WATER CURRENT

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SPECIAL EDITION

OGALLALA AQUIFER
– IN DEPTH –

COLORADO STATE UNIVERSITY

Nebraska Water Center
Daugherty Water *for* Food Global Institute

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Introductory Note

Dear Reader,

We are proud to showcase here one of our nation's most important natural resources—the Ogallala aquifer—and the region it enhances. Underlying 175,000 square miles across eight states, this aquifer drives agricultural productivity and identity. The Ogallala aquifer region hosts diverse landscapes and ecosystems that are sensitive to human impacts. The aquifer currently supports nearly 30% of U.S. irrigated crops and livestock. Communities in the High Plains are experiencing both urban growth and rural population decline. Increasingly, stakeholders are pushing for resource conservation as many communities and natural systems are experiencing and impacted by groundwater declines.

In this context, human resources like cooperation and partnership are reasserting themselves as keys to managing scarce resources like water. A prime example is the Ogallala Water Coordinated Agriculture Project (OWCAP), led by a multi-state team including the Nebraska Water Center (NWC). Since its inception in 2016, this USDA National Institute of Food and Agriculture (NIFA) funded effort has brought together producers, scientists, groundwater managers, students, and public and private organizations into a coherent project that supports research and encourages greater visibility and adoption of practical approaches to help extend the productive life of the Ogallala aquifer.

This special edition of the Nebraska Water Current chronicles some of OWCAP's innovative research and outreach activities, and the people behind them. In all, some 70 researchers, extension specialists, students, and postdoctoral researchers based at ten institutions in six Ogallala states have meshed to form a regional body.

Regan Waskom, director of the Colorado Water Institute and OWCAP co-director, sees this breadth as integral to the project's mission."This project is really all about scale—from U.S. to local management to farm level. I think that is transformative to change the direction of the future of this aquifer," Waskom says.

The synergies across the diverse team of faculty, students, and postdocs are paying dividends. For instance, the Testing Ag Performance Solutions (TAPS) program that spawned from conversations between a key producer and junior and senior faculty at the University of Nebraska–Lincoln's West Central Research & Extension Center is now in year four, and recently a new, spin off TAPS program has started at Oklahoma State University (page 24). Additionally, postdocs who made significant contributions, like Erin Haacker and Vaishali Sharda, have landed tenure-track positions (page 28).

Meagan Schipanski, associate professor in the Department of Soil and Crop Sciences at Colorado State and OWCAP co-director, credits the stakeholder advisory group in making the science relevant."This is a non-academic group that includes farmers, water managers, state policy makers, and others. We want the science to be useful and applied, and this group has been key to linking large scale analyses and field level results to on-the-ground applications," she notes.

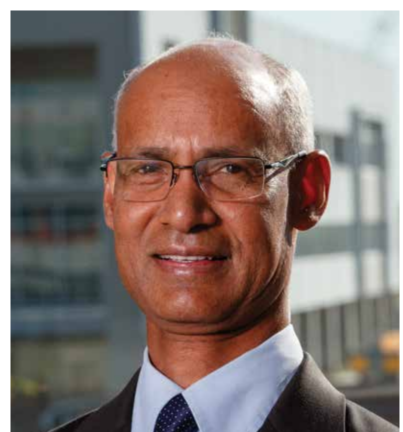
According to NWC Director Chittaranjan Ray, one of the key tools in the OWCAP toolbox is modeling that integrates groundwater hydrology with agronomy and economics (page 5). "There are so many variables that can influence the sustainability of the aquifer. We want to provide foresight for producers and managers so that when a new policy is implemented, we can confidently estimate its effects on producers today and the long-term impacts," Ray says.

As OWCAP enters its final project year this spring, the team is channeling its network and efforts to build capacity for more collaboration and conversation across the region. With project team members currently involved in new proposals or initiatives to extend different aspects of the OWCAP work, the social network it built is branching out.

To keep up on the project, we encourage you to visit *ogallalawater.org*.

Reagan Waskom

Meagan Schipanski



Chittaranjan Ray

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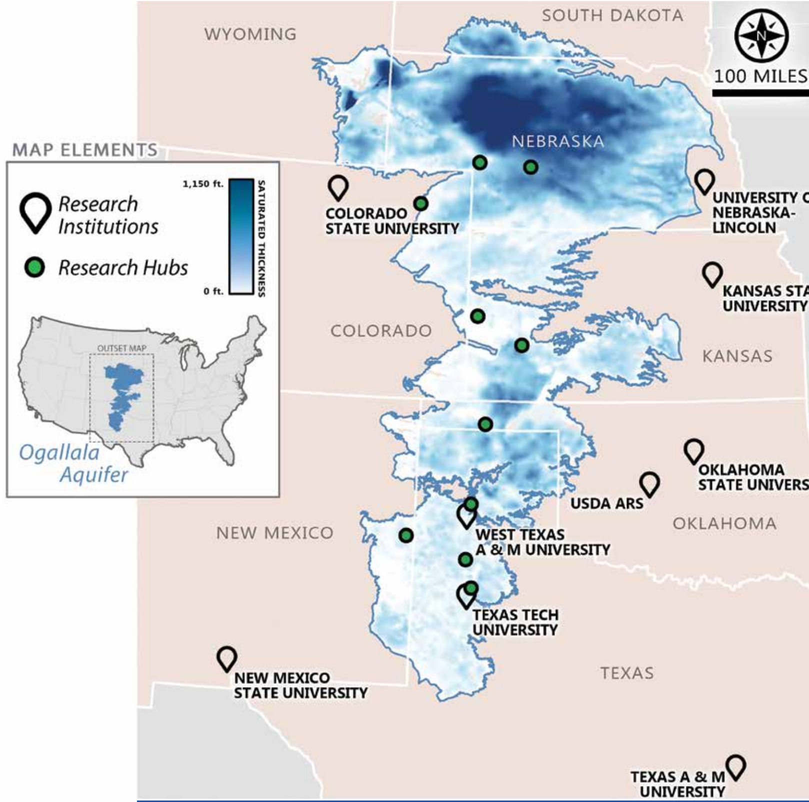


Map designed by Lacey Moore, Colorado State University.

OWCAP Project Objectives

1 Integrate hydrologic, crop, soil, and climate models, and related databases.

2 Develop and improve understanding of successful field-based management across the spectrum of dryland to fully irrigated production.

3 Investigate socioeconomic factors affecting water use decision making and identify incentives and policies effective at increasing efficient water use while maintaining productivity and profitability.

4 Encourage the adoption of tools and strategies effective at improving water use efficiency, water conservation, and farm operation profitability.

MOD$$AT: Ogallala Water CAP's Integrated Model

By Hannah Moshay

Hannah is an extension and outreach specialist for OWCAP based at Colorado State University.

Mani Rouhi Rad

Erin Haacker

Communities throughout the High Plains depend on the Ogallala aquifer. Intensified irrigation and variation across the aquifer region in terms of hydrology, climate, and cropping systems have contributed to varying depletion rates across the region. Understanding and preparing proactively for different ways in which these declines may affect agricultural production and communities is the main focus of the USDA-NIFA funded Ogallala Water CAP project or OWCAP.

A portion of the team includes modelers trained in different disciplines who have worked over the past few years to evaluate how decisions related to crop choice, water use, policy and climate will likely affect groundwater, surface water, and the regional economy over time. Their development of a new, robust, integrated model will help support discussions of what the future might bring under a multitude of scenarios, given different management practices, shifts in precipitation, and related impacts on the aquifer resource. Ideally, this model will help guide water management for farm profitability and increase the longevity of the use of the aquifer resource.

Mani Rouhi Rad and Erin Haacker, who joined the team as postdoctoral researchers, have been key contributors to different aspects of the project's integrated modeling effort. Mani is an economist, and Erin is a hydrologist. OWCAP Outreach and Extension Specialist Hannah Moshay asked them to share a little about their experience collaborating as part of this team.

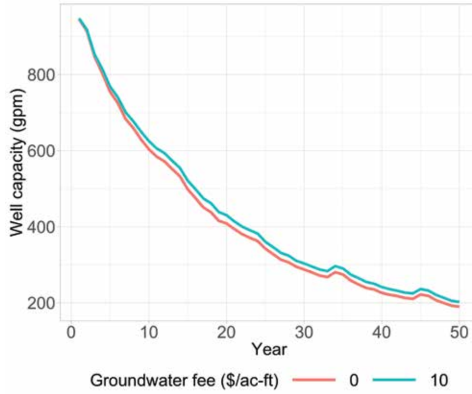
HANNAH: Could you give an overview of your work on the model?

Mani: Our team is currently investigating what the economic implications are for producers and communities as water levels change throughout the aquifer. I've collaborated with Ph.D. students and postdocs from other disciplines, such as soil and crop sciences, agricultural engineering, hydrology, and civil engineering, as well as other universities, including Kansas State, University of Nebraska–Lincoln, West Texas A&M, and Texas Tech University. It's been really rewarding to be part of such a diverse and skilled team.

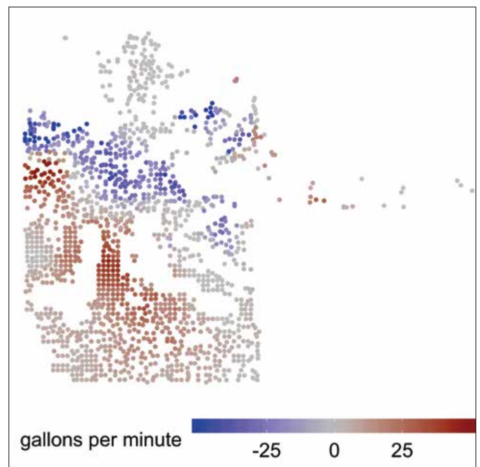
Erin: I'm responsible for the groundwater and surface water modeling in the Northern High Plains. Currently, I'm developing the MODFLOW groundwater model for the area between the Platte and Republican Rivers in Nebraska. We're hoping to use this to better understand the interactions between surface water and groundwater and how water moves through both systems.

HANNAH: What goes into creating an integrated model? What stage of development is the model in at this point in time?

Erin: An integrated model is a combination of two or more modeling "steps" essentially combining two or more processes that go into different models. This means bringing together researchers' work from different disciplines into a single system. Currently, the model is running, but we're working to troubleshoot the pieces that don't align with our expectations—sometimes that means we're learning something new, but other times, it's because pieces don't fit together like we want them to, and it's vitally important to figure out which is which!



Average well capacity projection for the next 50 years in Finney County, KS, under two scenarios: 1) no pumping fee, and 2) $10/acre foot pumping fee.
(Credit: MOD$$AT model team)



The spatial distribution of difference in well capacities with a $10 pumping fee and without any pumping fee. With a pumping fee, well capacities overall will be higher on average over time. However, there is spatial variability in the direct impacts of the pumping fees.

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Mani: Our integrated hydro-economic model relies on three main elements: first, a model of an agricultural producer, who makes decisions at the well level that impact water use; second, a model of crop growth and water use to simulate crop growth for different crops and under different scenarios of groundwater availability and irrigation; finally, a physical model of groundwater dynamics is required to simulate the flow of groundwater below ground across different wells. The integrated model we're working to develop connects these three elements with the hope that this data can be utilized by producers and policy makers. We are happy to say the model is currently running, and we have some preliminary results for Finney County in Kansas. We're also currently adapting it for areas of the Ogallala aquifer which underlie Colorado, Nebraska, and Texas.

HANNAH: Why is having an integrated model to represent the Ogallala aquifer region necessary?

Mani: An integrated hydroeconomic model provides two main advantages. First, it allows us to better understand depletion trends across the aquifer. As groundwater levels continue to decline, pumping costs increase and well capacities decrease. A model that does not include an economic component cannot account for shifts in irrigation decisions which respond to these changes throughout the system. An economic model allows us to better account for these human decisions. Second, a hydroeconomic model can help us compare the benefits and costs of different policies. For example, if a groundwater management district wants to reduce extraction by considering three different policies, let's say: a pumping fee, a groundwater allocation, or a cap and trade policy, a simulation using our model could generate economic trade-offs showing which areas are impacted the most. The hydro-economic model allows us to better understand the sustainability of groundwater use for irrigation across the High Plains aquifer [region] and helps us provide valuable and applicable information for producers and policymakers.

Erin: By integrating models of different components of the water system, we can have "moving parts" in place of assumptions. For example, a traditional hydrogeology model would make some assumptions about how much water would be pumped across a season and from year to year. However, the system as a whole is very sensitive to those assumptions, which can end up causing blind spots in the model results. Model integration is meant to incorporate all the sensitivities of the system, so that we can foresee unintended consequences and prepare for changing conditions.

