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

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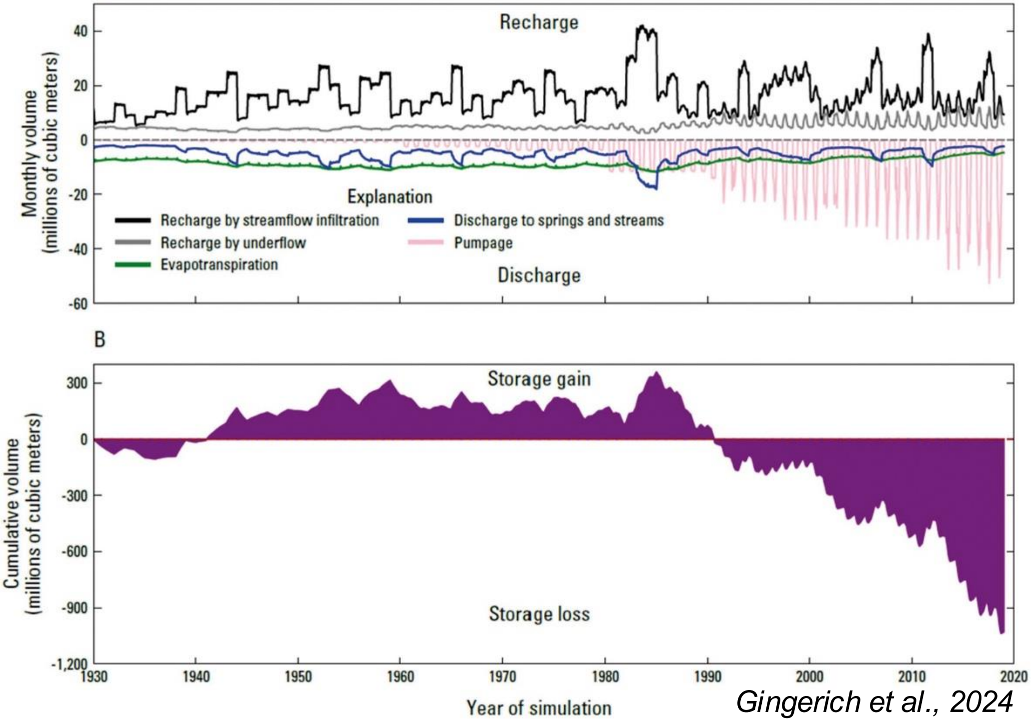
Multi-objective optimization seeks optimal solutions that balance competing objectives, using a model, satisfying strict constraints.

Formal optimization can find efficiencies missed by discrete scenarios.

