

Machine Learning Guided Optimization (MLGO!) for Sustainable Groundwater Management and Decision Support



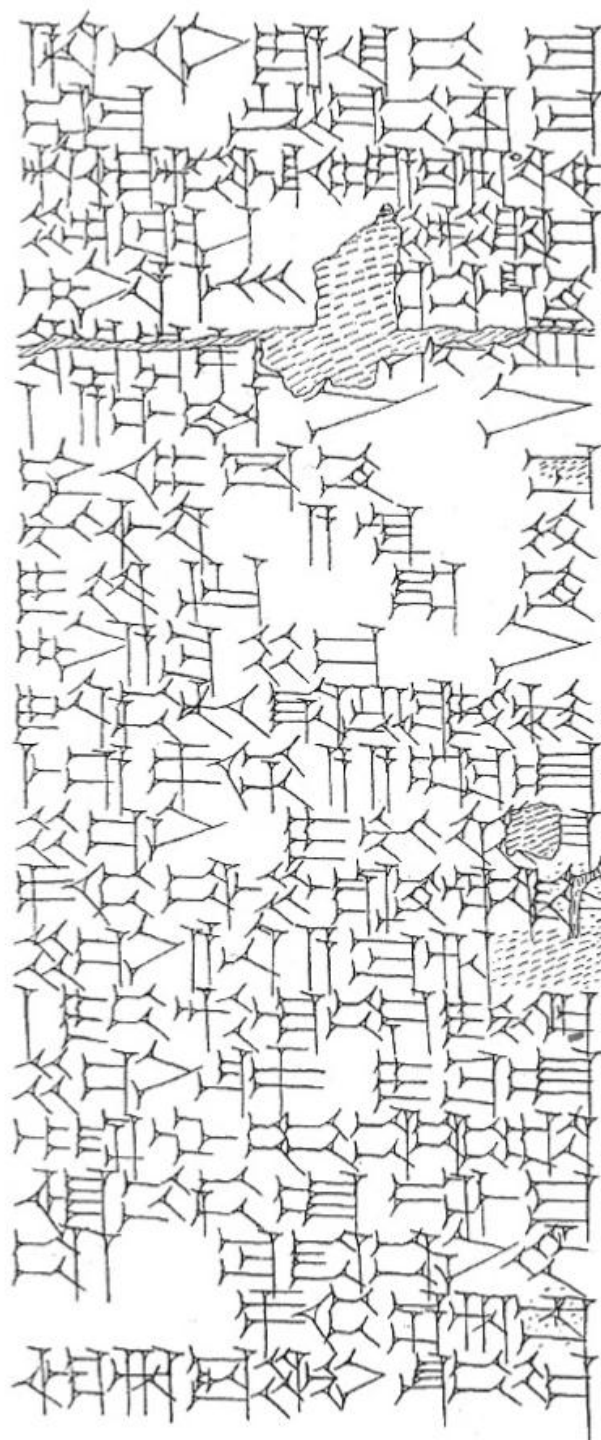
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Ancient Problems



<https://cdli.earth/artifacts/306542>



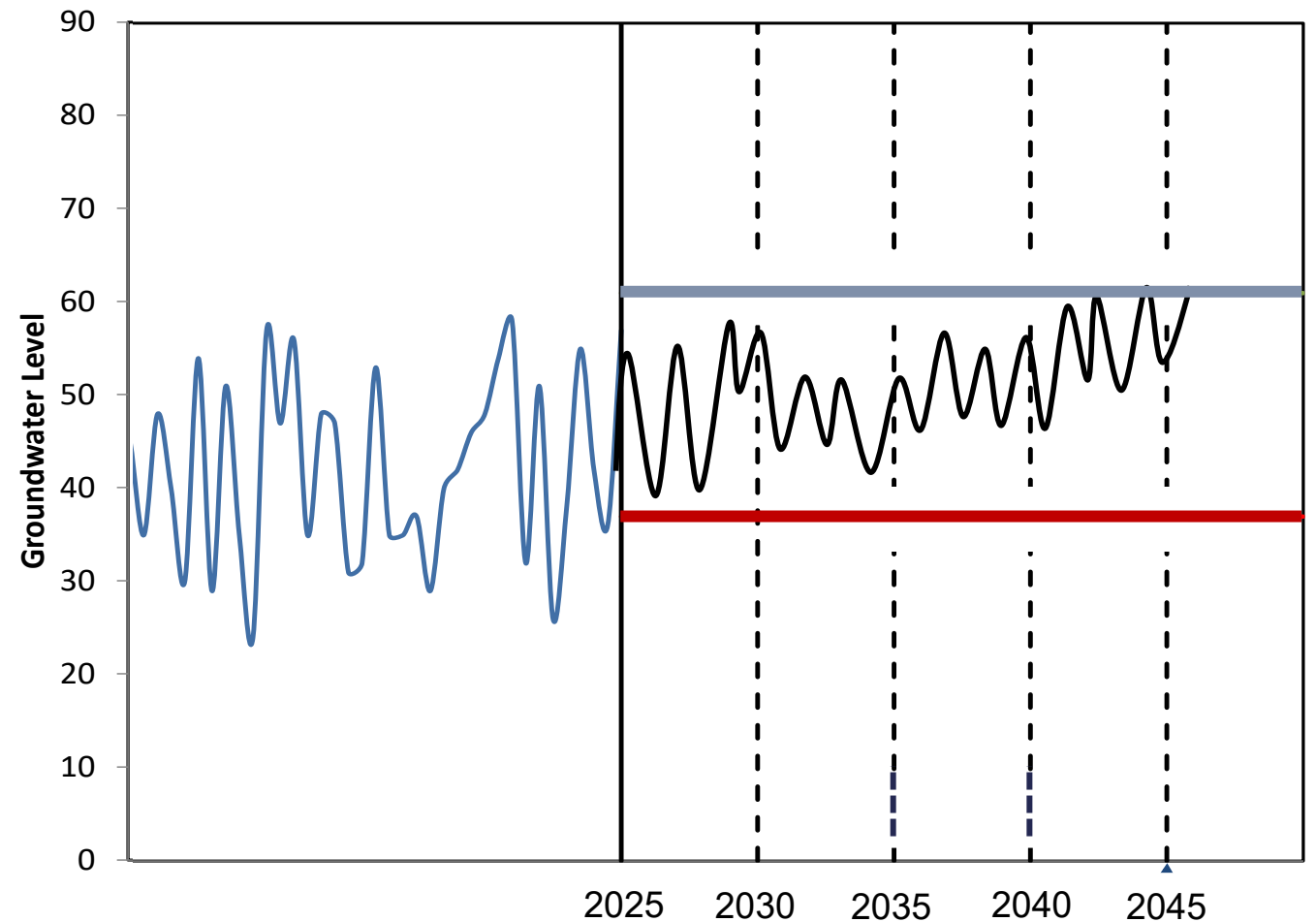
“As to the sesame field, I am not getting water from Sin-id-dinam's hands; The sesame will die.

Do not say "You did not write me"! [...] that sesame will die. I have written to you, let me hear what you say.”

