The Development of MOD$$AT: An Integrated Model to Inform Groundwater Management

AUTHORS

Mani Rouhi Rad
Clemson University
rrad@clemson.edu

Jordan Suter
Colorado State University
jordan.suter@colostate.edu

ACKNOWLEDGEMENTS

Dale Manning
Colorado State University
dale.manning@colostate.edu

Chris Goemans
Colorado State University
chris.goemans@colostate.edu

Karina Schoengold
University of Nebraska-Lincoln
kschoengold2@unl.edu

OGALLALA WATER PARTNERS

COLORADO STATE UNIVERSITY

KANSAS STATE UNIVERSITY

UNIVERSITY OF CALIFORNIA-DAVIS

UNIVERSITY OF NEBRASKA-LINCOLN

NEW MEXICO STATE UNIVERSITY

OKLAHOMA STATE UNIVERSITY

TEXAS A&M UNIVERSITY

TEXAS TECH UNIVERSITY

USDA-ARS GRAZINGLANDS RESEARCH LABORATORY

USDA-ARS CROPPING SYSTEMS RESEARCH LABORATORY

WEST TEXAS A&M UNIVERSITY

Summary

The USDA NIFA-funded Ogallala Water Coordinated Agriculture Project (OWCAP) team developed MOD$$AT, a novel integrated model that simulates well-level water use and profitability across time. This model combines a spatially explicit hydrological model (MODFLOW) with a daily time-step crop production model (DSSAT) and an economic decision model that determines well-level crop planting and irrigation strategies taking groundwater availability and historical weather data or future climate projections as inputs.

This project partnered with local groundwater management districts across the Ogallala aquifer region in using this model to evaluate potential hydrologic and economic impacts of real-world policy and management scenarios over time. In addition, an extensive set of interdisciplinary datasets was developed to validate and calibrate the model. The data includes information on soil types and characteristics, water use and harvestable yields for different crops and management practices, and well-level data on groundwater levels and extraction capacity. A new series of scripts was also developed to automate and increase the speed of completing runs of the integrated model.

Policies that intend to reduce aquifer depletion, extend the economic life of the aquifer, and, eventually, improve the livelihood of the communities that rely on the aquifer will have tradeoffs. Groundwater saved today can be used in the future by the same or other producers for production. What's more, most policies that are uniformly applied to a region will have heterogeneous effects on producers who use groundwater. The hydro-economic model developed and introduced as part of the project allows for the study and comparison of the tradeoffs of specific aquifer management policies over time.

Highlights

- The hydro-agro-economic modeling framework MOD$$AT is the first of its kind.
- MOD$$AT is a tool to assess the tradeoffs associated with groundwater management strategies at regional scales, including assessment of water savings and increased profitability from different irrigation strategies and management policies.
- The use of programming language tools like Python helped speed up simulations and facilitated the integration of model components across disciplines.
- This approach overcomes bias common to models that ignore changes in well-level water use over time that result from diminished groundwater availability by integrating dynamic economic decisions with changing, spatially heterogeneous groundwater levels.

Why was this model developed (the need and the novelty)?
The model was developed to:

1) Fill a gap that exists in the hydro-economic modeling literature, especially when it comes to groundwater management. The existing models often over-simplify one of the model components.
2) Provide a reliable tool for understanding the tradeoffs between different policies and management strategies that intend to extend the life of the High Plains Aquifer (HPA).

What is this model?
The novelty of the model (Figure 1) is that it brings together, in an interdisciplinary way, three models that are well-respected within their disciplines. The DSSAT model is widely used by agronomists, while the MODFLOW model is routinely used by hydrologists.

The economic model developed for MOD$$AT appropriately captures the nature of producer decision-making. The representative producer in the model makes irrigation decisions in two steps: first, at the beginning of a growing season, the producer determines which crops to grow, how many acres to irrigate, and the soil moisture target for irrigation, based on the historical weather distribution in the region; second, during the growing season, the producer observes weather and makes irrigation decisions. These irrigation decisions determine annual groundwater use at each well.

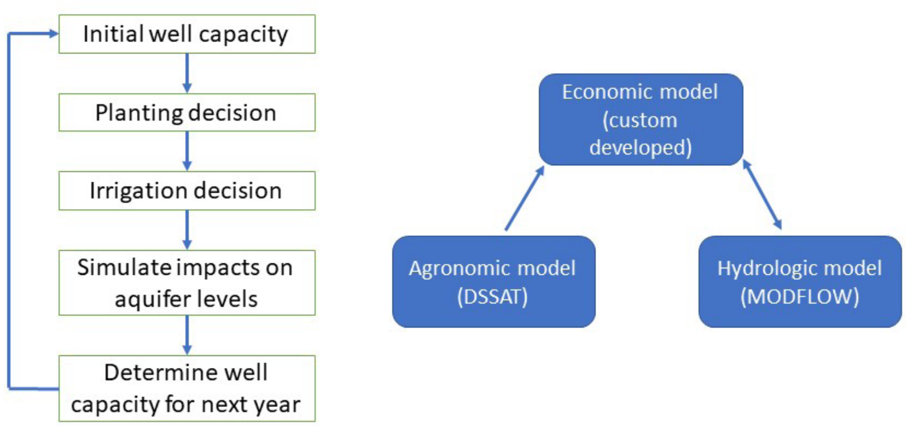

Figure 1. MOD$$AT brings together and integrates models from hydrology, agronomy, and economics to produce a groundwater decision-making tool.