Project Background



Gingerich et al., 2024

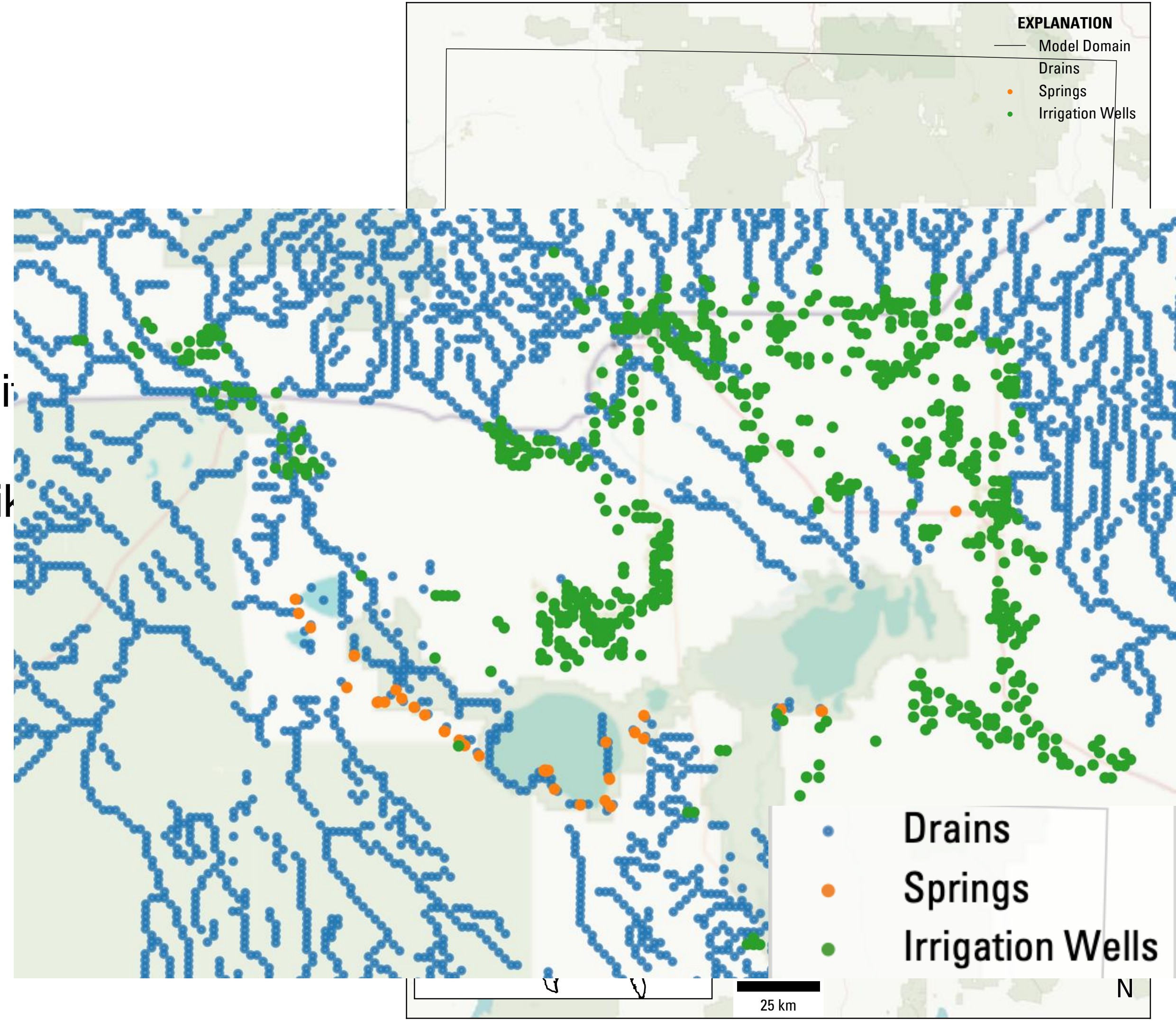
Harney Basin, southeastern Oregon

Primary crop: alfalfa

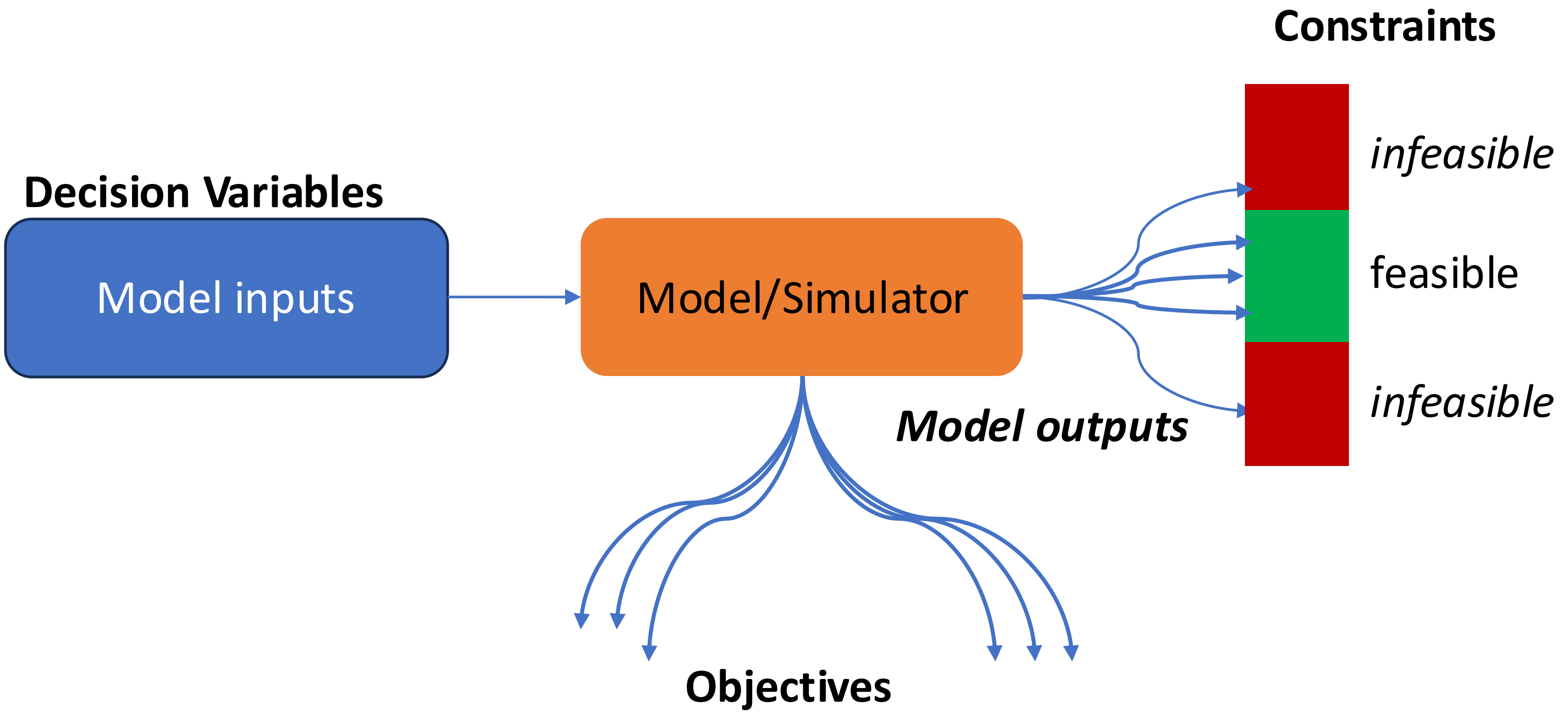
Permitted pumping for irrigation started increasing in 1990’s, leading to water level/storage declines