Sin-Gamil, Babylonia, 1900 BC

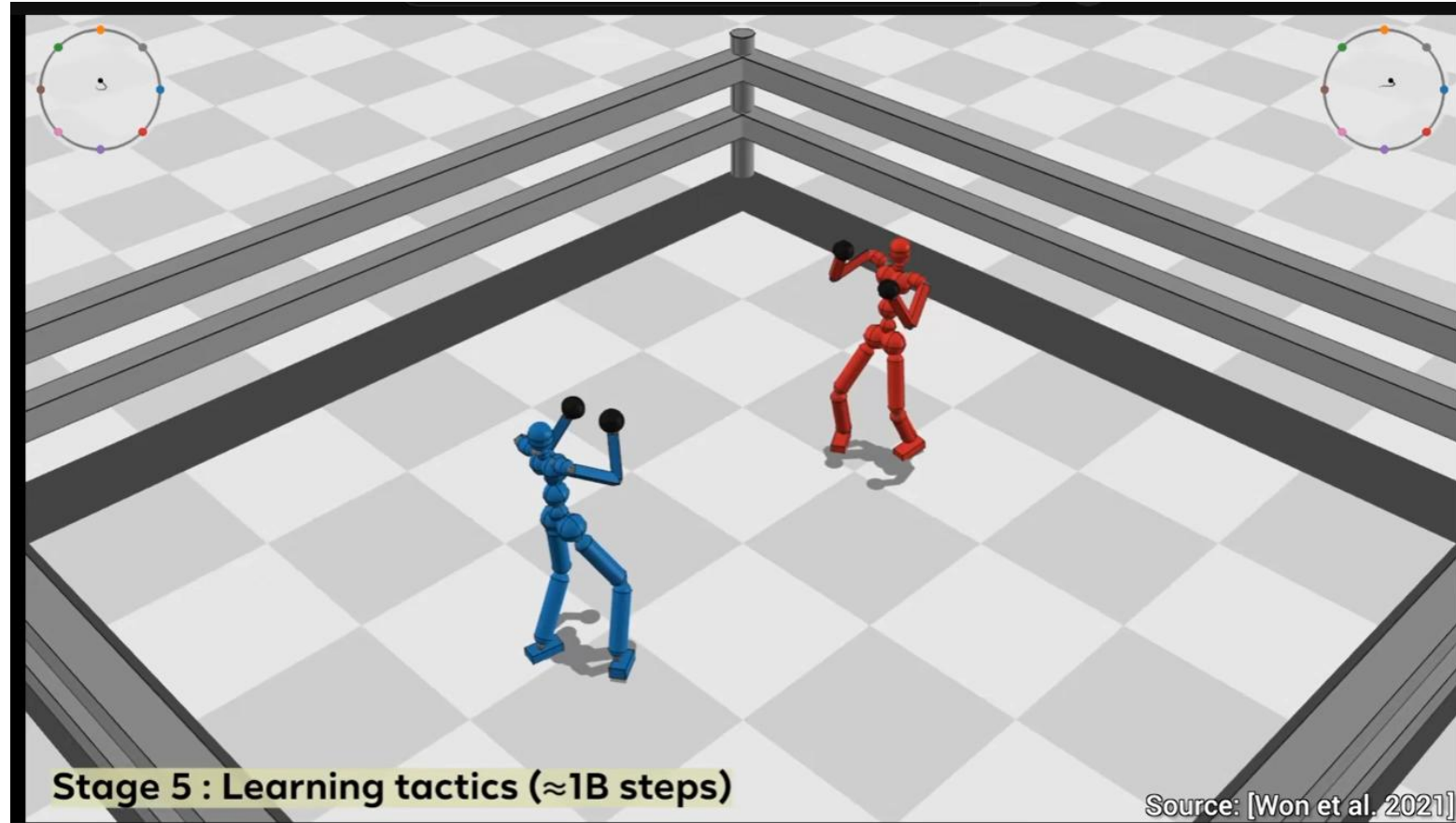
Modern Problems

- California has moved from GSP development, to GSP implementation
- Requires optimization of sustainability projects
- Physical groundwater models preferred due to inherent physics
- Time-consuming optimization process
 - Complex multi-objective optimization frameworks
 - Long groundwater model runtimes



Modern Solutions

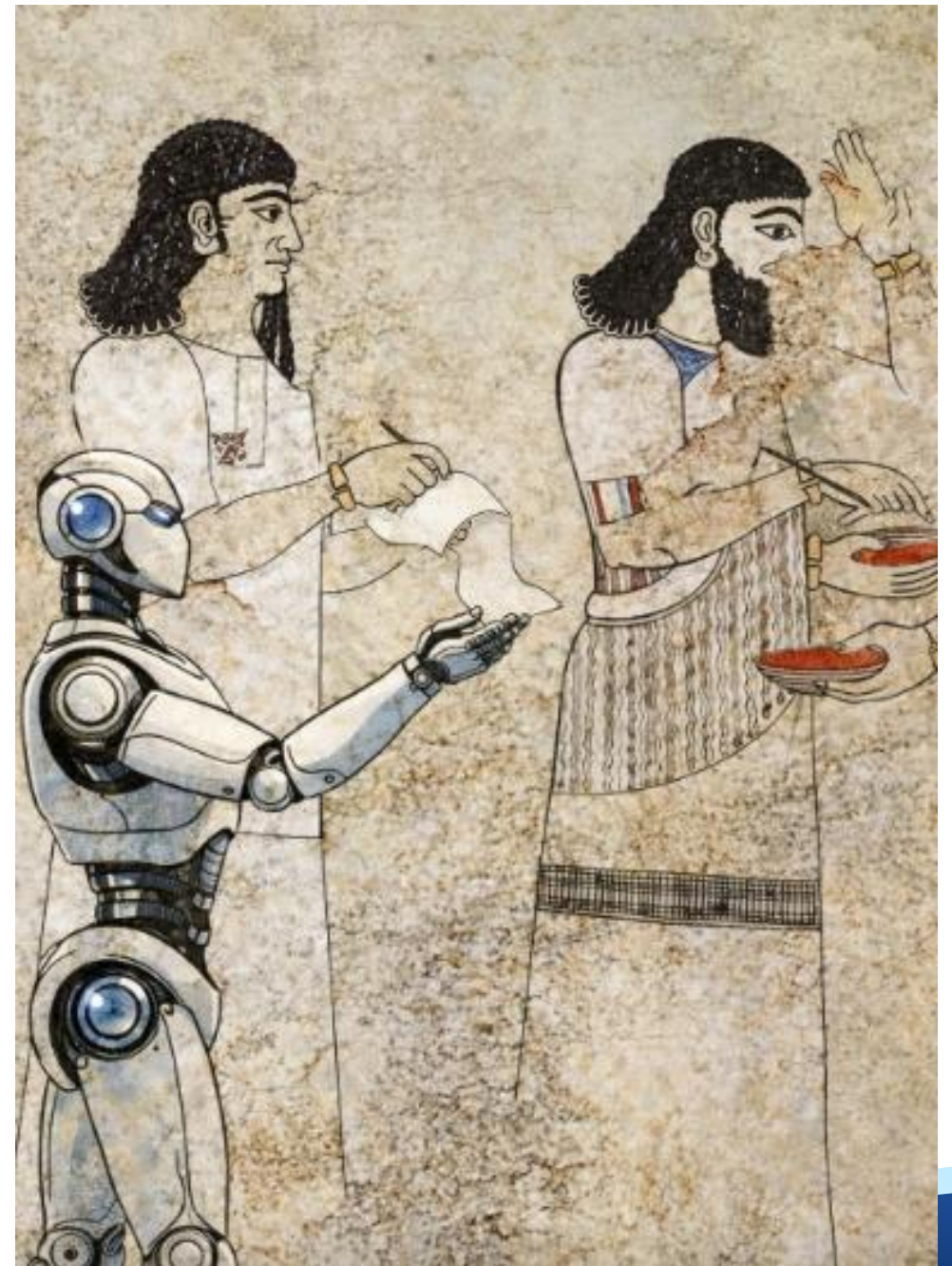
- What if an ML tool could run a physical model on its own, and 'play' it like a game?
- Could this tool could learn from its mistakes and 'evolve' over time?
- Could it help us optimize groundwater management systems?



