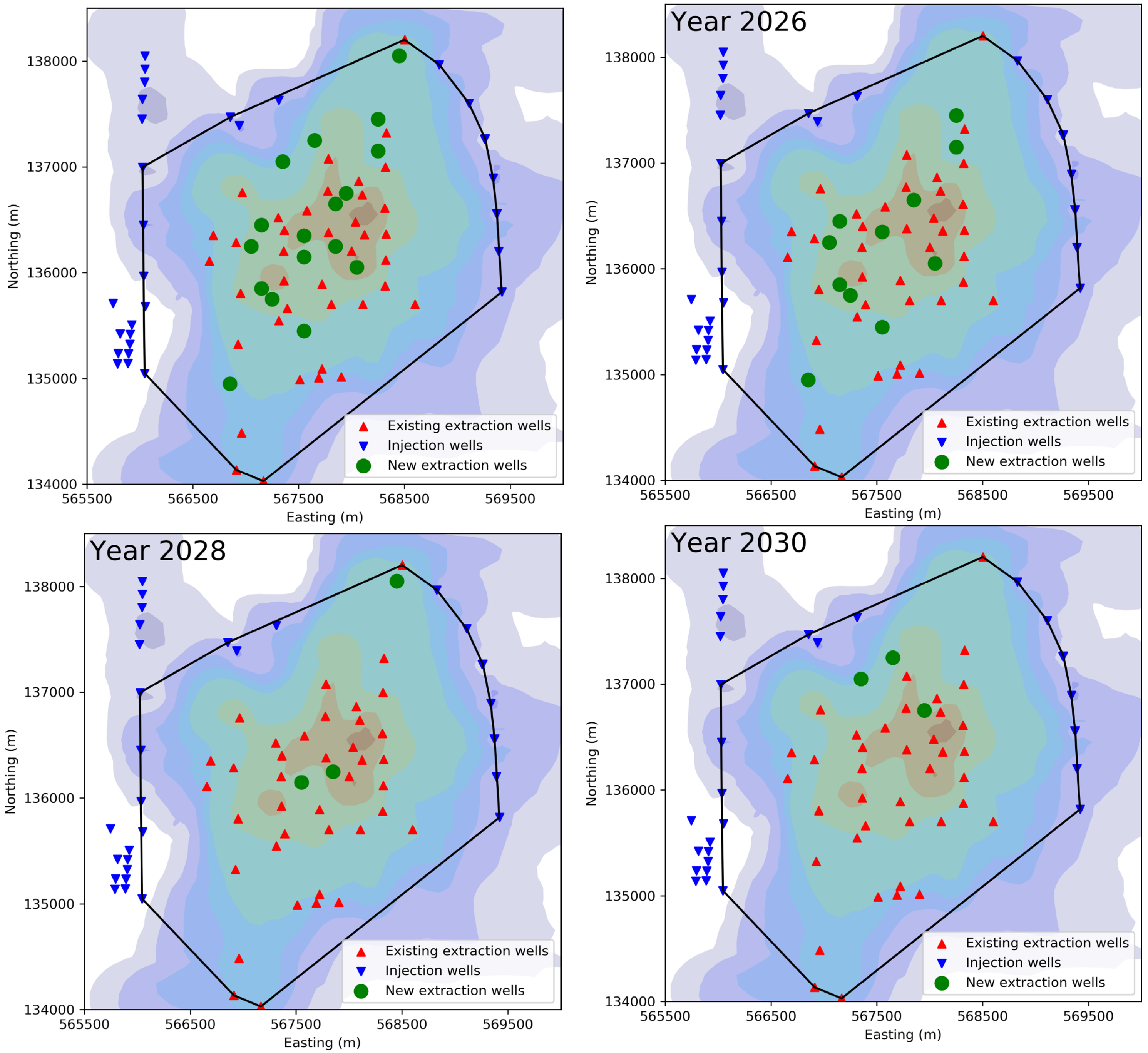




Scenario2: Optimal Solution at 4500 GPM