Agricultural economy is at odds with spring flow, streamflow, and habitat science for a changing world

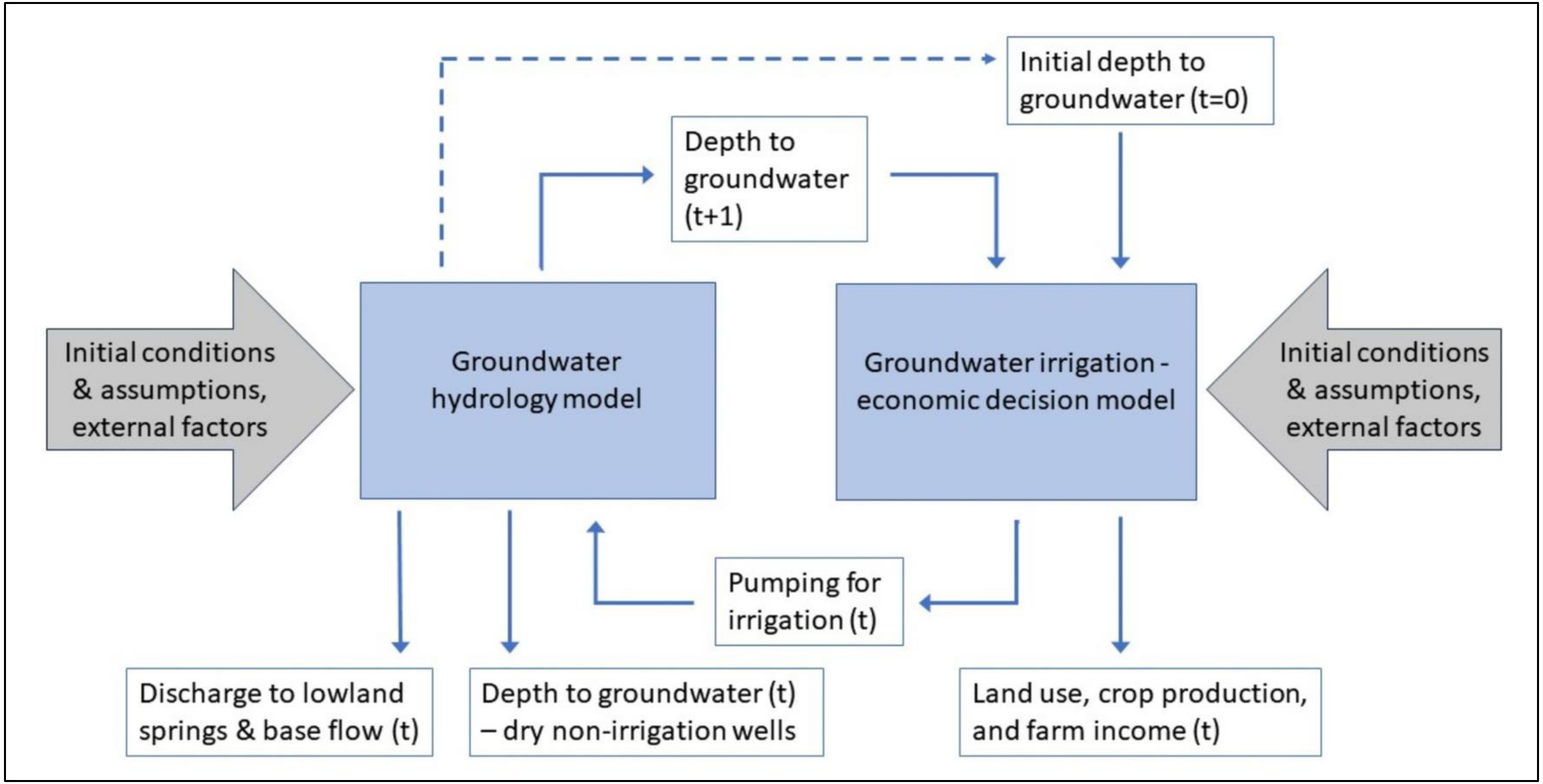
- Basin closed to new permi
- Pumping curtailment will lik necessary