<https://research.facebook.com/file/559394838468486/Control-Strategies-for-Physically-Simulated-Characters-Performing-Two-player-Competitive-Sports.pdf>

MLGO!

- **M**achine **L**earning **G**uided **O**ptimization (MLGO!)
- AI tool to autonomously create, run, and evaluate physical model simulations
- Can discover new water management solutions!
- Can help solve complex problems



Lets Get MLGO-ing! – Optimization Framework

Quantify outcomes

- Sustainability
- Feasibility
- Supply goals
- Contamination
- Cost

Quantify management options

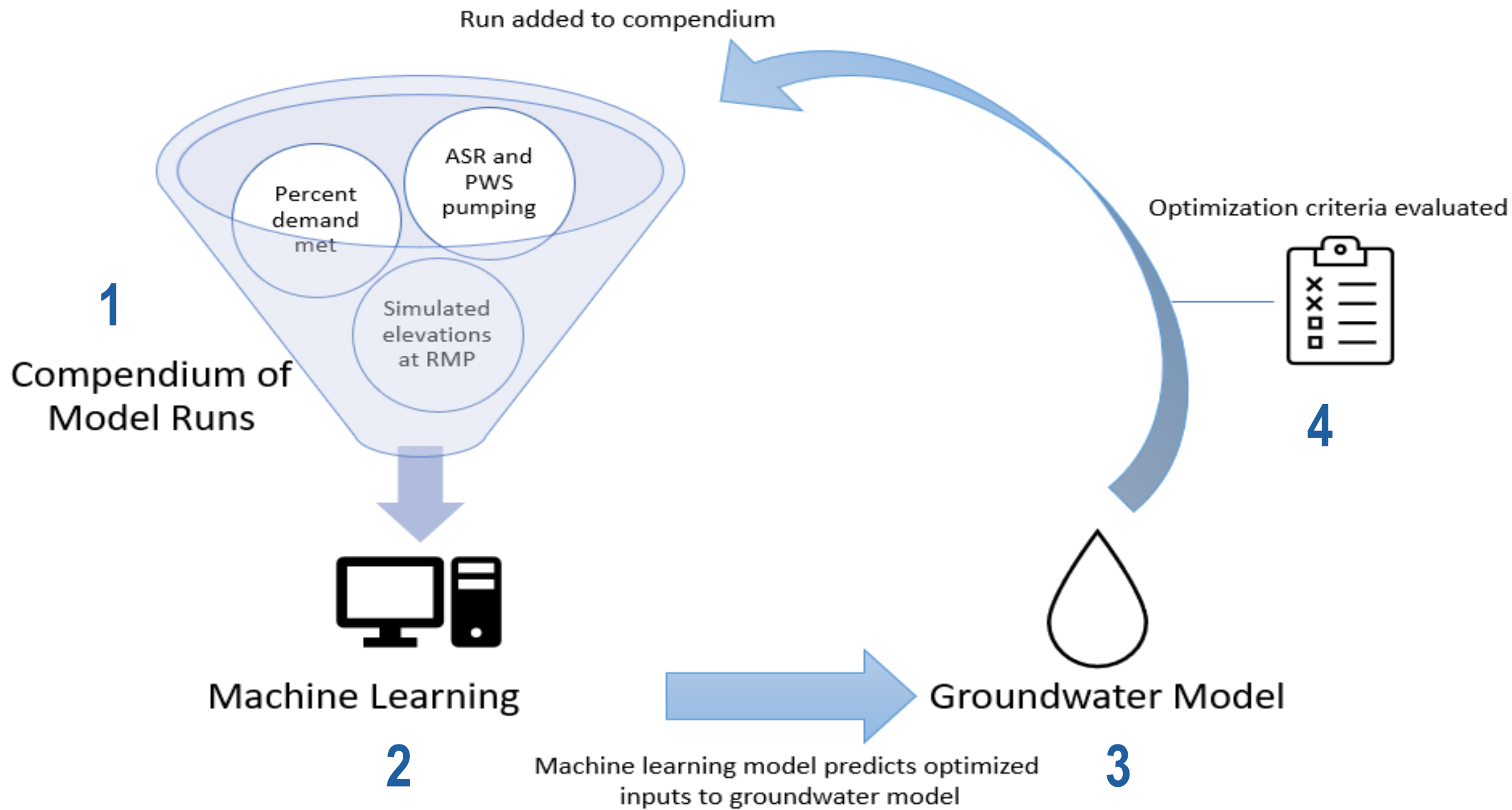
- Recharge well placement
- Extraction well placement
- Injection volumes
- Pumping volumes
- Transfer volumes

(X Tensor)

Inverse Modeling

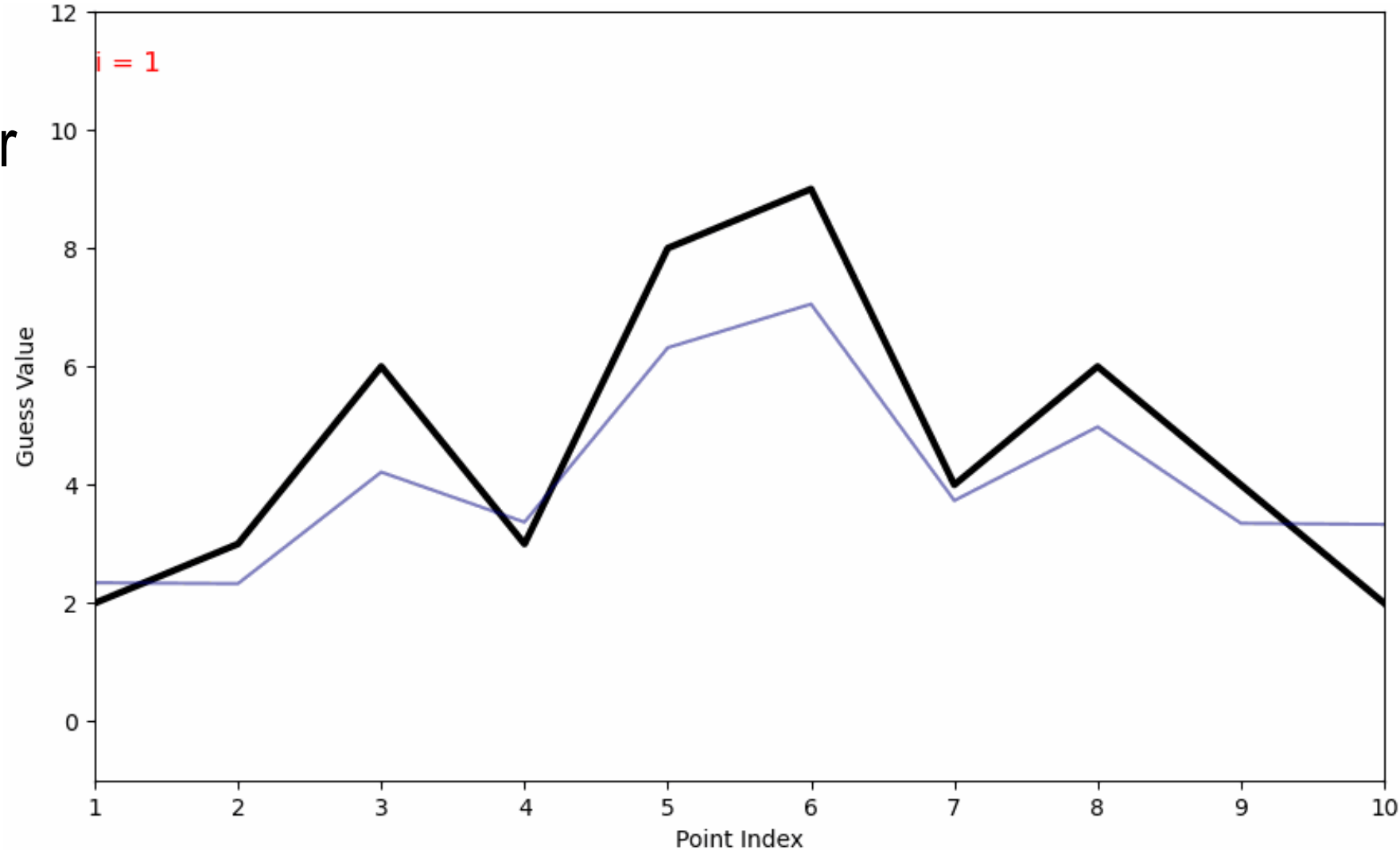
(Y Tensor)