HANNAH: What value might the model have for Ogallala aquifer region producers and communities?

Mani: I think our model is especially valuable for areas where the water is depleting very rapidly, where there is really a need for immediate action. The model can help us to understand the costs of aquifer depletion and select policies that can result in greater benefits for the next generation of producers.

Erin: Hopefully, this means that producers and communities in the Ogallala aquifer region will get a chance to understand the connections between these [human, climate, and biogeophysical] systems, and how much control they have over the aquifer lifespan.

HANNAH: How do you explain your work when talking with people who don't trust models?

Erin: I don't think people should blindly trust models, but there are a lot of people who say they don't trust models, they only trust data. Well, a model is a framework for data. It's a line that connects the dots, which makes it easier to see what's happening. I would encourage people to be informed consumers of models and to ask about the assumptions a model is making, and to ask where the data is coming from. A model can never be better than its data, so if people want better models, it's important for them to also support more data collection.

Mani: Every model relies on some simplifications and assumptions. The real question is whether the model is useful for what it was created given the assumptions made. For example, we want our model to be used by local policymakers such as groundwater management districts. These policymakers often already rely on models to simulate groundwater levels, crop yields, and water use. However, there is often no model of decision-making in the analysis of policy. Without this behavioral response, it is difficult to understand how a given policy could affect groundwater levels and the resulting costs and benefits.

HANNAH: Where would you like to see this work go?

Erin: I would like to continue building our collaboration, and to keep making our models better and better. There are data sources we haven't been able to incorporate yet, and techniques like sensitivity analysis that could tell us a lot about the system. I always try to remember that the model isn't the point, it's just one tool in our toolbox. The point is to help people manage their water.

Mani: We are currently working on a few papers that are based on the model. We hope to publish these papers in journals that reach a broad audience, not just economists or hydrologists. I would also like to see the model adopted by policymakers. I am currently working to develop an R package for the economic component for our model, MOD$$AT, so that anyone that has access to the MODFLOW model of a given aquifer and with the [the crop model] DSSAT (Decision Support System for Agrotechnology Transfer) models of the crop they are interested in can download this package and do simulations to evaluate policies anywhere in the world. MODFLOW and DSSAT are two of the most widely used simulation models for groundwater and crop production modeling, so there are a number of folks who could use our model. By adding the economic component and integrating these models, we have made these accessible but separate elements even more useful for tackling the complex challenge of managing critical local resources.

The Lowdown on Soil Moisture Monitoring

By Daran Rudnick, Jonathan Aguilar, Allan Andales, Joel Schneekloth, and Chuck West

This article's authors are all members of the USDA-NIFA Ogallala Water CAP team. This article was originally published as a downloadable resource guide, available at http://ogallalawater.org/soil-moisture-monitoring/.

Knowing when and how much water to apply is an important aspect of irrigation management. Effectively monitoring and making water use decisions using soil moisture data, while having a good understanding of shifts in crop water demand over the growing season, helps farmers increase their water use efficiency, on-farm profitability, and potentially how much groundwater they can conserve, particularly in normal-to-wet growing years.

However, the number of producers using soil sensors to help decide when to irrigate is still very modest. In USDA's most recent Irrigation and Water Management Survey, fewer than 25% of farms in a majority of U.S. states reported using soil moisture sensor data to decide when to irrigate.

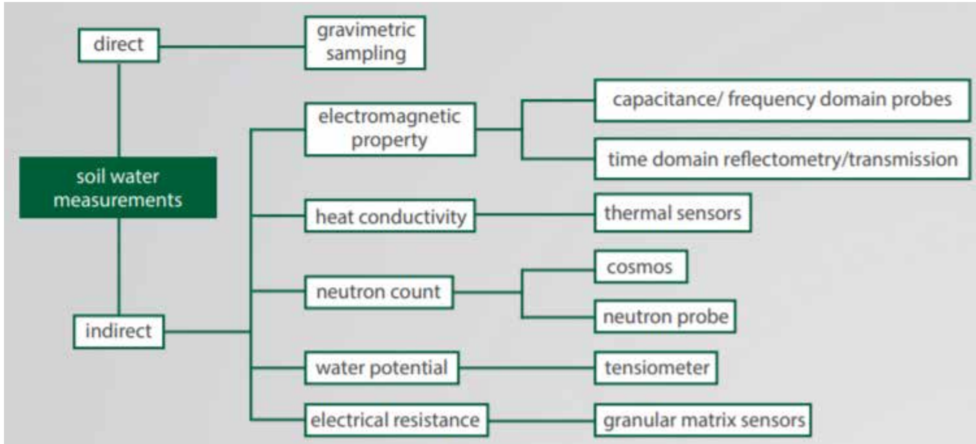
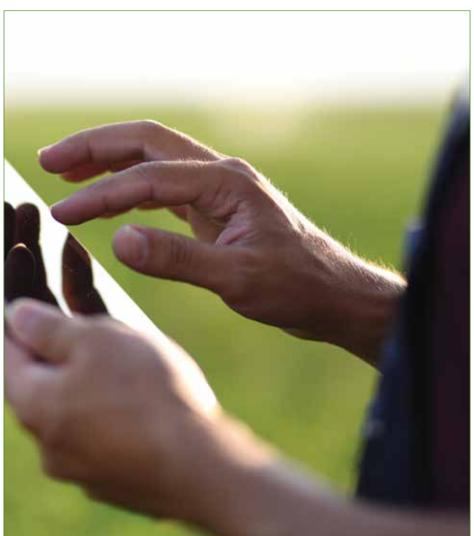


FIGURE 1: Methods of monitoring soil moisture broken out between direct and indirect, the monitoring method, and technology.



Soil moisture sensors enable farmers to tap into data for decision making.

What are the available options for soil moisture monitoring?

Soil moisture has traditionally been measured either by hand feel, or by weighing field-collected samples before and after being dried to determine soil water content. Feeling soils by hand is valuable but inaccurate, and this "gravimetric" method of drying and weighing soils is accurate but destructive to soil, in addition to being tedious and time-consuming.

Consequently, other indirect methods and technologies (Figure 1) have been developed. These methods vary in terms of how they estimate soil moisture and perform under different conditions.

What are some recent improvements in soil moisture sensors?

Most soil moisture sensor technologies have been around for decades, but considerable improvements have occurred recently in data processing, data display, and user friendliness. These advances, combined with industry and university consultation, have increased interest in and reliance on soil sensors for informing irrigation management decisions.

Another notable advancement in soil moisture monitoring is the development of sensors that spatially and remotely monitor soil water status, such as the cosmic ray probe (Hydroinnova, Albuquerque, New Mexico) and passive microwave reflectometry (divirod, Boulder, Colorado). Advances in spatial water monitoring can help identify differences in crop water availability across the field, so that irrigation decisions can be triggered or prompted based on field-level economic thresholds and/or through use of variable rate irrigation. Furthermore, spatial soil water status can help inform other agronomic practices, such as planting date and depth, hybrid/cultivar type, population density, and nutrient management (Rudnick et al., 2017).

With so many options, how to choose which soil moisture sensor(s) to use?

Understanding how each sensor works is helpful in weighing advantages and disadvantages of different sensor options. Key factors to consider include convenience (of installation and use), financial cost, remote access capability, availability of product and consulting support, sensitivity and calibration factors that can affect accuracy, and the number and placement of sensors needed for informative readings that can guide decision making effectively. Choosing a sensor and accompanying user interface which relays this information in an intuitive and clear way is also important.

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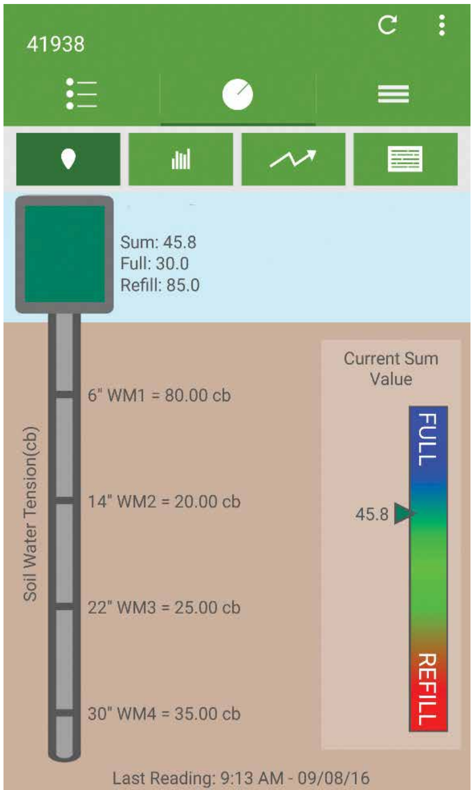

FIGURE 2: Example of mobile interface of one soil moisture probe service.

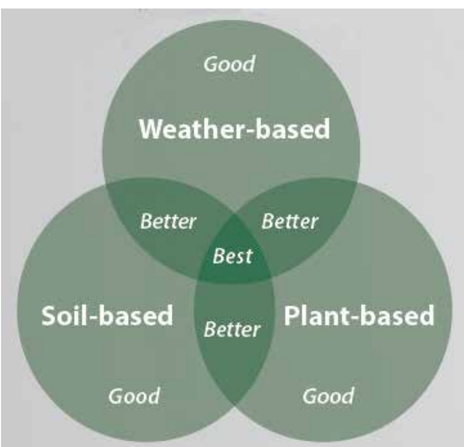

FIGURE 3: Methods of informing irrigation management.

It may be advantageous to install sensors at multiple soil depths (Figure 2). Tremendous insight can be provided by observing sensor responses over time at various depths, including: the extent and depth of root growth, infiltration depth of irrigation and precipitation, soil field capacity (water retained in a freely drained soil about two days after wetting), and possible evidence of over- or under-irrigation.

What are the limitations of soil moisture sensors?

In general, the limitations of soil moisture monitoring for irrigation management include challenges in correctly selecting, installing, and maintaining sensors in order to provide an accurate and representative picture of soil moisture status across a producer's operation. Addressing these limitations involves determining: an adequate number of sensors (or measurements), where to install sensors, determining a representative sensing volume, and having an adequate sensor response time that supports decision making. Having a reasonable idea of soil moisture "full" and "refill" levels, is also important, and requires a solid understanding of how different soil types hold water and how crop water needs shift throughout the growing season.

Soil moisture sensor accuracy can be affected by several factors including temperature, salinity, and soil texture. In addition, although some sensors may report moisture levels to the nearest hundredth of an inch, producers should evaluate irrigation applications to the nearest tenth of an inch, reflective of the overall application accuracy irrigation systems can achieve due to variation across the entire system.

Clay soils in particular can influence soil moisture readings. Because clay has a higher surface area than other soils, contacting a service provider or extension specialist for assistance with calibrating electromagnetic soil water sensors, including reflectometers, is recommended for accurate readings. Without calibration to clay content, soil moisture sensors become less accurate as clay concentration increases.

Trusting soil moisture sensor data

In addition to the technical limitations posed by soil moistures, it can take some producers a considerable amount of time—several growing seasons—to develop sufficient trust in soil moisture sensor data to integrate this information into their water use decision making. Continuing with (rather than abandoning) hand feel methods and other established techniques to assess soil moisture and crop water demand while trying soil probes, can help in building trust.

"It was a true learning experience. Trust was the main thing, to be able to trust the technology. It really meant believing what you were seeing through the probe was actually there in the soil. Over time it gets easier, and you start to know what the probe is telling you is true. Then it really teaches you. You really learn a lot about your irrigation."
Producer—Hershey, Nebraska

"The first year I put them (soil moisture probes) in the field, I would look at the readings, take a soil sampling tool and pull a soil core, look at it, and decide whether I thought the probe was even close. Well, that year we had substantially better corn, and we used like 4 or 5 inches less water to do it. Since then I put them in, and I don't irrigate unless the probe says we need to."
Producer—Marienthal, KS

One tool among many

Irrigation scheduling tools that use water balance models based on weather information are a terrific compliment to soil moisture sensors. While the models used for irrigation scheduling tools can provide acceptable irrigation requirement estimates, their errors can accumulate through the growing season. Using soil moisture measurements during the growing season to correct weather-based water balance models can increase producers' confidence in their water use decisions (Figure 3; Andales, 2019, Aguilar, 2018).

Although soil moisture monitoring should not be expected and solely relied upon to provide a high degree of precision and accuracy in all on-farm scenarios, moisture sensors can be a useful tool when their data is combined with feedback from other tools and field-level observations of soils and crops.