Show me how to optimize

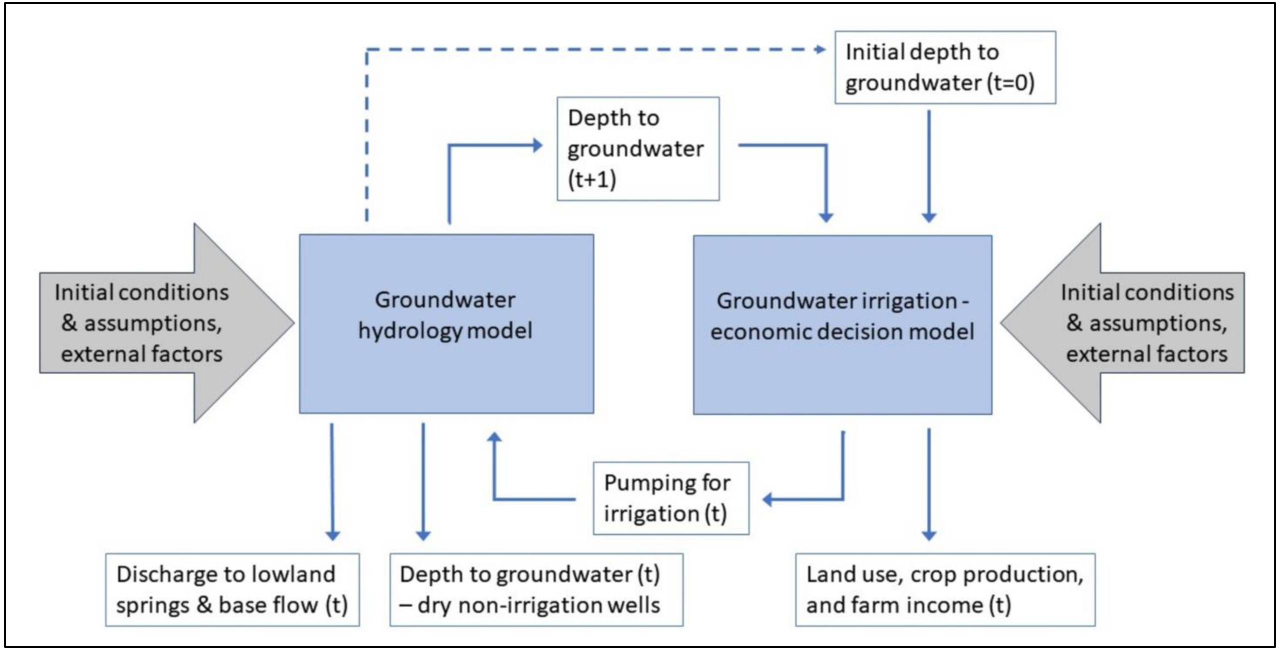


Hydro-economic Model



Jaeger et al., 2024; available at Gingerich et al., 2024

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)

MAXMIZE
Agricultural
Profit

vs.