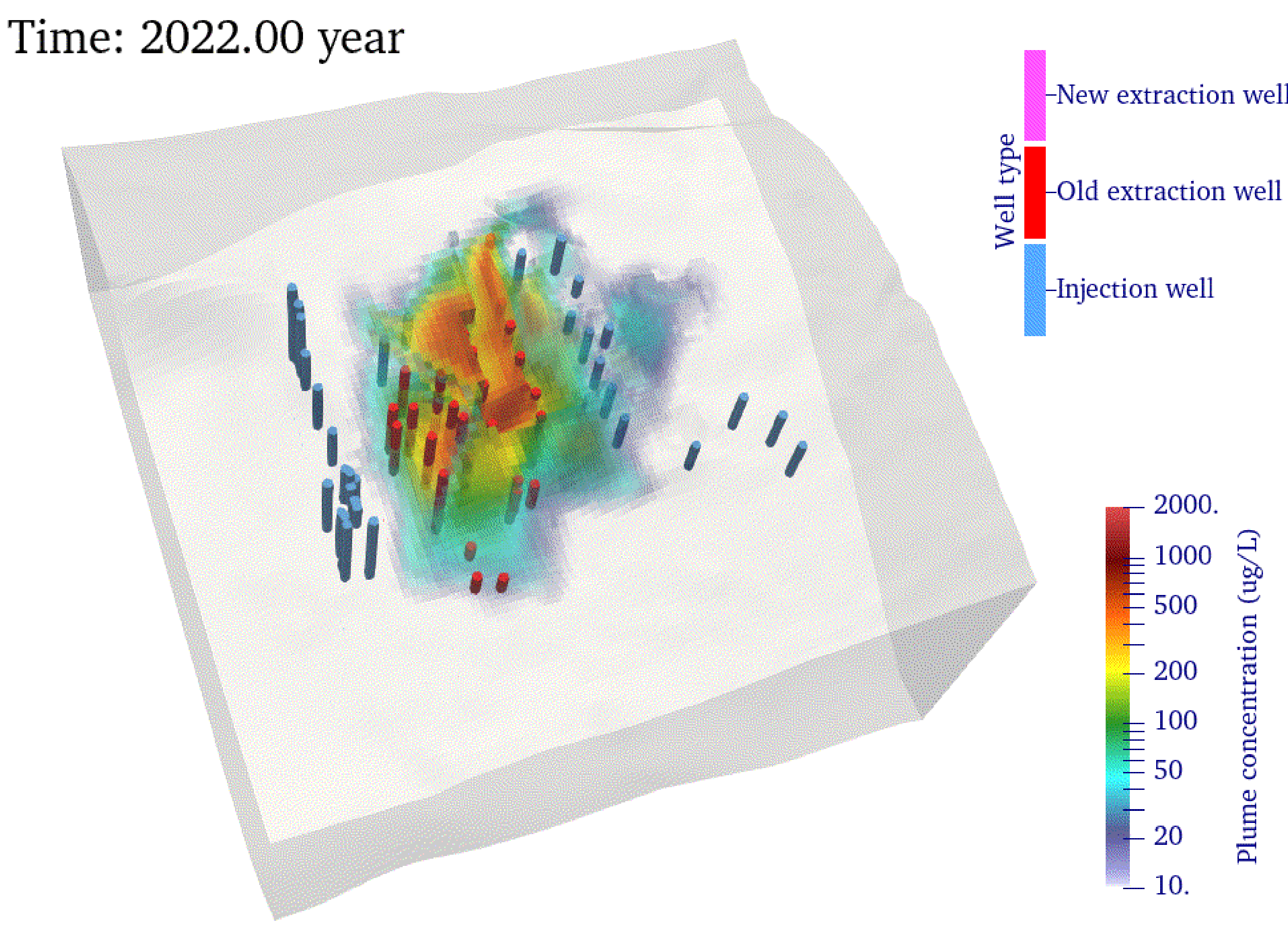
- Installation schedule and new well locations



