



Balancing environment and economy in an agricultural basin: Moving beyond scenarios with multi-objective optimization

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Project Background

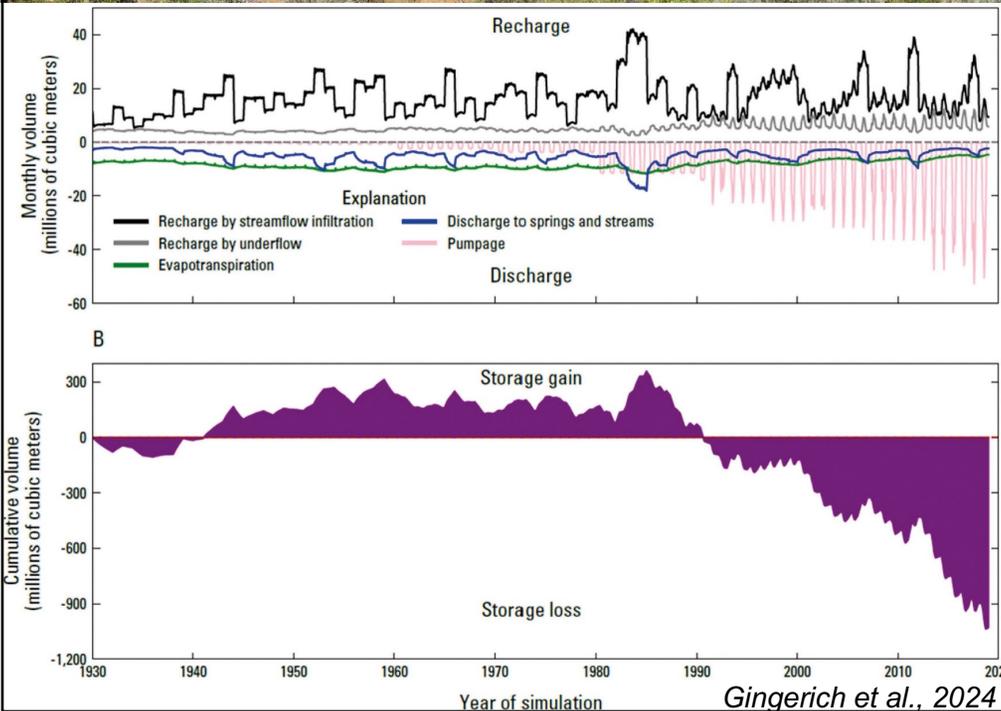


Harney Basin, southeastern Oregon

Primary crop: alfalfa

Permitted pumping for irrigation started increasing in 1990's, leading to water level/storage declines

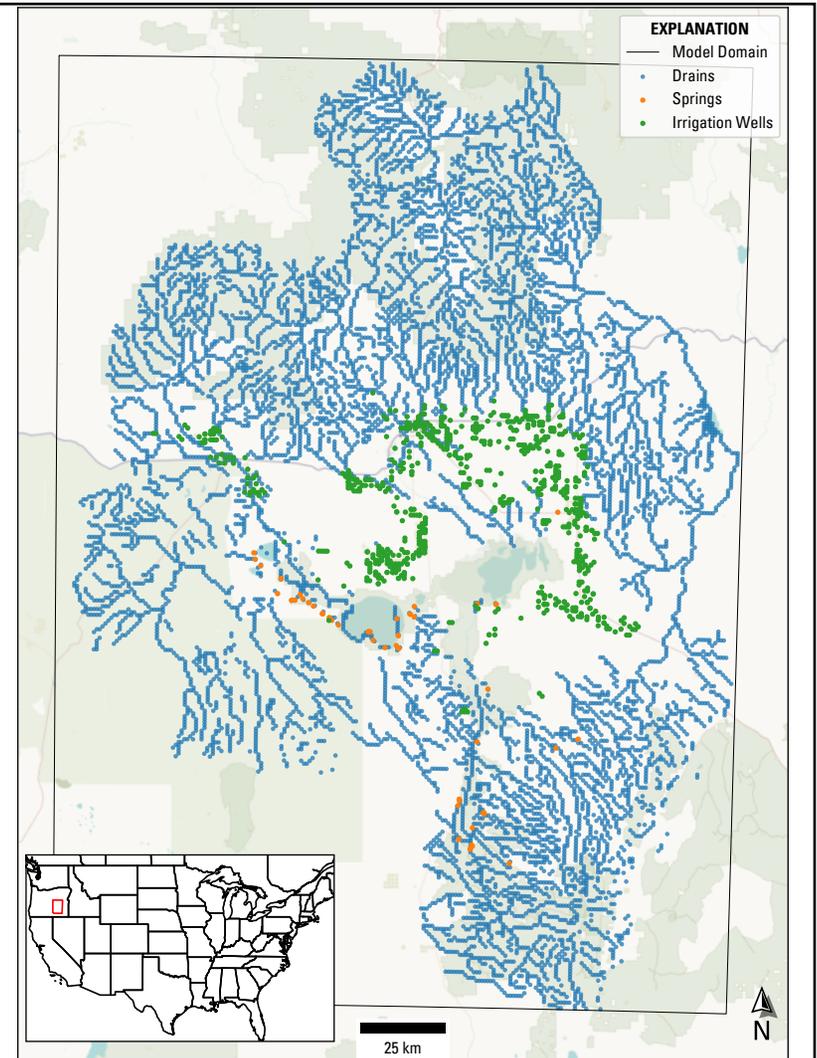
Agricultural economy is at odds with spring flow, streamflow, and habitat





- Basin closed to new permits in 2016
- Pumping curtailment will likely also be necessary

U.S. Department of the Interior
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Water Resources Research

RESEARCH ARTICLE
10.1029/2023WR036972

Key Points:

- A hydro-economic groundwater model (HEM) of the Harney Basin shows that HEMs can improve understanding and advance successful management
- Modeled scenarios reveal, for example, that proposed technology or spatially-targeted solutions do little to stabilize groundwater levels
- HEM studies can alter the way researchers understand a system, bringing focus toward key factors or even changing the key research question

Advancing Sustainable Groundwater Management With a Hydro-Economic System Model: Investigations in the Harney Basin, Oregon

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Abstract Groundwater resources frequently trend toward unsustainable levels because, absent effective institutions, individual water users generally act independently without considering the impacts on other users. Hydro-economic models (HEMs) of human-natural systems can play a positive role toward successful groundwater management.