MAXIMIZE
Flow in springs

Constraints

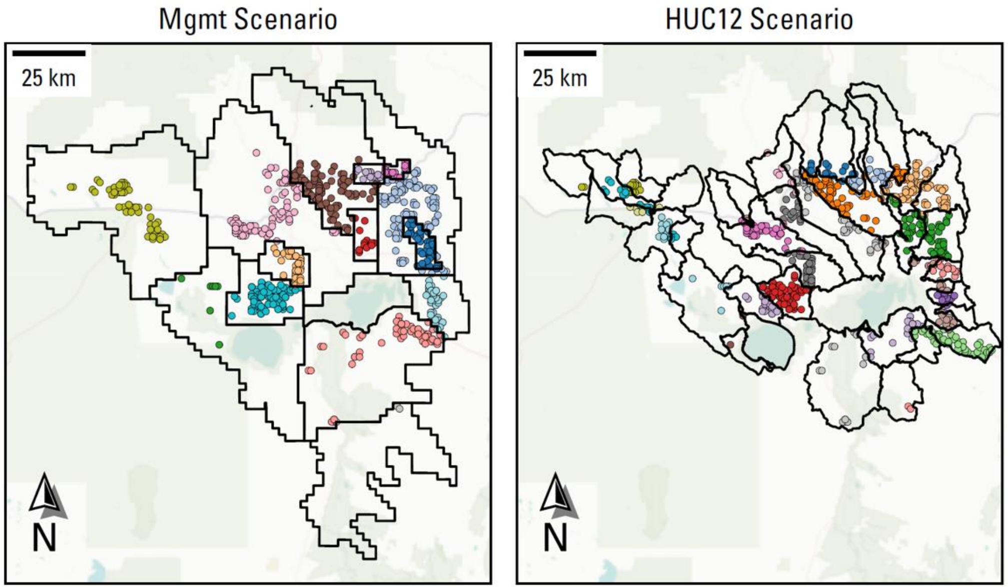
1. Spring flows cannot fall below 25% of their initial values
2. Stream base flows cannot fall below 25% of their initial values

Undesirable conditions

3. Management area pumping rates cannot fall below 50% of their initial values

Embeds fairness into optimization algorithm

Base Scenarios



14 areas

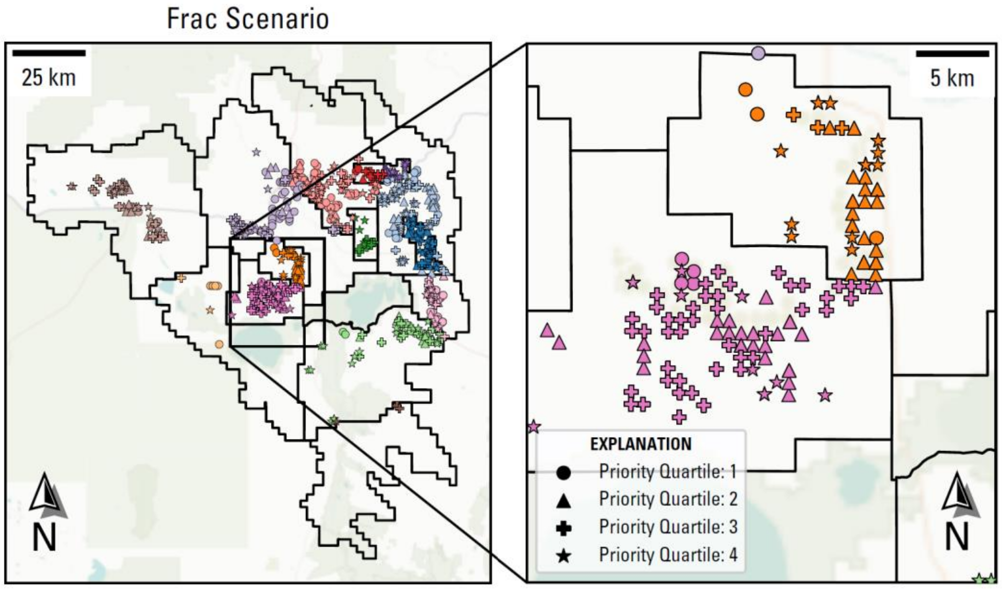
38 areas

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



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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Contents lists available at ScienceDirect