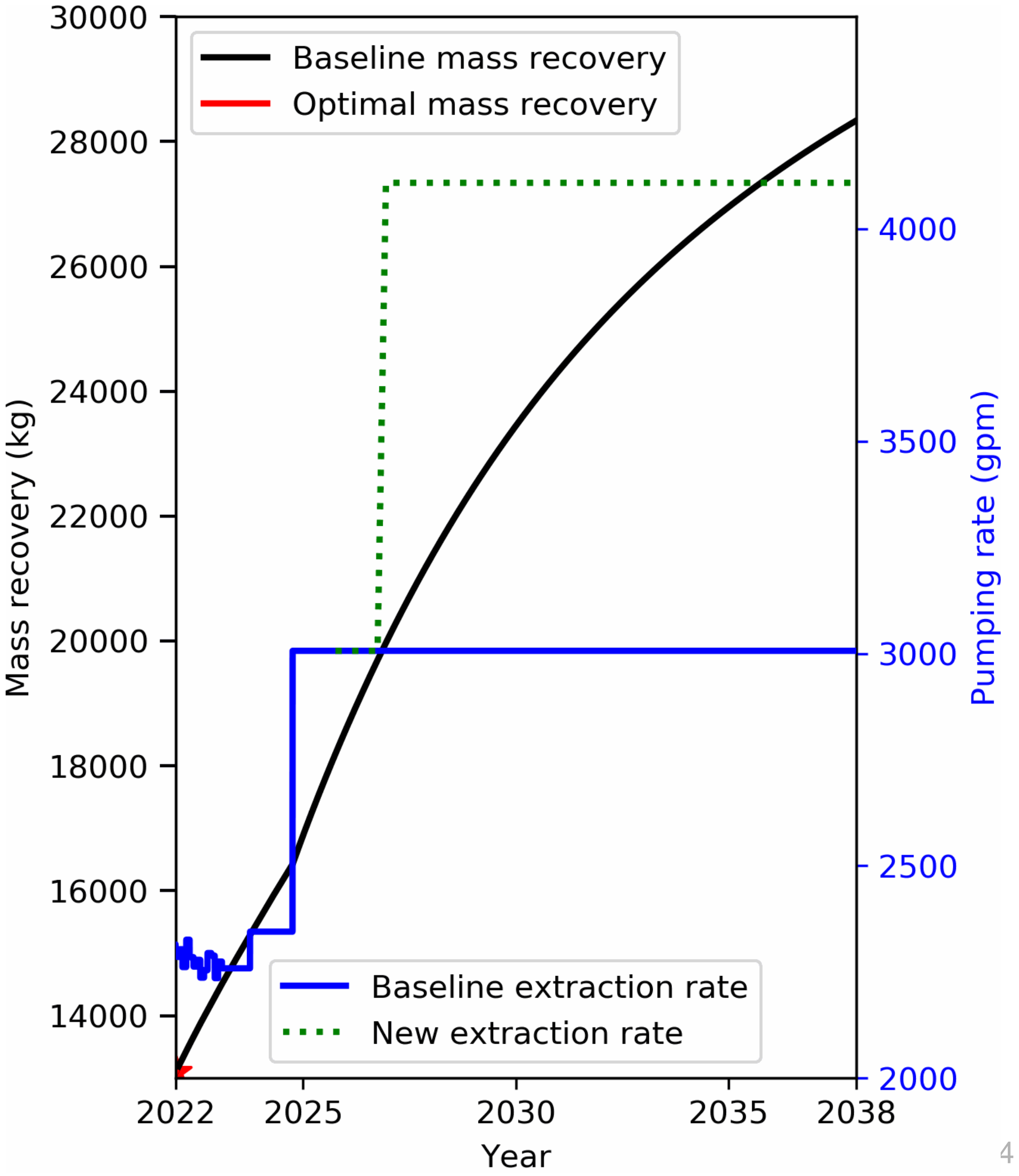


3D Animation of the Optimal Case

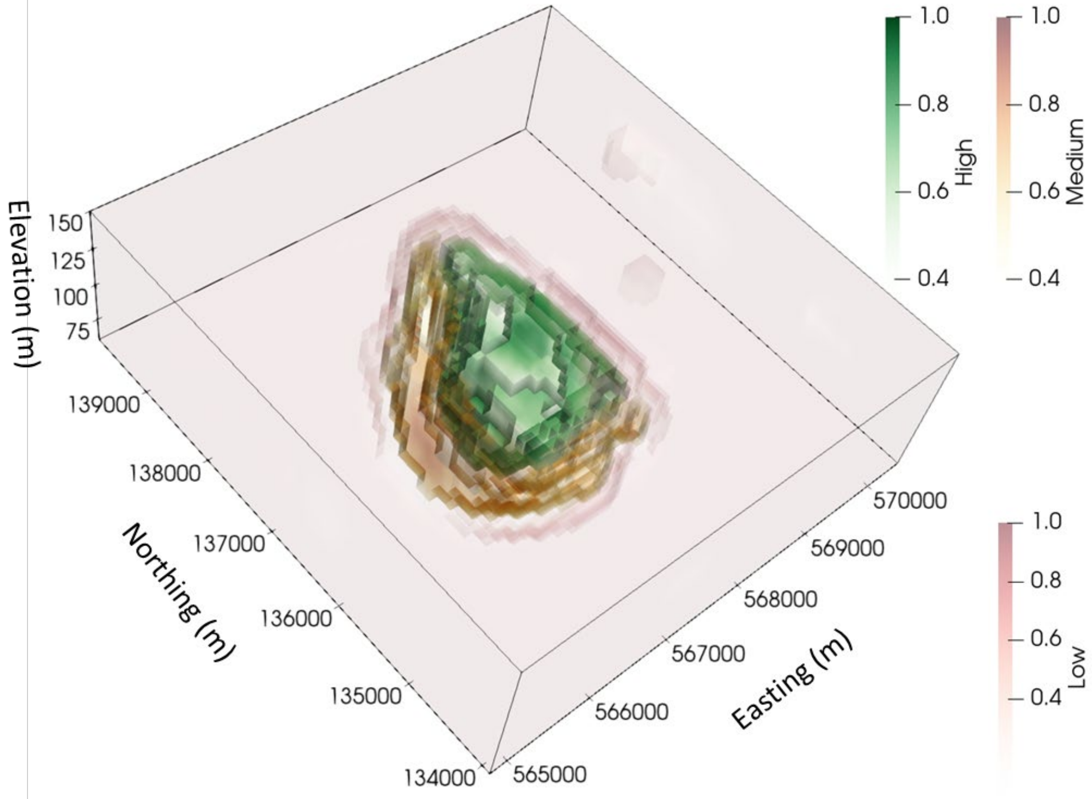
Predicted plume dynamics



Predicted mass recovery



Part 3 –