Table 1 Scenario Descriptions and Present Value of Farm Profits (\$2022M)

| Scenario | Description | Present value of farm profits |
|-------------|--|-------------------------------|
| Scenario 1 | Baseline or business-as-usual. | 306.0 |
| Scenario 2 | Water conserving technology required (LESA and LEPA allowed). | 293.9 |
| Scenario 3a | Land idling #1- on fields with lowest profit per unit of water, pumping reduced 80% by year 3. | 205.4 |
| Scenario 3b | Land idling #2-fields with lowest profit per unit of water reduce pumping to zero by year 3. | 176.8 |
| Scenario 3c | Land idling #3-on fields with lowest profit per unit of water pumping reduced 50% by year 3. | 247.5 |
| Scenario 4a | Incentive-based #1-pumping cost raised to \$1/kwh by year 3. | 179.6 |
| Scenario 4b | Incentive-based #2-cost of pumping raised to \$0.80/kwh by year 3. | 213.1 |
| Scenario 4c | Incentive-based #3-cost of pumping raised to \$1.20/kwh by year 3. | 133.7 |
| Scenario 4d | Incentive-based #4-cost of pumping raised to \$1.40/kwh by year 3. | 90.7 |
| Scenario 5a | Targeted regulations #1-in areas where declines exceed 20 feet; pumping reduced gradually from years 2-5 by 50%. | 241.6 |
| Scenario 5b | Targeted regulation #2-in areas where declines exceed 30 feet; pumping reduced gradually from years 2-5 by 50%. | 282.6 |
| Scenario 6 | Regulating of junior water rights with priority dates 1992 and later. | 166.2 |
| Scenario 7a | Pumping limit #1-maximum rates lowered gradually from years 2%-5% to 60% of initial levels. | 189.1 |

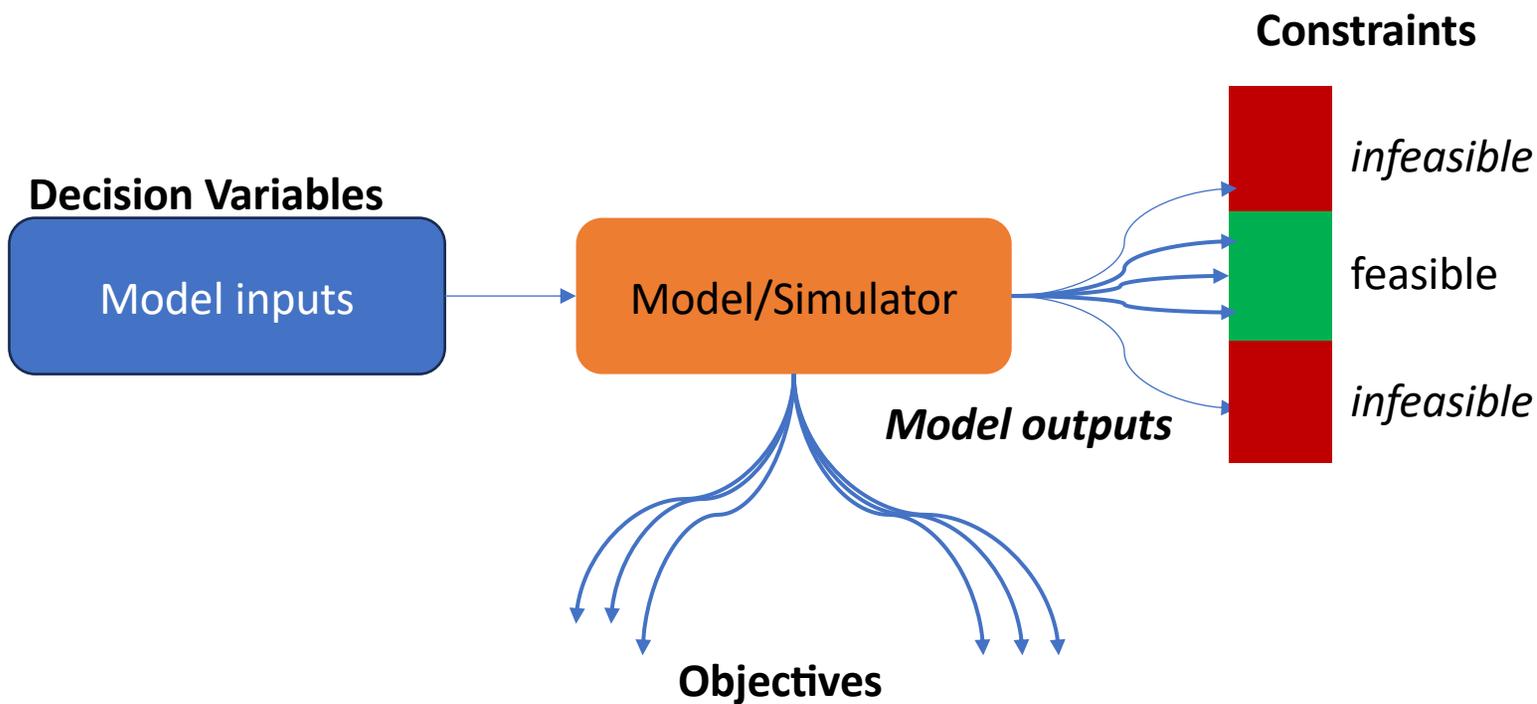
Jaeger et al. (2024) developed a hydro-economic model of the Harney Basin to explore various scenarios for reducing pumping in the basin



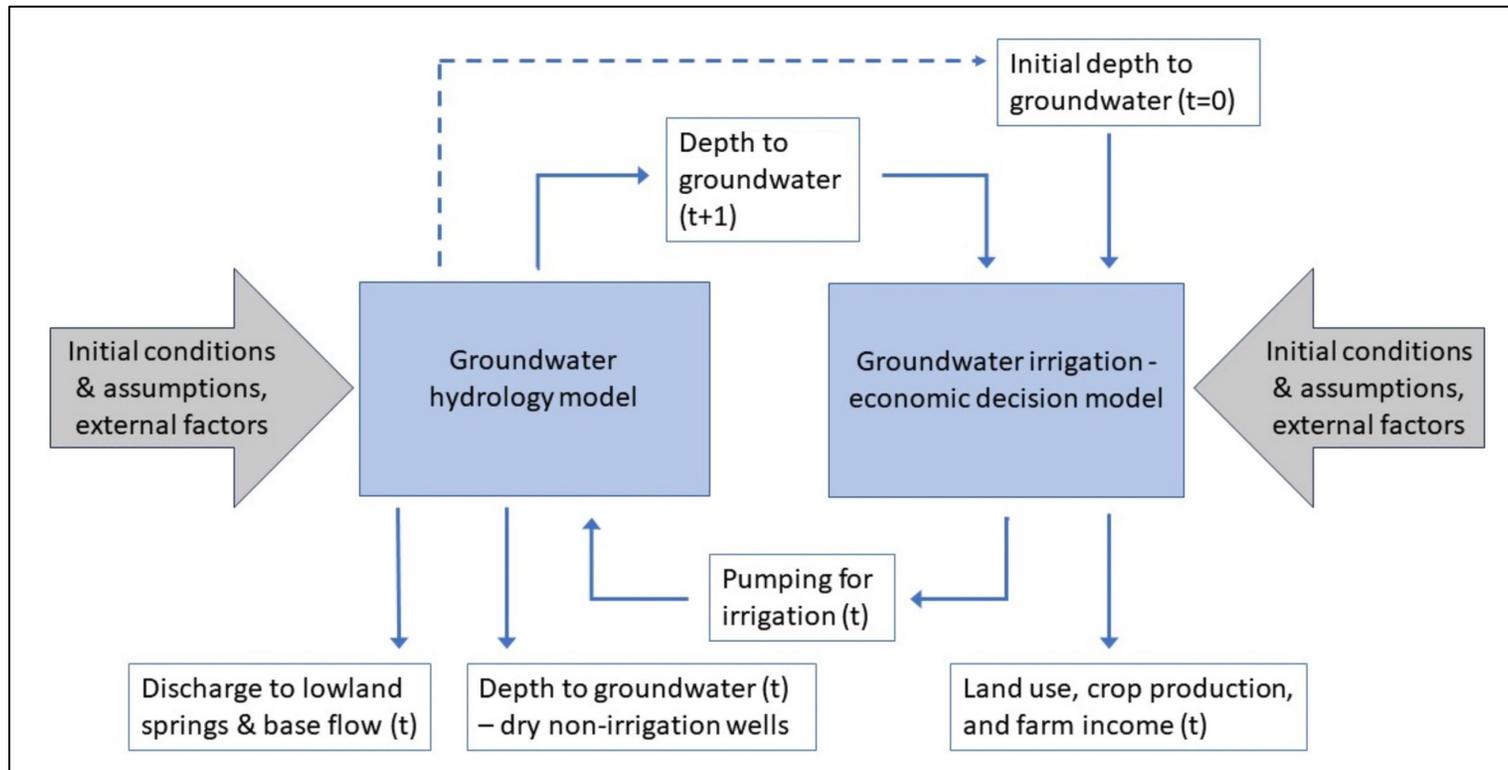
Multi-objective optimization seeks optimal solutions that balance competing objectives, using a model, satisfying strict constraints.