Given ideal outcomes, predict ideal management



Simple Example

- MLGO plays a number guessing game
- After each attempt, guesses and error are recorded for training
- Understands system relatively quickly





Mid-County Groundwater Basin Optimization Study



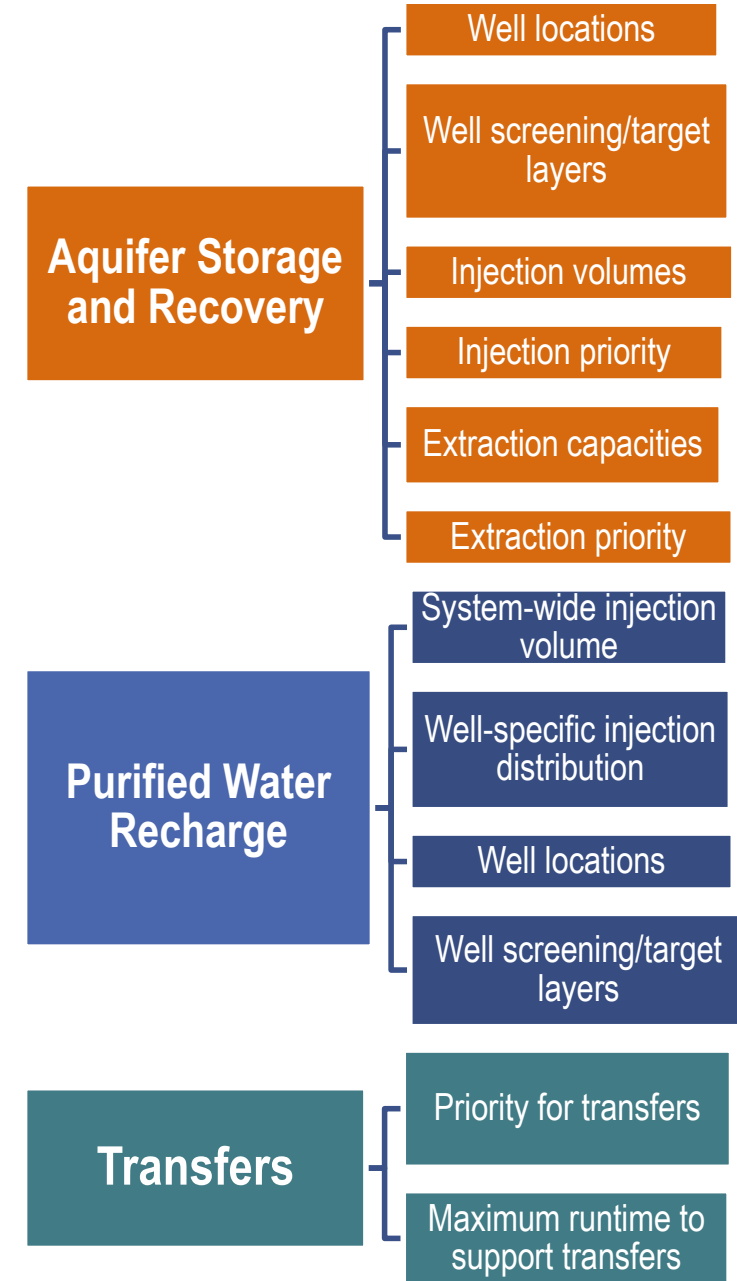
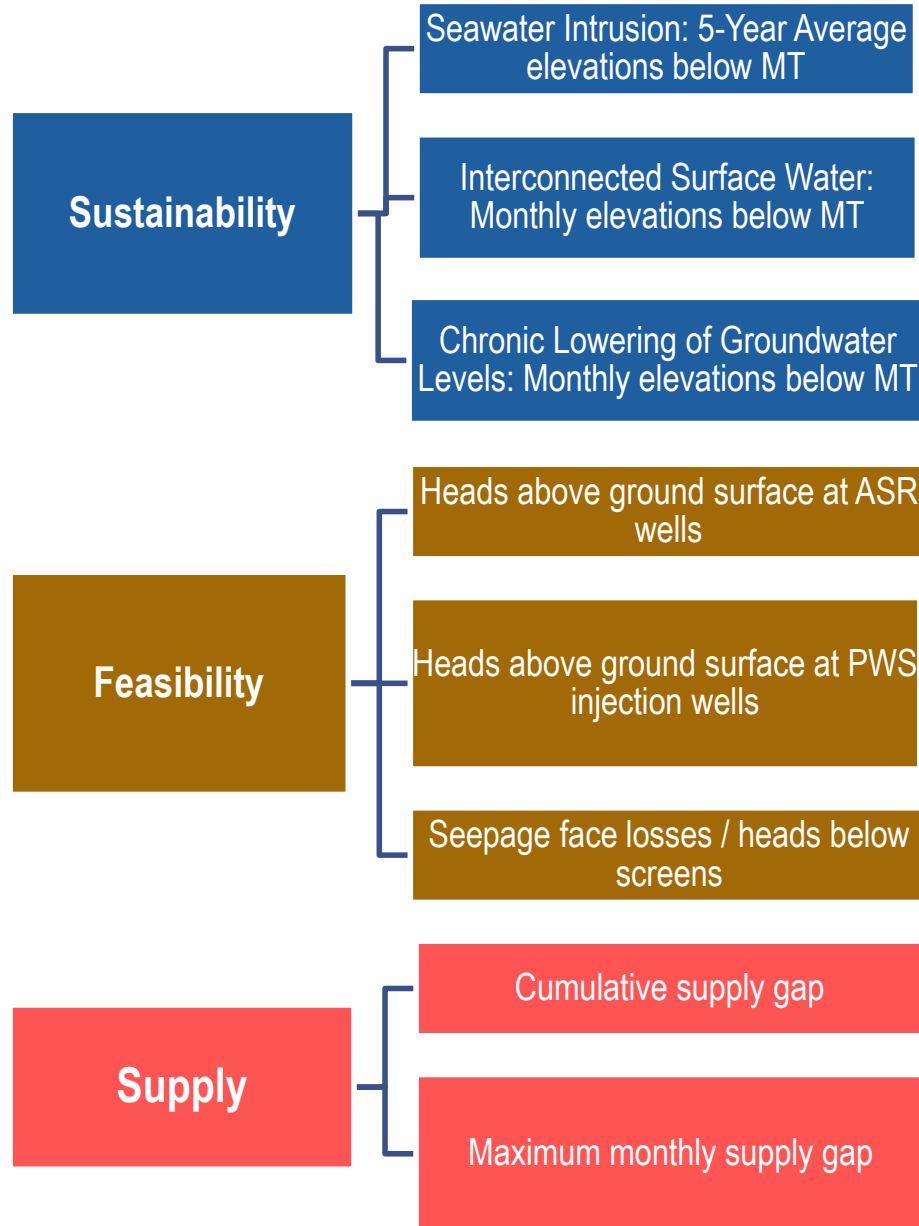
- Critically overdrafted coastal Basin
- Two agencies share the basin
 - Soquel primarily uses groundwater
 - Santa Cruz primarily uses surface water
- Sustainability projects are planned:
 - Aquifer storage and recovery (ASR),
 - Pure Water Soquel (PWS) purified water recharge
 - Interagency transfers
- *Can we better optimize these projects?*