Aguilar, J. (2018). *Tips On Selecting a Soil Water Sensor.* Retrieved from https://www.bookstore.ksre.ksu.edu/pubs/MF3407.pdf

Andales, A. (2019). Irrigation Scheduling Using a Water Balance Model and Soil Moisture Sensors. *Proceedings of the 31st Annual Central Plains Irrigation Conference, Kearney, Nebraska, Feb. 26-27, 2019.* Retrieved from https://www.ksre.kstate.edu/irrigate/oow/p19/Andales19.pdf

Rudnick, D., Chávez, J., Aguilar, J., Irmak, S., Bordovsky, J., & Burr, C. (2017). Advances in Irrigation. *Colorado Water,* 34(6), 29-32.

Innovations in Forages and Grazing in the High Plains

By Chuck West, Philip Brown, Rick Kellison, and Crystal Powers

Chuck West, Philip Brown and Rick Kellison are researchers at Texas Tech University and members of the OWCAP team. Crystal Powers is the research and extension communication specialist at the Nebraska Water Center.

Vast stretches of treeless grasslands are emblematic of the Great Plains. Before Euro-American settlement, indigenous tribes were supported by abundant herds of bison and antelope grazing on diverse grasses and forbs. Beef cattle were introduced with settlement and the plow opened the soil for rainfed cropping. Today beef cattle graze in every county of the Great Plains (Figure 1). Land allocation between grazing and cropping depends largely on soil productivity and availability of water for irrigation. Cow-calf ranches predominate on extensive stretches of non-tillable, non-irrigated grasslands, and concentrated feedlot operations for fattening beef cattle and dairy production are found near irrigated cropland. In both situations, beef and dairy production enhance the economic value of grasses and grain.

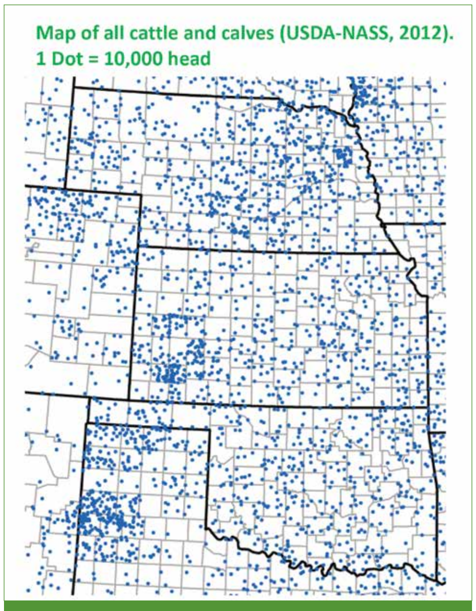

FIGURE 1: Map of all cattle and calves in the Ogallala aquifer region. (Source: USDA-NASS, 2012)

The vast agricultural area overlying the Ogallala aquifer provides around 30% of the nation's beef supply, thanks largely to irrigation use to support corn production. Grazed grasslands and cultivated forage crops provide important complementary feed sources in the beef and dairy industries, helping to sustain breeding herds and providing low-cost dietary protein and fiber. Besides the well-known role of corn as the main source of energy-concentrated grain for cattle, corn silage is also one of the most valuable forages with the combination of high productivity and nutrition in the form of digestible fiber and energy. Being high in water content (around 35%), it is an expensive crop to transport, therefore having production fields close to livestock facilities is ideal. However, corn silage requires significant inputs to produce a profitable harvest, requiring nitrogen fertilizer (typically 200 lbs/acre per year), and more than 30 inches of effective in-season rain plus irrigation. With Ogallala aquifer water supplies in decline, interest in finding alternatives to corn silage has increased.

One of the most promising alternatives are the many varieties of sorghum. The short-statured grain sorghum (milo) is a dryland-adapted, alternative source of high-energy feed grain. The tall-growing forage sorghums and sorghum-sudangrass hybrids are displacing corn silage in some areas where pumping capacity is too limited to support corn production. Maximum yields of forage sorghum require 25-30% less water compared to that required for maximum corn silage yields, with similar amounts of water consumed per ton of forage produced. However, the lower grain content of sorghum silage than of corn is a drawback. Breeders have incorporated a trait called brown midrib (BMR) into forage sorghum to unlock more digestible energy from the sorghum fiber and narrow the difference in energy nutrition relative to corn. This is an example of how improving the digestibility of a water-use efficient forage can boost its usefulness where irrigation conservation is critical.

Grazing winter wheat is another common forage alternative in Texas and northward to southern Kansas, thanks to relatively mild winters. This is a common alternative for young growing cattle, called stockers, before they reach finishing or the milking herd. Such wheat is managed as a dual-purpose crop, with grazing finished by early March and allowed to regrow to produce grain in late spring. One of the challenges for grazing wheat is that in much of the High Plains rainfall is too low or variable in late fall and winter, limiting availability of wheat forage for grazing, and where irrigation is available, the economics of irrigating wheat pasture are often unfavorable. Raising stocker cattle is another key sector on the High Plains.

Summer stocker programs can be carried out using annual forages such as sorghum-sudangrass and pearl millet, but also using perennial forages so that pasture establishment and maintenance costs are spread over many years. These can be an option in no or low irrigation areas, as summer-adapted forage crops are highly responsive to modest levels of available water.

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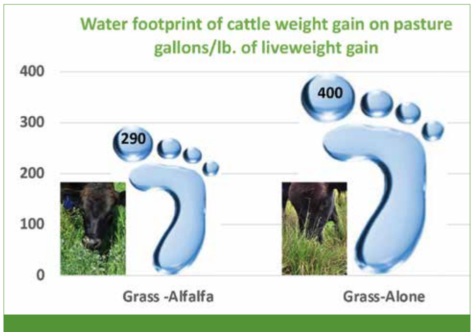

FIGURE 2: The water footprint of cattle weight gain (gallons/lb.) on pasture.

Dr. Daren Redfearn, University of Nebraska–Lincoln extension forage crop residue specialist.

In Nebraska, Daren Redfearn, extension forage crop residue specialist at the University of Nebraska–Lincoln, is conducting a four-year integrated crop-forage-livestock systems experiment to evaluate conversion of marginally productive cropland to perennial grassland and integrate grazing animals into the system. This project is part of a USDA-NIFA CAP collaboration with USDA-ARS and the University of Nebraska–Lincoln and led by South Dakota State University. An objective of the project is to evaluate system performance and sustainability of beef gains, hay and corn grain yields, greenhouse gas emissions, cover crop growth, and economic evaluation for yearling steers grazing smooth bromegrass in spring and fall and switchgrass during summer. Early results show variable beef gains, corn grain yields, and economic net returns. Look for discussion of the full results in future editions of the Water Current.

Growing winter cover crops as a forage source has also increased in the Great Plains. They can provide benefits beyond forage such as reducing wind erosion of soil and rebuilding soil organic matter content. While it is difficult to recover the cost of cover crop establishment through soil health alone, these spring grazing cover crop species can improve returns while enhancing the soil benefits. Grazing cover crop species include triticale, rye, vetch radishes, and turnips. Even crop farmers who do not own cattle can contract with cattle owners for 2-4 months of grazing as a means of diversifying their income streams.

A specific production system that we investigated was how to improve cattle gains by looking at combinations of traditional perennial grass, improved grass varieties, alfalfa interseeding, and irrigation. In the Lubbock area of Texas, young cattle typically gain around 2 lbs. per head per day on perennial grasses from mid-May to late July, before dropping to 1.5 lbs. through September using 9-12 inches of irrigation. A variety of Old World bluestem, WW-B.Dahl, has performed consistently well in terms of persistence, with stands established in 1997 still highly productive. In 2009, alfalfa was interseeded into some of these bluestem pastures. Other pastures were planted with a plot of alfalfa and tall wheatgrass, 20% of the total grazed area, called a “protein bank.” All received 9 inches of irrigation. During 2014-2016, steers were grazed on these pastures so that cattle in the alfalfa-grass system rotated weekly between the alfalfa-bluestem (5 days on) and alfalfa-wheatgrass (2 days on). The grass-only system contained no alfalfa and received 60 lbs. per acre annually of nitrogen fertilizer, whereas the alfalfa-grass system received no nitrogen fertilizer.

Weight gains of cattle on the alfalfa-grass system averaged 2.1 lbs. per day, while gains on grass-alone were 1.7 lbs. per day. The amount of irrigation applied to the alfalfa-grass pastures was slightly more than the grass-only pastures, but cattle produced 60% more gain per acre on the alfalfa-grass system, resulting in 27% less groundwater use for each pound of weight gain than without alfalfa.

Alfalfa has been dismissed as a water-wasting crop. However, used in these systems, it can boost the economic productivity of High Plains cropland over grass-alone. Its superior nutritional value supported faster steer growth and its deep root system allowed access to soil water below the grass root system.

A possible scenario could be a center-pivot, formerly a corn field, whose well has experienced reduced pumping capacity to the point that only one-fifth of the area can be occasionally irrigated. That wedge could contain an alfalfa-dominant protein bank, which cattle would have limited access to as a protein and energy supplement, while most of the grazing would take place on the non-irrigated remainder of the field. After fall weaning of calves, the dry cows could also rotate grazing with an adjacent corn or sorghum field to scavenge the crop residue.

These are just a few of the options available for greater use of annual and perennial forages to enhance the sustainability of agriculture in the Ogallala aquifer region. Forages provide diversification of commodities to even out market volatilities, prevent soil erosion, inhibit weeds, build water-retaining soil organic matter, exploit the deep rootedness of perennial crops, and provide alternatives to corn where irrigation output is in decline.

More information is available at http://bit.ly/SARE_SHP_Bulletins.

Cattle graze on alfalfa in Texas’s High Plains region near Lubbock. (Credit: Lisa L. Baxter)

Effects of Aquifer Depletion on Irrigated Agricultural Productivity

By John Tracy, Jennifer Johnson, Leonard Konikow, Gretchen Miller, Dana Osborne Porter, Zhuping Sheng and Steve Sibray

Lead author John Tracy is the director of the Texas Water Resources Institute and professor of water resources in the Zachry Department of Civil Engineering, in the Dwight Look College of Engineering at Texas A&M University.

Introduction

Approximately 70% of groundwater withdrawals worldwide are used to support agricultural production, and within the United States, about 65% of groundwater withdrawals are used for irrigating crops. This percentage is even higher in arid and semi-arid areas, where the use of groundwater typically exceeds the rate at which it is naturally replenished. Groundwater depletion has occurred in many important agricultural production regions, including the Great Plains Region (Nebraska, Colorado, Oklahoma, New Mexico, and northern Texas), the Central Valley of California, the Mississippi Embayment aquifer (Mississippi River lowlands bordering Arkansas and Mississippi), aquifers in southern Arizona, and smaller aquifers in many western states. The groundwater resource with the greatest long-term depletion is the High Plains (Ogallala) aquifer in the Great Plains region. The most obvious consequences of depleting groundwater resources are the loss of a long-term water supply and the increased costs of pumping groundwater as the water table declines further below the ground surface. Other consequences associated with groundwater depletion include: the loss of groundwater well capacity; reduced stream flows that are hydrologically connected to aquifers; subsidence of land surfaces; and intrusion of saline or poor quality water from other subsurface formations. The most effective approaches for addressing groundwater depletion focus on reducing the imbalance between the inflow and outflow of water to an aquifer. These can include Managed Aquifer Recharge (MAR) approaches, increases in water use efficiency and conservation, and providing economic incentives for reducing water use. All of these methods should be considered when developing plans to address groundwater depletion, along with policies that regulate the use of groundwater.

This article is a condensed version of CAST (Council on Agricultural Science and Technology) Issue Paper Number 63, Aquifer Depletion and Potential Impacts on Long-term Irrigated Agricultural Productivity published in February, 2019. The full article can be found at: go.unl.edu/aquifer.

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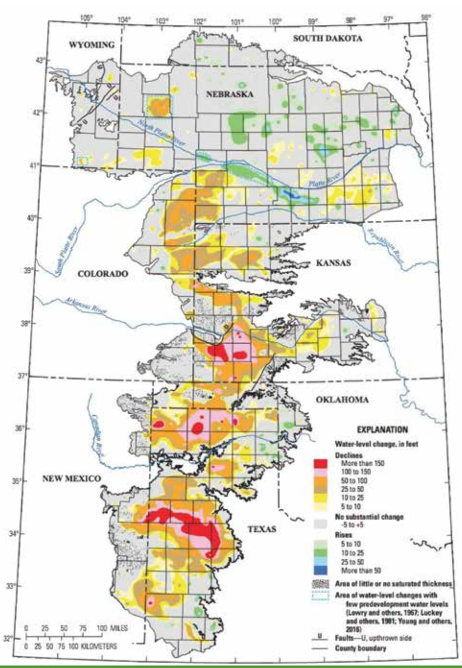


FIGURE 1: Changes in water levels in the High Plains aquifer, predevelopment (about 1950) to 2015.