Formal optimization can find efficiencies missed by discrete scenarios.

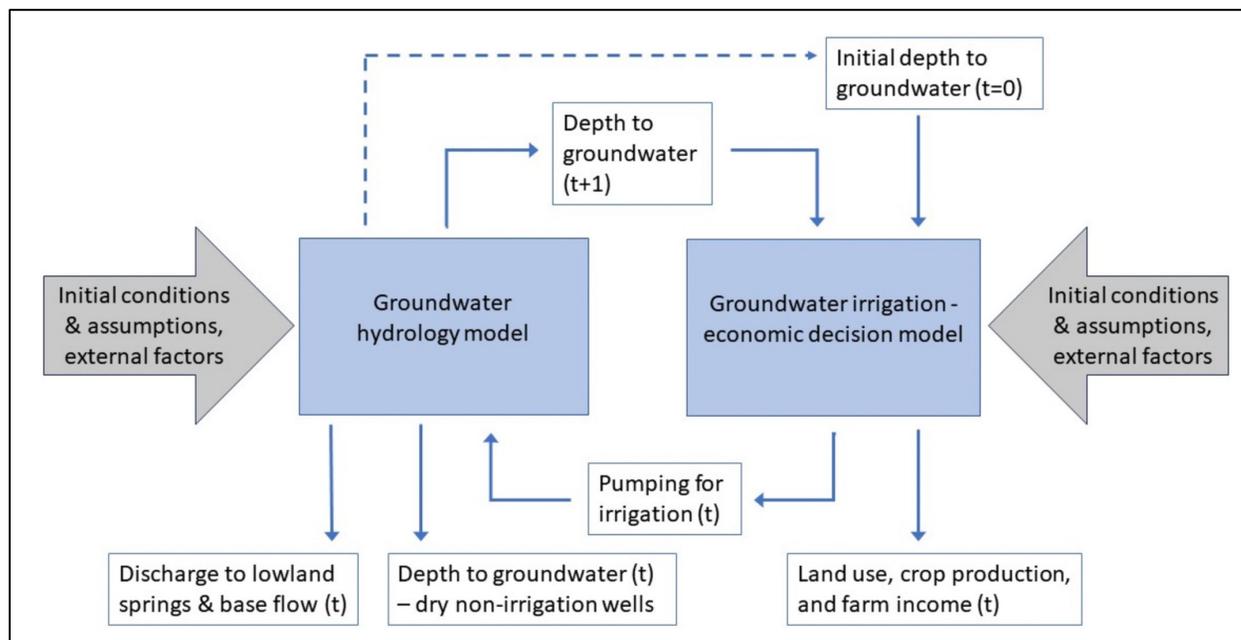
Show me how to optimize



Hydro-economic Model



Decision Variables



Regulatory cap per well group limiting total pumping –*fun fact, model can self-limit*



Competing Objectives

1. Cumulative profit (profit summed across all fields and over 30-year predictive period)
2. Cumulative spring flow (flow summed across all key spring groups and over 30-year predictive period)

MAXIMIZE
Agricultural
Profit

vs.

MAXIMIZE
Flow in springs

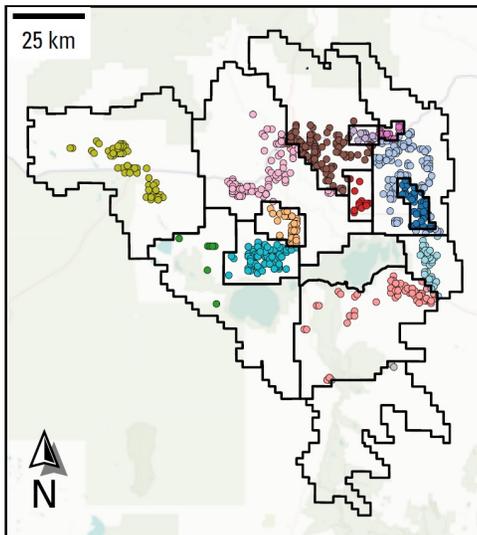


Constraints

1. Spring flows cannot fall below 25% of their initial values
 2. Stream base flows cannot fall below 25% of their initial values
 3. Management area pumping rates cannot fall below 50% of their initial values
- } Undesirable conditions
- } Embeds fairness into optimization algorithm