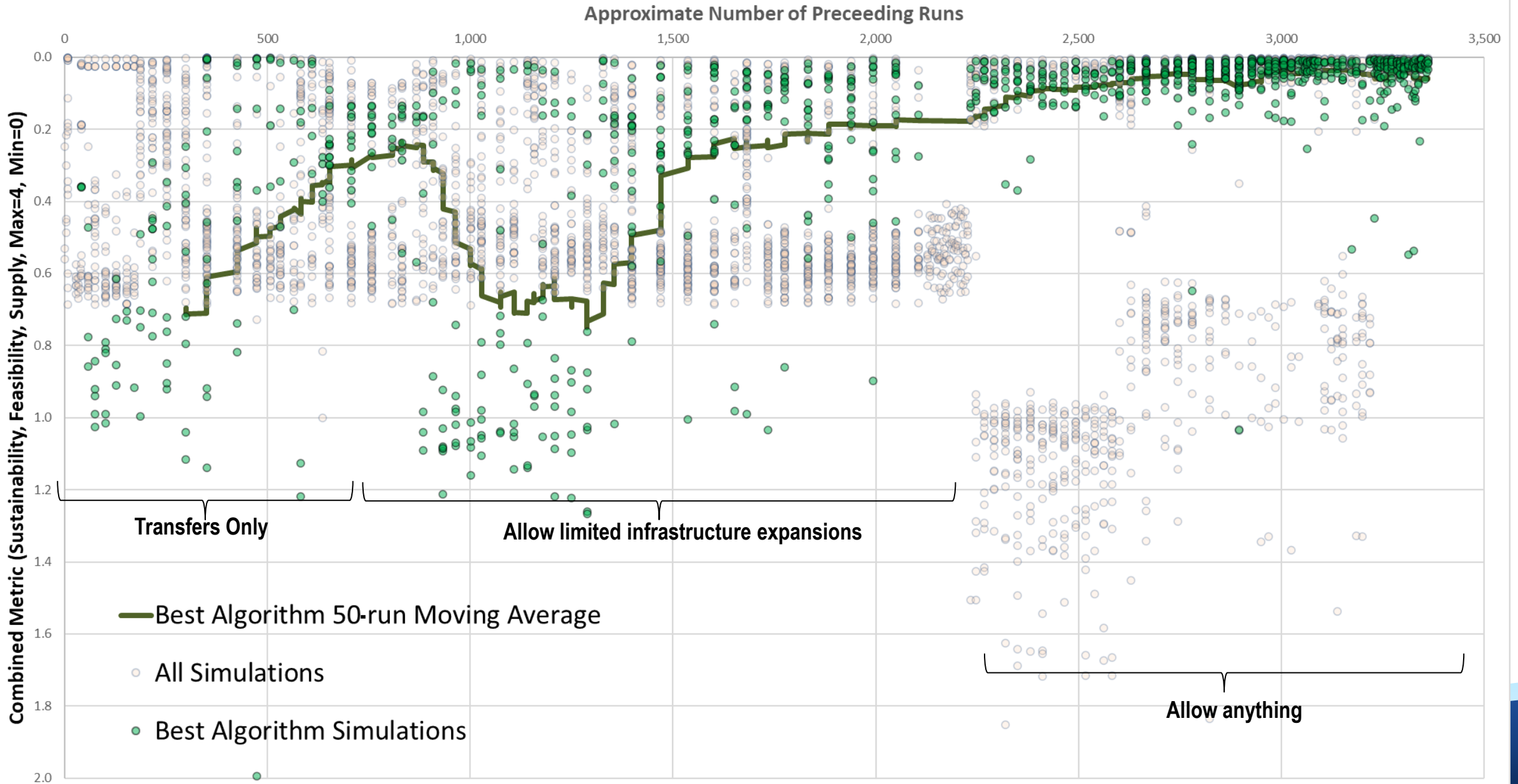
Outcomes (58)

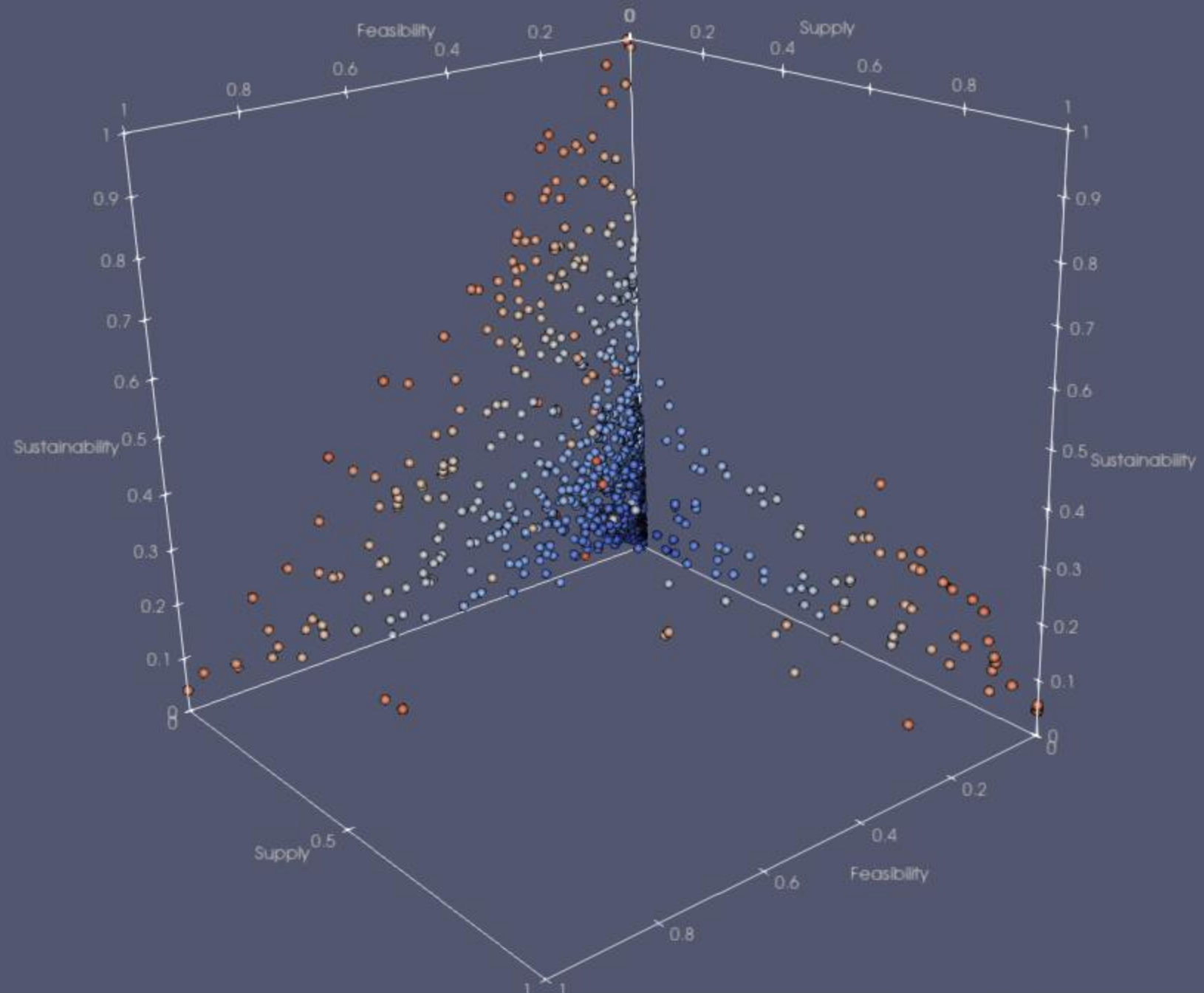


Management Parameters (119)