The model is spatially explicit. In studying groundwater management, where and when groundwater levels will be affected by different policies and practices is often more important than average changes in groundwater availability. Understanding this spatial and temporal variation can help to better target groundwater management policies.

DSSAT(***D***ecision ***S***upport ***S***ystem for ***A***grotechnology ***T***ransfer) - Agronomic model comprising crop simulation models for over 42 crops.

MODFLOW - Hydrological model developed by the United States Geological Service (USGS) that is one of the most widely used groundwater simulation frameworks.

MOD$$AT - Integrated model for evaluating the effects of groundwater management policies on producer profits that combines three system components: 1) a hydrological model (SWAT-MODFLOW), 2) an agronomic model (DSSAT), and, 3) a custom economic decision-making model developed for this project.

What regions does the model cover and why?

Although the High Plains Aquifer is one aquifer system, it varies across space in terms of groundwater levels, recharge rate, climate, soil type and groundwater use. Four general study areas were selected across the High Plains aquifer to capture the heterogeneity of this large aquifer (Figure 2).

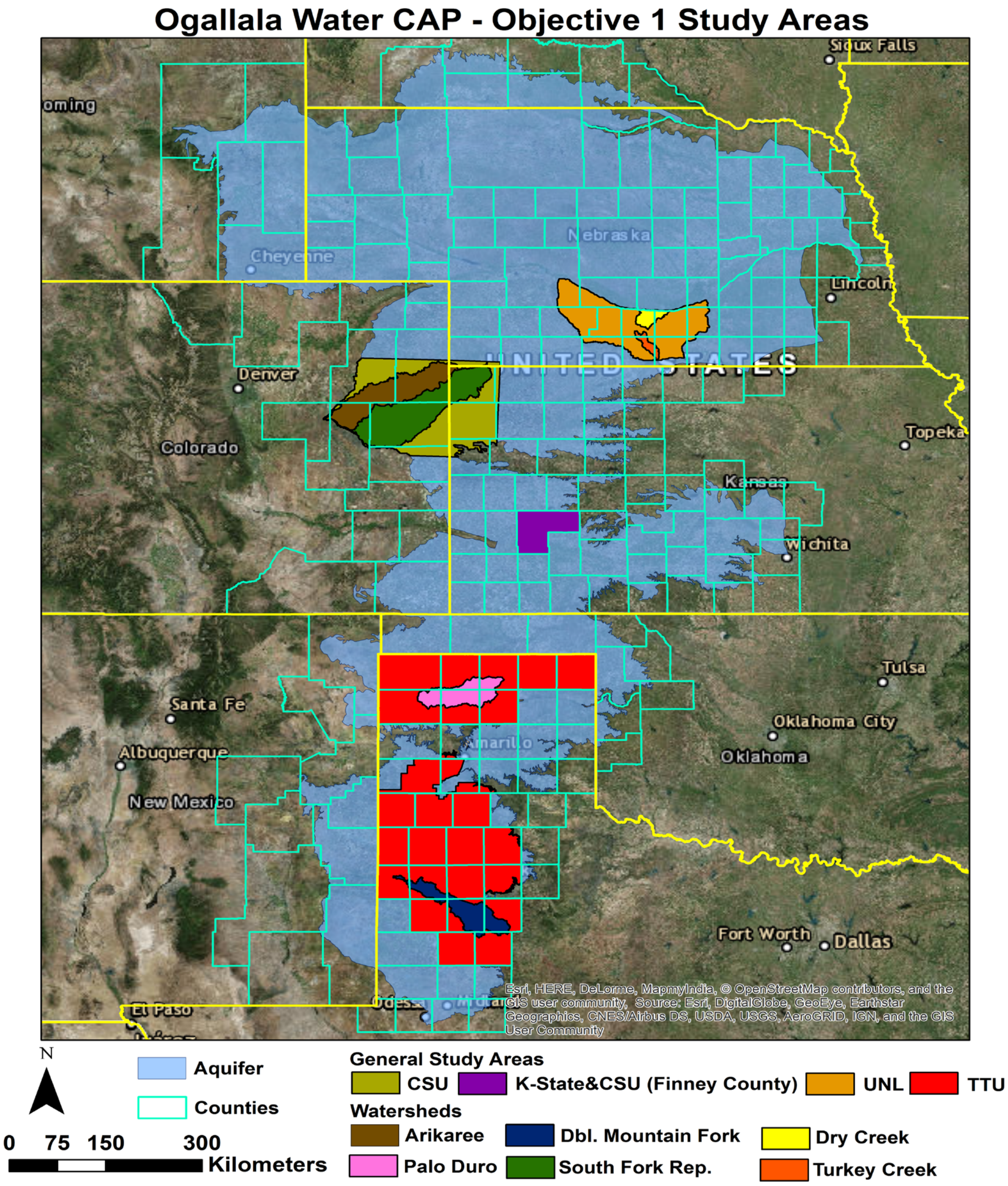

Figure 2. This modeling project (known as OWCAP Objective 1) captured four general study area across the Ogallala aquifer region.

What was learned?

1. The shared nature of the aquifer and temporal changes in aquifer levels are important for understanding the effectiveness of different policies. Reducing competition for the shared groundwater resource by taking some wells out of production can result in more conservation in the short-run, but over time, as aquifer levels increase in response to conservation, groundwater use can increase.
2. A water rights retirement policy provides benefits to producers in the future, but the benefits vary greatly over space.
3. Subsidizing small reductions in water use can increase economic net benefits relative to water rights retirement. However, the design of policies matters for groundwater conservation. For example, a poorly designed subsidy policy can be less effective than a water rights retirement policy.