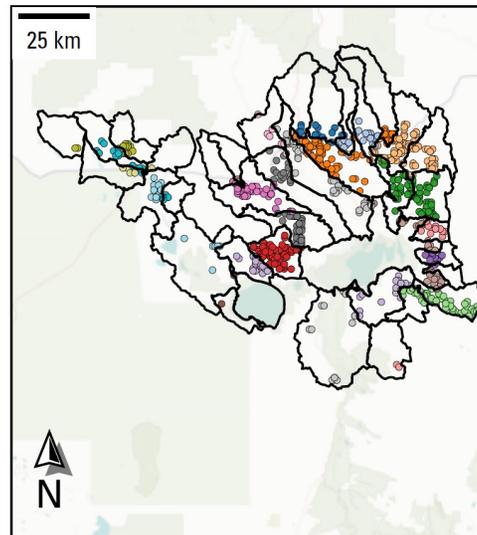
Base Scenarios

Mgmt Scenario



14 areas

HUC12 Scenario



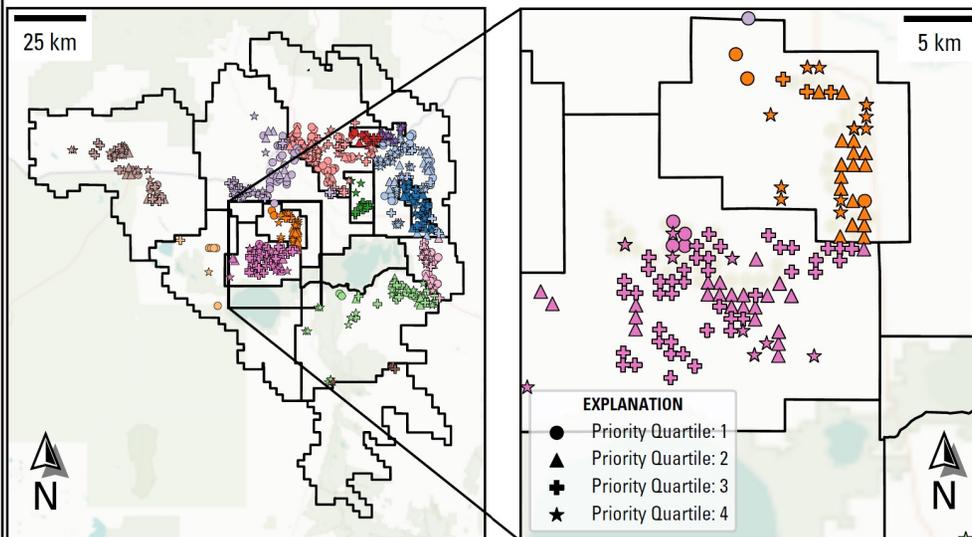
38 areas

Decision variables were set by management areas.

Wells within each area:
Sorted by priority date.
Most junior is cut to zero until
the curtailment volume for a
given year is achieved.

Relaxing Prior Appropriations

Frac Scenario



Pumping curtailed in a management area by fractionally reducing wells according to their priority date quartile

Lower bound for fraction set by quartile, 0.6 for most senior, down to 0 for most junior

Optimization Algorithm and Tools

- PEST++ Multi-objective Optimization under Uncertainty (MOU)
- Environmental selector: Non-dominated sorting genetic algorithm (NSGA-II)
- Population generator: particle swarm optimization (PSO)
- Reproducible in python with FloPy, pyEMU, and git



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journal homepage: www.elsevier.com/locate/envsoft

A model-independent tool for evolutionary constrained multi-objective optimization under uncertainty

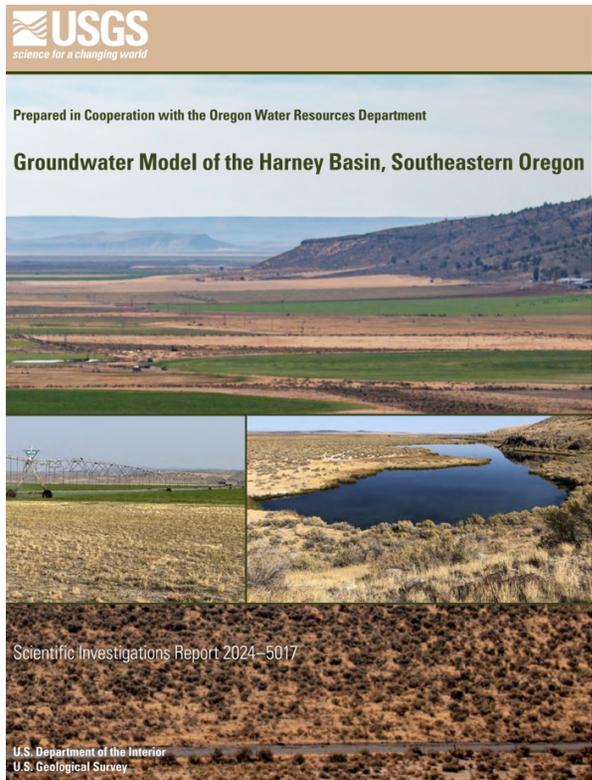
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Off-the-Couch Model Files



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ScienceBase Catalog → USGS Data Release P... → MODFLOW 6 model u...

MODFLOW 6 model used to simulate groundwater flow in the Harney Basin, southeastern Oregon (ver. 2.0, May 2024)

View

Dates

Publication Date : 2024-01-02
Start Date : 1930-01-01
End Date : 2018-12-31
Revision : 2024-05-06

Citation

Gingerich, S.B., 2024, MODFLOW 6 model used to simulate groundwater flow in the Harney Basin, southeastern Oregon (ver. 2.0, May 2024); U.S. Geological Survey data release, <https://doi.org/10.5066/P9OEKEIO>

Summary

A three-dimensional groundwater flow model, MODFLOW 6, was used to simulate groundwater flow in the Harney Basin, southeastern Oregon. The model was used to investigate anthropogenic groundwater demands. The model was calibrated and output files for the simulation described in the associated journal article (<https://doi.org/10.1029/2024WRXXXX>)

Child Items (1)

- Hydro-Economic model used to simulate future withdrawal

Contacts

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Originator : [Stephen B Gingerich](#)

ScienceBase Catalog → USGS Data Release P... → MODFLOW 6 model u... → Hydro-Economic mod...

Hydro-Economic model used to simulate future withdrawal scenarios in the Harney Basin, southeastern Oregon

View

Dates

Publication Date : 2024
Start Date : 2019-01-01
End Date : 2049-12-31

Citation

Gingerich, S.B., 2024, MODFLOW 6 model used to simulate groundwater flow in the Harney Basin, southeastern Oregon (ver. 2.0, May 2024); U.S. Geological Survey data release, <https://doi.org/10.5066/P9OEKEIO>

Summary

A hydro-economic model was developed by coupling a three-dimensional groundwater flow model of the Harney Basin, southeastern Oregon (using MODFLOW 6) with a hedonic agricultural economic model. The hydro-economic model was used to investigate a set of hypothetical future scenarios having different groundwater pumpage conditions. The model looked at conditions 30 years beyond the 2018 conditions at the end of the HBGM transient simulation. This USGS data release contains all of the input and output files and needed Python scripts and Jupyter Notebooks for the simulations described in the associated journal article (<https://doi.org/10.1029/2024WRXXXX>)