Use of Deep-Learning Approaches in the Pre-Screening Tool Framework



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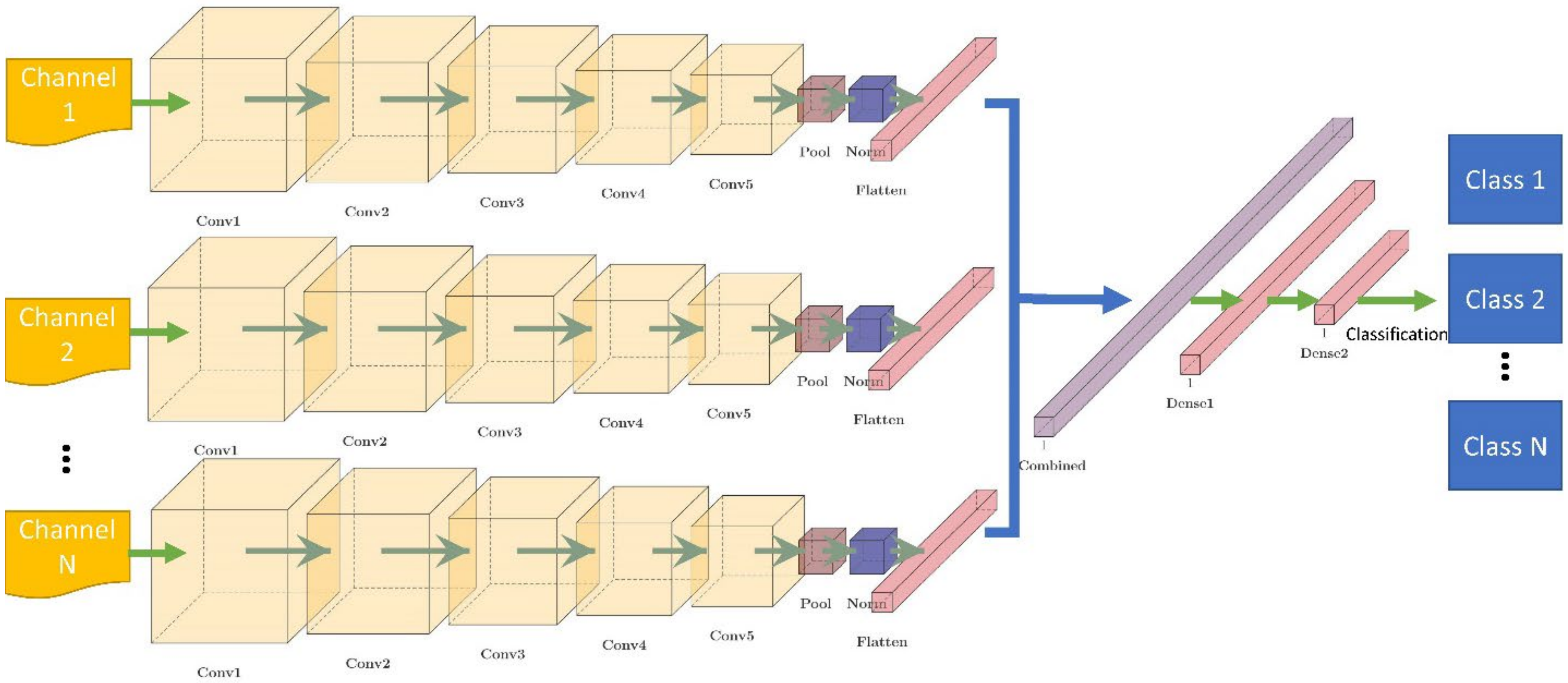
Alternative Approach: Well Location Selection

