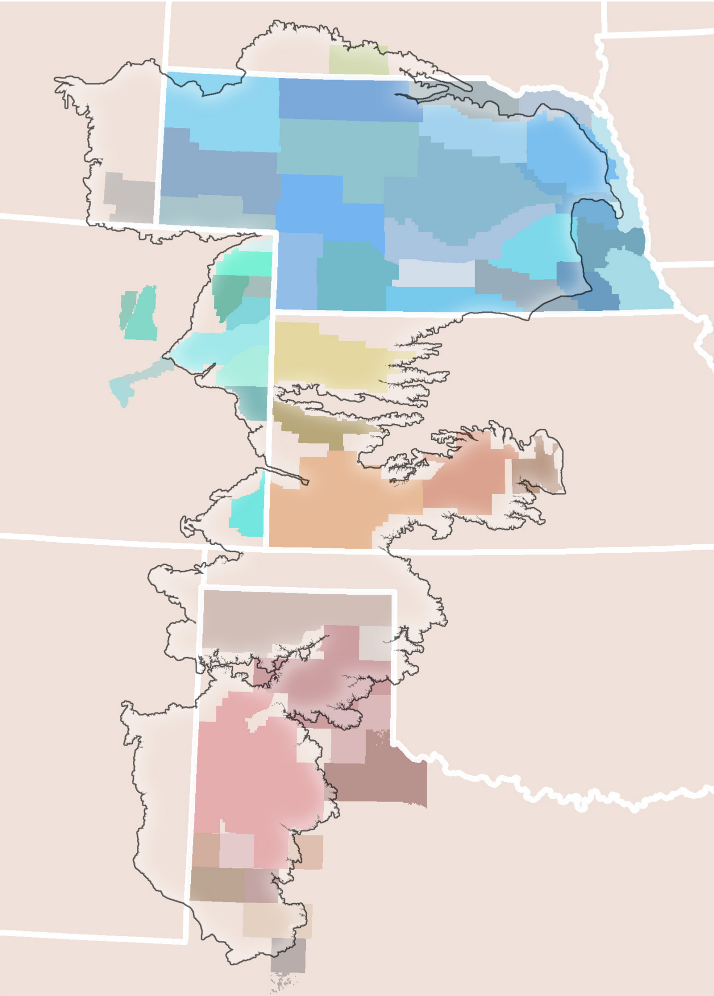
Ogallala Aquifer

SUMMIT

APRIL 9 - 10, 2018 | GARDEN CITY, KANSAS



Colorado

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Introduction

The Ogallala aquifer underlies nearly 14% of Colorado, stretching across the Eastern Plains from the northern border with Nebraska to the southern border with Oklahoma. Management of Colorado groundwater in designated basins has progressed from unregulated pumping (prior to 1957), to regulated pumping based upon a principle of maximum utilization (1957 to 1965), to integration within a modified prior appropriation doctrine (1965) that effectively limited the amount of water available for appropriation. The Ogallala aquifer in Colorado is managed with the understanding that it is in an over-appropriated condition, and that as water levels decline and wells' ability to pump declines, use of the water will decline as physical availability and economics dictate.

Policy

Colorado generally manages groundwater use in the Ogallala to limit the depletion of the resource to a 25% depletion in 100 years. This limitation has been in place for many years and is enforced through the well permitting system. The biggest recent push to manage groundwater use in Colorado has come from obligations related to the Republican River Compact, signed by Colorado, Nebraska, and Kansas in 1942. To meet obligations of a 2002 settlement approved by the U.S. Supreme Court, the Colorado State Legislature created the Republican River Water Conservation District (RRWCD) in 2004. The RRWCD is an independent, self-governed entity with 15 Board of Director members appointed by the Commissioners of local counties, Boards of ground water management districts, and the Colorado Ground Water Commission (CGWC). The RRWCD promotes conservation through voluntary participation. A major project has been the voluntary retirement of irrigated acres under incentive payments provided through Federal initiatives that are enhanced with RRWCD payments. The RRWCD's geographic extent covers much of the Northern High Plains Designated Basin. To help manage water supplies in the area the Division of Water Resources promulgated metering rules for groundwater uses in 2008.

The main mechanisms for ensuring compact compliance have been: RRWCD fallowing programs to reduce consumption, State Engineer curtailment of post-compact surface water rights, and RRWCD's operation of an augmentation pipeline, completed in 2012, which delivers pumped groundwater into the North Fork of the Republican River, near the Nebraska border. The water source for the pipeline came from the purchase and transfer of appropriations from 53 existing irrigation wells in eastern Yuma County. Along with other junior surface water rights, Bonny Reservoir, with a post-compact water right on the South Fork of the Republican River, was required to pass all inflows and was finally drained in September 2011. The fallowing programs (over 49,500 acres), curtailment of junior water rights, and the augmentation pipeline help Colorado comply with the Compact.

The CGWC has enforcement authority to manage groundwater resources within the State's Designated Ground Water Basins. Two Designated Basins within Colorado, the Northern High Plains, and the Southern High Plains contain Ogallala aquifer water. Well permits, required for all groundwater users in the region, are issued and adjudicated by the CGWC. Totalizing flow meters or alternative measurement methods approved by the State Engineer and submission of pumping data to the State are required for high capacity wells in much of the Northern High Plains Designated Basin. Some high capacity wells in the Southern

High Plains Designated Basin, typically those wells that have undergone a change in water right, must be metered and submit pumping data to the State.

There are eight local Ground Water Management Districts (GWMD) within the Northern High Plains Designated Basin, and one local Ground Water Management District within the Southern High Plains Designated Basin. Each GWMD has the authority to implement rules and regulations related to groundwater use to supplement the rules provided by the CGWC. Although the individual GWMDs have taken responsibility for monitoring and enforcing rules related to new well development and well spacing, they have done little to implement mandatory groundwater conservation policies within their borders (Best, 2014). A few years ago, concern over decreasing groundwater levels in the Ogallala aquifer spurred several farmers from the Northern High Plains Basin to form the Water Preservation Partnership (WPP). In 2017, the WPP drafted a resolution stipulating a 25% reduction in groundwater pumping in GWMDs by 2025. Outreach and discussions related to the proposed resolution are currently ongoing.

Science and Data

Ogallala-related research underway at Colorado State University (CSU) and at USDA's Limited Research Irrigation Farm is currently focused on:

1) Increasing adoption of more efficient irrigation technologies

2) Increasing use of more precise

irrigation scheduling methods and tools

3) Shifting toward more water efficient crop varieties and crops

4) Improving water conservation through soil and residue management

5) Shifting more marginally productive irrigated lands to dryland management

6) Using modeling to support producers and GWMDs as they evaluate the potential impact on the aquifer of different management scenarios (producer practice and policy-related)

Scientists are working on:

1) Identifying plant traits, mechanisms, and agronomic practices that increase productivity per unit of water used by the crop

2) Improving irrigation scheduling efficiency by developing accurate methods to quantify evapotranspiration (ET) in agricultural systems under limited water availability, including the use of remote sensing

3) Creating Water Production Functions (WPF, yield per ET) for crops produced with limited water

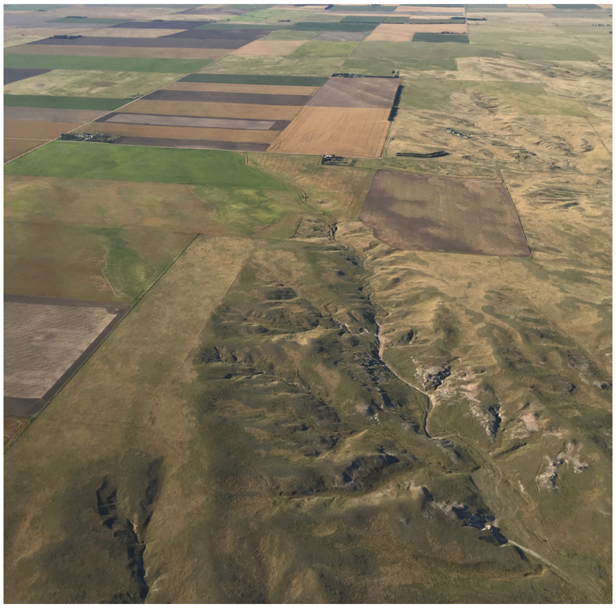
Recent research from CSU involving the use of a novel hydroeconomic modeling framework to evaluate groundwater conservation-oriented policies led to heterogeneous impacts projected for producers in the Northern High Plains and Southern High Plains Designated Basins, in part because well capacity and soil type are not uniform across the region. This study highlighted the importance of including the role of well capacity in groundwater models in order to avoid coming to misleading conclusions about the magnitude and distribution of groundwater use and policy impacts over time.

Producer Practice

At the individual farm level, water use efficiency has improved over the past several decades as farmers implement advanced irrigation management and technologies. Partnering with USDA's Natural Resources Conservation Service (NRCS), the RRWCD seeks to voluntarily enroll 1,280 acres in the Republican River Ogallala Aquifer Initiative Program (OAI), offering a total of $50,000 for soil moisture monitoring systems, for converting sprinkler systems to underground drip systems or modifying a conventional sprinkler to a mobile drip system. RRWCD is also encouraging Republican River Basin producers in Colorado to enroll in a voluntary Agricultural Water Enhancement Program (AWEP) that provides incentives and cost-sharing to participants who elect to remove irrigation water from enrolled acres permanently. Producers can also participate in the Republican River Conservation Reserve Enhancement Program (CREP), a program through the Farm Services Agency (FSA) in which a water right is permanently retired and the land must be put into a grass habitat for 15 years, treated much like CRP ground. The land may be used for grazing or dryland production after the 15-year period has ended. To qualify for the program, the land enrolled in the program must have been irrigated during the year just prior to enrollment, irrigated during four of the six previous years, and be able to legally and physically irrigate the next year.

Moving Forward

The state is in the process of implementing rules requiring that all wells within the Republican River Basin (i.e. the Northern High Plains Designated Basin) replace their depletions to reduce stream impacts for purposes of assisting Colorado in meeting the requirements of the Republican River Interstate Compact. These rules could have an effect that well owners/users may decide to reduce the amount of acres irrigated.



Kansas

Authors: Tracy Streeter (Kansas Water Office), Susan Metzger (Kansas State University), Chris Beightel (Kansas Department of Agriculture), Susan Stover (Kansas Geological Survey), Jonathan Aguilar (Kansas State University), Bill Golden (Kansas State University)

Introduction

The Ogallala aquifer is the largest, most economically important groundwater source in Kansas, and is the primary water source for western and south-central Kansas. It consists of the Ogallala aquifer in western Kansas, and the Great Bend aquifer and Equus Beds in south central Kansas. The High Plains aquifer is heavily developed, particularly for irrigation, with most of the Ogallala portion in long term, serious decline. Projections of how many more years the aquifer will support a particular level of withdrawal indicates large areas that have less than 25 to 50 years at current usage rates. Some regions in Haskell County may have a decade or less of large scale withdrawals. Widespread significant conservation measures must occur to extend the useful life of the aquifer.