Contacts

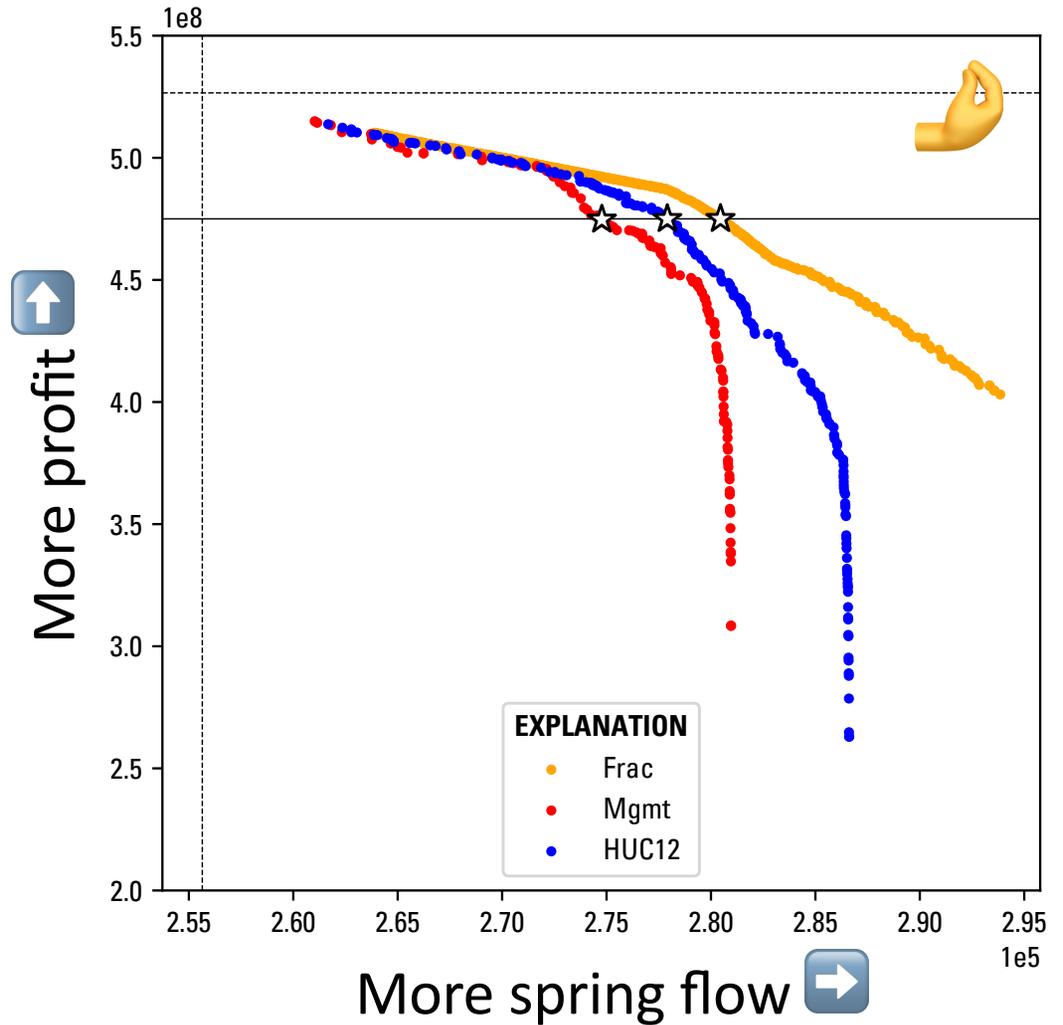
Point of Contact : [Stephen B Gingerich](#)
Originator : [Stephen B Gingerich](#)
Metadata Contact : [Oregon Water Science Center Public Information Officer](#)
Publisher : [U.S. Geological Survey](#)
Distributor : [U.S. Geological Survey - ScienceBase](#)



Pareto curve: set of optimal solutions that satisfy environmental and water rights constraints

Degrees of freedom (finer resolution of management subareas or relaxing prior appropriations) leads to less profit loss per spring flow gain

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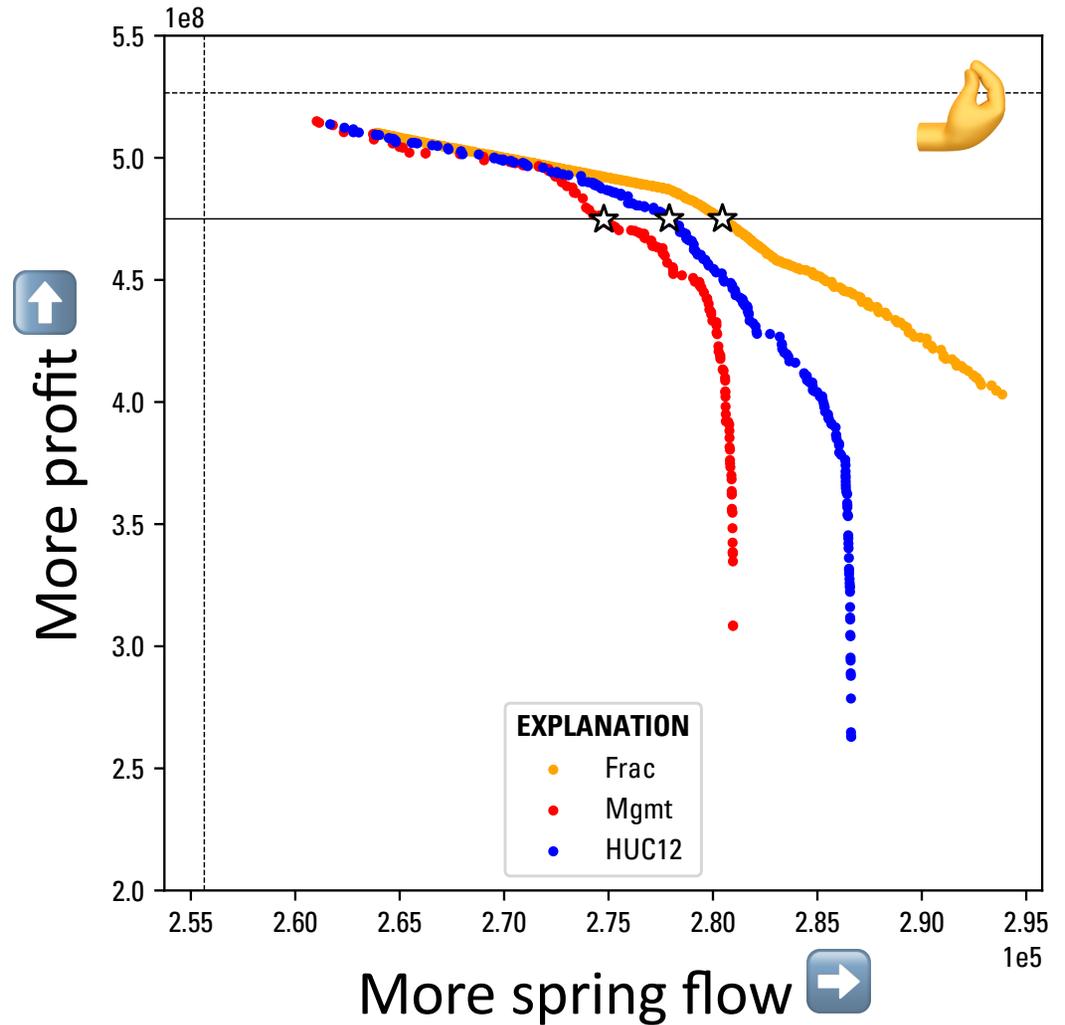




Pareto curve: set of optimal solutions that satisfy environmental and water rights constraints

Degrees of freedom (finer resolution of management subareas or relaxing prior appropriations) leads to less profit loss per spring flow gain