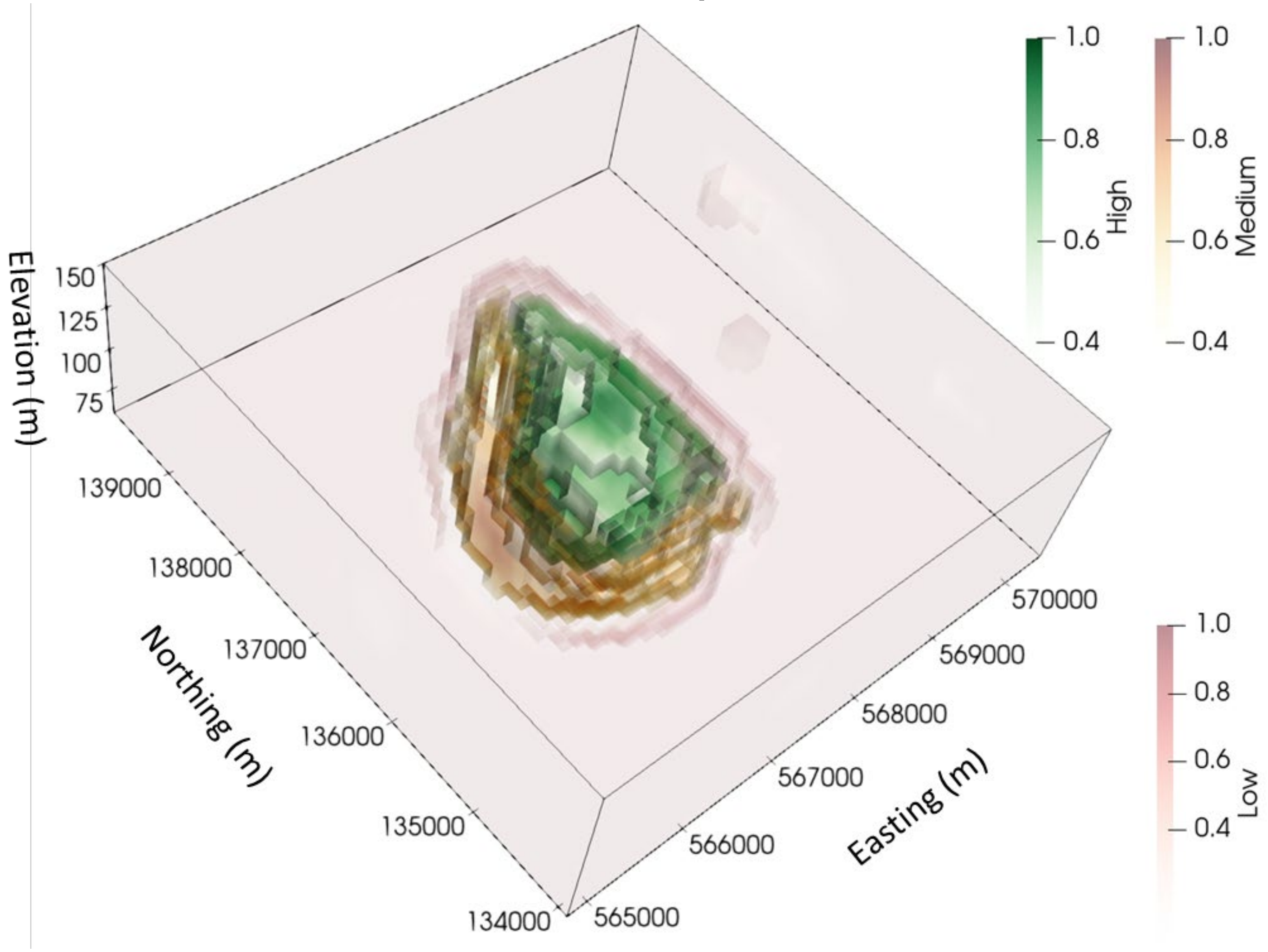
- A deep-learning model was developed for predicting extraction well performance for a given location in the model domain
  - Model relies on existing well performance data (2012-2023) and the data on site geology