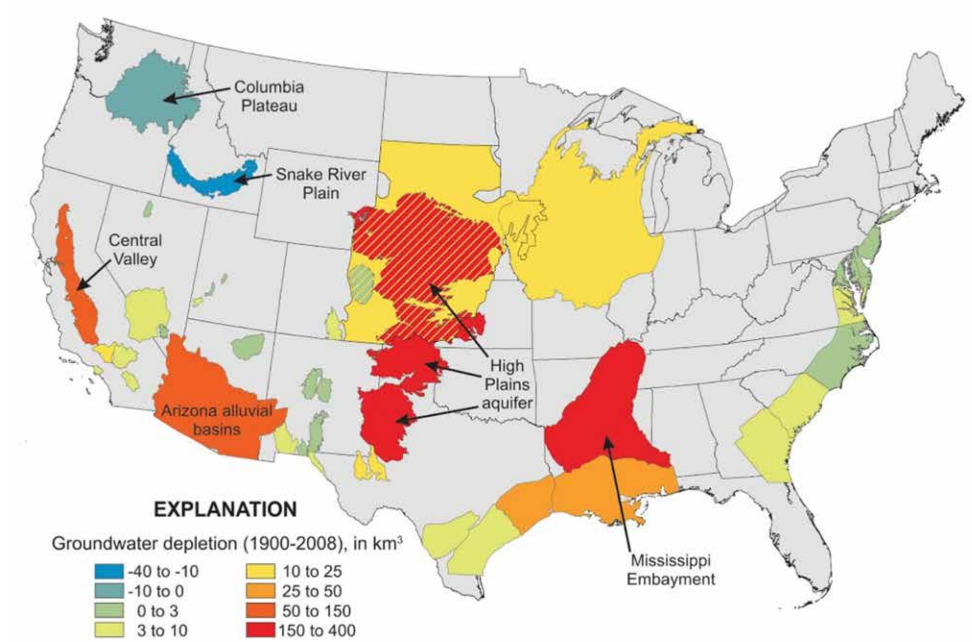


FIGURE 2: Cumulative long-term volumetric groundwater depletion in the United States during 1900–2008 in km^3. Hatched areas are where a shallow aquifer overlies a deeper aquifer.

Groundwater Depletion across the United States

In the High Plains aquifer system, significant long-term groundwater storage depletion has occurred (nearly 325 million ac-ft by 2013). In the southern part of the High Plains aquifer, water levels have declined more than 150 feet (Figure 1), resulting in the loss of more than half of predevelopment saturated thickness. Similar problems are pervasive in aquifers across the United States and globally. A map of long-term (1900–2008) groundwater depletion in major aquifers (Figure 2) shows large losses in the Central Valley of California, the Mississippi Embayment aquifer, the alluvial basins of southern Arizona, and numerous smaller aquifer systems—especially in the arid western states.

Economic and Management Factors Driving Groundwater Depletion

Groundwater flows across property boundaries, and therefore, it is difficult to exclude others from obtaining benefits of its use, even if they do not provide support to manage or sustain the use of the resource. Unless measures are taken to limit use of the resource, these individuals may be inclined to maximize their benefit of its use, resulting in overuse and decline of the groundwater's overall value. Over time, overuse can be a somewhat self-correcting problem, because the costs of groundwater extraction tends to increase as water levels drop. When costs of extracting groundwater exceed the benefits for lower-value water uses, overall pumpage from the aquifer will be reduced, as observed in several regions, including portions of the High Plains aquifer in Texas, Oklahoma, and Kansas.

Sustainable aquifer use could be achieved if groundwater recharge is increased and the pumping cost becomes high enough that groundwater extraction is decreased to the point of a dynamic equilibrium of the groundwater table. This laissez-faire approach to managing groundwater, however, does not prevent groundwater depletion, nor has it been advocated as a viable policy by any state.

In semi-arid regions where water is a major factor limiting agricultural production, irrigation greatly increases agricultural yields and profits. Given the significant net economic benefits of developing groundwater for agricultural irrigation, benefits from groundwater management are most likely minor for areas like the Texas High Plains, especially relative to reasonable costs of regulating pumping.

A strict regulatory approach to groundwater management may not give the best economic outcome for areas that rely heavily on groundwater. An alternative approach is management through privatization of groundwater pumping rights. This can be done through an allotment or allocation process in which private entities have fixed allocations of groundwater. This approach is used in Nebraska through the use of natural resource districts (NRDs) that typically allocate water on a five-year basis and occasionally allow some "banking," or carryover, of water across allocation periods. In the Texas High Plains, groundwater conservation districts (GCDs) establish pumping limits as part of their management plans to achieve adopted desired future conditions (stakeholder derived groundwater conservation targets). The Kansas Groundwater Management Districts also now employ this approach after a change in state law.

Agricultural Management Approaches to Mitigating Depletion

Strategies to decrease groundwater depletion include changes to crop selection and agricultural practices, which are being implemented in the High Plains region of Texas. In the Northern Texas High Plains, grain corn is the predominant irrigated crop. However, in the Southern Texas High Plains, where aquifer storage and well capacities are more limited, more drought-tolerant crops are prevalent, including cotton, grain sorghum, and winter wheat. Applied research programs in the region evaluate—and regional water planning efforts advocate—water conservation strategies, including conversion to higher efficiency irrigation technologies, data-based irrigation scheduling, changes to less water-demanding or more drought-tolerant crops and varieties, conservation tillage methods, and conversion from fully irrigated production to limited irrigation or dryland (rainfed) production.

In the Texas High Plains, adoption of more efficient irrigation technologies and strategies and more drought-tolerant crops and varieties has been encouraged by water-limited conditions (limited well capacities), availability of low-interest loan and cost-share programs, and suitability of the technologies to the local production systems. These strategies are distinguished from solely improving irrigation efficiency. With improved efficiency, often water is simply used to irrigate more acreage and overall consumptive use and aquifer depletion can increase.

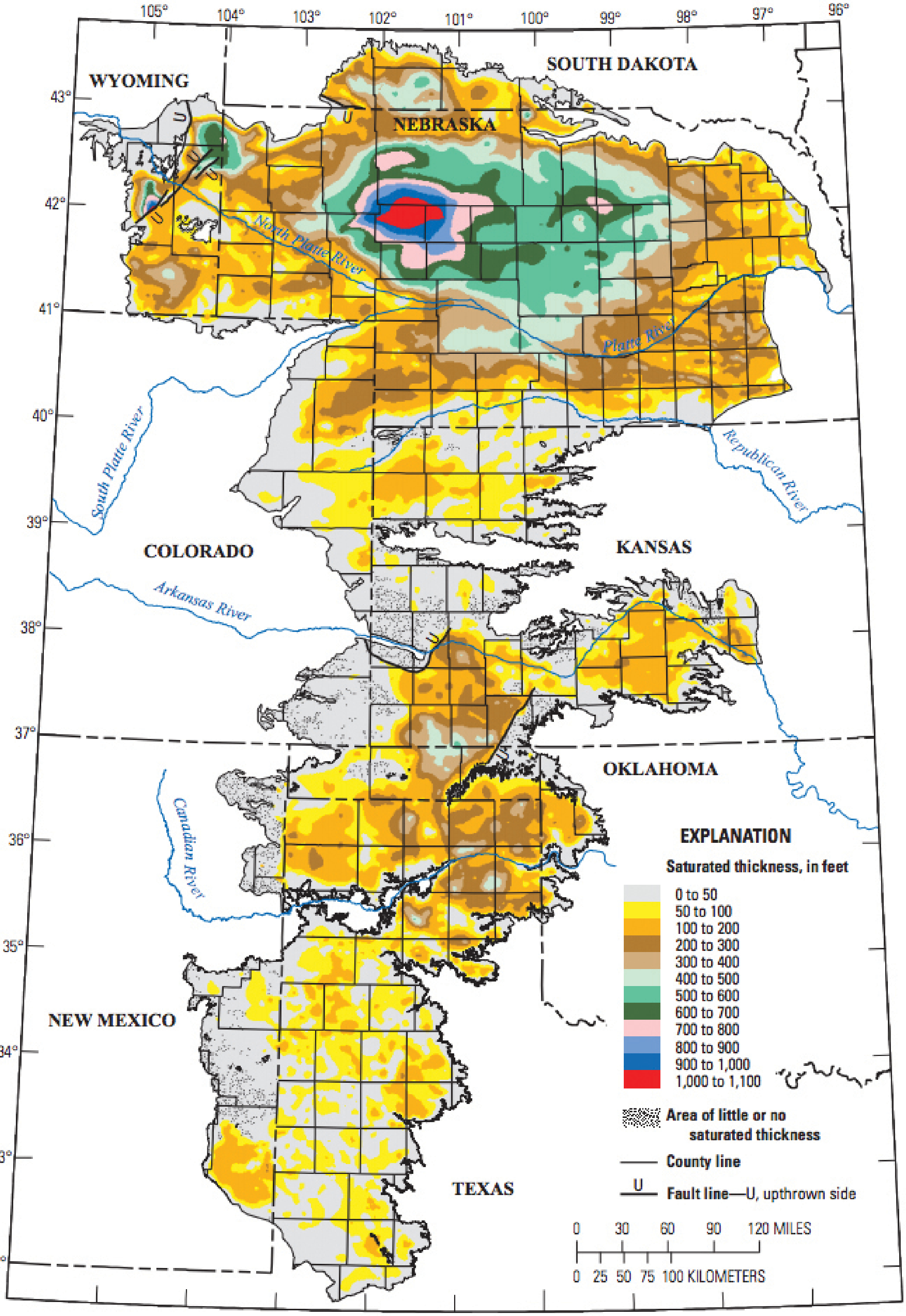
Figure 1 Source: McGuire, V. L. 2017. Water-level and recoverable water in storage changes, High Plains aquifer, predevelopment to 2015 and 2013–15: U.S. Geological Survey Scientific Investigations Report 2017–5040, 14 p., https://doi.org/10.3133/sir20175040.

Figure 2: Modified from Konikow, L. F. 2013. *Groundwater Depletion in the United States (1900–2008)*. U.S. Geological Survey Scientific Investigations Report 2013–5079. 63 pp., http://pubs.usgs.gov/sir/2013/5079 (10 April 2018).

Case Study: Pumpkin Creek Watershed

There are many areas where policies and practices have been implemented to reduce the depletion of groundwater resources. A case study of an attempt to mitigate the impacts of groundwater depletion in the Pumpkin Creek Watershed in the Nebraska Panhandle region can be found in the CAST Issue Paper Number 63, Aquifer Depletion and Potential Impacts on Long-term Irrigated Agricultural Productivity, which can be found at: *go.unl.edu/aquifer*.

When developing policies and practices to manage the use of groundwater resources, the potential consequences of groundwater depletion needs to be fully assessed to determine trade-offs that exist between the undesired impacts of groundwater depletion and the benefits associated with groundwater use.



Saturated thickness of the High Plains aquifer, 2009. (Source: https://pubs.usgs.gov/sir/2012/5177/sir12-5177.pdf)

New Irrigation Pumping Plant Calculator Compares Current Costs and Potential Savings

By Joel Schneekloth and Lee Wheeler

Joel Schneekloth is a Water Resources Specialist at Colorado State University, based in Akron, CO, and Lee Wheeler is an engineer based in Hesston, KS.

The content covered in this article was first published in the Proceedings of the 32nd Annual Central Plains Irrigation (CPIA) Conference, Kearney, NE, February 18-19, 2020. To access the complete CPIA proceedings for the 2020 conference, please visit: https://www.ksre.k-state.edu/irrigate/oow/cpic20.html.

Introduction

Irrigation can be a major input cost in irrigated agriculture. While informed irrigation scheduling can improve water use efficiency in the field, the mechanical efficiencies of a well and irrigation system are also important factors when considering system wide irrigation efficiency and reducing overall irrigation costs.

The Irrigation Pumping Plant Calculator was based upon the IRRICOST calculator, a tool developed by the University of Nebraska–Lincoln – Lancaster County Extension (lancaster.unl.edu/ag/crops/irrigate.shtml), which calculates the annual cost of owning and operating an irrigation system. IRRICOST is a useful tool for comparing costs of alternative energy sources and looking at the potential costs of installing a new system. However, the Irrigation Pumping Plant Calculator directly compares current costs and potential savings.

