The future of groundwater management in the high plains: evolving institutions, aquifers and regulations

By Karina Schoengold[1] and Nicholas Brozović[2]

Abstract:
Common groundwater management concerns that are driving policy change worldwide include aquifer depletion, surface water-groundwater interaction, and water quality degradation. This article discusses recent innovations in groundwater quantity management from around the northern and central High Plains region of the United States, where much of the policy change has occurred at a local level. There are several principles underlying the development of new groundwater management tools. Local and stakeholder input are common, generally effective, and are often more politically feasible than top-down regulations. Evidence is emerging that the behavioral and signaling aspects of policy have been effective in changing producer behavior.

Introduction

Managing groundwater resources has become a concern worldwide in regions with a high dependence on groundwater, including in the High Plains Aquifer in the Central United States, the Central Valley Aquifer in California, the Indus Basin in India and Pakistan, and the North China Plain. Across these areas, a wide variety of policies have been implemented to try to mitigate negative impacts of groundwater extraction. Some of the policies that have been considered or used include pumping limits (e.g. Kansas, Nebraska), groundwater extraction fees or taxes (e.g., Colorado's San Luis Valley), groundwater acreage fees (e.g., Nebraska's Republican River Basin, California's Arvin Edison Water and Storage District), elimination of energy subsidies (e.g., India), tradable groundwater markets (e.g., Nebraska, Australia), and cost-share programs for efficient irrigation technology (e.g., United States) (Kuwayama et al., 2016). The empirical evidence on the effectiveness of groundwater management policies is mixed. For example, Smith et al. (2017) find that groundwater irrigators in Colorado have responded to a self-imposed irrigation fee while Fishman et al. (2016) find no evidence that a voluntary

1 Associate Professor, Department of Agricultural Economics, University of Nebraska-Lincoln
2 Professor, Department of Agricultural Economics, and Daugherty Water for Food Global Institute, University of Nebraska

program in India to reduce groundwater use had a measureable effect on either energy or water use. Groundwater markets in some parts of Australia are heavily used while others are not very successful (Wheeler, Schoengold, and Bjornlund, 2016; Brozović and Young, 2014; Young and Brozović, 2016).

Background on the High Plains Aquifer

One region that relies heavily on groundwater for agricultural production is the High Plains Aquifer (HPA) in the Central United States. The HPA underlies portions of eight states (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming). Groundwater availability and changes in saturated thickness across the HPA vary between states. From pre-development to 2015, average water level change has decreased by 26.2 feet in Kansas, 14.8 feet in Colorado, and 0.9 feet in Nebraska (McGuire, 2017). Nebraska has a substantial proportion of the HPA, both in terms of saturated thickness and percent of the state with access to groundwater. Kansas and Colorado have less access to the HPA resources on both measures. Differences also exist across states with respect to the importance of the HPA for the agricultural industry. In 2010, groundwater provided 13.4, 94.7, and 76.0 percent of irrigation water in Colorado, Kansas, and Nebraska, respectively (Maupin et al., 2014).

The underlying laws regarding groundwater use in the High Plains Aquifer vary by state. Nebraska uses correlative rights, which allow all groundwater users to have equal access to groundwater, along with equal responsibility to reduce use when it is necessary. Kansas and Colorado both use prior appropriation rights for groundwater. While the legal doctrine differs by state, all three states use some type of local management district to regulate groundwater. Nebraska uses a system of 23 Natural Resources Districts (NRDs), with each governed by a publicly-elected board of directors and supported by managerial and technical staff. Each NRD is responsible for groundwater management, and has considerable autonomy with respect to taxation, passing regulations, eminent domain, and other governmental powers. Kansas has five Groundwater Management Districts (GMDs), with each governed by a board elected by local groundwater users, supported by managerial and technical staff. A critical distinction between Nebraska NRDs and Kansas GMDs is the authority to enact new regulation. NRDs have the authority to regulate groundwater quantity and quality, while GMDs can draft regulations, but those regulations need to be approved by the Kansas Chief Engineer. Although the level of power differs, the system of autonomous local decision makers, with some state-level oversight of those decision makers, has been a relatively popular method to manage groundwater use. When tough decisions about restricting groundwater use are being debated, local decision makers prefer the option to make those decisions themselves. Without this option, local decision makers run the risk of having regulations set by state- or federal-level regulators. Anecdotal evidence from Nebraska suggests that one of the deciding factors for NRD decisions has been to "make decisions ourselves, or risk that Lincoln (i.e., state regulators) will do it."[1]