State policy regarding water management is guided by the Kansas Water Appropriation Act which asserts that water in the State of Kansas is dedicated to the use of the people of the state, with the state charged to manage that resource. As such, surface and groundwater can be appropriated for beneficial use of that water, without waste, if that use does not cause impairment of an existing, more senior water right and does not unreasonably affect the public interest.

A water right does not constitute ownership of such water, only the right to use it for beneficial purposes. The date of a water right, and not the type of use, determines the priority to divert and use water at any time when supply is not sufficient to satisfy all water rights.

Science and Data

The pressing question driving ongoing research in Kansas is determining the aquifer response to reductions in pumping. Hydrologic models have been developed for most of the Ogallala-High Plains aquifer in the state. The hydrologic models help define the current water budget, and allow future management scenarios to be projected. Research on drought tolerant and low water crops, crop water management, and irrigation systems assist farmers as they transition to less available irrigation water. Economic models also provide guidance on transitions to less water use that have the least impact at the farm level and regional economy.

Kansas has very good data on water use, with all water right owners other than domestic required to submit an annual water use report. Additionally, the State has identified long-term trends through annual winter measurements of water levels in about 1,400 groundwater wells. Index wells have been placed throughout the Ogallala region to monitor real time aquifer conditions daily, capturing conditions when the aquifer is most stressed during the pumping season. Drillers' well logs, annual water use, and water levels are all available to the public online. The Kansas Geological Survey has a Master Well Inventory that assembles data from several agency databases. The accessibility of the data and its presentation in the online High Plains aquifer atlas is valuable in developing an awareness of conditions. Additional data on recharge and the spatial variability of the aquifer would further improve knowledge of the conditions.

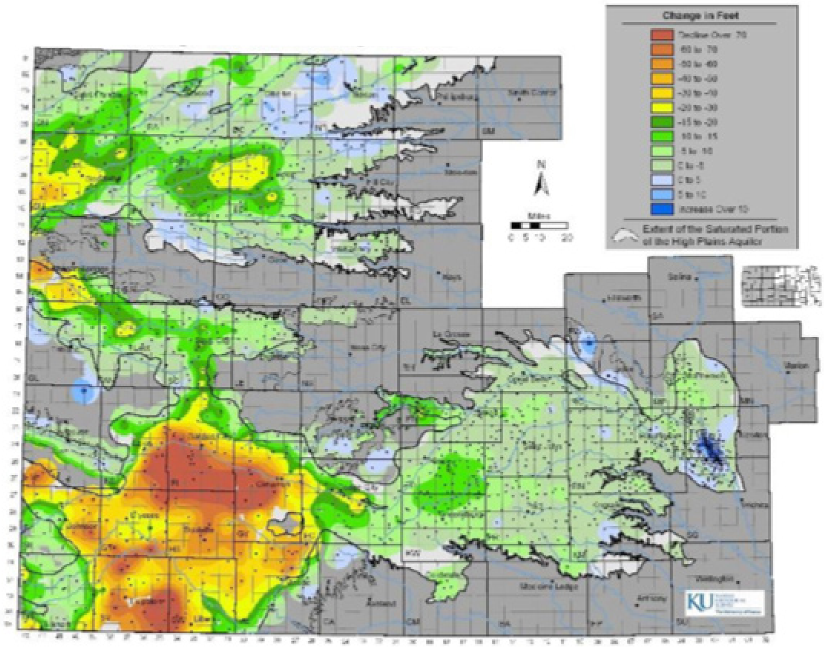


Figure 1: Interpolated Water Level Change, Kansas High Plains Aquifer, Average 1996-1998 to Average 2015-2017.

Policy

Recognizing the Ogallala-High Plains aquifer is the largest, most economically important ground water source in Kansas, many programs, policies, and individual management decisions have been directed towards conserving and extending the useable life of this resource. Examples of such activities include the development of Local Enhanced Management Areas (LEMAs) and Water Conservation Areas (WCAs), establishment of water banks, improved crop insurance, increased compliance and enforcement and implementation of various water conservation programs such as Water Transition Assistance Program (WTAP) and Conservation Reserve Enhancement Program (CREP).

Essentially all of the Ogallala and Great Bend Prairie aquifers, and most of the Equus Beds aquifer, are closed to new water right appropriation. Additionally, water users in the closed areas no longer risk abandonment of a water right for non-use.

Since 2012, the LEMA option allows a locally developed groundwater conservation plan to be proposed within a Groundwater Management District (GMD). If recommended by the GMD and ordered by the Chief Engineer, the conservation measures have the force of law. LEMA has the potential to be highly effective due to local commitment to its success, and GMD and state support in its implementation. The first approved LEMA, in Sheridan County, has a nearly 20% water conservation goal. A new district-wide LEMA was approved for GMD#4 on March, 1 2018. Additional discussions are occurring in localized areas in Southwest GMD#3.

In April 2015, Kansas Governor Sam Brownback signed into law a bill allowing for Water Conservation Areas (WCAs), a simple, streamlined, and flexible tool that allows any water right owner or group of owners the opportunity to develop a management plan to reduce withdrawals in an effort to extend the usable life of the Ogallala-High Plains aquifer. To date, more than 14,000 acres of irrigated land has been enrolled in a WCA.

In 2016, Kansas Department of Agriculture-Division of Water Resources (KDA-DWR) increased penalties for over pumpers. The penalties increase in severity with the number of offenses; the fourth offense is a water right revocation. Meter tampering or intentionally falsifying information may result in a water right suspension or revocation.

There are several state and federal programs for groundwater conservation in Kansas. The state funded WTAP pays water right owners in targeted areas closed to new water rights to permanently dismiss all or a portion of their water right. The Upper Arkansas River CREP is a state-federal program that pays irrigators to permanently transition acreage out of irrigated production, and temporarily into grass or another conservation practice. To date, more than 110 state CREP contracts on more than 18,000 acres have been approved by the State of Kansas. These contracts have resulted in the permanent retirement of nearly 40,000 acre-feet of annual water appropriation.

The Mobile Irrigation Lab, KanSched, and Crop Water Allocator are Kansas State University (K-State) Research and Extension products to help producers available make the most efficient, economic use of their crop water. Natural Resources Conservation Service's (NRCS's) Environmental Quality Incentive Program (EQIP) and Regional Conservation Partnership Program (RCPP) provide producers assistance to implement water conservation practices. Groundwater management districts are also using locally generated funds to offer financial assistance for irrigation management technology.

In partnership with USDA's Risk Management Agency, a federal crop insurance program has been developed in Kansas for limited irrigated crops, currently not covered by (fully) irrigated or dryland crop insurance. Production tables for corn and soybeans have been developed for expected reduction in yields with various cuts to irrigation water applied.

A water bank is a market based program to provide water conservation and move water rights away from critical decline areas to areas of need, through long term leases of water rights. A water bank has been established in Big Bend GMD#5.

Producer Practice

Water Technology Farms are three year pilot public-private partnerships where irrigation technology is demonstrated, related research is conducted on the field scale and water conservation is supported. New irrigation technologies, management techniques, and cropping patterns can be tested on a larger scale on these farms. They are also an opportunity for agronomy research to be conducted by the Kansas State Research and Extension office of southwest Kansas.

Water Technology Farms have been valuable in expanding the conversation and education of producers and decision makers on water conservation in areas overlying the depleting Ogallala aquifer. To date 12 Water Technology Farms have been developed in Kansas.

Many Kansas producers over the Ogallala are wondering if their current irrigation systems and management practices are the best in what they could use to reduce their water use. Many irrigators have changed their thinking from highest crop yield to highest return on investment – the most profit on a crop with less water and other input costs. Influencing this thinking is an analysis of water use versus water level declines that show attainable levels of reduced irrigation can greatly extend the useful life of the aquifer. They are looking at better applicators (e.g. mobile drip irrigation (MDI), low elevation spray application (LEPA) nozzles, irrigation scheduling tools (e.g. soil moisture sensors and KanSched) and management practices (e.g. circular planting, cover crop rotation and high planting rates) that they could integrate in their operation to increase water use efficiency while maintaining economic viability.

Although not all of these technologies are showing significant improvements in their crop yields (which is consistent with research plot results), just by using them some producers have significantly reduced their water use for their whole farm operation (e.g. T&O Farms used less than 76% of their WCA allocation through the use of technology). The use of technology has increased producer awareness of using water wisely and allowed them to capitalize on the occasional rainfall events.

Reducing water use while minimizing economic impacts is key to the success of water conservation programs in Kansas. The Sheridan County LEMA is a great example of how irrigators adjusted crop selections and rotations to ensure minimal to no impacts to their net return. Relative to their neighbors outside the LEMA boundary, irrigated crop producers within the boundary of the LEMA:

- Reduced total groundwater use by a statistically significant 25.7%
- Reduced irrigated corn acreage by a statistically significant 22.9%
- Increased irrigated grain sorghum acreage by a statistically significant 400.8%
- Increased irrigated wheat acreage by a statistically significant 87.2%

Producer reported data for the 2013 through 2016 crop year indicate irrigated corn producers within the LEMA boundary used 23.1% less groundwater, yielding 1.2% less corn as compared to irrigated corn producers outside the LEMA boundary. Somewhat surprisingly, irrigated corn producers within the LEMA boundary reported 4.3% more cash flow than their higher yielding counterparts outside the LEMA. The producers that grew irrigated grain sorghum inside the LEMA boundary applied an average of 4.1 inches per acre, 60.5% less groundwater, yielded 13.8% less grain, but generated 59.9% more cash flow than their counterpart outside the LEMA.

The economic result suggests that, given the certainty of groundwater use reductions, producers are able to implement strategies to maintain returns and apply less groundwater. On February 17, 2017, GMD#4, at the request of producers in the Sheridan County LEMA, submitted a request to the Division of Water Resources to extend the Sheridan County LEMA. On August 24, 2017, the Chief Engineer accepted the extension proposal for the period 2018 to 2022. This suggests that producers within the Sheridan County LEMA believe they can mitigate any negative economic consequences associated with reduced groundwater use and that benefits of groundwater conservation outweigh the costs.

NEBRASKA

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Nebraska Association of Resource Districts - Dustin Wilcox
Nebraska Dept. of Environmental Quality- Ryan Chapman

Introduction

Nebraska has long relied on its water resources to support its citizens and the economic development of the state. The economic viability of so many of Nebraska's cities and towns is directly tied to having sustainable, resilient water supplies to provide safe and dependable drinking water, as well as to fuel the agricultural economy of the state. This is evidenced by Nebraska's top ranking in the number of acres served by irrigation supplies (Figure 1). Agriculture relies on supplemental irrigation water supplies to increase crop production. The Nebraska Farm Bureau estimated the annual economic benefits of irrigation within the state at over $11 billion in 2012.

Recent projections developed by the United States Department of Homeland Security (2015) indicate that, at current usage rates, the majority of the state has in excess of 200 years of aquifer life. More vulnerable counties in the state are projected to face aquifer depletion at current usage rates in 50 to 100 years (Figure 2). Thus, with limited concerns related to aquifer life goals, Nebraska's primary groundwater management objectives relate to managing the wide-spread interconnectivity between the state's aquifers, rivers, and streams. This unique condition amongst Ogallala region states has allowed Nebraska water policies to be directed toward focused efforts to manage hydrological interconnectivity and ensure that stream flow resources are sustained in conjunction with the aquifer.