Energy Requirements

The largest cost in operating an irrigation system is energy (Martin et al., 2011). Several factors contribute to the overall energy required for pumping, mainly: 1) lift, 2) pressure, and 3) pumping plant efficiency. The main calculation in determining energy requirements is total dynamic head. Total dynamic head is a value (measured in feet), which describes how high water can rise in a pipe given a subset of physical conditions. The calculation incorporates lift, pressure, and friction losses. This is an important value, because it describes the relationship between water and energy in a pumping system.

Lift, often the major energy requirement, is generally not manageable in most systems unless it is operating over capacity. Every foot of lift is equivalent to 0.43 pounds per square inch (psi); 2.31 ft of water is equal to 1 psi of pressure. Once the total dynamic head is calculated, this value can be converted to water horsepower (wHp), the amount of work needed to lift and pressurize the system, and then to brake horsepower (bHp), the available power of an engine, assessed by measuring the force needed to brake it.

Calculator Description

The new pumping plant calculator is an Excel-based spreadsheet which allows producers to input information that enables them to evaluate their current pumping plant system operating conditions and several key conditions of the center pivot system. This information provides new insights to producers which can support them in making informed decisions regarding maintenance and upgrades to their irrigation or pumping systems to improve efficiency and profitability. The calculator contains six sheets: 1) opening page, 2) preface (provides an overall guide), 3) instructions (data to collect and units to use with that data), 4) input, 5) output, and 6) references.

Inputs for Determing Annualized Energy Cost of Operating an Irrigation System.

Field Information			
	Acres Irrigated	130.00	
	Average Gross Depth applied, inches	10.3	
	Return on Invest. (R.O.I), %	5%	
Well Information		**Current Reading**	**Original Condition**
	Depth of Well, ft	442	
	Static Water Level, ft	206	185
	Pumping water level, ft.	239	
	Screening depth - Top, ft		
	Screening depth - Bottom, ft		
Irrigation System Information			
	Design Flowrate, gpm	750	
	Design Pressure, psi	32	
Operational Information			
	System Flowrate - meter, gpm	756	
	System Pressure at well, PSI	25	
	System Pressure at base of pivot , PSI	56	
	System pressure on top of pivot, PSI	50	
	System pressure at end of pivot, PSI	40	
	Pressure Regulators, PSI	15	

FIGURE 1. Input sheet of calculator with field, well, and irrigation system information.

Inputs

The inputs sheet (Figure 1) is broken into several sections: field and well information, current operating conditions, economic data on the well system, past irrigation costs, and energy consumption of the current system. Alternative energy sources and their associated costs can also be entered to enable comparison of the operating costs of electric, natural gas, or diesel systems.

Producers enter a field location/name and the permit/allotted water rights information. The field information should be for current irrigated acres, which may differ from permitted acres. Data for the average irrigation applied can be calculated using the past three years of operating conditions. Information from the well log is entered, such as the depth of the well, where screens are located within the well, the original static water level, pumping water level, and the well's pumping capacity. Using the most current and accurate information for static water level and pumping water level is important. Using the current pumping water level is also important for calculating horsepower and energy requirements to lift the water to the irrigation system.

In describing the irrigation system, producers enter the design flow rate for the sprinkler package, the operating pressure for which the package is designed, and information provided on the sprinkler package design sheets. For operational information, producers enter current operating conditions of the system and well output. For accuracy, the well's flow rate should be a timed measurement if the system has a meter. To get the average flow rate, producers should do a timed test with the accumulator. They also need to take and include pressure measurements at the base of the pivot, at the top of the pivot point, at the end of the pivot, and the pressure at the regulator located at the last span of the pivot.

The economic input a producer provides is shown in Figure 2. These data represent infrastructural costs, as well as the past three years of pumping plant energy costs. Using three years of costs is important, because pumping amounts can change depending upon weather/precipitation, and years with low pumping can increase the average cost per acre-inch pumped if base costs associated with an energy source are relatively high and fixed. Using more than one year of data helps even out costs associated with infrastructure and provides a more accurate picture of actual costs.

System Output

In the output sheet, producers can see comparisons of their current well and irrigation system performance to performance of the original design and conditions. Information on this sheet provides insight on how improvements to a system and/or pumping plant could translate into improved application and operating costs. The first section of this sheet (Figure 3) looks at the current well output compared to the original output, using gallons per minute (gpm) per foot of drawdown. This well output value indicates potential degradation of the system that can be the result of several factors. For example, in many regions, declining groundwater levels will potentially decrease the well output per foot of drawdown. If groundwater levels are not declining, severe declines in the well output per foot of drawdown can indicate clogging issues with well screening that may need attention. This sheet also can show the impact to drawdown if the system capacity is adjusted. If a new design decreases well output, a new value for lift can be entered and a new assessment of operating conditions can be obtained.

Electric Motor				
	Initial Cost	**Life**	**Salvage**	
Irrigation Pump	$ 25,000.00	25	$ 1,250.00	
Gear Head	$ -	15	$ -	
Pump Base, etc.	$ 1,000.00	25	$ 50.00	
Electric Motor and Switches	$ 5,000.00	30	$ 250.00	
Diesel Engine				
	Initial Cost	**Life**	**Salvage**	
Irrigation Pump	$ 25,000.00	25	$ 1,250.00	
Gear Head	$ 2,800.00	15	$ 140.00	
Pump Base, etc.	$ 1,100.00	25	$ 55.00	
Diesel Engine & Tank	$ 11,500.00	12	$ 575.00	
Natural Gas Engine				
	Initial Cost	**Life**	**Salvage**	
Irrigation Pump	$ 25,000.00	25	$ 1,250.00	
Gear Head	$ 2,800.00	15	$ 140.00	
Pump Base, etc.	$ 1,100.00	25	$ 55.00	
Natural Gas Engine	$ 8,000.00	6	$ 400.00	
Average Electric Cost	***Utilize the last 3 years of usage and total paid including hook up/meter charges***			
Irrigation Pumping	**2 years ago**	**Previous**	**Current Year**	**Average**
Acres Irrigated	217	217	217	217.00
Ac-Ft applied (total)	231.64	271.13	267.34	256.70
Water Pump ac-in/ac	12.81	14.99	14.78	14.20
Total Charges	$ 13,983	$ 15,347	$ 15,743	$ 15,024
kWh	134,123	160,688	158,734	151,182
$ per kWh	$ 0.10	$ 0.10	$ 0.10	$ 0.099
$/kWh	$ 0.099	*If you do not have previous energy usage for this, enter an estimated value per unit of energy*		

FIGURE 2. Input sheet of calculator with economic input.

Continued on next page

The next section of the output sheet (Figure 3) shows potential pressure issues related to the current operating pressures versus the initial design pressures and well output. Comparing operating pressures at the end of the pivot and top of the pivot to design pressures can show if the system is operating efficiently and economically. Pressure values that are lower than the design pressure can indicate uniformity issues, where some portions of a field may be receiving less or more water than desired. Comparing design outflow and operating pressure can also show the potential cost savings related to replacement of worn components in a sprinkler package. Having higher flowrates than a system has been designed for while still maintaining design pressures can indicate that sprinklers or leaks are a problem and that system maintenance or replacement parts are needed.

Finally, the output sheet shows calculated horsepower for the operating conditions, which allows a producer to choose the proper motor size needed for greatest efficiency. Using the proper motor size can lower operating costs if electric motors are used. Peak demand charges are based upon the nameplate-defined parameters for the motor horsepower.

The new calculator estimates the operating costs based upon the Nebraska Pumping Plant Standards (Figure 4). The calculator can show the operating costs (energy) and ownership costs of the irrigation system based upon three different potential energy sources. Including ownership costs is important when considering energy source changes, as well as operating costs of that energy source. When making changes to use a different energy source, new equipment may be needed such as the gear head and new motor, and related additional infrastructural costs that might be incurred must also be considered.

The final section of the calculator's output sheet (Figure 5) provides a preliminary estimate of the producer's irrigation system efficiency, including an estimate of what could be spent now to increase the efficiency of that irrigation system and recoup that investment in five years with the potential energy savings. Depending upon what is being changed within the system to improve efficiency, a longer timeframe to recoup costs can also be considered.

Operating an efficient pumping plant is critical to optimizing irrigation, but pumping plants are generally neglected since many of their components cannot easily be accessed. In addition, the time period to make measurements and access the system coincides with the growing season, when producers' time is limited. This new calculator provides producers a tool they can use to quickly determine if their system is operating optimally and efficiently. If the calculator highlights issues that need to be addressed, the producer should bring this information to someone with expertise in performing irrigation system audits who can determine what corrections can be made in order to decrease operating costs.

Limitations

The calculator is based upon a seasonal average of pumping. There are limitations of the calculator because of the inputs that are needed. Some systems have large changes in pumping output where producers change nozzles multiple times per year. Also, systems with end guns that are not operating continuously will change the dynamics of the pumping system which will limit the use of the calculator.

Martin, D.L., T.W. Dorn, S.R. Melvin, A.J. Corr and W.L. Kranz. 2011. *Evaluation energy use for pumping irrigation water*. Proceedings of the 23rd annual CPIA, Burlington, CO Feb. 22-23, 2011.

Well Performance	Compare to well driller log for original conditions		
Current GPM per ft drawdown	7.60	fair	Well Performance Ranges - Pumping Rate per ft of Drawdown
Original GPM per ft drawdown	10.96	fair	< 5 Poor; 5 -20 Ok; 20 -50 Good; >50 Excellent
Information that is relevant to the system performance. Please look at these potential issues regarding pressure differences and design flow vs measured flow that can be fixed before looking at switching pumping plant/energy sources.			
Pressures difference that are negative may result in irrigation uniformity issues that well result in inefficient water applications. Pressure differences that are positive may result in excessive energy usage.			
Potential Pressure Issues			
End of pivot minus pressure regulator (PSI)	-6	Minor Low Pressure Issues	
Design Pressure vs observed Top of Pivot (PSI)	-2	Pressure adequate	
Design Flow vs measured flow (gpm)	21	nozzle package design greater than meter flow	
Water Horsepower	41.7	Useful work that the pump is doing at these conditions	
Brake Horsepower	55.5	Compare to the name plate horsepower - Calculated should not be greater than the name plate hp. Optimum conditions for electric motor is to not exceed the brake hp on the name plate.	

FIGURE 3. Operational output for the well and irrigation system.

Based on Nebraska Standard							
Costs based upon delivery of energy source is currently in position. Added costs will be incurred if infrastructure is needed to deliver energy to well. Labor costs are not factored into the total costs of operating.							
	Ownership Costs			Operating Costs			
Electric Motor	R.O.I.	Insurance + tax	Depreciation	Repairs	Electric	Energy $	Total Costs
	Cost				kW-hr		
Irrigation Pump	$ 656.25	$ 250.00	$ 950.00	$1,240.07			$ 3,096.32
Gear Head	$ -	$ -	$ -	$ -			$ -
Pump Base, etc.	$ 26.25	$ 10.00	$ 38.00	$ 30.80			$ 105.05
Electric Motor and Switches	$ 131.25	$ 50.00	$ 158.33	$ 308.04	136417	$ 13,557.00	$ 14,204.62
Infrastructure Cost							$ -
Total Costs							$ 17,406.00
						Cost per ac-in	$ 5.65
	Ownership Costs			Operating Costs			
Natural Gas Motor	R.O.I.	Insurance + tax	Depreciation	Repairs	Natural Gas	Energy $	Total Costs
	Cost				MCF		
Irrigation Pump	$ 656.25	$ 250.00	$ 950.00	$1,240.07			$ 3,096.32
Gear Head	$ 73.50	$ 28.00	$ 177.33	$ 71.88			$ 350.71
Pump Base, etc.	$ 28.88	$ 11.00	$ 41.80	$ 33.88			$ 115.56
Natural Gas Engine	$ 210.00	$ 80.00	$ 1,266.67	$ 492.87	1810	$ 9,050.13	$ 11,099.67
Infrastructure Cost							$ 943.93
Total Costs							$ 15,606.19
						Cost per ac-in	$ 5.07
	Ownership Costs			Operating Costs			
Diesel Engine	R.O.I.	Insurance + tax	Depreciation	Repairs	Diesel	Energy $	Total Costs
	Cost				gallons		
Irrigation Pump	$ 656.25	$ 250.00	$ 950.00	$1,240.07			$ 3,096.32
Gear Head	$ 73.50	$ 28.00	$ 177.33	$ 71.88			$ 350.71
Pump Base, etc.	$ 28.88	$ 11.00	$ 41.80	$ 33.88			$ 115.56
Diesel engine & tank	$ 301.88	$ 115.00	$ 910.42	$ 708.50	9658	$ 24,145.75	$ 26,181.54
Infrastructure Cost							$ 283.18
Total Costs							$ 30,027.32
						Cost per ac-in	$ 9.75

FIGURE 4. Operational output for the well and irrigation system.