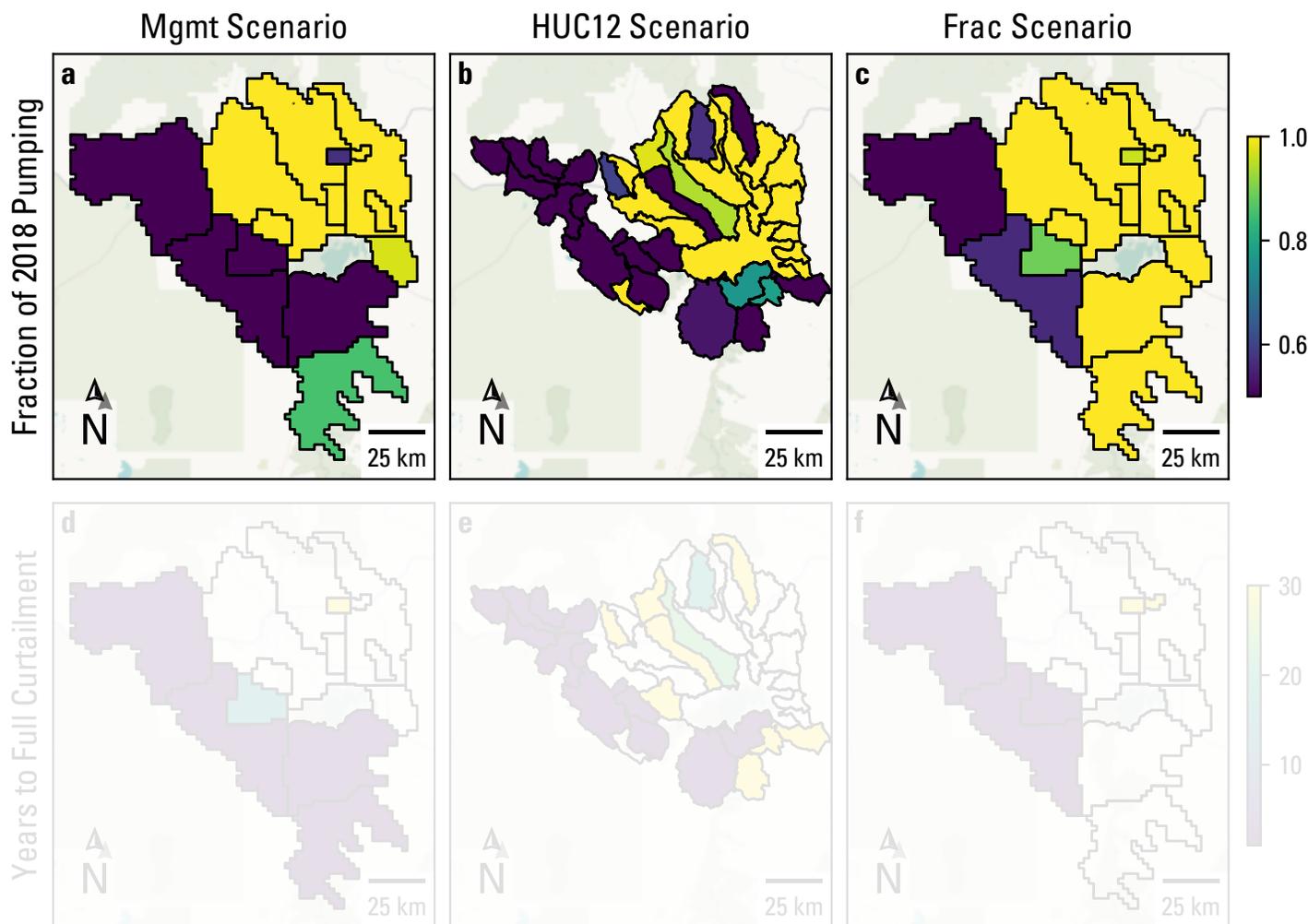
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Spatial coherence in where pumping is curtailed

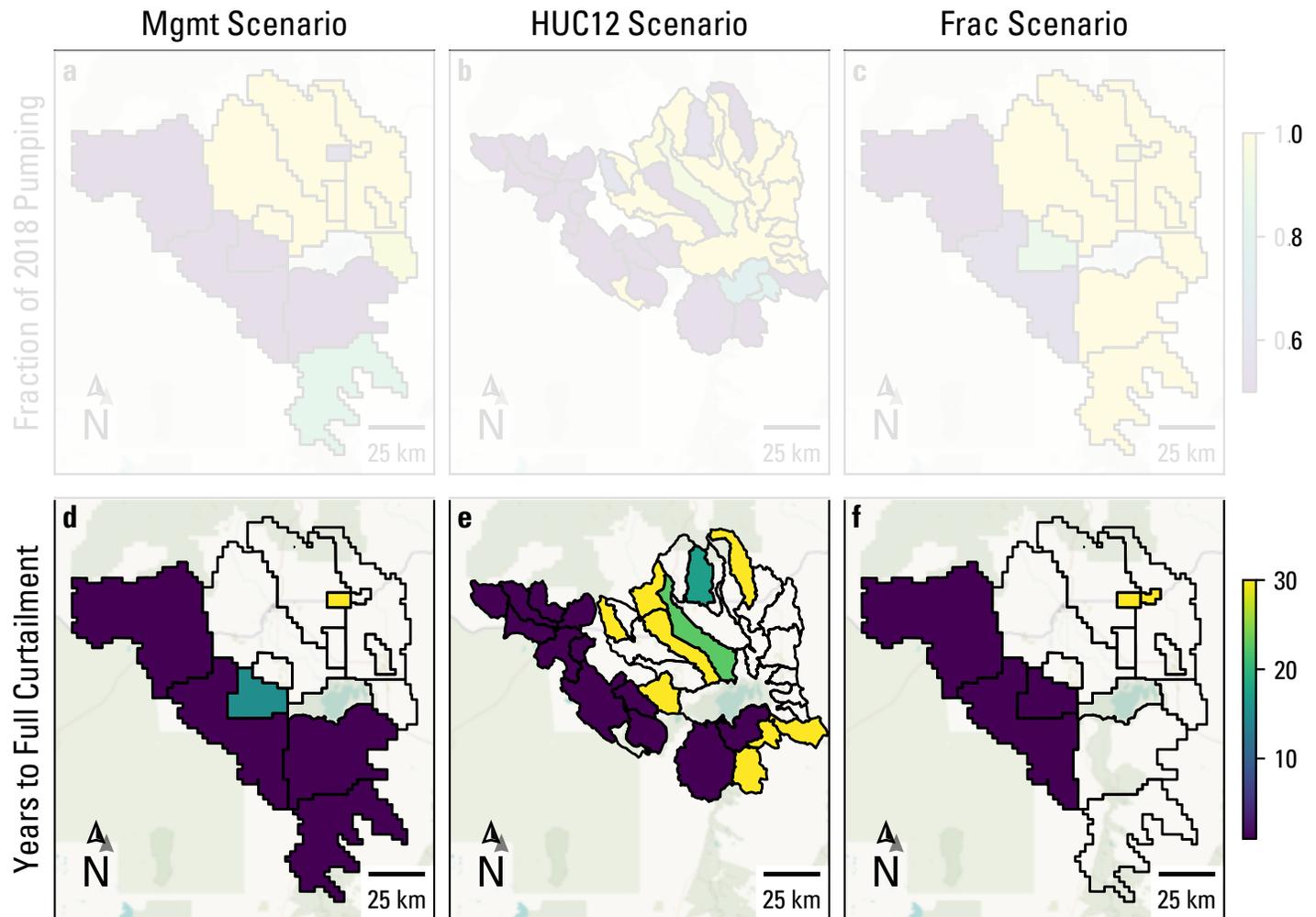
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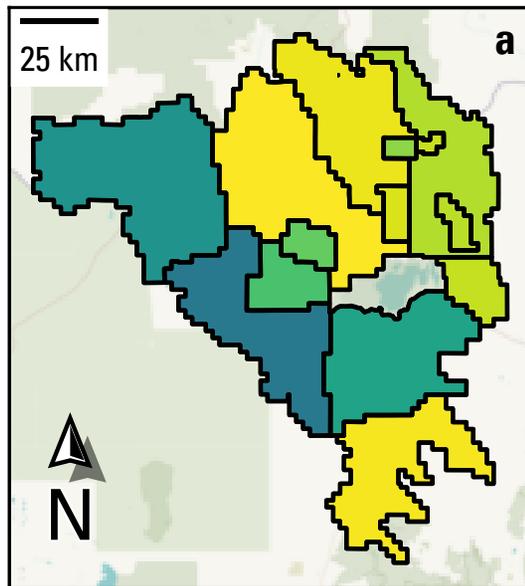