Science and Data

A comprehensive understanding of water supplies and uses is needed to facilitate water management decisions. Nebraska is fortunate to have a highly-developed monitoring network that supports a robust system of groundwater modeling tools and allows for a comprehensive understanding of water supplies and water uses. Much of this data is readily available to Nebraskans through a variety of online sources, including the Nebraska Department of Natural Resources' (NeDNR) INSIGHT web portal. The understanding of water supplies and water uses is continually enhanced through the cooperation and collaboration of NeDNR with local natural resources districts (NRDs) and local water users. This scientific foundation ensures that managers and water users can rely on a comprehensive network of information when making decisions.

Nebraska's science and data network is continually assessed and augmented with

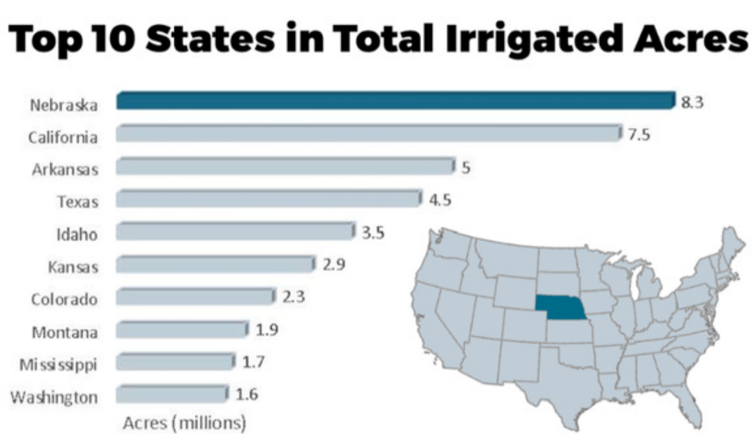

Figure 1: Top 10 states in total irrigated acres: 2013. (2012 Census of Agriculture, USDA, National Agricultural Statistics Survey)

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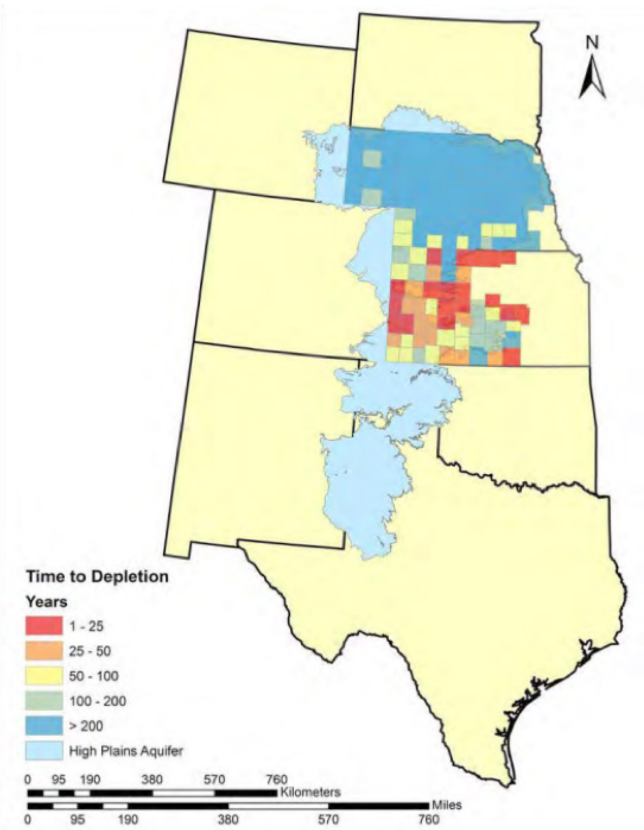

Figure 2: Time to depletion of High Plains Aquifer due to continued pumping (U.S. Department of Homeland Security, 2015)

new information. This process is structured through data hierarchies aimed at ensuring the best available information can be used in support of local and regional water planning. This approach supports the inherent variability in data sources and provides direct conduits for local NRD investments in improving data collection to be incorporated throughout the water planning process, which is important for ensuring technical credibility and a common factual basis for state and local decision makers.

Policy and Planning

State policy regarding aquifer water management is guided by the Ground Water Management and Protection Act, which affirms that water in the State of Nebraska is held by the state for the benefit of its citizens, with the 23 local NRDs charged with the primary responsibility to manage the quantity and quality of groundwater resources. Groundwater management occurs through a modified correlative rights system, which differs from the prior appropriation system used by NeDNR to manage and administer surface water rights. Water rights in Nebraska do not constitute ownership of water - only the right to use it for beneficial purposes.

With the Ogallala aquifer supporting a significant portion of the agricultural economic output in Nebraska, many programs, policies, and planning efforts have been directed toward conserving and sustaining this resource. Examples of such activities include the development of Ground Water Management Plans, with locally developed NRD-specific rules and regulations for both water quantity and quality; Integrated Management Plans and Basin-Wide Plans, both of which address hydrologically connected ground and surface water resources and are collaboratively developed by NeDNR, NRDs, and local stakeholders; and the establishment of other locally sourced management efforts and funding mechanisms to support conjunctive water management.

Water policy and planning in Nebraska places a significant emphasis on the integrated water management planning process that relies on a strong partnership between the NeDNR and local NRDs in conjunction with stakeholders and other water management agencies. The primary policy tenants guiding these processes include:

Customized and decentralized water management plans led by local NRDs with NeDNR support in conjunction with strong public engagement with multiple constituents and stakeholders groups ensures that both local and state needs are addressed.

A commitment to the protection of existing water uses and continuing investments in water resource development and protection, such as reservoirs and groundwater recharge projects.

- Expansion of science based conjunctive use and integrated water management strategies leveraged to optimize water supply utilization.
- Agricultural producer level innovation in water quantity and water quality management.
- Creation of flexible markets and management tools to address both short-term and long-term water supply shortages and challenges.
- Continuous improvement amongst water agencies to improve the coordination of water quantity and water quality management.

This water planning process relies on a highly-developed scientific foundation that allows for a thorough understanding of the water supplies and demands on those supplies. Building from that scientific understanding, stakeholders are engaged by NeDNR and partnering NRDs to review and develop goals and objectives specific to each local area. With that stakeholder input, NeDNR and local NRDs work to develop strategic actions aimed at achieving those goals and objectives (Figure 3).

The current status of NRD-level integrated management planning across the state is illustrated in Figure 4. With the high degree of variability in both water supplies and water demands in each basin across the state, the goals and objectives of plans can differ dramatically from one NRD to another. However, many common features tend to exist within a given basin, which gives rise to the desire for increased coordination among the various planning goals and objectives contained within each NRD plan. This coordination and supplemental planning is accomplished through basin-wide plans. Basin-wide plans have been developed in many of the basins in the state with the aim of further leveraging opportunities through collaboration of multiple NRDs and gaining efficiencies in plan implementation. The integrated management planning process does not stop with the development of a plan. The planning process is continual and adaptive with the aim of achieving goals and objectives and also identifying if new goals and objectives need to be incorporated, with emphasis toward improving outcomes for water users.

There are several state and federal programs used to support groundwater quantity and quality management in Nebraska. The state funded Water Resources Cash Fund and Water Sustainability Fund are used to

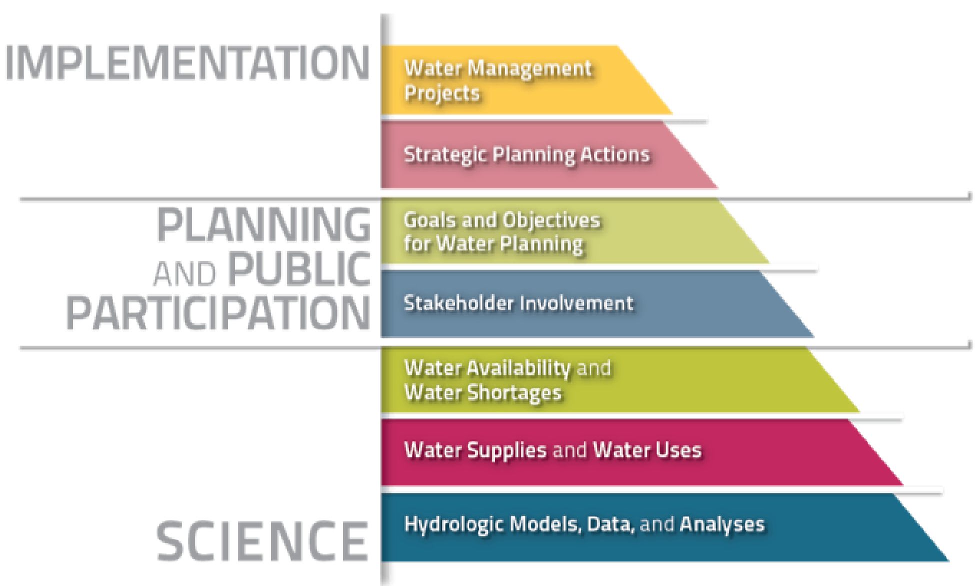

Figure 3: Foundations of water planning in Nebraska.

support programs targeted at reducing use and increasing water supplies through re-timing and storage, as well as investments in water supply infrastructure. These funds are matched with 40% local cost shares, typically with NRD participation. NRD funding is derived from locally sourced taxing authorities, property tax levies, and occupation taxes on irrigated acres that support plan implementation. Federal programs and funding sources, which are matched by state and local funds, are also leveraged and include the Conservation Reserve Enhancement Program (CREP), Agricultural Water Enhancement Program (AWEP), Natural Resources Conservation Service (NRCS) funding sources, along with federal grants from the United States Bureau of Reclamation (USBR) and Environmental Protection Agency (EPA).