	Electric	Natural Gas	Diesel
Efficiency compared to Neb Standard	90.2%		
Energy Improvement Cost for 5-year return	$ 6,353		
The energy improvement cost will give you an estimate of how much money you can invest in improvements to bring the pumping plant efficiency up to the Nebraska Standard with an estimated payback of 5 years at the interest rate you			
	lbs. CO2 emissions per year		
CO2 emissions in lbs.	Electric	Natural Gas	Diesel
Current	212,259		
Nebraska Standard	191,529	219,013	216,346
	tons CO2 emissions per year		
CO2 emissions in tons	Electric	Natural Gas	Diesel
Current	106		
Nebraska Standard	96	110	108

FIGURE 5. Calculation of efficiency and economics of updating the system to improve efficiency.

Master Irrigator Program in Texas Inspires Ogallala Region Spinoffs

By Steve Amosson, Brandi Baquera, Amy Kremen, Hannah Moshay, Kirk Welch, and Steve Walthour

In 2016, the North Plains Groundwater Conservation District (NPGCD), located in the Texas Panhandle, launched an innovative program for producers called Master Irrigator. Once a year, over four days, the program supports water conservation-oriented discussions and education for a class of up to 25 participants. The course covers the pros, cons, and possible costs and benefits related to a wide range of water management tools and strategies that aim to support farm profitability, productivity, and efficiency goals. To date, 90 participants have graduated from the Texas program, representing 78 irrigated farming operations and 263,000 irrigated acres.

> The National Agricultural Statistics Service's 2018 Irrigation Water and Management survey, part of the Census of Agriculture, provides an excellent overview on water and energy use efficiency methods currently being used by farmers, information they use in making irrigation decisions, and barriers affecting their adoption of conservation-oriented practices. See: Table 23. Methods Used in Deciding When to Irrigate: 2018, Table 25. Barriers to Making Improvements to Reduce Energy Use or Conserve Water: 2018, Table 26. Sources of Information Relied on for Reducing Irrigation Costs and Conserving Water: 2018
> The NASS 2018 Irrigation and Water Management Survey is available at https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/index.php

NPGCD recently surveyed its 2016 Master Irrigator class. Tellingly, all respondents have adopted one or more of the water conservation strategies covered during the program, with an average of 3.25 practices adopted per operation. All respondents reported gains in water use efficiency (yield/acre-inch applied), with 67% indicating that they've applied an average of 2.7 acre-inches less water each year since participating in the course. Given the generally modest adoption nationally of conservation-oriented practices, including the use of support tools for deciding when to irrigate, these data are a testament to the course's utility and effectiveness for producers.

The program's advisory committee (PAC) of growers, industry, USDA Natural Resources Conservation Service, and academics, is responsible for the program's format and curriculum. By combining their insights, the PAC has worked to put together a "reality-based" program that emphasizes practices and tools currently in use by other producers. Each day of the course, a panel of growers describes different aspects related to the practical application and economic implications of different practices and technologies. "These panels consistently receive some of the highest ratings from participants," says Kirk Welch, Assistant Manager of NPGCD.

Master Irrigator takes off in Colorado and Oklahoma

In 2018, NPGCD's general manager, Steve Walthour, presented on Master Irrigator at the Ogallala Summit held in Garden City, Kansas, and his talk deeply resonated with many in attendance from other Ogallala states. Subsequent conversations facilitated by the Ogallala Water CAP led to NPGCD hosting an all-day meeting for roughly 30 people from seven states at their offices in Dumas, Texas in September 2018. There, NPGCD program staff walked everyone through their process for developing and effectively delivering their program. Taking that information home, participants from Colorado and Oklahoma set in motion the development of their own programs modeled after Texas. Colorado Master Irrigator held its first program over four weeks in February and March of 2020, with 22 participants representing more than 20,000 irrigated acres within the Republican River Basin of northeastern Colorado. Oklahoma's program will launch later this year. All the programs—in Texas, Colorado, and Oklahoma—are working with NRCS to coordinate and create opportunities for eligible program graduates to access financial cost-share assistance through the Environmental Quality Incentives Program (EQIP).

In addition to graduates receiving priority ranking with NRCS, Colorado PAC members reached out to local industry representatives to line up additional incentives and discounts to help offset costs for equipment upgrades and soil moisture probe subscriptions. "Area energy co-ops also donated five energy audits for pivots that we raffled off to participants, along with an Arable Mark 2 weather and crop monitoring tool," shares Brandi Baquera, Colorado Master Irrigator program coordinator.

Based on producer input on the Colorado Master Irrigator advisory committee, the program applied for state funding to provide participation stipends of up to $2,000 per operation as a way to put a clear value to the time producers invest this program. "In return for accepting the stipend, our graduates will provide quantitative and qualitative information for three growing seasons about their thinking and efforts to manage energy and water use on their operations. We'll use these valuable insights to improve our program, and we hope that they will also help advance water management in our region, benefitting the aquifer and our communities over the long term," says Baquera.

What's happened in Texas suggests that these hopes will be realized. Based on their success using an advisory committee to guide program development, NPGCD applied this approach to developing new educational programming related to cotton production, producing an online video series that was viewed more than 2,000 times during the 2019 growing season. Economist Steve Amosson, who led the development of Master Irrigator while working for Texas A&M Extension, notes that involving extension and research faculty to help with content or as some of the program's speakers has also helped Extension to build credibility and closer relationships with top producers and others within the region. "This interaction," Amosson notes, "has led to cooperative engagement on grants and other opportunities and projects that producers have identified as being important."

For more on the Texas and Colorado programs, please visit:

- http://northplainsgcd.org/conservationprograms/communityedu/master-irrigator/
- http://www.comasterirrigator.org/

Interested in learning more about the Master Irrigator program for Oklahoma Panhandle producers that will launch this fall? Contact sumit.sharma@okstate.edu.

Continued on next page

2019 graduates of the original Master Irrigator program run by North Plains Groundwater Conservation District in the Texas Panhandle.

In addition to producer panels, the Colorado Master Irrigator program includes interactive activities each day for participants to work together on penciling out scenarios based on topics covered. Class members noted that these opportunities to share insights with one another were some of their favorite parts of the course.

Former OWCAP student researcher Himmy Lo behind the wheel at UNL's West Central Research and Extension Center in North Platte.
Read more about Lo's involvement in the project on page 24.

Nebraska producer Roric Paulman at his farm in Sutherland. Paulman recently received the Kremer Award for his dedication to conserving the state's groundwater and was an early champion of the Master Irrigator program.

Lee Orton, executive director of the Nebraska State Irrigation Association, presents the 2019 Kremer Award to Roric Paulman and his wife. (Credit: Jason Orton)

Roric Paulman delivering the Kremer Memorial Lecture as part of the Nebraska Water Center's Spring Seminar Series. (Credit: Jason Orton)

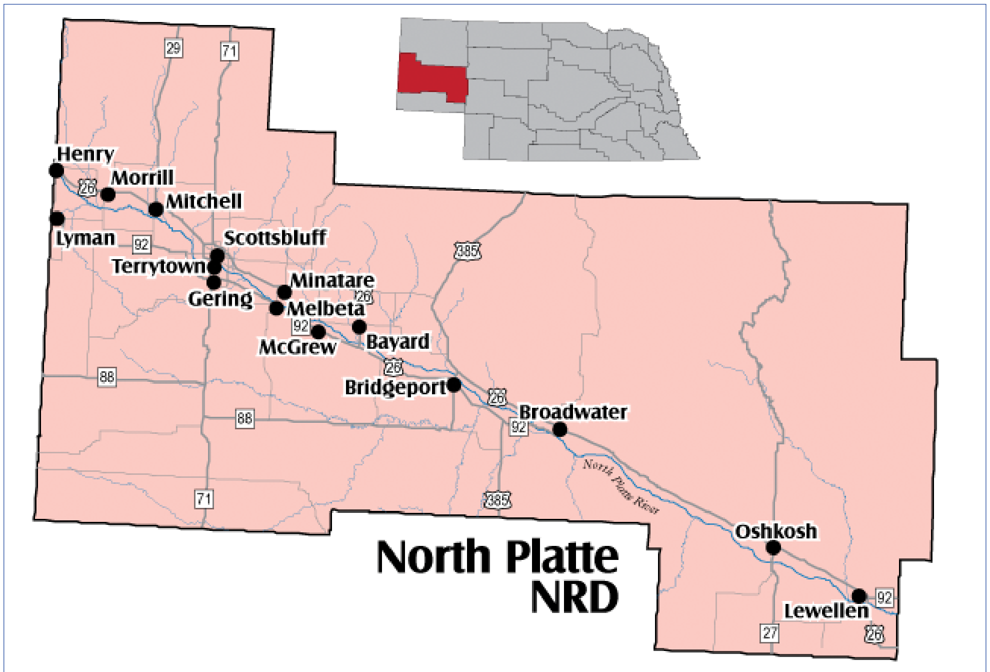
North Platte Natural Resources District Telemetry Project

By Jesse Starita

Jesse is the public relations & engagement coordinator with the Nebraska Water Center at the University of Nebraska–Lincoln.

Sandhills, prairie, and bluffs dominate the landscape of the North Platte Natural Resources District (NRD). Cropland covers one million acres—450,000 of which are irrigated—planted with corn, sugar beets, dry beans, alfalfa, sorghum, and wheat. Water used for irrigation is pumped from the Ogallala aquifer as well as the North Platte River.

> The North Platte River, sourced from the snow-packed mountains of northern Colorado, supplies 300,000 acres of irrigation water to eastern Wyoming and western Nebraska via a series of century-old dams and canals. The water vitalizes this semi-arid area, which receives only 14 to 17 inches of rainfall each year. Because the Ogallala aquifer and the North Platte River are hydrologically connected (see related article, on page 5), the confluence of canals, tributaries, infiltration and run-off from seasonal irrigation are largely responsible for aquifer recharge.



The North Platte Natural Resources District (NRD)

The North Platte NRD, located in the Nebraska panhandle, is one of twenty-three such districts entrusted with local management of natural resources including water, soil, forests, and fish and wildlife habitat. In order to better understand the district's groundwater withdrawals, five years ago the North Platte NRD invested $13,000 in installing telemetry units on pivots, coupling them with groundwater flow meters in producers' fields, in its aptly named "Data Access and Monitoring Program" (DAMP).

Quantifying irrigation's impacts on the aquifer is paramount to preserving it for long-term use, a fact recognized by the Nebraska legislature in 2004. That summer, it enacted a law requiring the state's Department of Natural Resources to conduct annual water balance assessments for each watershed, designating them as being under, fully, or over-appropriated. Certain areas within the North Platte NRD—parts of the North Platte River Valley and Pumpkin Creek Basin (see related CAST article page 11)—were deemed to be over-appropriated, which ushered in several policies to enhance water management, including a moratorium on new wells and development and implementation of an integrated management plan for surface and groundwater.

These policy changes required more data collection, and aggregating field-level telemetry data has made it possible to better understand water use on a regional scale, says John Berge, North Platte NRD general manager and OWCAP advisory board member.

In early 2016, the Nebraska Environmental Trust awarded $750,000 to the NRD to expand DAMP. This funding facilitated the purchase of the telemetry units manufactured by AMCi, and the training of the NPNRD team members who installed the units throughout the district. A camera in each unit captures an image of the flow meter each day, which is then wirelessly delivered to a website run by the district, where the data is digitized to make it accessible to landowners and managers.

An example photograph of the flow meter reading.

Since the initiation of DAMP, the North Platte NRD has used nearly $2 million in funding to equip 863 flow meters in the district with telemetry units.

"We had no monitoring before so we couldn't really answer the question of what was happening to the aquifer," Berge says. Now, they can use the data provided by telemetry in their modeling efforts to assess aquifer drawdown, pumping, and recharge. Telemetry has helped the district in another important way. Stop and consider: the entire state of Connecticut fits inside the North Platte NRD boundary. Each year, the NRD spends nearly $170,000 in salaries, fuel, wear and tear on vehicles, and other expenses in collecting data from 1,800 flow meters. Manually recording flow meter readings takes a lot of time, and can even pose safety risks to staff. Telemetry largely automates this process, saving the district money and also notifying staff when problems occur, allowing for more timely repairs.