Spatial coherence in where pumping is curtailed

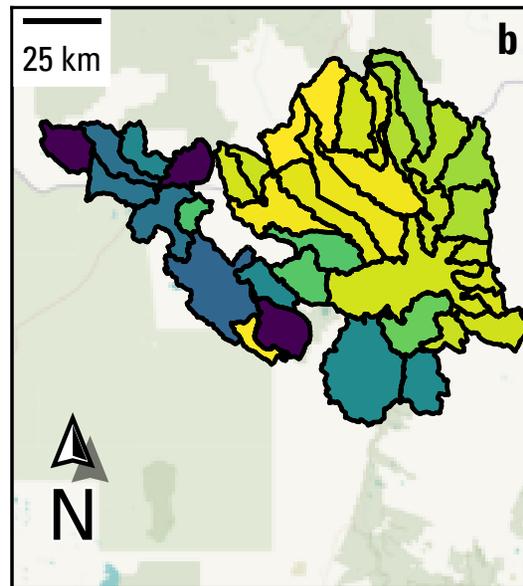
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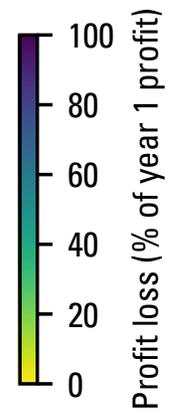
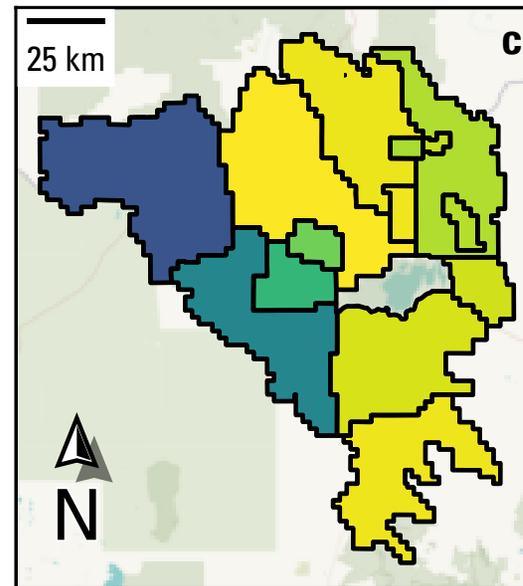
Mgmt Scenario



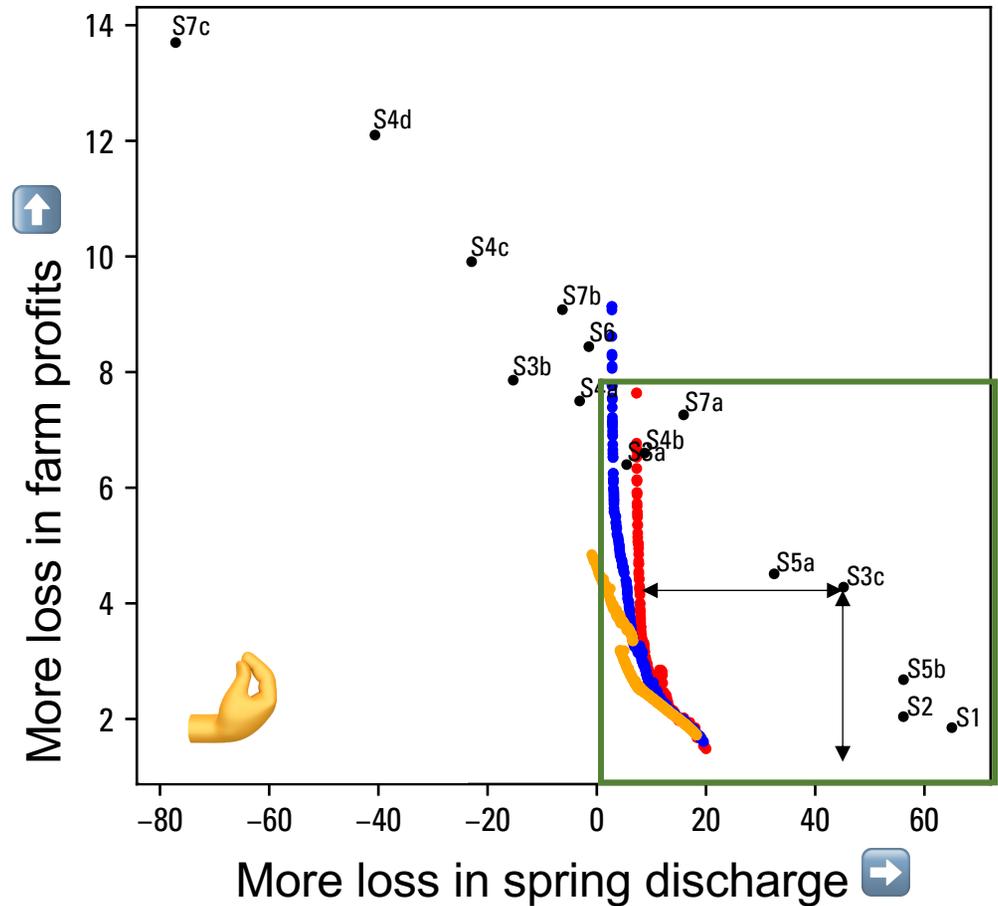
HUC12 Scenario



Frac Scenario



Not a direct comparison because objectives and management decision variables differ, but opt scenarios are far more efficient than the scenarios which resulted in lower losses to profit