4. Groundwater is a critical resource for production in the HPA region, but its value is not uniform. Willingness to pay to increase well capacity for production is higher in hotter and drier counties across the aquifer.

What are some remaining knowledge and research gaps?

- Making this knowledge most useful to stakeholders, such as by developing an online dashboard where users can enter inputs and then quickly see outputs (Figure 3) related to projected crop yield, groundwater storage, groundwater levels, and well capacity looking into the future.
- Additional research to better understand interactions between system components (human, soil, crop, groundwater, and climate).
- Current crop models need improved algorithms to simulate water stress and yield responses.
- Irrigation scheduling tools that incorporate weather forecasts alongside expected crop yields.
- Integrating this data-driven simulation approach into a range of future water conservation plans focused on ag and community economic viability, taking into account regional biogeophysical heterogeneity.
- Determining how to transfer this model to other regions.

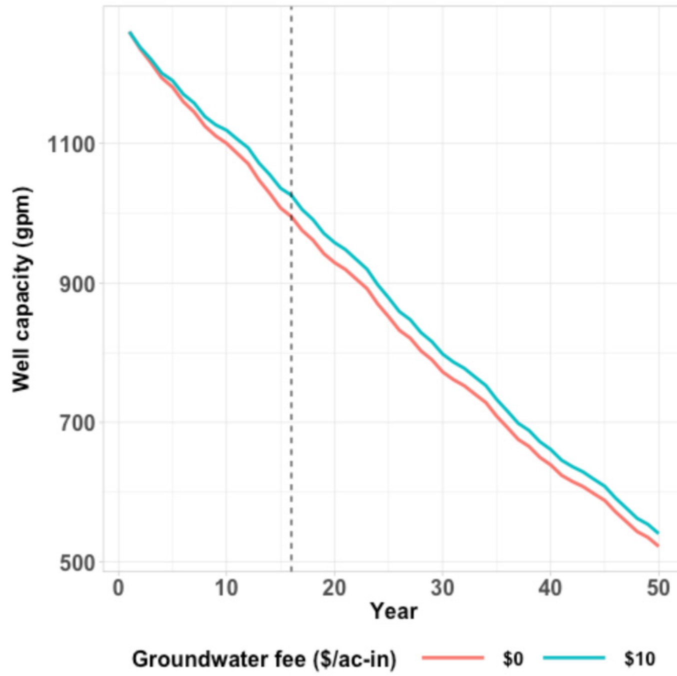

Figure 3. This figure shows a comparison for well capacities under a scenario where a $10/ac-in groundwater pumping fee (blue line) is implemented for the first 15 years (the dashed line shows the end of the policy) and a scenario without any groundwater fees (red line) for wells in Finney, County, Kansas.

Acknowledgement

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2016-68007-25066, "Sustaining agriculture through adaptive management to preserve the Ogallala aquifer under a changing climate." Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Ogallala Water Coordinated Agriculture Project (OWCAP)

Citation: Rouhi Rad, M. & Suter, J. (2021). *Ogallala water coordinated agriculture project executive summaries: The development of MOD$$AT: An integrated model to inform groundwater management* (OWCAP-2021-Executive Summaries-Integrated Model).

Editors: Meagan Schipanski, OWCAP, Project Co-Director and Amy Kremen, OWCAP, Project Manager

Content coordinator: Diane DeJong, Extension Specialist, Colorado State University

This publication is available online at www.OgallalaWater.org

USDA United States Department of Agriculture National Institute of Food and Agriculture

Publication Number: OWCAP-2021-Integrated Model (October 2021)