Telemetry offers even more for irrigators, enabling remote monitoring and control of center pivot systems, it is an extremely valuable tool for High Plains. Producers can use telemetry to speed up or slow down center pivot systems, and stop or start them. The units that North Platte NRD has installed can be equipped with additional sensors to deliver soil moisture, weather, and other data to apps on farmers' phones, tablets, or desktop computers. Having this information at their fingertips can help support decisions related to scheduling applications and amounts of irrigation and other inputs. Operators being notified quickly to problems with their pivot system leads to savings in time and money.

Farm-level irrigation decisions involve managing a lot of risk in a very dynamic setting. Together, the decisions of the district's individual landowners have significant system-wide impacts on water quantity and quality, which can significantly affect their neighbors and future generations. By using technology to aggregate data as well as satisfy state-level policy requirements, the North Platte NRD's DAMP program is making strides in helping monitor water management at the local and regional level in order to ensure the sustainability and future prosperity of the irrigated agriculture economy in their district.

More information is available at go.unl.edu/npnrd.

North Platte NRD General Manager John Berge with a telemetry unit outside of Scottsbluff, Nebraska. (Credit: North Platte Telegraph)

An AMCi MeterEye telemetry unit installed in Western Nebraska.

TAPS Program Taps New Ground

By Daran Rudnick, Jason Warren, Meagan Schipanski and Krystle Rhoades

Daran Rudnick, Jason Warren and Meagan Schipanski are faculty researchers and members of the OWCAP team. Krystle Rhoades is the TAPS program coordinator at UNL's West Central Research & Extension Center.

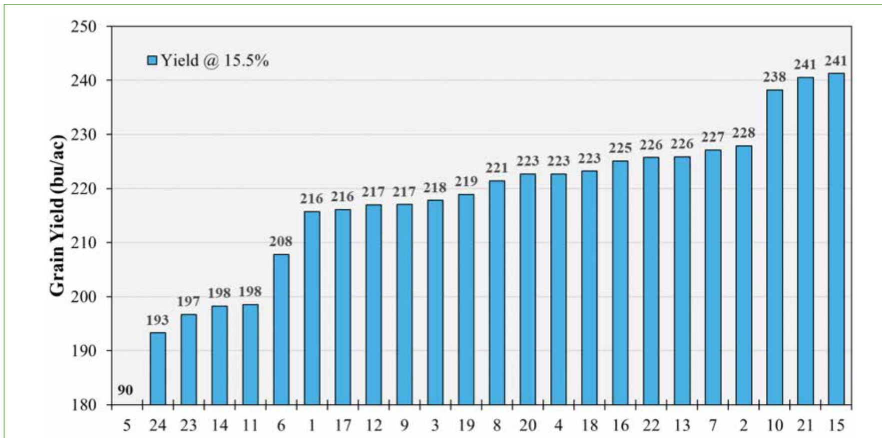
Introduction

Like most of us, farmers love competition. In an era where increasing profitability and input use efficiency are the name of the game for successful producers, the Testing Ag Performance Solutions (TAPS) program has provided a new, innovative extension approach. TAPS provides farmers with unparalleled access to technology and research and an engaging learning experience they can then use to apply new concepts and integrate new strategies and tools on their operations.

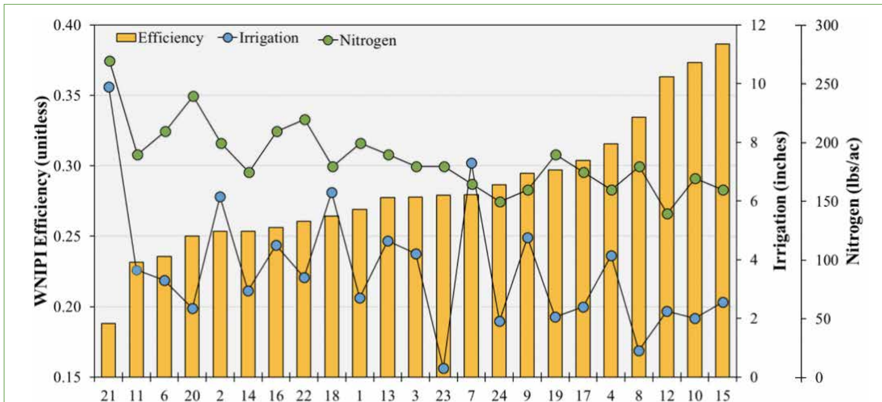
TAPS participants compete to see who can be the most profitable and the most efficient with inputs, as well as who has the highest yield. The most profitable category is determined by how profitable producers are based on their marketing and the cost of their input use. Participants have access to a wide range of data throughout the growing season to inform their irrigation and nitrogen applications, including imagery, soil moisture probe and plant sensor data, and more. Competitors have control over choosing their seeding rate, crop variety, crop insurance, and marketing decisions—choices that are all made as if for a full-size operation of several thousand acres. With so many competing technologies available to choose from today, TAPS offers participants a no-risk opportunity to: try out many new technologies and their user interfaces throughout a growing season; push their input use efficiency more aggressively; and explore how to take advantage of marketing opportunities in new and different ways than they might typically do on their own operations.

Because TAPS participants' decisions are documented and applied on randomized, replicated field plots, the data produced support research that is improving our understanding of how input timing and quantity impacts both productivity and profitability. Meanwhile, TAPS has also provided an invaluable professional development opportunity for several students and early-career researchers.

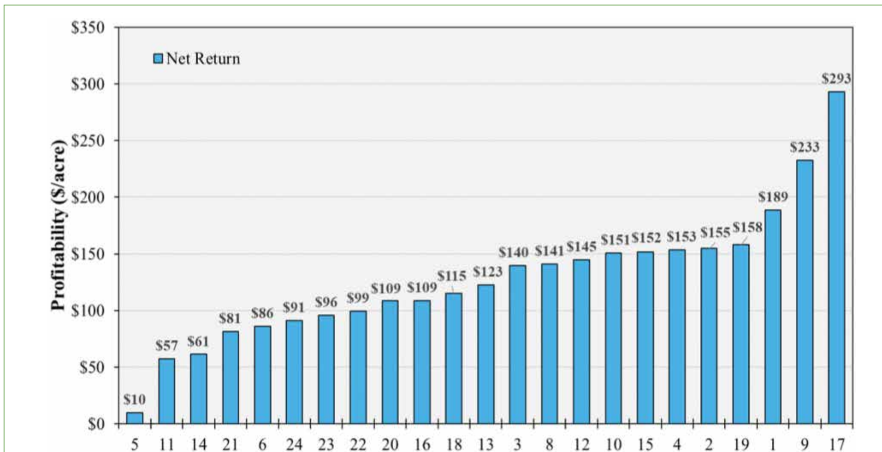
Continued on next 3 pages



The results of yield in the UNL-TAPS 2019 sprinkler corn competition



The results of input efficiency in the UNL-TAPS 2019 sprinkler corn competition



The results of profitability in the UNL-TAPS 2019 sprinkler corn competition

Tsz Him Lo (Himmy) on His Research and Experience Working with TAPS

Himmy Lo, while completing his graduate degree and working as a postdoctoral researcher at UNL, significantly contributed to the development and delivery of the UNL-TAPS program. Himmy's research, supported in part by Ogallala Water CAP funding, focused on variable rate fertigation and soil sensors to inform and manage water and nutrient application and improve input efficiency.

Lo shares the following:

"Through my research at UNL, I had the opportunity to acquire hands-on experience in field research as well as the opportunity to meet many wonderful people during my graduate and postdoctoral programs. I am very grateful for the guidance of my Ph.D. advisor Daran Rudnick whose mentoring has benefited me tremendously. I conducted research on variable rate fertigation through center pivots and the use of sensors to measure soil moisture, plant canopy temperature, and plant canopy reflectance. Much of this work was integrated with the Testing Ag Performance Solutions program. Through the incorporation of my work into TAPS, variable rate fertigation served as a tool that contestants could use in their decisions on in-season nitrogen application. Throughout the season, various types of sensors were deployed to collect information for analyses of those and other decisions.

'Approaches to evaluating grower irrigation and fertilizer nitrogen amounts and timing' by Tsz Him Lo and co-authors lays out the process by which new indices of on-farm water and nitrogen input efficiency were created and adapted for the UNL-TAPS competition.

The intersection and interaction between irrigation and fertilizer management is something I've really been drawn to. I find that I enjoy working with complex problems. Managing water and nutrient inputs through technology in an efficient and profitable way, across varied soils and under different seasons, has a number of moving parts. Tackling these questions with the support of my advisors and through the TAPS program has been very enjoyable and a significant learning experience.

I think scientific advancement and understanding is critical to positive transformation in public mindsets, agricultural practices, and government policies. I hope my work can contribute to this, particularly for reducing or even reversing declines in groundwater levels in the Ogallala aquifer and in improving rural vitality. God has given me a particular passion for rural prosperity and sustainable agricultural systems. Seeing present and future generations of farm families thrive is what has motivated my work and research. I look forward to seeing young professionals I've mentored continue to develop in their careers. I also look forward to seeing TAPS continue to flourish, and to spark fruitful changes in farming operations and to witnessing Nebraska agriculture continue to become more financially and environmentally sustainable.

In December 2019, I am pleased to say I have started as an assistant professor of irrigation engineering at the National Center for Alluvial Aquifer Research, which is a new joint operation between Mississippi State University Delta Research and Extension Center and USDA Agricultural Research Service. My time at UNL has equipped me with theoretical and practical knowledge of irrigation and with a first-hand perspective on agricultural extension. Combining this training with humility and an open mind to learn from local farmers, officials, and scientists, I will seek to understand the agricultural water challenges (i.e., flooding and groundwater depletion) of the Mississippi Delta and to partner with stakeholders to progress towards solutions.

Even though I have stepped away from UNL-TAPS, I look forward to seeing it continue to flourish and to spark further improvements in the financial and environmental sustainability of Nebraska agriculture. As for the students I have mentored at UNL, I look forward to seeing them become professionals who honor God in their careers and in all aspects of their lives."

Himmy Lo with his advisor and TAPS co-creator Dr. Daran Rudnick.

Jason Warren on Starting OSU-TAPS

Dr. Jason Warren, associate professor of soil and water conservation, Oklahoma State University.

Warren shares the following:

"I started this program by just calling up a bunch of farmers saying, 'Hey can you help me beta test this new project? I'll call you and text you every week and ask you how much water and fertilizer you want', and they said, 'Yeah, I'll do it.' We have a very small community of irrigators in the [Oklahoma] Panhandle and the ones we're working with, they're really 'tip of the sword' in using advanced technology. With this program we can add to their knowledge, even with technology they're already using.

Through TAPS, participants can compare treatments and tools and get to learn more about how technology works instead of just looking at pretty pictures of aerial imagery or just looking at their own soil moisture sensors. Even these good producers that are progressive in their technology and adoption can learn in this setting [and figure out what they] might be willing to pay for on their farm [of several thousand acres].

Through TAPS, we're not just reaching producers, but we're reaching their crop consultants as well. It's important to remember, the farmer isn't just growing the crop, he's marketing the crop. In some cases, he's more of a businessman than an agronomist, and it's his crop consultant that you really need to get to.

TAPS also creates a direct avenue to engage with the technology providers. Today, I visited with a Lindsay Irrigation regional representative and told him about some of the issues that we're having [on the pivot we're using for the TAPS competition]. It's important to have our equipment work for the participants who are competing. Technology and equipment dealers are more than happy to help us, because they are getting their product exposed, and because I'm teaching people how to use it."

Growth and Development

Since its inaugural year in 2017, TAPS has expanded from a single competition for center pivot irrigated corn hosted at the West Central Research and Extension Center in North Platte, to a comprehensive competition which includes center pivot irrigated sorghum, subsurface drip irrigated corn, and dryland wheat. UNL-TAPS participants hail from across Nebraska as well as from Kansas and Colorado. Through connections forged via the USDA-NIFA funded Ogallala Water CAP between Daran Rudnick at UNL and Jason Warren at Oklahoma State University (OSU), a new TAPS program, OSU-TAPS, also launched in 2019 involving producers in the Oklahoma Panhandle.

Starting Conversations

TAPS has created a space for stakeholders to be part of a community engaged in conversation and inquiry to advance agricultural management in light of very complex and dynamic agricultural challenges. Regulatory agencies such as the Nebraska Department of Environment and Energy team (2018 winners for the most profitable farm award) shared how TAPS made them actively aware in a way they had not been to the many questions and challenges producers face every growing season.