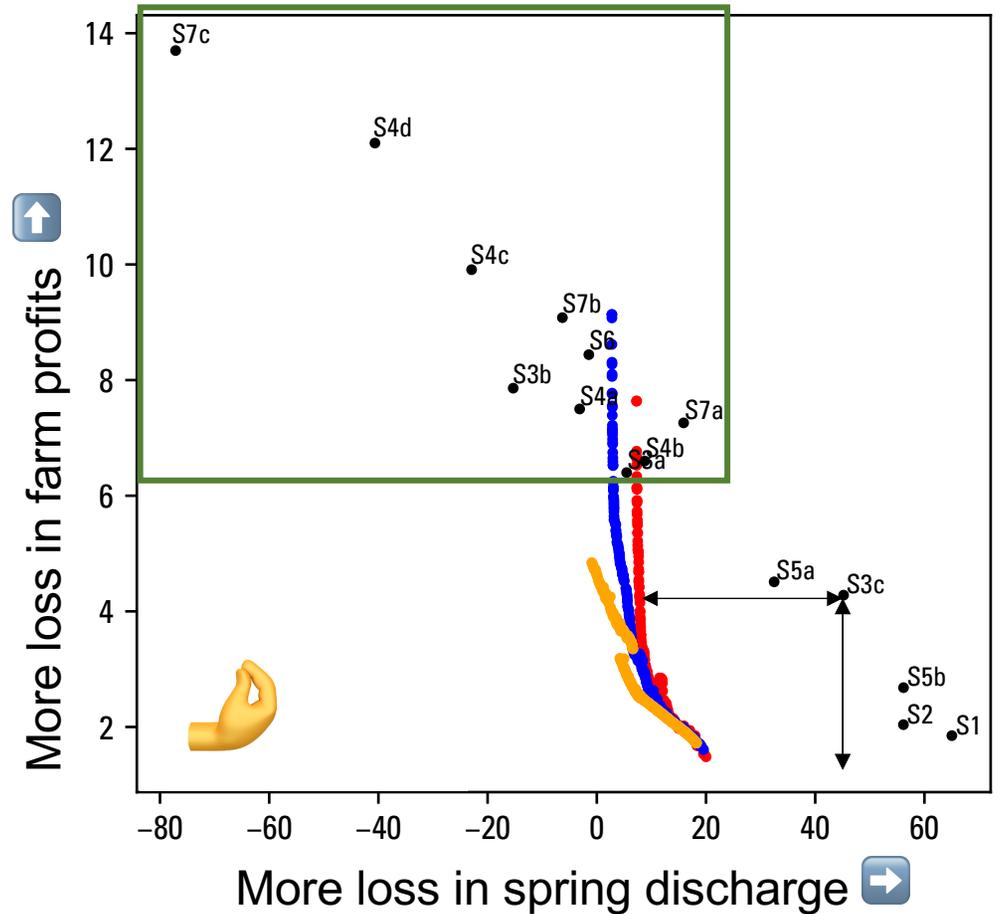




Scenario-based approaches have the advantage of exploring a wider range of management options

Kinda unrealistic given large profit losses

Still, these options could be brought in the formulation of the optimization as decision variables





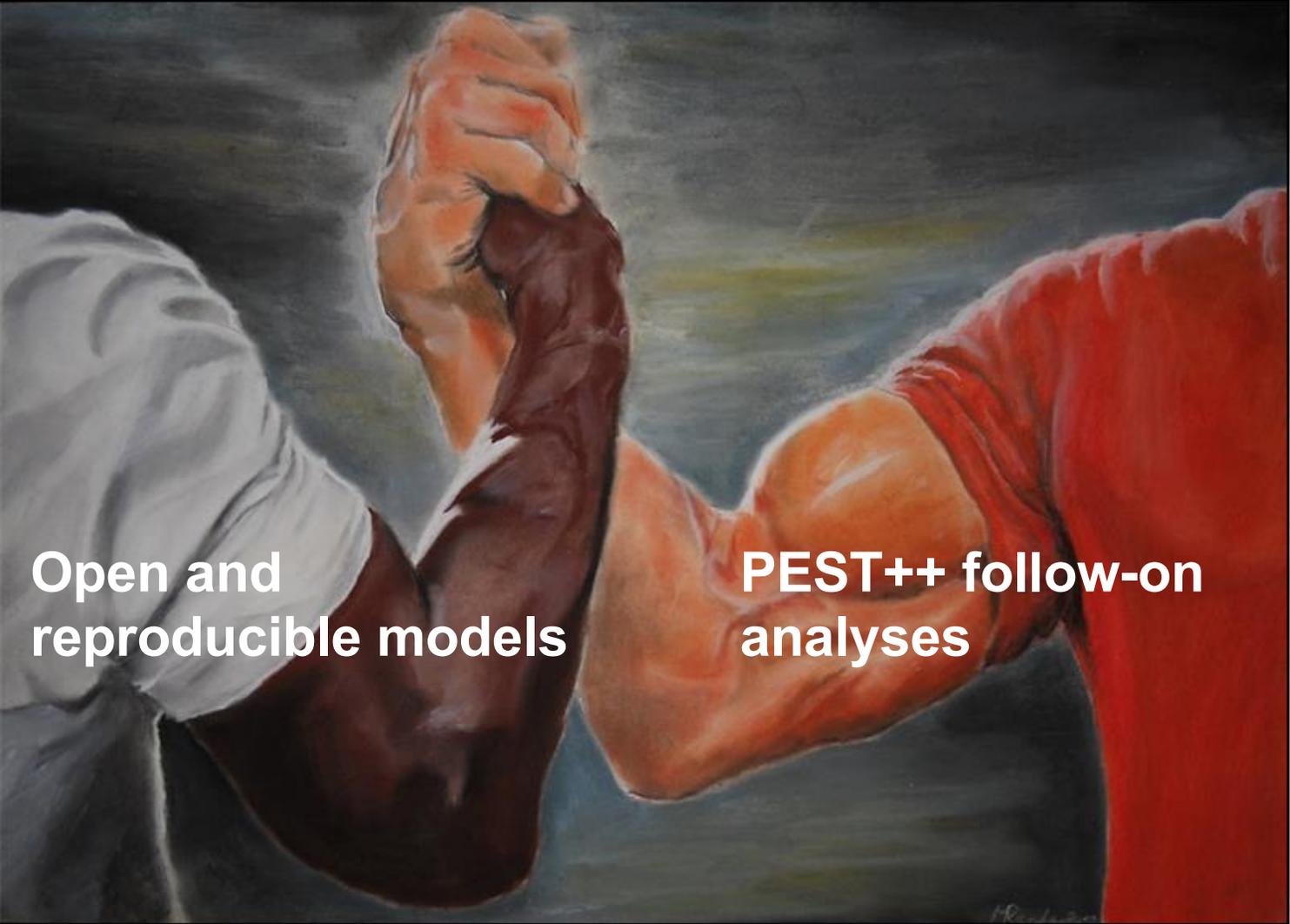
Conclusions

Multi-objective optimization found optimal solutions (despite water rights constraints) that were more efficient than scenario-testing results

More management areas led to a little more efficient solution.
A more sophisticated clustering approach may yield better results.

Least water-rights restrictive scenario was most efficient, but least realistic given prior appropriation law.

Could be used to target non-regulatory interventions?

A detailed oil painting of two muscular arms in a fist-bump gesture. The arm on the left is wearing a white long-sleeved shirt, and the arm on the right is wearing a red t-shirt. The background is a dark, textured grey with some green and blue tones. The lighting highlights the musculature of the arms.

**Open and
reproducible models**

**PEST++ follow-on
analyses**

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