Producer Practice

Nebraska producers have implemented cost saving irrigation efficiency practices that have also proven to dramatically conserve and protect water resources. The NRDs have been successful in working with state and local partners including NeDNR, the Nebraska Department of Environmental Quality (NDEQ), Universities, and UNL Extension, to research groundbreaking technology, cropping strategies, and input practices that best address local management needs. This research has been used to engage producers and stakeholders and demonstrate both the economic and conservation impacts of best management practices. Several NRDs have developed their own programs and networks that work to demonstrate efficiency impacts and offer producers real-time data and information to assist in making effective conservation-minded management decisions. While there are special Water Quality and Quantity Management Areas where certain practices are required, many of the most effective practices being implemented by producers across the state are done so voluntarily. Utilizing NRD funds to leverage state and federal dollars, local boards have

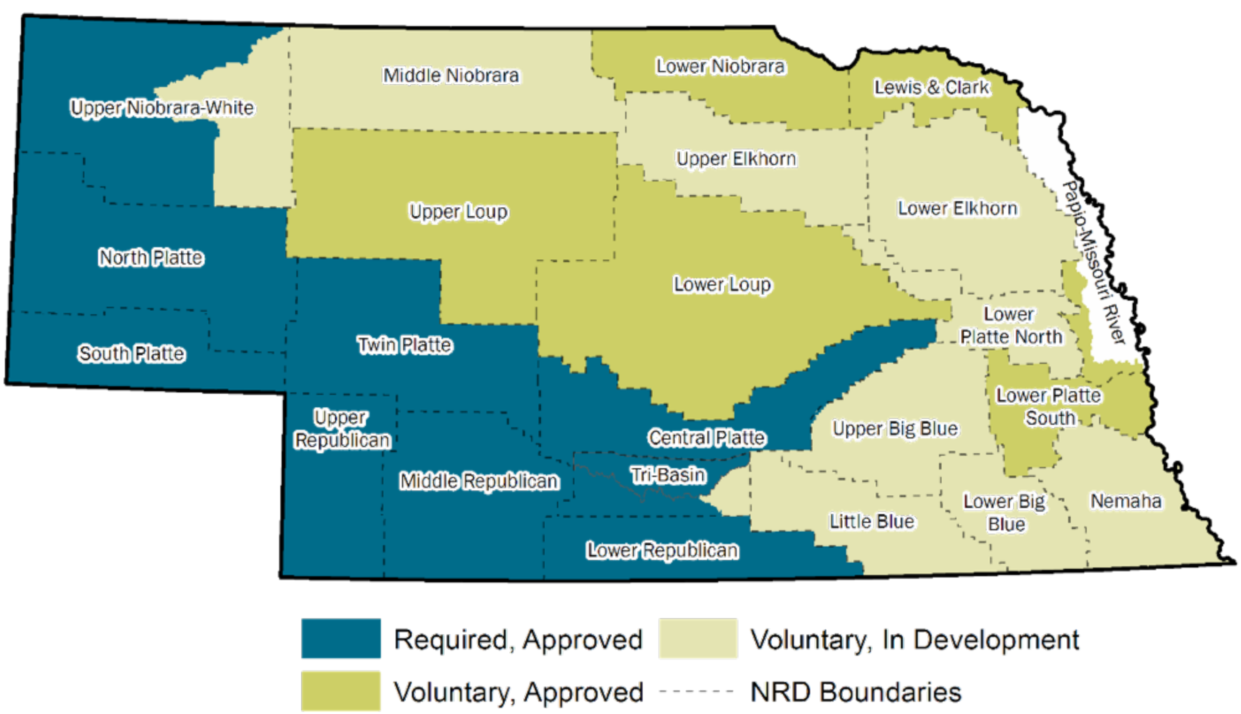

Figure 4: NRDs currently involved in integrated management planning (2018).

Program Target	Program	Description	Results
Quantity	Soil Moisture Sensor Program	NRD-level cost-share program offering technical assistance and 0-100% on purchase of soil moisture sensing equipment	Offered by 18 of 23 NRDs > 436,000 acres > 2,000 producers
Quantity	Ground-water Well Flow Meters	Required flow meters on groundwater wells over specified capacity	Required by 20 of 23 NRDs
Quantity	Allocations	Allocates a certain number of inches that can be pumped over a certain number of years	Required by 12 of 23 NRDs
Quality	Soil Sampling	Required soil sampling for water quality indicators	Required by 15 of 23 NRDs

Table 1: Selected examples of producer programs offered or required by NRDs.

been able to provide cost-share incentives to producers for innovative, research-driven advances in irrigation management. A few examples of some of the programs offered or required by NRDs are listed in Table 1.

In addition to support from extension offices, NRDs, and NRCS district conservationists, locally driven producer groups, such as the Nebraska Water Balance Alliance, have worked to provide producer seminars and education events on technologies and practices that can be adopted by producers to improve irrigation management.

A recent example of a creative program to engage producers in adoption of new technologies is the esting Ag Performance Solutions (TAPS) program (taps.unl.edu). This program provides opportunities for producers to virtually compete against each other as well as UNL scientists for (1) most profitable farm, (2) highest input (water and nitrogen) use efficiency, and (3) greatest grain yield. The goal of the competition is to promote efficiency and profitability while giving a chance to learn from those who grow corn profitably. The competition is supported by UNL Extension, NRDs, non-profit organizations, and agricultural industries, among others.

Moving Forward

Challenges to the reliability and protection of the Ogallala aquifer do exist. Many areas of the state face nitrate concentrations in excess of 10 mg/l (Figure 5). With much of the state's drinking water being provided through aquifer extractions, efforts to provide safe and affordable drinking water supplies for rural communities will need to be enhanced. Portions of the state are more susceptible to drought, resulting in increased in-season aquifer drawdowns and less resilient streamflows. These drought related impacts can create well interference issues between irrigation wells and domestic wells, and reduced streamflows can create challenges in meeting the requirements for Compacts and Interstate Agreements.

These challenges will serve to sharpen the focus of water management and planning in Nebraska. The science and monitoring being developed to support planning efforts must continue to be invested in to ensure that the extensive data networks throughout the state can support the information needed to make well-informed management decisions. Funding will continue to be necessary to revitalize and repurpose water supply infrastructure to meet the new challenges of the future. With a continued focus on leveraging activities such as conjunctive management, retiming water supplies, producer driven innovation, and implementation of best management practices, Nebraska will work to create more resilience within each basin. It is through these extensive water planning efforts, scientific investment, and locally sourced collaborative solutions, that Nebraska intends to meet its management challenges.

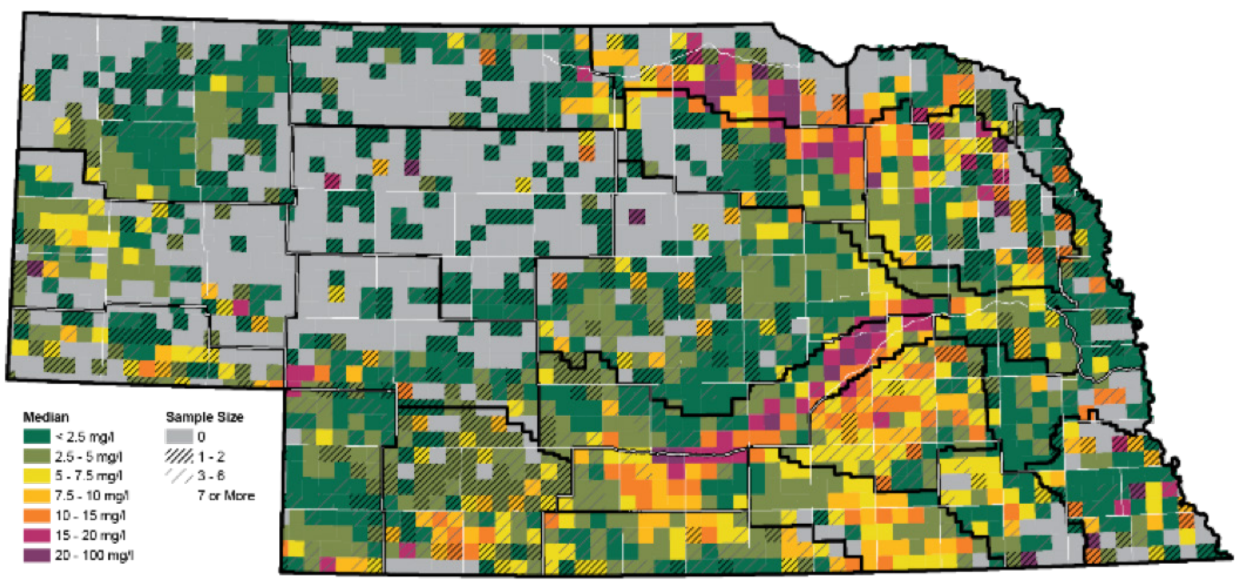

Figure 5: Median of the most recent Nitrate-N concentrations by township of 18,160 wells from 1997-2016. Empty areas indicate no data reported, not the absence of nitrate in groundwater. (Source: Quality-Assessed Agrichemical Database for Nebraska Groundwater, 2017. Published by Nebraska Department of Environmental Quality, 2017)

New Mexico

Authors: Mark Marsalis (New Mexico State University), Tom Blaine (New Mexico State Engineer) & Rajan Ghimire (New Mexico State University)

Introduction

The Ogallala aquifer in New Mexico is the most economically important groundwater source in eastern New Mexico, and is the primary driver for crop production in the High Plains region. The six counties that overlie the Ogallala are responsible for over 1/3 of all agricultural cash receipts in New Mexico, and over 25% of all crop cash receipts. The Ogallala aquifer is heavily pumped for irrigation of various agricultural crops that support farming and livestock industries, which, in turn, sustain the many small- to medium-sized cities dotted throughout eastern New Mexico. Primary crops grown in the region are corn, sorghum, wheat/triticale, and alfalfa. The majority of these crops are utilized as silage, hay, or grain to supply the large dairy industry in both eastern New Mexico and West Texas. There are over 142,000 milk cows in the three major New Mexico counties over the Ogallala aquifer.

Water levels in the New Mexico portion of the Ogallala, like much of the Southern High Plains, have been in a long-term, serious decline for decades. Water usage is unsustainable, as extraction far exceeds the minimal amounts of recharge into the aquifer. Agricultural producers are currently experiencing declining well pumping capacities at an alarming rate, particularly in the more southern stretches of the aquifer range in New Mexico. In addition, decreased water levels in existing municipal wells have led to many wells being shifted from agricultural use to municipal usage in both the Clovis and Portales areas in order to meet municipal water demands. Recent samplings from 2004 to 2007 to 2010 to 2015 of 121 wells in Curry and Roosevelt counties indicated that there has been an estimated loss of close to 2M acre-feet in the aquifer during the time periods, with a 7-year average loss of 277,586 acre-feet per year. Over the sampling period, 75% of the wells experienced a decline in water levels (median well decline of 4.2 feet) (Figure 1). No significant surface water resources exist in the High Plains region of New Mexico.

Science and Data

The primary focus of the majority of research to date has been on finding low water-use cropping alternatives to the current slate of traditional crops grown in the region. Most of the research has been conducted at New Mexico State University's (NMSU) Agricultural Science Center at Clovis. Well capacities are

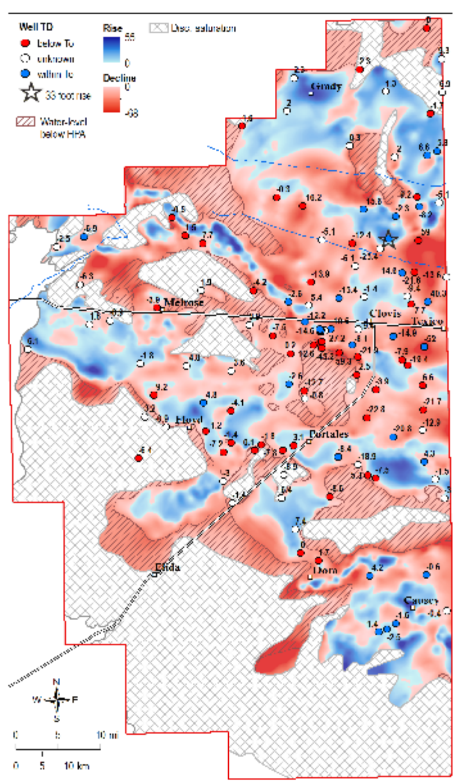

Figure 1: Change of saturated thickness of the Ogallala Formation in Curry and Roosevelt Counties, NM, from 2004–2007 to 2010–2015 (in feet). Source: Rawling, 2016.

increasingly becoming less capable of supplying enough water to grow high water demand crops such as corn.