TAPS also supports shared inquiry and insights among producers and other participants. Normally, another producer's decisions are a mystery. What TAPS encourages through friendly competition is opportunity for people to talk about what many are thinking about all the time: the "how" and "why" of the countless decisions that are made during a growing season and which ones make a difference, particularly in terms of profits, but also in terms of resource use efficiency which is subject to ever more scrutiny. By sharing decisions and results through TAPS in a risk-free environment, competition drives shifts in thinking, management, and farming culture that can help sustain agricultural communities dependent on the Ogallala aquifer resource.

Takeaways

The 2017, 2018, and 2019 UNL-TAPS competitions have generated several key insights. One significant takeaway is the importance of marketing in determining the competition's outcome. Marketing isn't everything, but for those who are great managers, if they engage in effective marketing, they are bound to be profitable. Perhaps not too surprisingly, another significant takeaway is that the highest yielding teams in the competition weren't necessarily the most profitable or most efficient. In fact, many participants have expressed appreciation for how TAPS has supported their shift in mindset to focus on improving efficiency and profit rather than focusing on improving yields.

Another important aspect of TAPS is how the program engages extension researchers and educators in fostering exchange among producers, technology providers, and others. Fusing everyone's expertise through exchange ends up serving a broader audience, reaching more people than traditional extension programs. Sharing TAPS results throughout the Ogallala region and beyond has inspired conversations and new collaborative efforts that continue to grow.

Further Growth and Development

In late 2019, TAPS was awarded a USDA-NRCS Conservation Innovation Grant, which will provide three years of funding to help support existing TAPS programs in Nebraska and Oklahoma, as well as lay the groundwork for the creation of new TAPS programs in Colorado and Kansas.

Research takeaways from the 2019 sprinkler corn TAPS competitions in Nebraska and Oklahoma were recently featured at the Central Plains Irrigation Conference in Burlington, CO, on February 18-19, 2020. To read the proceedings article and see data generated from the competitions, visit: https://www.ksre.k-state.edu/irrigate/oow/p20/Rudnick_20.pdf.

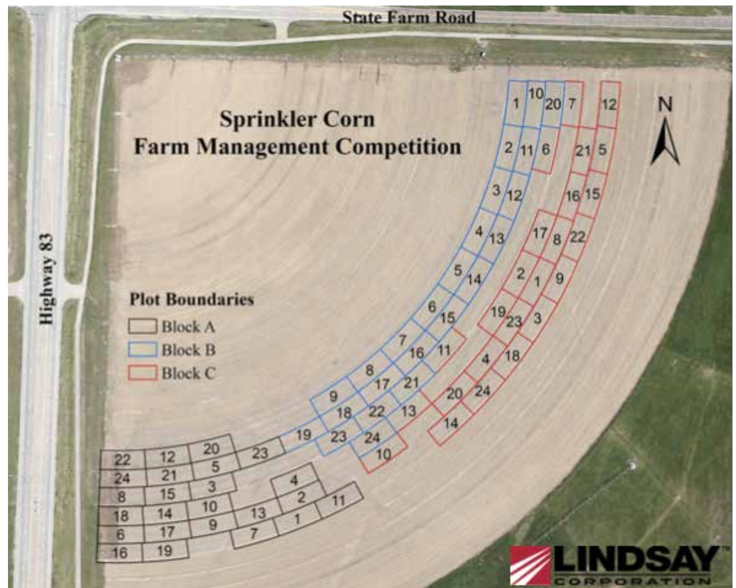
"The thing that is good about TAPS is the technology—just about everything you could imagine is there and offered which you could use and you don't have to pay for it on your own farm and can experiment. I've experimented with the nitrogen side of it and have cut back on pounds per bushel, and it's been a good learning experience."

Producer—Gothenburg, NE

"We've darn sure learned a lot, that it's not all about trying to grow the biggest yield, and really learned how important the marketing is. You can grow a big yield and survive, but growing a smaller yield and being more efficient with better marketing will let you [keep] more dollars."

Producer—Hershey, NE

Application of fertilizer to 2018 UNL-TAPS sorghum competition.



The 2019 UNL-TAPS sprinkler corn competition randomized team plots.

2019 UNL-TAPS Banquet.

Movin' On Up: OWCAP Researchers Enter Faculty Positions

By Hannah Moshay

Erin Haacker, former OWCAP and NWC postdoctoral researcher, recently started a faculty position at the University of Nebraska–Lincoln.

Erin Haacker

A Nebraska native, Haacker grew up in Washington State and moved to Montana for college. In early 2019, Haacker became an assistant professor in UNL's Department of Earth & Atmospheric Sciences. Her work with UNL as a postdoc and now as an assistant professor has contributed significantly to the Ogallala Water CAP's integrated modeling effort.

Haacker shares the following:

"I thought at first I was going to study dinosaurs, but after spending some summers working in natural history museums, I decided that wasn't for me. I ended up, by chance, taking a class with Bill Woessner and switching into water resources. [Bill Woessner is a prominent hydrogeologist educator and researcher whose work has centered around groundwater contamination and groundwater-surface water interactions with a focus on modeling.]

The USDA-NIFA Ogallala Water CAP funded my postdoc position at UNL to work on an integrated model for the Northern High Plains. My piece of this work primarily deals with the groundwater piece of the model, called MODFLOW, as well as some work with a surface water model, SWAT. I've been communicating with our team overall, and have been trying to put together a model which is similar enough to other models our team has developed in terms of methodology without sacrificing the unique feature of subsurface interbasin transfer in this Northern High Plains system.

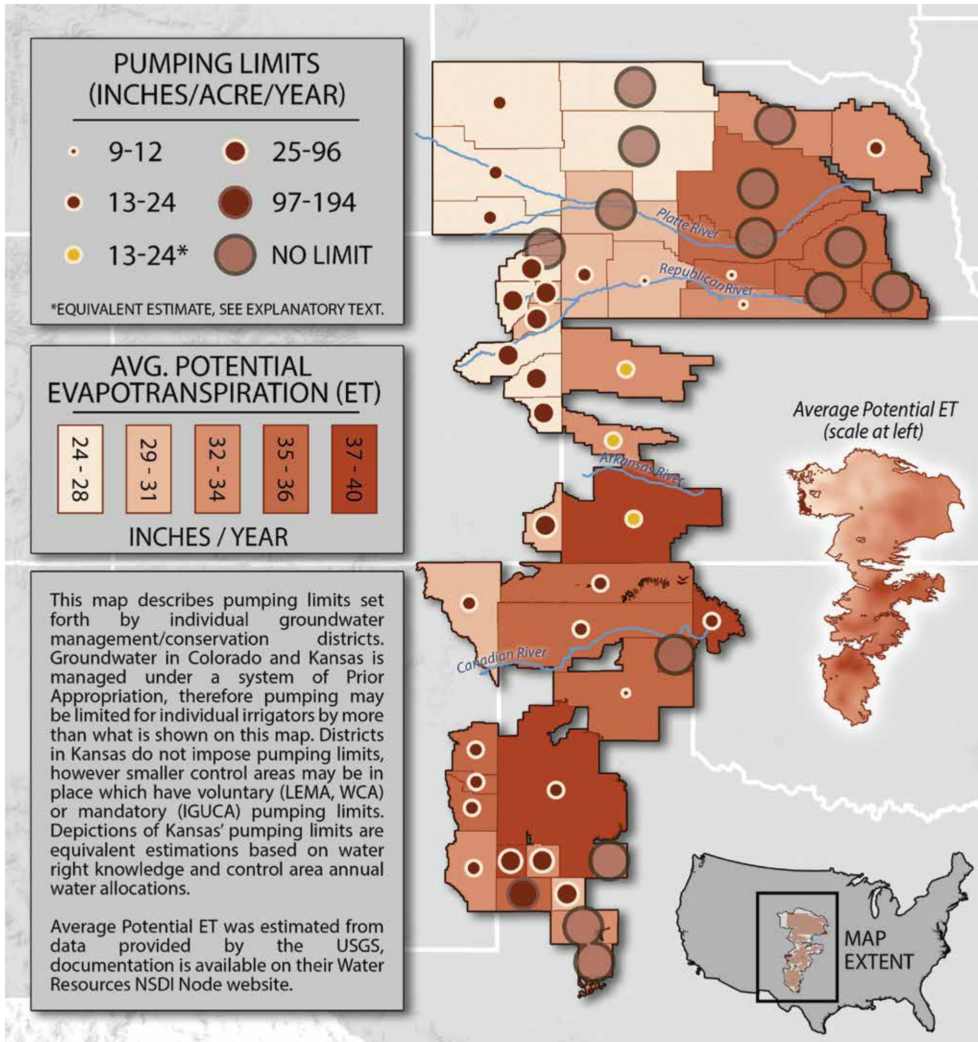
Interacting with other researchers and students across disciplines is one of my favorite aspects of my work. Last year I got a group of postdocs and students currently working on the OWCAP project together, and we wrote a review paper together on integrated modeling (*Transition Pathways to Sustainable Agricultural Water Management: A Review of Integrated Modeling Approaches*). That was really fantastic. Through that paper a lot of students and postdocs with similar research interests came together, and that's led to a lot of new professional relationships.

Beyond connections between researchers that come through interdisciplinary work like integrated modeling, we're giving people who want questions answered about this system another point of view. We're quantifying how much water has gone from the Platte system to the Republican system since the canals started being built. That's something people can use for policy reasons. It matters to me to have a very good quality model. There's a lot of trust that goes into accepting a model outcome, so I need to be worthy of that trust. It's important to me to train students to do useful ethical science. It's put me in the path of lots of water people throughout the state that I want to continue working with. This model opens the door to conversations with policy makers and the public. Working for a state university, anyone should be able to call me up on the phone and say, 'Hey, can you answer 15 minutes worth of questions about hydrogeology?'

The ultimate hope is that with this model, people can have a greater understanding of cause and effect in this aquifer system, and maybe, this knowledge can be transferred to other aquifer systems throughout the world. It's not my place to advocate for sustainable water use. It's what I want personally, but there are places where the water recharge is so slow that if you said to the user, 'You have to be sustainable,' that would mean they could water their garden and that's it. However, there are other places where if you use a little less water you could still make the same amount of money. Your yields might not be as high, but you'd have fewer inputs and you'd come out ahead all while ensuring you would still have that water down the line.

Personally, I want to continue contributing to this research. I want to be one of those people who hasn't stopped coming into the office, who is 85 and publishing and still has students. But beyond academia, I'd like to work with as many stakeholders in the state as I can. I'd like to work with people who are actually turning the pumps on and off. They're ultimately the ones who are driving changes to this system and having the biggest impact. I'd ultimately like them to see me as a resource. Having a connection with those people and building trust is critical."

Vaishali Sharda, former OWCAP and NWC postdoctoral researcher, recently started a faculty position at Kansas State University.



Map designed by Lacey Moore, Colorado State University.

Vaishali Sharda

Vaishali Sharda works on integrating agronomic and hydrologic models, climate data, and farm management scenarios to explore the complex dynamics of food, energy, and water systems. As a postdoc based at the University of Nebraska–Lincoln and in her current role as an assistant professor at Kansas State University, Vaishali has contributed to the integrated modeling effort of the Ogallala Water Coordinated Agricultural Project (OWCAP). Her work has focused on tailoring the crop model component, Decision Support System for Agrotechnology (DSSAT) to local conditions and making it compatible with other aspects of the project's integrated model. She enjoys working directly with producers and working on solutions that can improve our understanding of agricultural water availability in the Ogallala aquifer region.

Sharda shares the following:

"I really enjoy working on this project because I feel like the work we're doing is grounded in immediate challenges communities are facing. We're tackling a complex issue, but the solutions we're developing through our work are practical and accessible. That really motivates me when I'm sitting down with my computer trying to troubleshoot the model, so that I can mimic the real world and the physical interpretation of a phenomenon.

Talking to farmers and noting down their observations and experiences to incorporate in our models has probably been my favorite aspect of my work. Overall, working on this project has been one of the most fulfilling experiences at a personal and professional level, along with connecting with many wonderful scientists in this multi-institutional and multi-disciplinary project.

This work matters because it presents solutions and steps that we can take (both the scientific community and the stakeholders) to ensure our use of natural resources is sustainable so that our future generations can benefit from them as well. I would like this work and the integrated model to be put to use in making more informed decisions while withdrawing water from the Ogallala and thinking about the overall sustainability of this resource.

I recently started my tenure-track faculty position as an assistant professor in the Department of Biological and Agricultural Engineering at Kansas State University. Looking ahead, I want to be a teacher who can make a difference in the lives of her students. As a researcher, I want to advance the science in the field of water resource management and provide the stakeholders (farmers and related communities) with tools that they can use to make forward-looking decisions to ensure the sustainability of critical and limited natural resources, given a changing climate."

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