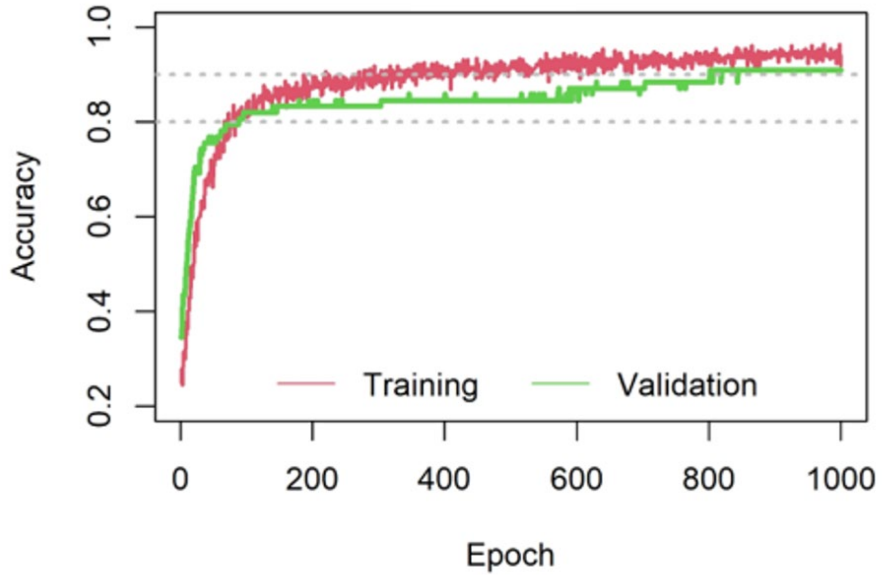
Multi-Channel Three-Dimensional Convolutional Neural Network (MC3D-CNN) framework

Deep Learning Model #1: A MC3D-CNN Framework for Well Performance Prediction

- The trained deep learning (DL) model was used to predict future well performance ranking on each 100×100×5 m pixel for entire model domain.



3D performance ranking map. Green, orange, and red colors indicate high, medium, and low performance rankings.