While corn silage remains a staple component of dairy feeding rations, research has shown that forage sorghums certainly have a fit into the high-energy diets of dairy cows, while saving considerable amounts of water. Extensive testing on sorghum types, varieties, and fertilizer and seeding rates has led to a much-improved understanding of the proper management of this crop, as well as the water-saving benefits and flexibility it provides.

Farming systems in eastern New Mexico are characterized by a small handful of annual cereal crops with limited diversity. As such, broadleaf alternative crops may be able to provide rotational benefits in these systems while stimulating economic impact in the region. Research conducted on winter canola has shown that irrigation may be reduced by as much as 40% (compared to winter wheat dual-purpose systems), while providing both grazing and high-value seed harvest options for producers.

Crop diversification through cover cropping and legume integration in crop rotations could be another strategy to harness soil health and water conservation benefits in the region.

Figure 2: Underground water basins in eastern New Mexico. Source: NM Office of the State Engineer.

Research reveals the need of at least five tons of biomass carbon input to maintain soil organic matter at present levels. Increasing biomass carbon input through cover cropping not only increases soil organic matter, but also increases microbial activity and improved soil health. Cover crop studies under limited irrigation crop rotations have shown improvement in the response of selected soil health indicators by at least 17% without any difference in water use and crop yield.

Farming with limited irrigation is a challenge, and it is a greater challenge to produce crops in a strict dryland situation. However, half of the eastern New Mexico farms have been already turned into dryland production. Research on conventional tillage, strip-tillage, and no-tillage comparison in dryland situations show the many benefits of reducing tillage. Specifically, no-tillage in dryland corn-sorghum rotations has increased soil water storage, reduced soil erosion, and maintained comparable crop yields.

This research provides information to assist farmers as they transition to farming systems that utilize less irrigation water and other crop inputs.

Policy

The Office of the State Engineer (OSE) has authority over the measurement, appropriation, and distribution of all surface and groundwater in New Mexico, including streams and rivers that cross state boundaries. New Mexico State laws govern the appropriation of groundwater and have been developed since the early 1930s. Beneficial use of water is the basic tenet for both surface water and groundwater statutes with priority administration governing in times of shortage. There are seven underground water basins that have been declared by the OSE in the Ogallala aquifer region (Figure 2).

Groundwater rules have been developed that identify more specific detail on the Administration of Groundwater. In addition, Basin Guidelines are used to ensure regional consistency for some of the more active

Groundwater Basins located on the East side of the state. The Basin Guidelines are meant to help give clear procedures for agency staff when reviewing water rights applications filed by farmers, ranchers, and municipalities.

There are approximately 29,000 wells drilled in the Ogallala aquifer in New Mexico. While only approximately 65% of the wells drilled into the Ogallala are currently metered, any new well must be equipped with a totalizing meter and reported to the OSE. All new and replacement wells drilled today are metered as part of an Application to change an element of a Water Right submitted to the agency. There are a total of 329 wells in the measurement program in the Ogallala region.

In critical regions of a basin, the agency has developed hydrologic modeling to evaluate additional requests for appropriations. If a region is experiencing high levels of water withdrawals and thin saturated thickness within the underlying aquifer, then these areas are designated as Critical Management Area's (CMA's). Great lengths to protect these CMA's from additional water level declines are undertaken. When an application for appropriation is requested in a CMA, a regional assessment using the hydrological model is conducted. Any excessive drawdown and reduction of saturated thickness of the Aquifer will result in the denial of the application or the reduction in the amount of water that can be withdrawn or diverted.

In addition, starting July 1, 2017, the State Land Office began reviews of hydrological information before renewing or approving new access to drill wells on trust land that involve the use of fresh water from the Ogallala aquifer for oil and gas production and related activities.

Finally, local, state, and federal funding is being pumped into to a 150-mile pipeline project that is designed to bring billions of gallons of drinking water a year to parts of eastern New Mexico. The Eastern New Mexico Rural Water System Project ("Ute Pipeline"), with an estimated price tag of $500M, has been decades in the making to provide a renewable water source for eastern New Mexico communities, including Clovis and Portales, and to ease the strain on the Ogallala aquifer.

Producer Practice

Agricultural producers on the High Plains of New Mexico have always been a resilient group. Many have experienced and survived multiple year droughts, low commodity prices, and high input costs. Also, many irrigated farmers also practice dryland cropping in this hot, dry, and windy environment. As such, farmers are always looking for new information on best management practices and ways to improve their operations under increasingly harsh growing conditions.

Water conservation techniques such as no-tillage and reduced tillage management, selection of short season, drought tolerant varieties of traditional crops, and planting alternative crops are all currently being integrated into the farming fabric of the region. More efficient irrigation practices such as LEPA and LESA on center pivot systems have been implemented, but subsurface drip irrigation acceptance has been limited, primarily due to initial installation costs and traditionally low-value crops.

Finding adapted and acceptable alternatives has been a challenge. However, canola is an exceptional success story. While the rotational benefits of canola have long been understood, acceptance was limited due to a lack of storage and/or processing facilities nearby. Due to the opening of a canola crusher plant in Lubbock, Texas, growers not only have another good grazing forage option, but also they now have a market outlet for the seed harvest of this dual-purpose crop.

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Oklahoma

Authors: Oklahoma State University - Saleh Taghvaeian & Kevin Wagner

WHITE PAPERS

Introduction

The Ogallala aquifer is a major aquifer in Oklahoma, underlying portions of nine counties of the Panhandle and northwestern region of the state. In the eastern Panhandle, the Ogallala formation often sits atop 250 million years old consolidated sediments. In the western Panhandle, a younger formation of shale and sandstone called the Dockum group overlies the redbed. Other formations including the Dakota Sandstone and Morrison Formation are also found in the Oklahoma Panhandle. The Ogallala aquifer supplies more than 98% of total water demand in the Oklahoma Panhandle. Other sources such as alluvial aquifers and streams contribute less than 2%.

Irrigation is the largest user of water in the Panhandle. Since the predevelopment period (prior to 1950s), about 3000 irrigation wells have been drilled into the Ogallala aquifer. The largest number of drilled wells (over half of them) were in Texas County, followed by Cimarron, Beaver, and Ellis counties. Based on 2007 crop mix data, there are approximately 230,000 acres of irrigated land in Cimarron, Texas, and Beaver counties alone, requiring over 290,000 acre-feet of water per year. This is about 85% of the total water demand in the region. The major irrigated crops are corn and wheat, accounting for about three quarters of total irrigated area. The expansion of irrigated agriculture in the Oklahoma Panhandle has been a major driving force for economic development and prosperity of this region. This irrigated cropland is not only critical for grain production, it also supports major livestock production enterprises in the region – i.e. cattle feedlots, dairies, and hog operations.

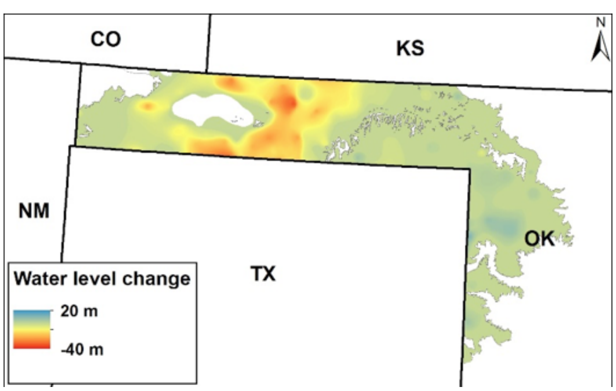

Figure 1: Water level changes pose threats to producers in the Oklahoma Panhandle because irrigation is the largest user of water in the area.

Science and Data

According to USGS analysis, from predevelopment (about 1950) to 2015 the Oklahoma portion of the Ogallala aquifer experienced a decline in water level of 12.5 feet. This estimate is an area-weighted average and thus smaller than the local declines in areas where the saturated thickness is larger. In parts of Texas County, the decline was over 50 feet. The Oklahoma Water Resources Board has also published data on Ogallala water level change over the period from 1966 to 2015, reporting declines of about 80 and 60 feet for Texas and Cimarron counties on average, respectively.

In contrast to the Panhandle, groundwater levels in Roger Mills and Beckham counties have been rising over the last 20 years. However, there are concerns that pumping in some portions of the Ogallala aquifer could induce upward movement of saline water that exists in the underlying Permian formations.

Considering the importance of irrigated agriculture in the longevity of the Ogallala aquifer in Oklahoma, researchers with the Department of Biosystems and Agricultural Engineering at Oklahoma State University (OSU) have initiated several programs to 1) evaluate the performance of commercially available soil moisture sensors to optimize irrigation management and 2) audit water application uniformity and conveyance efficiency of irrigation systems in the Panhandle region. Most soil sensors tested to date had error rates less than 10%. Irrigation systems tested to date have averaged a coefficient of uniformity of 72.3% and a distribution uniformity of 60.5%, indicating poor uniformity and the need for full system maintenance and adjustment of nozzle packages. Water conveyance efficiency was 93%, meaning that about 7% of water was lost on average between the pumping point and the soil surface.

The OSU Plant and Soil Science Department is also working to identify production practices for corn, wheat, and grain sorghum that improve profitable irrigation management under declining well capacity scenarios, to help producers adjust input rates, or adopt alternative crops that require lower irrigation rates such as grain sorghum or forage crops.

Policy

Oklahoma ground water law allows landowners or lessees to obtain a permit from the Oklahoma Water Resources Board to use ground water at a rate determined based on the number of acres of the applicant's land that overlies an aquifer. According to this law, passed in 1972, those individuals who had a water right prior to 1972 would be allowed to continue to extract water at their previously permitted rate. Temporary permits are issued for aquifers where the amount of stored water has not been identified, allowing for extraction of up to two acre-feet per year (AFY) per acre of land owned or leased by the applicant. If a study has been conducted and the total water storage determined, the permittee is allowed to extract water at a different rate based on the area of land above the aquifer and a minimum basin life of 20 years. For the Ogallala aquifer, the rate of two AFY per acre has been issued for groundwater use in the three Panhandle counties and 1.4 AFY per acre for other counties in the overlying the Ogallala.

Agricultural producers in the Panhandle region have formed the Oklahoma Panhandle Agriculture and Irrigation (OPAI) Association to protect the property rights of members and to study proposed and enacted legislation, rules, and regulations. OPAI also works to initiate, sponsor, and promote research to increase profitability of agricultural operations for its members. OPAI collaborated with other local groups in developing the Panhandle Regional Water Plan, which called for more financial and technical assistance by programs such as the County Conservation Districts' cost share and the councils of government to find new ways to extend the life of the aquifer in economically viable ways.