Learning Over Time

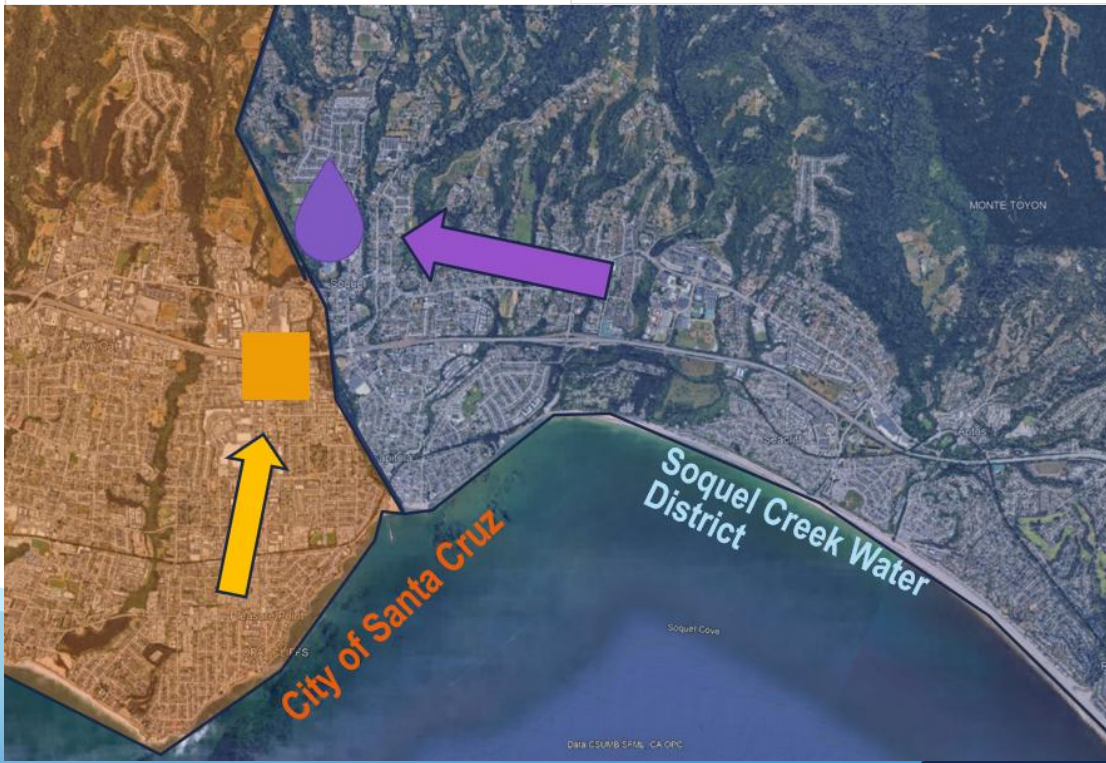
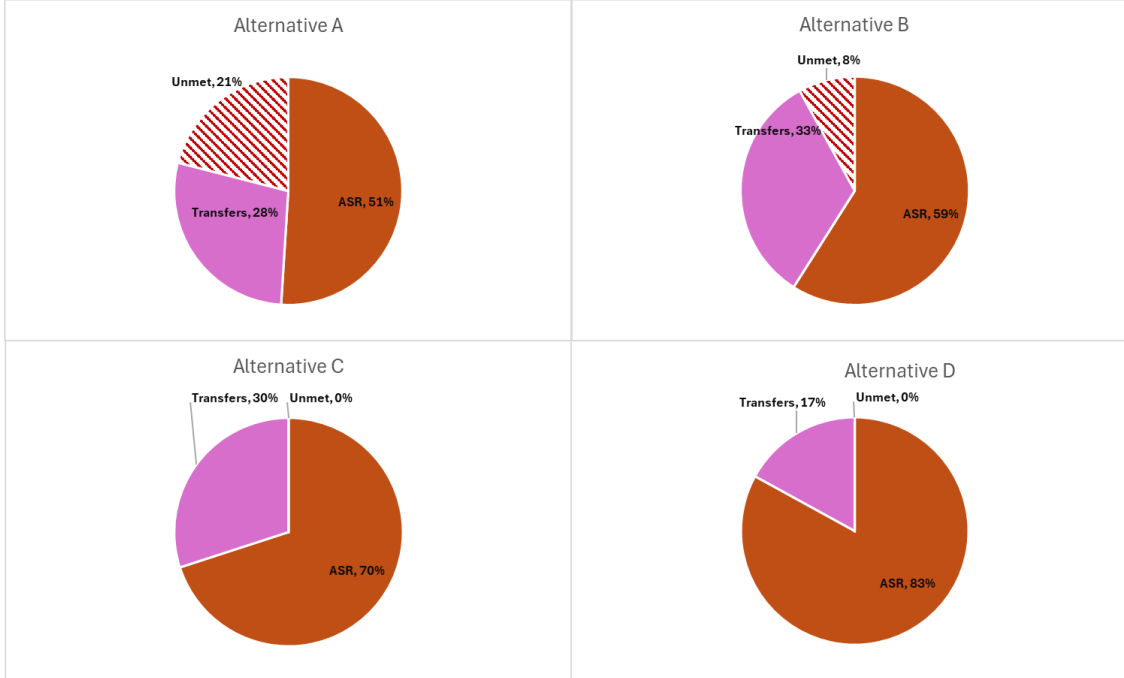