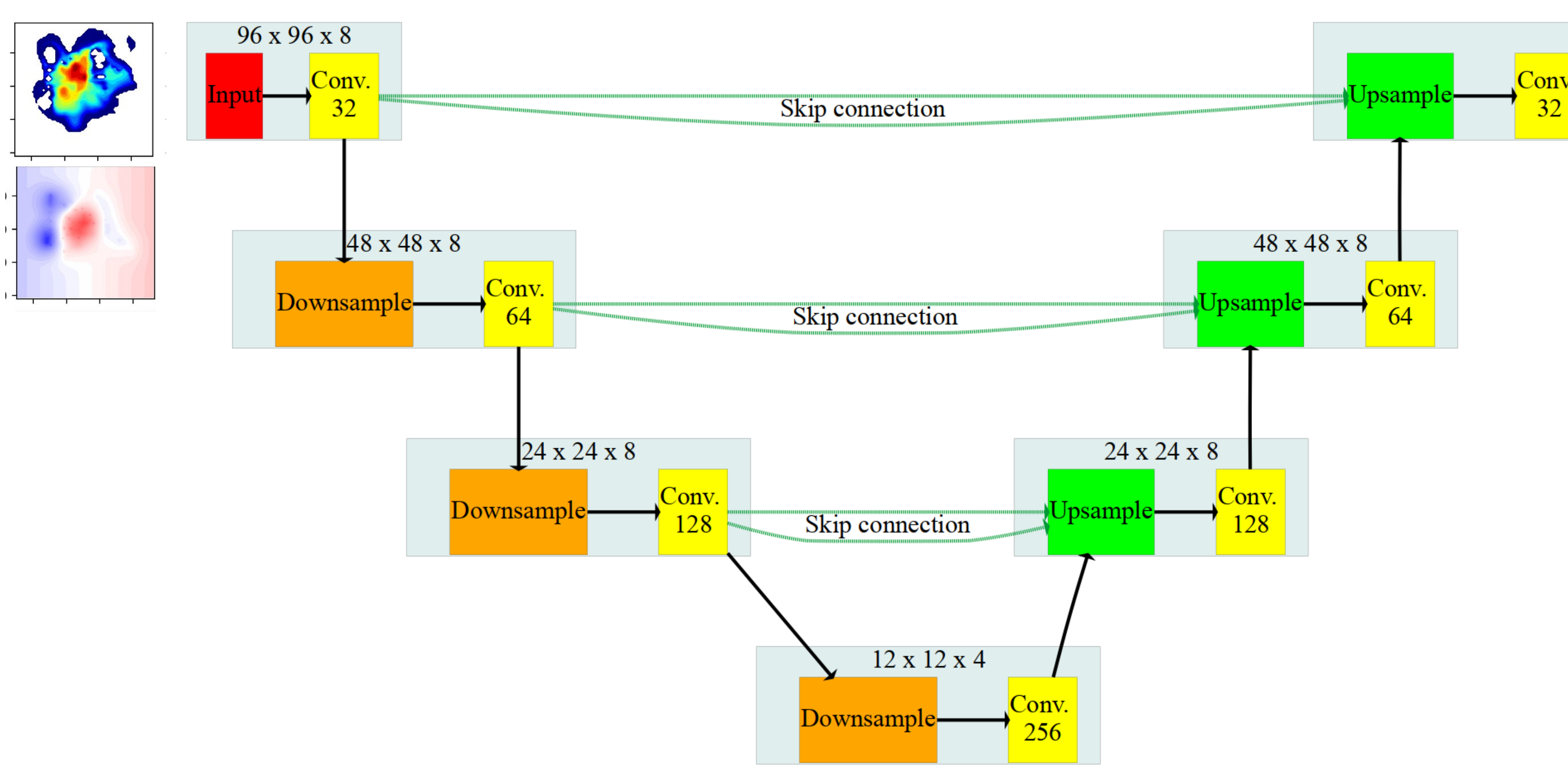


MC3D-CNN model accuracy during model training

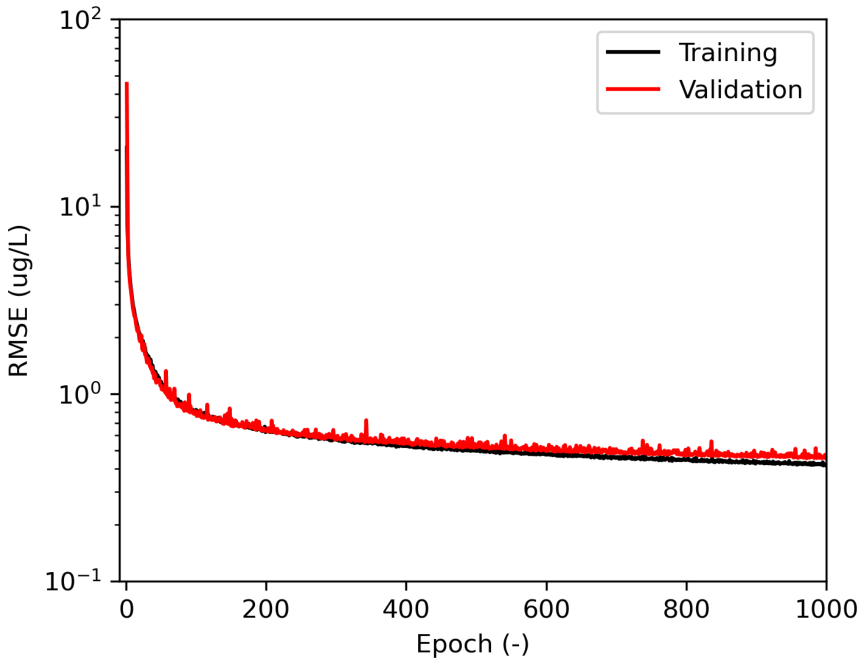
- Application of the MC3D-CNN DL model
  - Rebalance pumping rate of existing wells
  - Reduce number of candidate well locations for P&T optimization simulation
  - Integrate into flow and transport models to provide on-the-fly optimization of pumping rate

Alternative Approach: 3-D Plume Model

- An alternative deep-learning model is currently being developed to replace parts of the F&T model role in the pre-screening tool framework