Producer Practice

The major change in producer practices in the Oklahoma Panhandle over the past several decades has been the type of irrigation systems used. Satellite imagery reveals the majority of irrigated fields in the region were under flood irrigation in the late 1970's, with only a few center-pivot systems used. Over the next 30 years, however, most irrigated fields switched to center-pivot systems. According to the most recent Farm and Ranch Irrigation Survey (FRIS) by USDA (2013), about 95% of all irrigated acres in Oklahoma are under sprinkler irrigation.

Center pivot systems were the dominant type of sprinkler irrigation, occupying over 96% of all sprinkler-irrigated acres. Compared to flood irrigation, center-pivot systems can apply water in smaller amounts and more uniform patterns, resulting in reduced runoff and deep percolation. As a result of this increased efficiency, a significantly larger portion of pumped water is used by crops under center-pivot systems. Currently, almost all center-pivot systems are equipped with Mid-Elevation Spray Application (MESA), where nozzles are about halfway in between the main line and the ground. This setting significantly reduces wind drift and direct evaporation losses compared to traditional impact sprinklers. In addition, about 70% of all center pivot systems operate on less than 30 psi of pressure, thus having smaller energy requirements compared to high-pressure systems. Twenty-nine percent of center pivot systems in Oklahoma run on pressures between 30 and 59 psi and only 1% require pressures larger than 60 psi.

In addition to adoption of center pivots, many growers have transitioned to minimum tillage which has a great potential to improve soil health and consequently water storage.

Moving Forward

To encourage conservation, efficiency, recycling and reuse of water, the Panhandle Regional Water Plan recommends the following:

- Actively identifying incentive programs beneficial to water users
- Promoting a culture of water efficiency by reducing unit water demands
- Supporting research, development, application, and implementation of water-efficient technologies and practices (i.e. drought - tolerant crops, alternative crops, efficient irrigation technologies)
- Supporting initiatives and seeking funding to support eradication of salt cedar and other invasives
- Encouraging water reuse programs and incentives

Significant opportunities exist to adopt irrigation systems with higher efficiency than MESA center pivots. LEPA and LESA systems have been developed and tested successfully in the Texas Panhandle, with the potential to minimize water losses to only a few percent. Drip systems (mainly subsurface or SDI) has been also used on a limited basis in the Oklahoma Panhandle. One issue that has contributed to the low adoption of drip systems is land ownership. For producers who lease the land, it is much easier to purchase center pivot systems and then move it to another location at the end of the lease than to invest in permanent SDI installation. Innovative approaches such as the Mobile Drip Irrigation (MDI) have been tested in southwest Kansas and should be considered as alternatives to existing center pivot systems to further reduce irrigation losses.

In addition to advancements in irrigation hardware, water use efficiency has tremendous potential through irrigation scheduling. Based on FRIS data, the majority of surveyed producers (88%) mentioned the condition of crop as their main method of deciding when to irrigate. Feel of soil was the second most widely used factor in irrigation scheduling, reported by 39% of growers. Use of soil moisture sensors was mentioned as a decision making factor by only 11% of growers.

South Dakota

Authors: Todd P Trooien[1], Syed Huq[2], John McMaine[1], David Kringen[1] & Adam Mathiowetz[3]

Introduction

The northern terminus of the Ogallala aquifer lies beneath South Dakota and the Rosebud Reservation. Saturated thicknesses range from a few feet to greater than 200 feet. There are eleven production wells in the Ogallala supplying 70% of domestic, municipal and industrial water needs of the population on the Rosebud Reservation. Non-tribal water use is dominated by irrigation, municipal, rural water system, and domestic uses.

Science and Data

The South Dakota Department of Environment and Natural Resources (DENR) has 77 observation wells in the Ogallala aquifer as part of their statewide network of 1,584 observation wells (visit http://apps.sd.gov/nr69obswell for more). The DENR observation wells in the Ogallala have been measured since the late 1970's to the early 1980's. The DENR-Water Rights Program relies on the water levels measured in their observation wells along with studies done by the SDGS, the USGS, and others. The DENR observation well data show that average annual withdrawals (i.e.: pumping) from the aquifer have not exceeded average annual recharge. The Rosebud Sioux Tribe (RST) has 28 observation wells in the Ogallala, including seven monitored in real time via satellite data links. The RST have been monitoring since 1984.

A model of the aquifer by the RST in conjunction with USGS using the existing water table data simulated a 30-year drought and 50% increase in pumping over a 30-year period. In general, the simulation showed that recharge and discharge did not change significantly, indicating a long useful life for the aquifer. Hydrographs based on the compiled water table fluctuation data during the monitoring period show that the water table has fallen only by a few feet in some observation wells near the concentrated center pivot irrigation systems.

Irrigators in South Dakota are required to report their water use annually and limit their total diversion to a maximum of two or three feet of water per acre, depending on when the permit was originally granted. Each of the approximately 2,000 irrigators in South Dakota receives and is required to complete an irrigation questionnaire for each of their permits each year.

Policy

Tribal management of the aquifer is guided by the Tribal Water Conservation Code and managed by the RST Water Resources Office under the supervision of the Land and Natural Resources Committee and Tribal Council. In addition, the RST has developed a Drought Vulnerability Assessment Plan and is working toward development of a Drought Mitigation Plan.

For the Ogallala aquifer in South Dakota outside of the tribal lands, the Water Rights Program is overseen by the Water Management Board and administered by the DENR. The Water Management Board is a committee of seven citizens appointed by the Governor.

To initiate the permit application process, a prospective water user submits a request for a water permit (visit https://denr.sd.gov/des/wr/watrightsapps.aspx for more). If the DENR recommends approval and no one contests the application, the Chief Engineer of the Water Rights Program can issue an uncontested permit. If there are objections from neighbors or the public, a contested case hearing is scheduled. The Water Management Board

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conducts any contested case hearing then makes and issues their decision to approve, deny, or defer the application for further study. A decision by the Water Management Board can be appealed to the Circuit Court.

All water uses in South Dakota require a permit except for domestic uses or water distribution systems requiring flow rates of less than 18 gal/min. Water permits in South Dakota are transferable by filing a notice with the Water Management Board. Changes in use (e.g. point of diversion, change in use, or other change) can be made to a permit but an irrigation permit can be changed only to domestic water use or a water distribution system permit. If a water use is changed, neither the pumping rate nor volume can be increased.

The State of South Dakota has a strict no-depletion policy that prevents over-appropriation of any aquifer, including the Ogallala aquifer. Aquifers in two areas in central and north central South Dakota are fully appropriated and the Water Management Board has declared those areas closed to new water permits. There is a waiting list for permits and these aquifers are re-evaluated every five years to determine if unappropriated water is available for new appropriations. This same process of closing areas to further water rights permits could be applied to the Ogallala aquifer in South Dakota if the aquifer were to become fully appropriated in South Dakota.

The combination of current recharge rates, modest current use, water use reporting, and strict legal protection mean that this northernmost part of the Ogallala aquifer is relatively well protected from over pumping.

Producer Practice

Irrigation in this area is via center pivot. Crops are feed grains (corn) and forages, including alfalfa. There are more than 90 center pivot irrigation systems of which 16 are owned by the RST. There are 2,550 acres irrigated by the Tribal center pivots. There are 143 irrigation water rights/permits authorizing the irrigation of 25,900 acres under more than 180 irrigation systems on file with DENR. There are also 29 water right/permits authorizing water use for non-irrigation purposes, primarily for municipal and rural water system use, and four future use permits reserving water from the aquifer for municipal use.

Moving Forward

The checkerboard land ownership by RST or tribal members and non-tribal members (non-Indians) of lands on the Reservation is a challenging factor in the management of water resources including the Ogallala aquifer. Non-Indians are served by the State of South Dakota. On technical issues pertaining to the Ogallala aquifer there is some interaction between the State of South Dakota – DENR and RST – Office of Water Resources.

South Dakota Codified Law (SDCL) 46-6-3.1 states: "Annual withdrawal of groundwater not to exceed recharge..." If it appears the Ogallala aquifer withdrawal volumes are approaching recharge volumes, the Water Rights Program will further analyze the observation well data and any other studies done on the aquifer and determine if the aquifer is fully appropriated. Ultimately, the Water Management Board is charged with making a final determination. The Water Rights Program does not anticipate that the Ogallala aquifer will be closed in South Dakota in the near future.

Texas

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Introduction

Texas has some of the most diverse climate conditions of any state in the United States. Precipitation can vary from over 60 inches per year in the eastern part of Texas near the Gulf Coast, to less than six inches per year near El Paso in the west. In addition, the agricultural growing season can range from year round in the lower Rio Grande Valley in southern Texas, to approximately a half a year in the northern panhandle region of the state. Thus, it is no surprise that Texas produces a diverse range of agricultural products and is one of the largest agricultural producers in the nation.

In the semi-arid to arid regions of western and northern Texas, much of the agricultural production requires irrigation to be profitable, and in these same regions, the only reliable source of water is groundwater. This is particularly true in the panhandle region of Texas, which overlies the southern end of the Ogallala aquifer. Groundwater supplies over 95% of the water for agricultural, municipal and industrial uses in this region, with irrigation composing over 90% of water use. Thus, the Ogallala aquifer is one of the most important resources that Texas has to support its agricultural economy, especially related to its livestock industry, where the High Plains region produces 78% of fed beef, 60% of dairy cows, 94% of hogs, 63% cotton, and 41% of corn for the state.

However, there is a great deal of concern related to declining water levels across the Ogallala aquifer in Texas, with some areas declining by as much as 100 feet over the last half century. Declining water levels have sharpened the awareness of the Ogallala aquifer as a limited resource and prompted actions to address the sustainability of water use for a robust agricultural economy. An increased emphasis has been placed on understanding how to best utilize the Ogallala aquifer to provide the greatest long-term value to water users.

Science and Data

Extensive monitoring activities continue to characterize the status of the Ogallala aquifer in Texas. The Submitted Drillers Record (SDR) Database maintained by the Texas Water Development Board (TWDB) has nearly 80,000 lithological records that depict the sand thicknesses and depths of the aquifer. This information is used to map variations in water availability across the Southern High Plains of Texas. Extensive use of groundwater in the region, particularly after the 1950s, led to the creation of the High Plains Underground Water Conservation District (HPWD), which was the first Groundwater Conservation District (GCD) in Texas (of which Texas now has over 100). HPWD and other GCDs have been conducting annual groundwater monitoring campaigns that have yielded a rich water level dataset spanning several decades with measurements at over 10,000 locations across the Southern High Plains. In addition, there are automated water level loggers which report water level measurements on an hourly basis and help assess changing hydrogeological response in "near real-time." Such high resolution information is useful to understand how the aquifer responds to droughts, to characterize the hydraulic recovery at the well and to evaluate losses in well yields over time. These datasets are publicly available and extremely valuable to help improve the public awareness of groundwater resources in the region.