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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

Prepared in Cooperation with the Oregon Water Resources Department

Groundwater Model of the Harney Basin, Southeastern Oregon

ScienceBase-Catalog Communities Help

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)

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 g
Geological Survey data release, https://doi.org/10.5066/P9OE

Summary

A three-dimensional groundwater flow model, MODFLOW 6, w
Basin, southeastern Oregon. The model was used to investiga
anthropogenic groundwater demands. The model was calibrat
and output files for the simulation described in the associated

Child Items (1)

Hydro-Economic model used to simulate future withdrawal

Contacts

Point of Contact : Stephen B Gingerich
Originator : Stephen B Gingerich

ScienceBase-Catalog Communities Help

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

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
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Publisher : U.S. Geological Survey
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Water Resources Research

RESEARCH ARTICLE
10.1029/2023WR036972

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

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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

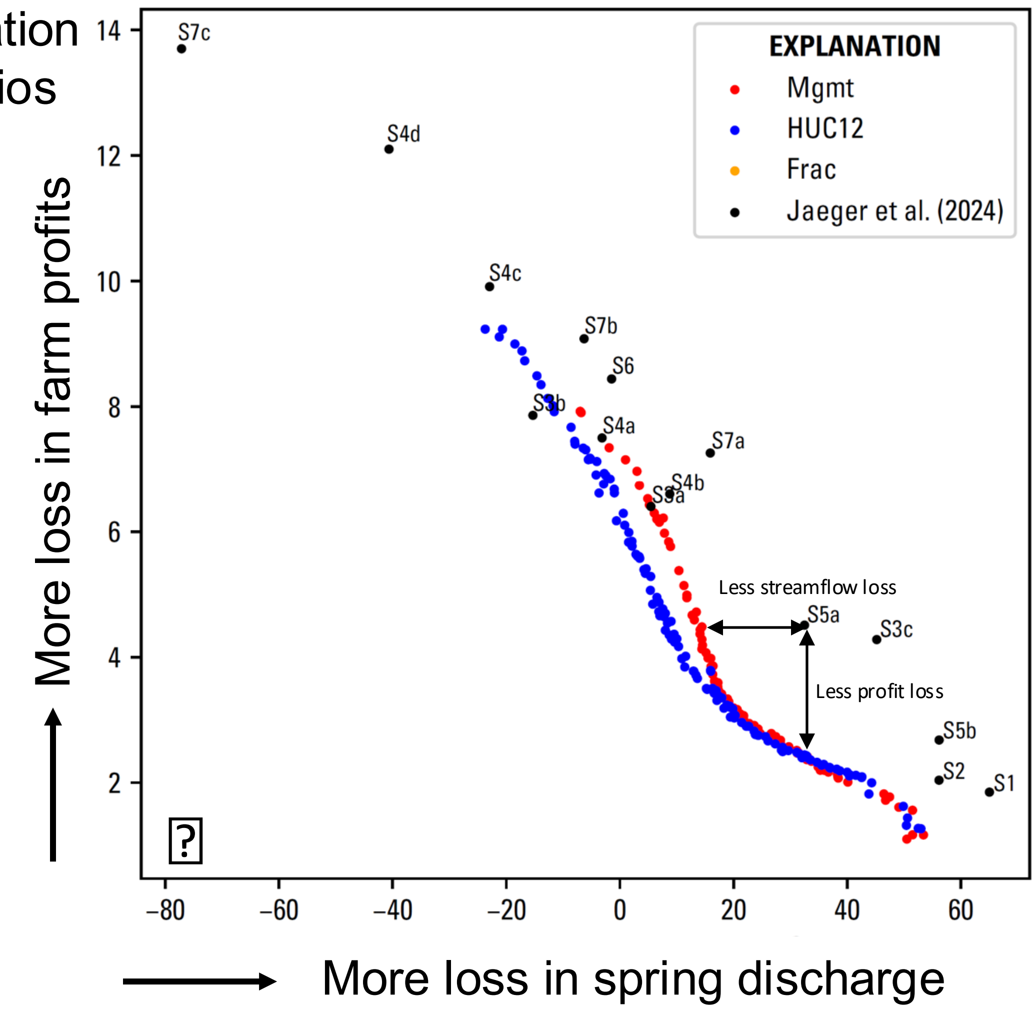
Abstract Groundwater resources frequently trend toward unsustainable levels because, absent effective institutions, individual water users generally act independently without considering the impacts on other users. Hydro-economic models (HEMs) of human-natural systems can play a positive role toward successful groundwater management by yielding valuable knowledge and insight. The current study explores how an HEM that captures essential physical and economic characteristics of a system can shed light on the system's processes