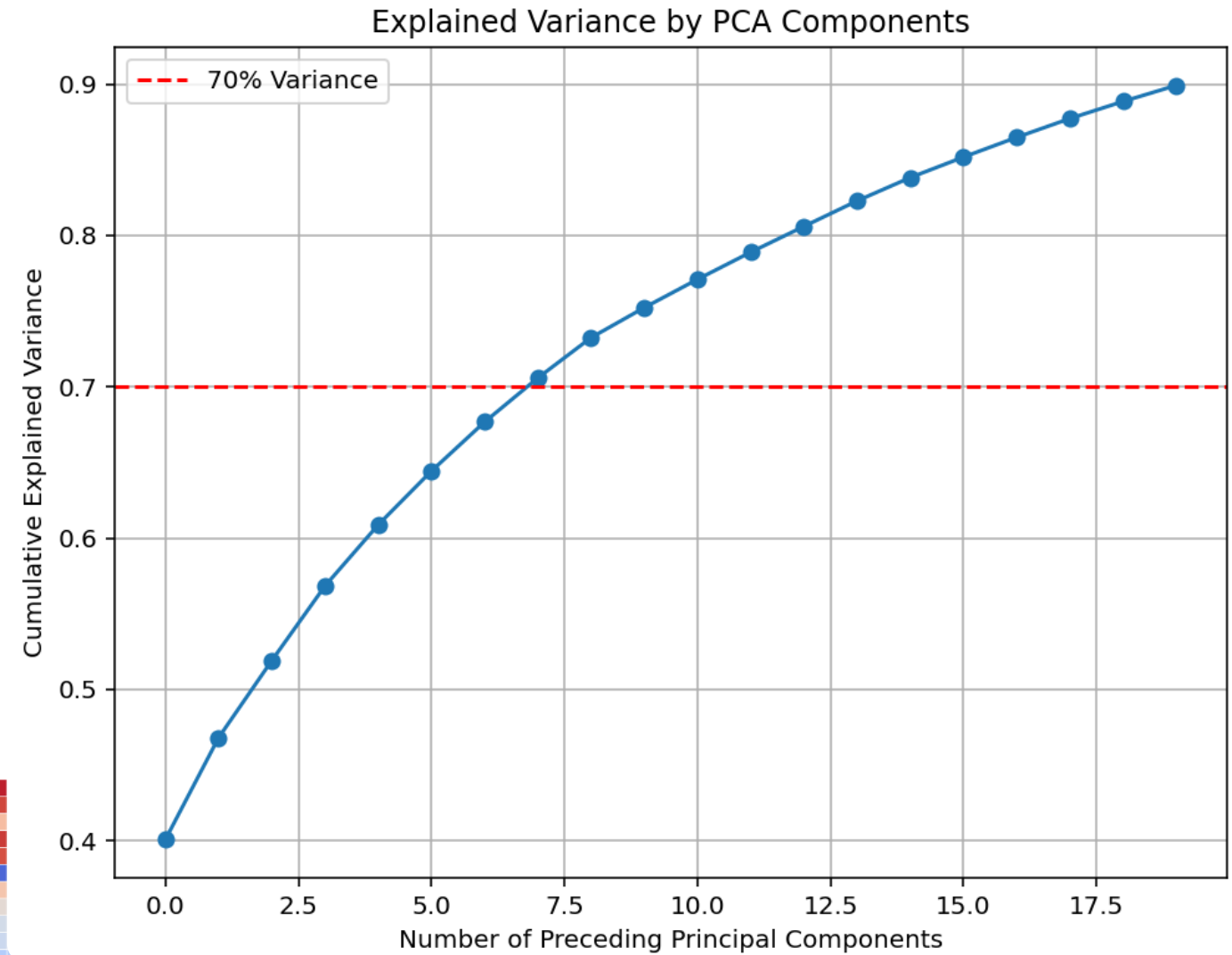
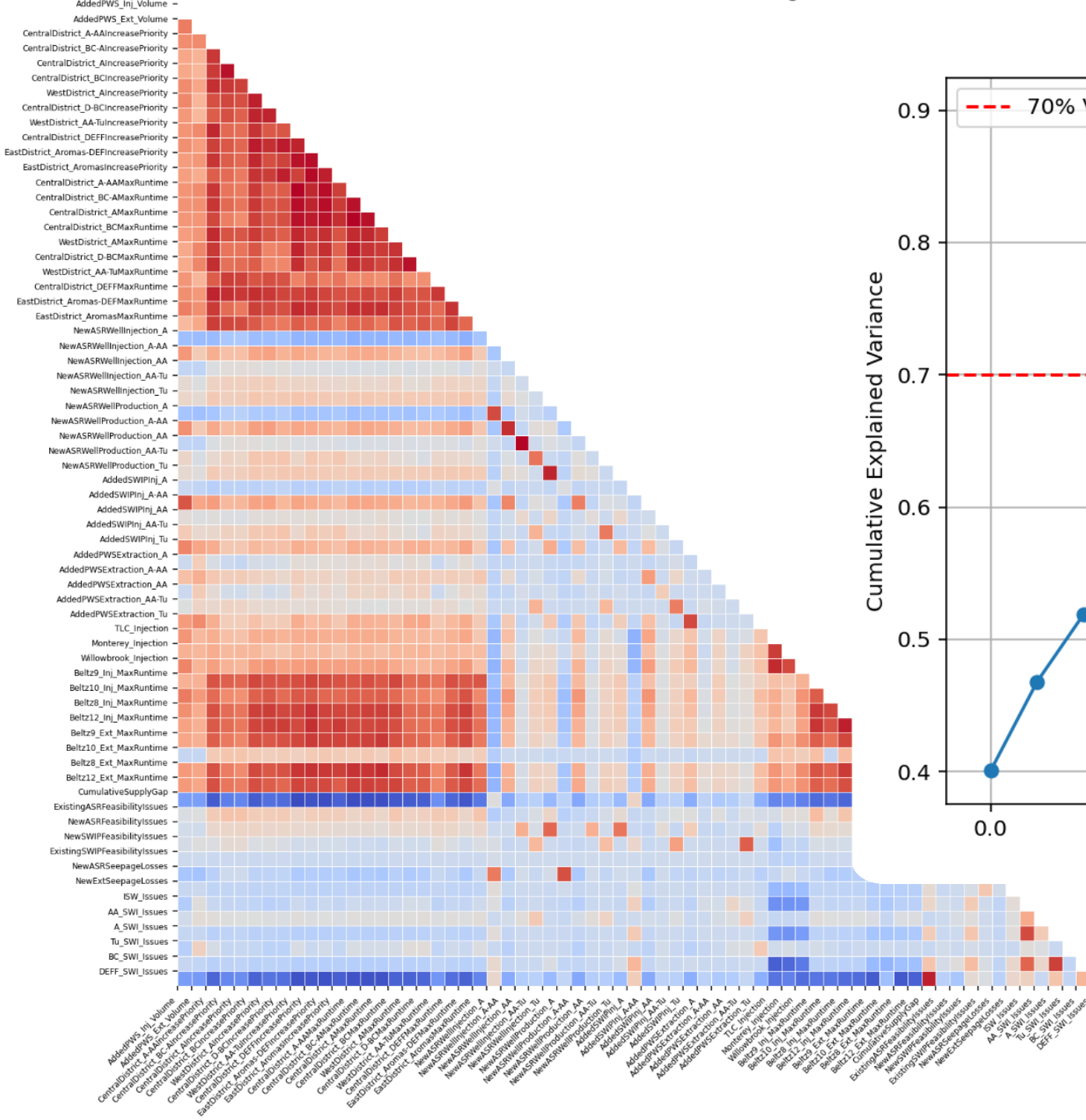