Several scientific studies have been undertaken to elucidate recharge mechanisms

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and highlight the important role that depressional wetlands (playas) and associated annual infiltration play in recharging aquifers. Baseflow separation analysis indicates that surface water-groundwater interactions have diminished considerably in the last five decades coinciding with the large-scale groundwater production, which started in the 1950s. GCDs in the region have established production limits for wells that produce significant amounts of water, which are referred to as non-exempt wells. Barring a few exceptions, direct metering of non-exempt wells or using alternative approaches, such as nozzling packages or electrical usage to estimate groundwater production, is now required or recommended by most groundwater conservation districts in the region. However, only aggregated groundwater production data (typically summed over a county) are made publicly available. A suite of regional groundwater flow models has been developed for the Ogallala aquifer dating back to the Regional Aquifer Systems Analysis program of the 1980s. Groundwater models have been developed by the TWDB to support groundwater policy and planning studies in the region. A comprehensive regional groundwater flow model at 0.5 mile x 0.5 mile resolution was recently developed and includes not just the Ogallala Formation but also the deeper (older) geological units of the High Plains aquifer. These models are used to guide regional groundwater planning endeavors and support regulatory actions aimed at maintaining the "desired future conditions" of the aquifer as required by the statutes of the State of Texas.

Several GCDs have been part of focused studies to evaluate crop water requirements, and the most efficient methods to irrigate crops under water stressed conditions. State-funded programs, such as the Texas Alliance for Water Conservation (TAWC), have also conducted field studies to evaluate crop water requirements and improve irrigation efficiencies. These efforts are supported by comprehensive research programs of the USDA-ARS (Conservation and Production Systems Laboratory at Bushland and Crop Stress Laboratory in Lubbock) and university systems (Texas A&M, Texas Tech, and West Texas A&M). Programs emphasize the understanding of crop water use (evapotranspiration); advanced irrigation technologies; optimizing management of limited irrigation resources for cropping systems; development of drought-tolerant and salt tolerant crop varieties; water efficient crop rotations, soil management, and other best management practices; and development of irrigation decision support software.

Policy

Texas is the only state overlying the Ogallala aquifer to operate under the common-law rule of capture, under which the landowner owns the water beneath and has the right to pump that water. The rule of capture is commonly referred to as the "law of the biggest pump," indicating that landowners face incentives to pump groundwater before their neighbors do. The rule has been modified to prevent waste, subsidence, and harmful or malicious use (Texas Water Code § 36.002).

Although the rule of capture alone may lead to increased use in some instances, legislative actions have been taken to help conserve and protect groundwater resources in Texas. The state government has begun to exercise its right to control groundwater resources through a change to the Texas Constitution, known as the conservation amendment. The amendment provides for the creation of GCDs to manage natural resources (Texas Water Code § 36.0015). Subsequently, groundwater management areas (GMAs) were established to facilitate planning between GCDs within a common area that share the resource. In 2005, GMAs were required to adopt Desired Future Conditions (DFCs), which amount to quantifiable goals for the future state of the resource (Mace et al. 2006). The individual conservation districts are then tasked with developing their own plans for meeting the applicable DFC. GCDs have authority to permit wells, establish and enforce rules (such as pumping limits and well spacing requirements) to achieve their DFCs.

The most common DFC in the Texas High Plains is the 50/50 rule, meaning that 50 percent of the current aquifer level would remain in the aquifer in 50 years. Implementation of this DFC has not been easy, and different conservation districts have taken different approaches. For example, the North Plains Groundwater Conservation District has set a limit for allowable annual use of 1.5 acre-feet of water per acre per year. Adjustments may also be made to the limit in order to reach the targeted DFC. In this particular district, the DFC is set at 40/50 for counties with higher historical water use and at 50/50 for all other counties (North Plains Groundwater Conservation District, 2015). In the HPWD, the allowable production rate is limited to 1.5 acre-feet per contiguous acre per year for all groundwater users.

Producer Practice

The Texas High Plains produces the overwhelming majority of the state's beef, dairy, pork, corn, and cotton. Since the 1970s, feed corn and corn silage have been intensively irrigated to supply the Texas High Plains' extensive livestock industries. However, regional corn producers are finding it increasingly difficult to meet the crop water demands necessary to maximize yield and profit as a result of declining water levels in the Ogallala aquifer. Although the total seasonal water use of corn can approach 30 inches per year in the Texas High Plains due to the region's high evaporation potential, corn is still widely grown thanks to its high yields, historically high profit potential, and livestock demands. Conversely, cotton is the predominant crop in the South Plains region of Texas (near Lubbock). Cotton requires less water than corn for profitable economic returns. As a result of the lower crop water demand, roughly half the South Plains' cotton acreage is not irrigated, and northern Texas High Plains' cotton acreage has more than doubled since 2015.

Various practices have been implemented by producers to stretch supplies of groundwater for irrigation such as altering the allocation of crop types and irrigation to their land and implementing technical changes that more precisely target water to the crops in space and time. Some examples of these practices are:

- Splitting center-pivot circles into sectors that grow different crops, such that part of the area is planted to lower water use, limited irrigation or dryland (rain fed) crops
- Irrigation methods shifting to the use of low energy precision application (LEPA) since the 1980s, and more recently to subsurface drip irrigation, which can achieve 90-plus percent application efficiency
- Monitoring water status using soil water sensors and crop-canopy temperatures, which help prevent excessive irrigation
- Employing online irrigation scheduling tools to allow daily tracking of evapotranspiration demand and needs of their crops, with real-time updates that factor in rain events
- Shifting cotton in the South Plains to very low irrigation inputs and dryland production
- Adopting new varieties of cotton and corn with increased drought tolerance, that maintain or improve yields with decreased water inputs
- Planting early-maturing corn hybrids to shorten the duration of irrigation, and planting corn later in the season to shift the periods of peak water demand out of the hottest periods in July and early August
- Replacing corn by grain sorghum in the dryland or low-irrigation sectors, and opting for newer, early-maturing cotton varieties having enhanced yield potentials and lint quality

These changes in crop and water management practices have been rapidly implemented across the Texas High Plains, as producers in the region are notably progressive adopters of efficient irrigation technologies, especially in areas where well capacities have long been a limiting factor to crop production. Low pressure center pivot irrigation systems and subsurface drip irrigation are well suited to Texas High Plains' crop production conditions, and an established "infrastructure" of applied research and extension programs, industry expertise, and financial incentives (including low interest loan and cost-share programs) support the adoption of these technologies.

Moving Forward

Improvements in water and agricultural management practices have enhanced crop water use efficiencies across the region, but this improvement has increased farm profitability, which has contributed to increases in High Plains irrigated acreage in recent years. Consequently, historical improvements in irrigated agriculture water use efficiencies have not resulted in a regional reduction in groundwater withdrawals within Texas. Thus, the future challenge facing the management of the Ogallala aquifer in Texas occurs at the intersection of technological advances, understanding the physical limitations of the resource, and the economics of agricultural production, with some of the most pressing knowledge and technology needs being:

- Improved irrigation management and scheduling tools using location targeted weather-based evapotranspiration estimates and in-field monitoring of soil and plant water stress
- Integrated multiple irrigation scheduling methods and data into user-friendly decision support tools
- Development of improved crop water use functions that are specific to varieties, hybrids and irrigation methods
- Development of water-efficient crop production strategies that allow in-season management changes due to changing weather and crop conditions
- Development of variable rate irrigation systems which allow for within-field adjustment of water application according to localized soil water capacity and crop yield ability
- Understanding the economics of agricultural and water management technology adoption at the farm and regional scales

Producers serve on numerous commodity check-off and stakeholder advisory boards which provide vital linkages between problem identification, technology development, and technology adoption. There also has been strong public support for the testing and demonstration of technologies and education of producers on the mechanics, agronomic management, and economic returns at the farm and regional scale. Thus, a key factor for the Texas High Plains Region to sustain its agricultural economy is to ensure that agricultural producers continue their engagement with higher education and public agencies to inform research priorities and collaborate with extension activities.

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Wyoming

Author: Wyoming State Engineer's Office

Introduction

The High Plains aquifer occupies about 8,200 square miles of the southeast corner of Wyoming, translating to less than 10% of the state's area. While the High Plains aquifer system occupies over 170,000 square miles of the United States, less than 5% is within Wyoming. Despite the geographic scale, the High Plains aquifer is the most heavily exploited aquifer in Wyoming.

In Wyoming, the High Plains aquifer consists of Oligocene aged White River Formation, Miocene aged Arikaree and Ogallala, and localized Quaternary-aged deposits. Groundwater monitoring wells and isolated numerical modeling efforts suggest that parts of the High Plains aquifer are in long-term decline whereas other areas are relatively unchanged as compared to pre-development.

State groundwater management is guided by the State Constitution, State Statute, and the Wyoming State Engineer's Office Rules and policies. The Wyoming State Constitution provides that water from natural streams, springs, lakes, and other collections are property of the state. The Constitution also declares that priority of appropriation shall give better rights to water and that no appropriations shall be denied except when a denial is demanded by the public interest (Wyo Const. Art. 8).

In Wyoming, groundwater rights have no statutory guarantee of potentiometric surface. Where surface water and groundwater are so interconnected as to constitute one source of supply, priorities of rights can be correlated and a single schedule of priorities apply to the common water supply. Although early developments for stock and domestic uses were exempt from permitting, statutes amended in 1969 require that a permit be obtained before any water source is developed for beneficial use.

Science and Data

The State Engineer's Office maintains approximately 50 groundwater monitoring wells to measure water levels in the High Plains aquifer. These wells are predominantly located in areas with heavy agricultural groundwater use. Consequently, most of the monitoring wells show seasonal variation associated with irrigation-season pumping. Furthermore, many wells show a steady decline in water levels measured over time.

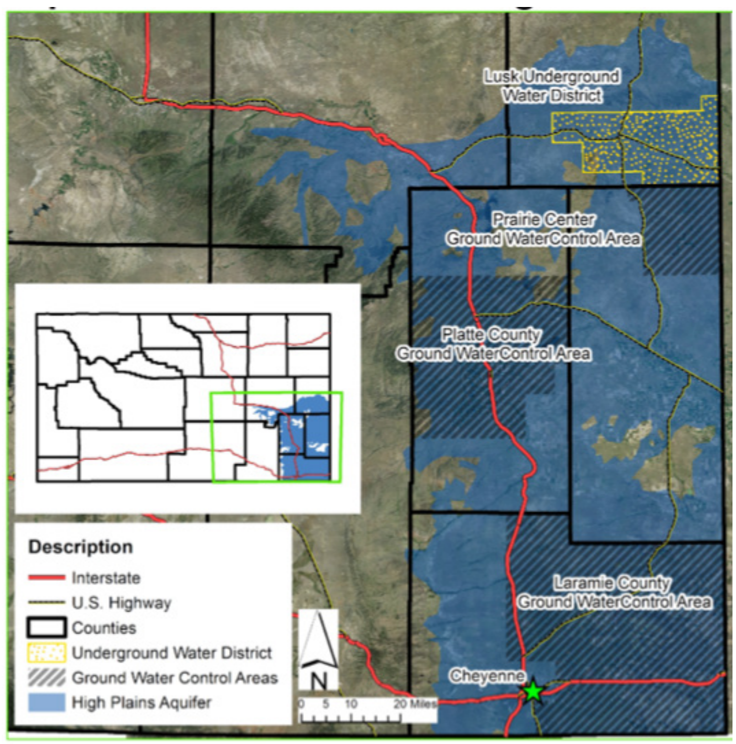

Figure 1: Wyoming High Plains Aquifer System special groundwater management areas.