Strict Prior appropriation Optimization Scenarios

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

38 management area scenario performs a bit better than **14 management area scenario**

More efficient than non-optimized scenarios!



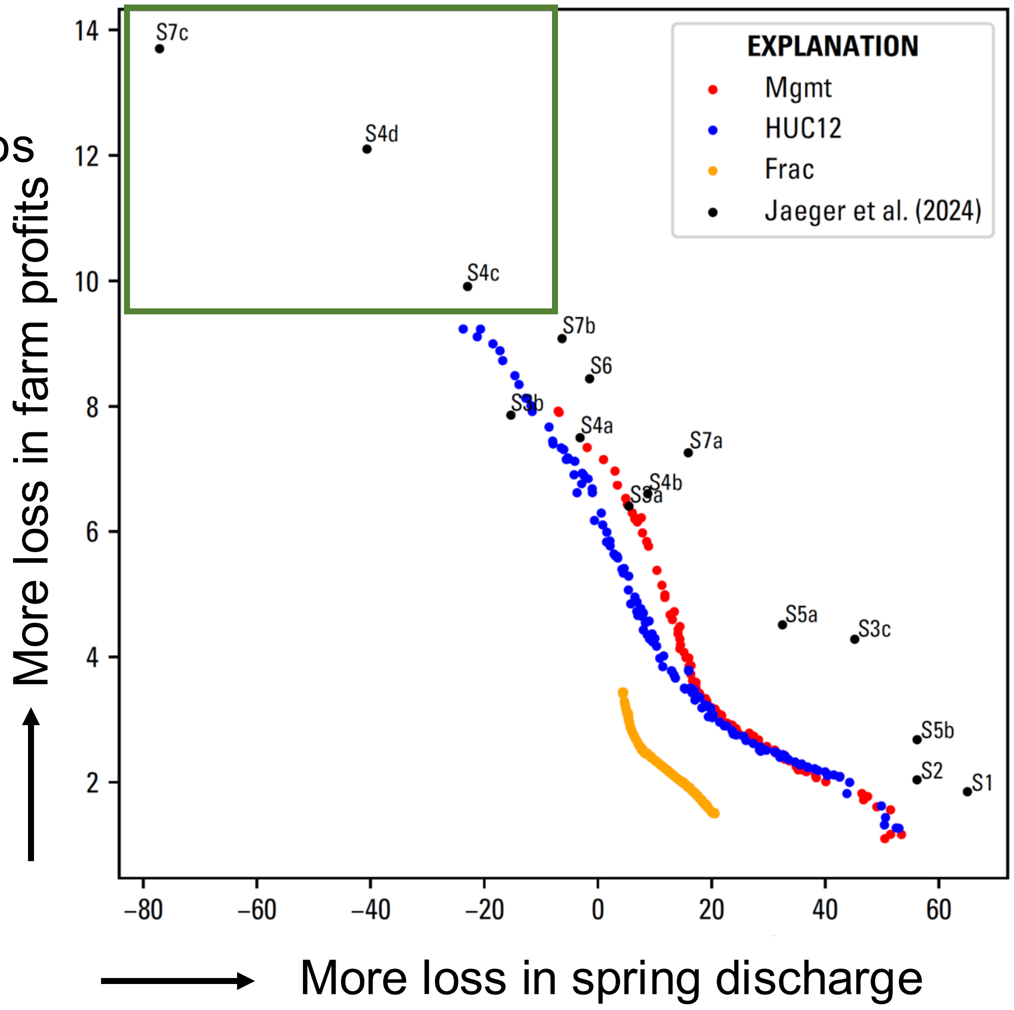
Relaxed Prior appropriation Optimization Scenarios

Most efficient allocation of water by far

Scenarios explore a wider range of pumping curtailment options

In this case, kind of unrealistic

Could be brought into the optimization



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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?

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