Alternative Futures

Sustainable options to fill the supply gap

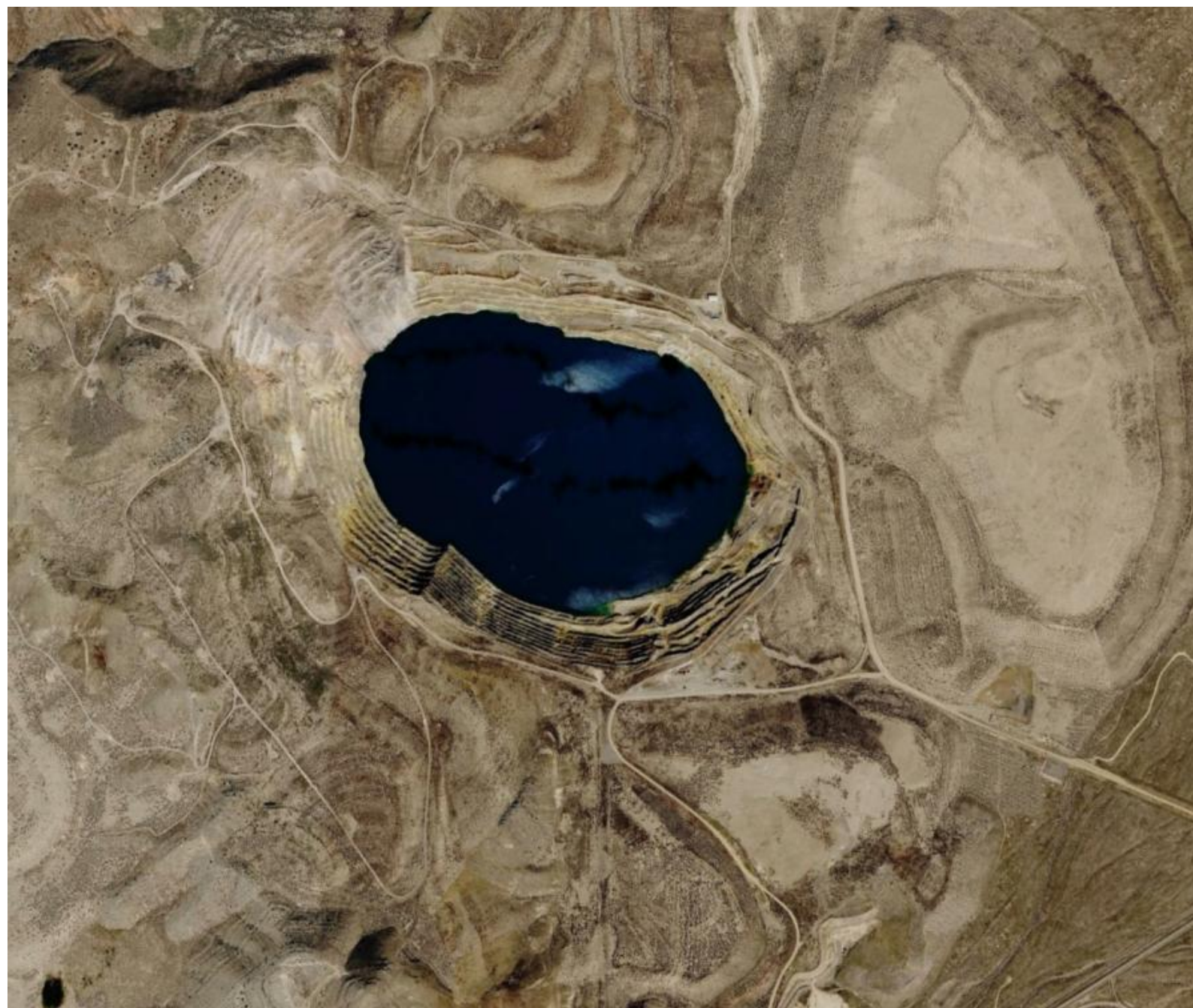
- Hundreds of viable options, and dozens of excellent ones
- Able to recommend many different reasonable strategies
- MLGO trended towards symbiotic management -- infrastructure that benefits both agencies





Mine Dewatering Study

- Historical mining operation
- Mining stopped decades ago
- Mine restarting but huge pit lake present
- How to effectively dewater the workings?



Outcomes (<5)

Cost – Residual Passive Inflow

Well Installation Costs

Pit Pumping Costs

Capital Expenditure (CAPEX)

Operational Expenditure (OPEX)

Management Parameters (>50)

Well Placement

Well Installation Date

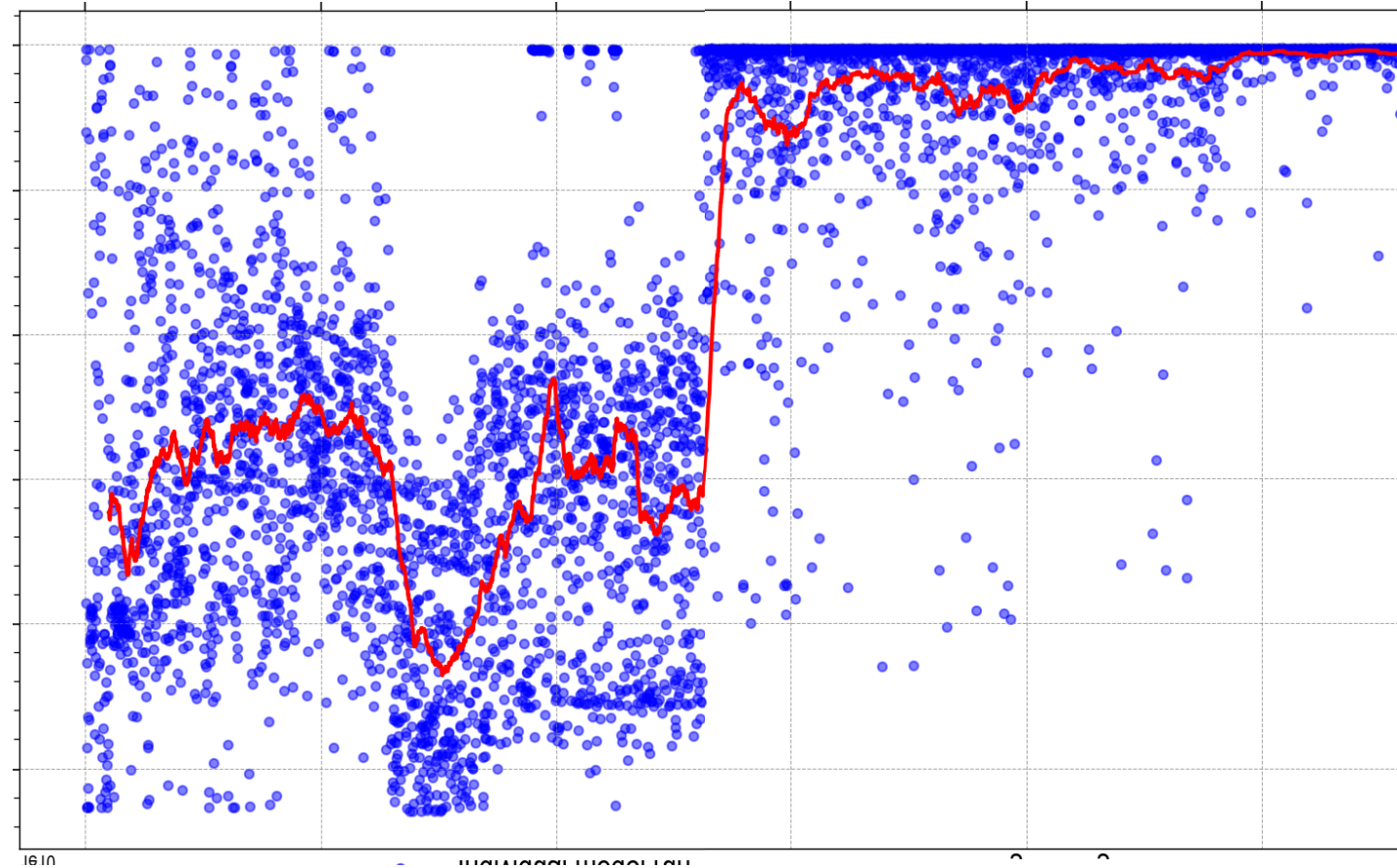
(Each of these for n
number of wells)

Well Pumping Rate



Learning Over Time - Adaptation

- Difficult problem - many very different setups result in nearly identical outputs
- Cloud computing
- Exploring many different unique options - but not converging fast enough
- New algorithm incorporated into MLGO workflow:
 - Sample forward surrogate model with Bayesian algorithm
 - Very good at sorting through data



(Management)

Forward Modeling

(Outcomes)

How MLGO Improved Project Outcomes

- Explored options autonomously
- Identified new unique solutions
- Added confidence
- *Helped solve complex groundwater management problems*

Questions and Acknowledgements



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