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Additionally, Wyoming has performed or conducted several studies in the past decade to assess changes in water levels over time and help predict future water levels in the High Plains aquifer.

In the northern High Plains aquifer area (also known as the Lusk Underground Water District), water levels from nearly 180 wells were measured and compared to pre-development measurements. The investigation showed that some areas had experienced 30-foot declines in water level; the declines represented about 5% of the total aquifer thickness (Hinckley Consulting, 2009).

In the extreme southeast corner of the state (including the Laramie County Ground Water Control Area, discussed further in the policy section), over 300 High Plains aquifer wells were measured in the spring of 2009 to compare water levels to pre-development and also incorporate lithologic data to more completely characterize the hydrogeologic environment (Bartos, 2011; Bartos, 2013).

The State Engineer's Office completed a hydrogeologic study for the Laramie County Ground Water Control Area in 2014. The backbone of the study was a groundwater flow model which was used to evaluate the effects of current and hypothetical groundwater withdrawals and assess impacts of future administrative controls on groundwater levels. Based on the modeling results, if current production rates are sustained, portions of the High Plains will be exhausted in less than 50 years; however, areas with scant irrigation use showed negligible water level changes over the same 50-year period. Modeling also indicated that, to stabilize current water levels, some areas may need 90% demand reductions. Finally, the modeling demonstrated that modest growth of the last 10 to 20 years imparts a very small impact on future groundwater declines – rather it is production from wells developed through the 1970s (predominantly agricultural) that impacts water levels the greatest (AMEC, 2014).

Within the last decade, the State Engineer's Office has developed and implemented a system to make permits, well logs, and water right certificates publicly available. Within the last two years, the State Engineer's Office has developed an on-line reporting system for collecting groundwater production information, and expects to use those data for groundwater modeling refinement.

Statewide, Wyoming does not have very much groundwater production data. Many wells were permitted before standardized production reporting requirements and, absent a State Engineer's Order, these appropriators are not required to track or report water production. The State Engineer's Office is now collecting groundwater pumping quantities for all wells other than stock or domestic within the Laramie County Control Area. The production reporting burden is placed on the appropriator. Early data suggest approximately one half of the required wells are equipped with totalizing meters.

Policy

The first Wyoming groundwater laws were enacted in 1945 with significant amendments in 1958 and 1969. Control Areas are special groundwater management districts established through Wyoming Statute (W.S. § 41-3-912 through 41-3-915). Control Areas may be established when groundwater levels decline excessively, conflicts occur between water users, etc. Special groundwater production permitting procedures apply in Control Areas.

Once an area is designated a Control Area, the State Engineer may close the area to further appropriation, determine total permissible withdrawal and order apportioned use accordingly, order junior appropriators to cease withdrawals, order rotation of use, or order well spacing requirements for new wells. Additionally, Wyoming Statute provides an avenue by which appropriators of groundwater may voluntarily agree to a method of controlling withdrawals, well spacing, apportionment, rotation or proration (W.S. § 41-3-915); however, no appropriators have availed themselves of the process. Wyoming currently has three Ground Water Control Areas – all overlying the High Plains aquifer system.

In 2015, the State Engineer issued the Laramie County Control Area Order. The Order required adjudication and meter installation on wells other than stock or domestic use, reporting of water production for those uses, and instituted spacing requirements for new wells based on their location and proposed annual production. In the most severely impacted areas, no new appropriations will be granted which propose to produce greater than five acre-feet per year. No order or spacing restrictions are currently in place for the other Ground Water Control Areas.

The State Engineer also has the authority to determine and establish areas and boundaries of Underground Water Districts including the establishment of subdistricts when parts of an aquifer require separate regulations. In the far northern High Plains aquifer area (Lusk Underground Water District), permit conditions require that new high-capacity wells (over 25 gpm) be installed more than one mile from existing high-capacity wells.

Producer Practice

The Laramie County Conservation District, in cooperation with the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), secured funding under the Agricultural Water Enhancement Program (AWEP) for conversion of irrigated cropland to dryland crops or pasture grazing. As a result, over 2,000 acres of land irrigated with groundwater were converted between 2010 and 2013. Unfortunately, this program is no longer available.

Moving Forward

In a time of low revenue and severe budget cuts, Wyoming will need to identify additional resources or tools to encourage producer reporting of volume pumped. Until then, non compliant wells, when discovered in violation of a State Engineer Order, will be foreclosed from pumping. There is also significant need to expand the water-level monitoring program in the High Plains aquifer. Wyoming is very interested in learning how other states collect High Plains aquifer production and water-level information – whether from state or private sources.

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Crop Insurance

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Introduction

Crop insurance benefits helps producers manage risk related to crop failure and price reductions. This allows for incremental increases in investment to improve crop performance without the risk of total crop failure leading to large financial losses. The level of coverage (based on revenue or yield) is based on historical county yield data used to determine transitional yield (T-yield) or the farmer's actual production history (APH). Therefore, as producers adopt technologies to increase crop performance, their level of coverage increases. In part, this serves as a positive feedback that drives the advancement of technology and increases yields.

Despite the benefits of crop insurance for agricultural producers and the advancement of yield-increasing technologies, it does, however, result in unintended consequences with respect to resource conservation. This is particularly true with respect to water conservation in irrigated crop production where increasing yields can drive increasing water use for crop production, or at least disincentivize the adoption of water conserving practices if these practices lead to lower average yields.

Limited Irrigation

Historically, irrigated crop insurance policies required that adequate water be used to produce the APH. As such, water use was tied to APH and a reduction in irrigation water applied below a threshold could be deemed as out of compliance, leading to loss of coverage for that crop. This creates a strong disincentive to reduce irrigation. As a result, policies have been developed to allow for reduced irrigation applications (limited irrigation). This has helped producers comply with water conservation programs such as those recently implemented in Kansas.

Prior to 2017, limited irrigation crop insurance was only available within very few select areas. In 2017, the United States Department of Agriculture-Risk Management Agency (USDA-RMA) expanded coverage in Kansas to 28 counties for soybeans (Figure 1) and 47 counties for corn. This limited irrigation coverage facilitated the adoption of recently enacted water conservation policies. The limited irrigation insurance policies allow for reduced water applications and use of a Limited Irrigation calculator to calculate the resulting reduction in coverable yield. This allows a producer to use their historical APH, projected water quantity available for the coming year, and the limited irrigation calculator to calculate what levels of yield coverage is available to them for the water quantity available. With the development of multi-year water conservation plans in Kansas, producers within water conservation plans may have enough quantity of water some years to maintain full irrigation coverage, with the option to go into a Limited Irrigation policy if there is a water short year. Each year under a Limited Irrigation policy creates a Limited Irrigation APH track, which is separate from the historical Irrigated APH track, so that producers preserve their Irrigated APH level.

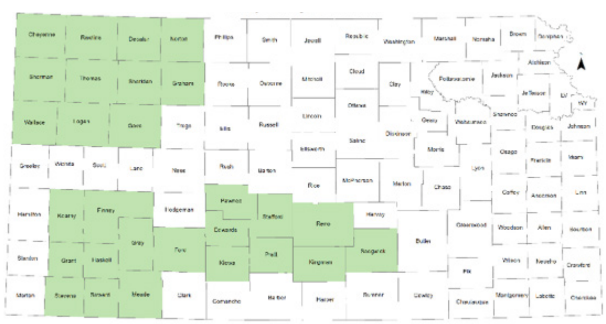
This change in policy is critical for the adoption of water withdrawal goals set by Local Enhanced Management Areas (LEMA). Specifically, it provides farmers the option to continue to grow corn and soybeans with reduced water use and reduced expected yields. This expands the flexibility producers have when complying with conservation goals without penalizing the lower yield with the loss of insurance coverage or a reduction in APH. This flexibility should facilitate achievement of

LEMA conservation goals.

Crop Selection

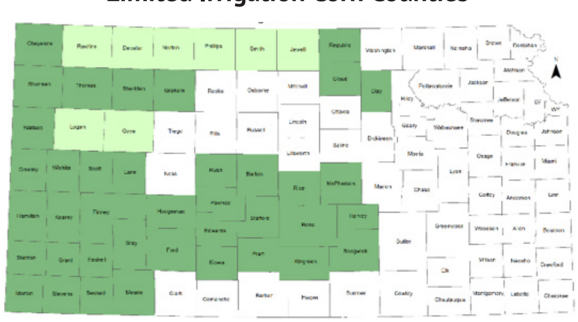
Crop insurance can have a significant impact on the adoption of crops such as grain sorghum, which requires less irrigation, in place of corn. Empirical evidence suggests that producers respond to crop insurance by altering the crops and acreage planted. For example, Deryugina and Konar (2017) find that producers use more water when purchasing crop insurance, and this is driven by an increase in acres planted in cotton. Claassen et al. (2017) also find that crop insurance increase the number of acres in production while altering crop mixes and rotations. If producers shift to more water intensive crops, this can exacerbate depletion of groundwater resources. Crop insurance may also allow producers to continue to grow these crops despite well capacity depletion below thresholds needed for viable production.

Kansas Limited Irrigation Counties for Soybean Program Consideration



Proposed expansion of Limited Irrigation Program

Limited Irrigation Corn Counties



County meets RMA standards for corn
County does not meet RMA standards but is requested

Figure 1: Kansas Counties for limited irrigation standards for soybeans (proposed) and corn (approved and requested).

A recent comparison of the cost of crop insurance for corn compared to grain sorghum provides an informative example. This comparison was conducted after an economic analysis suggested that in the panhandle of Oklahoma, production of grain sorghum was economically advantageous when irrigation capacities fell below 4.2 GPM/acre (CR-2173). However, irrigated grain sorghum acres have continued to decline as corn acres increased (CR-2174) despite the fact that well capacities have declined to below this threshold in some areas of the panhandle.

Discussions with growers suggest that the recent advance of the sugar cane aphid (a devastating new pest in the 2015 and 2016 crop years) contributes to a reduction in the willingness of farmers to produce grain sorghum. Yet, the key missing economic driver in the comparison of corn to sorghum was the cost of crop insurance premiums. An analysis of premium costs confirms this. In fact, irrigated grain sorghum premiums are 3.5 to 5.6 times higher than premiums paid by farmers producing corn based on data generated for Texas County, Oklahoma using the RMA Crop Insurance Decision Tool. Additional analysis is needed to understand the geographic extent of this discrepancy and the causes. This preliminary information suggests that serious assessment of crop insurance policy costs must be included in evaluations of the profitability of all crops, especially those under consideration to reduce water demand in the Ogallala Region.

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