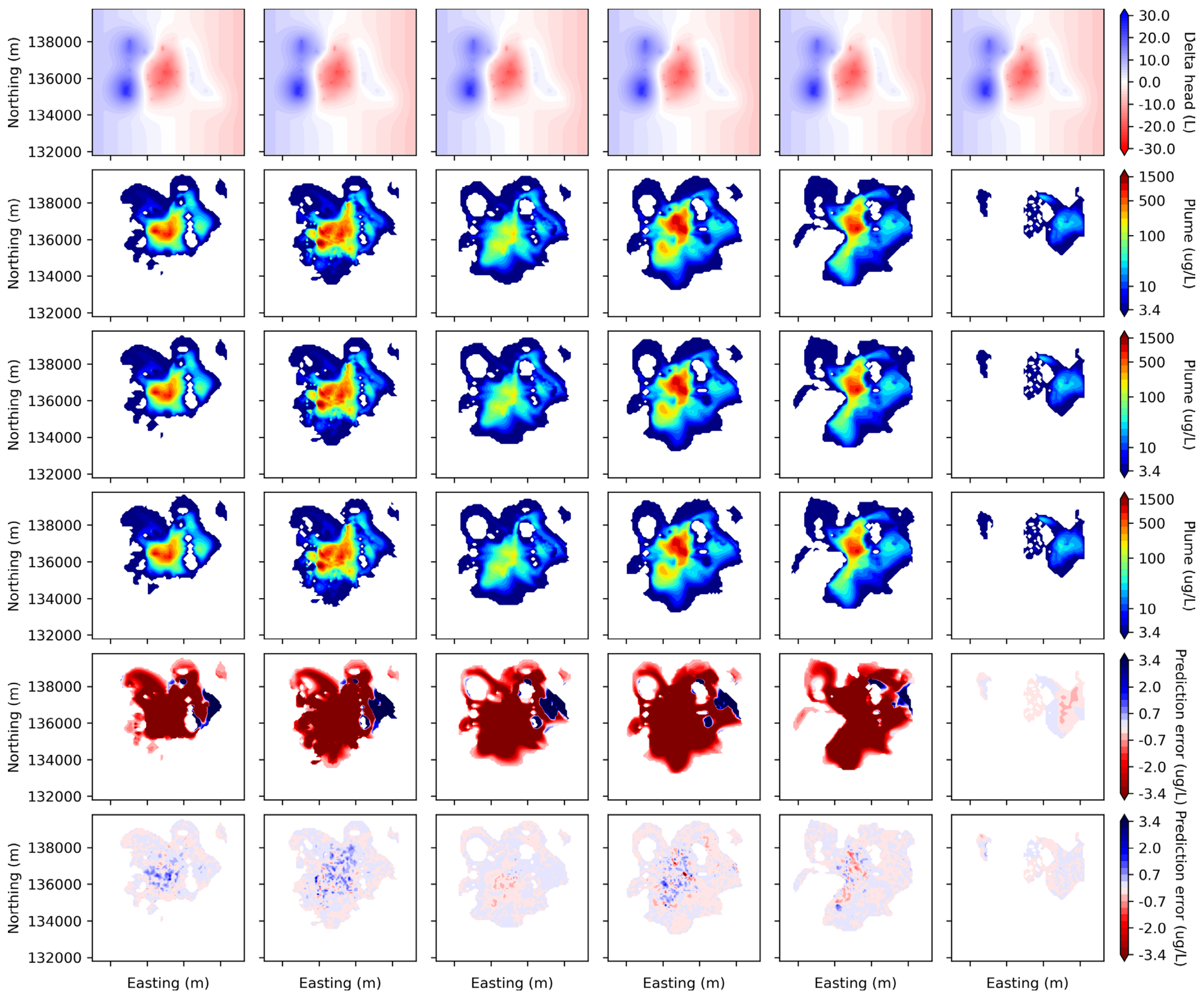
U-Net Convolutional Neural Network Model Structure



U-Net model accuracy during model training

Deep Learning Model #2: U-Net Architecture for 3-D Plume Prediction

- 100~1000 times faster surrogate model



Input #1: Thiem solution

Input #2: plume at year N

Target: plume at year N+1

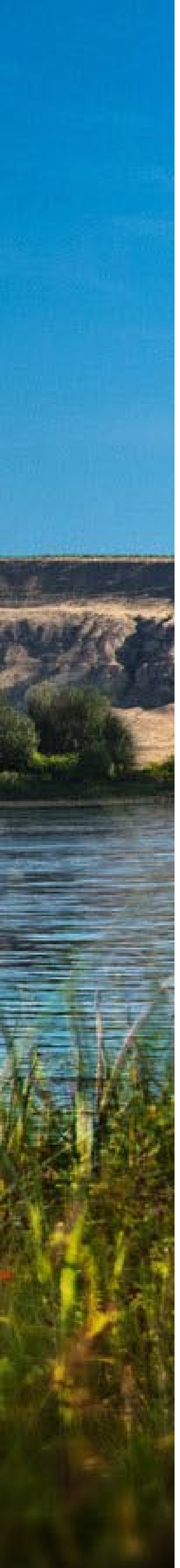
Prediction: plume at year N+1

Plume change over year N (row 3-row 2)

Prediction error (row 4-row2)

Conclusions

- P&T optimization pre-screening tool
  - Readily allows evaluation of system behavior for multiple scenarios
  - Leads to proposed active management strategies to achieve the defined optimization goals
- Formal optimization of a P&T well network was demonstrated
  - Well network size, well locations, and pumping operational strategy to meet optimization goals
  - Can include treatment capacity considerations
  - Results show potentially to reduce cleanup timeframe and increase mass recovery
- Optimal outcomes vary with optimization objectives and constraints
  - Maximum mass recovery selected as the optimization goal may not provide the shortest cleanup timeframe
- Deep-learning approaches can significantly improve computational application of the framework



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Questions?