Recent Groundwater Policy and Management Changes in the High Plains Aquifer

State-level changes

LB962 and the legal recognition of hydrologically connected groundwater and surface water in Nebraska: Until recently, the NRDs in Nebraska had the responsibility of managing groundwater, and the Nebraska Department of Natural Resources (NDNR) had the responsibility to manage surface water. The hydrological connection between surface water and groundwater is scientifically well established and exists in many areas (e.g., Idaho, Nebraska). However, the legal system in Nebraska did not recognize the connection until the passage of LB962 in 2004. Under certain circumstances, LB962 requires an NRD and the NDNR to jointly develop an Integrated Management Plan (IMP) that incorporates groundwater and surface water management. The tools that are used in the IMPs vary across NRDs, but include well moratoria, transferable and/or non-transferable groundwater allocations, flowmeter requirements, and bans on developing new irrigated acres.

State control of groundwater development in Kansas: Much of the power to regulate groundwater in Kansas is in the office of the Chief Engineer. In addition to the underlying appropriative rights, the Kansas Groundwater Management District Act allows the formation of Intensive Groundwater Use Control Areas, or IGUCAs. An

1 Personal anecdote from the authors. See http://nrdstories.org/stories/ for more anecdotes on NRD history and management.

IGUCA is a top-down approach to regulating areas of significant groundwater depletion and can be initiated through the GMD or the Chief Engineer. While a few GMD-initiated IGUCAs in the late 1970s were developed due to groundwater depletion, more recent IGUCAs have focused on areas where groundwater extraction is reducing surface water availability (Kansas Division of Water Resources, 2009; Griggs, 2014). While some IGUCAs exist, there are many parts of Kansas with rapidly depleting aquifers where the Chief Engineer has not established an IGUCA. This suggests that state-mandated regulations are not currently a politically feasible way to reduce groundwater extraction (Griggs, 2014).

Infrastructure changes: capital investment in water conservation and conveyance for groundwater-surface water management

A recent policy change in Nebraska is the use of occupation taxes, or taxes on irrigated acres. LB701 (2007) allowed NRDs to impose additional fees on irrigated land, up to a maximum of $10 per irrigated acre per year.[1] While these fees are unlikely to be high enough to provide an incentive to convert irrigated land to rainfed land[2], the revenue from the fee has been used to fund NRD projects that reduce groundwater use. Several NRDs assess occupation taxes, and these are generally below the potential cap. Most of the funds have been used for land retirement and infrastructure projects. These projects include the Nebraska Cooperative Republican Platte Enhancement Project (N-CORPE), which retired a large farm of over 15,000 acres of irrigated land and installed the capacity to deliver the conserved groundwater into the Republican and/or Platte Rivers when necessary. This transfer is used to meet obligations arising from depletion of surface waters by groundwater pumping under the Republican River Compact, which allocates surface waters of the Republican River between Colorado, Nebraska, and Kansas. The Upper Republican NRD (URNRD) has also constructed the Rock Creek Augmentation Project, which can provide additional water to the Republican River when necessary to meet its interstate surface water compact obligations.

A similar management tool has been used in the Republican River Water Conservation District of Colorado, which has enacted a per-acre fee of $14.50 on all irrigated land. As in Nebraska, the cost is an insufficient incentive for farmers to shift from irrigated to dryland farming. However, the funds have been used to permanently retire groundwater rights. Additionally, these funds were also used to construct a pipeline to move conserved water into the Republican River at necessary times (Best, 2014).

Local policy change: water allocations, transfers, fees, and other tools

The requirement to create IMPs within Nebraska, as well as the ability of NRDs to raise revenue, has allowed NRDs to experiment with a range of other policy tools to manage groundwater. The NRD system allows local regulators to choose how to manage groundwater. The authority at the local level means that different NRDs, even those with similar groundwater conditions, have chosen to regulate differently.

Water Allocations: Water allocations, which define a quantity of groundwater that an individual can use in a certain period of time, are a common policy tool in the HPA. In some cases (e.g., Kansas, URNRD), pumping rights have been limited for decades, but the amount of water allocated has decreased in recent years. Generally, the recent changes have been accomplished by reducing the permitted extraction per irrigated acre (e.g., reducing per-acre allocations from 22 acre-inches to 13 acre-inches in the URNRD in Nebraska, or by 20 percent in parts of GMD 4 in Kansas). In other cases (e.g. Lower Republican NRD, Middle Republican NRD), allocations are a more recent policy change. Whether or not the allocations actually reduce groundwater extraction depends on whether producers are constrained at the allocation level relative to no regulation. Recent evidence from Kansas and Nebraska (Golden and Liebsch, 2017; Mieno et al., 2017; Drysdale and Hendricks, 2018) shows that at least some producers are constrained, and that irrigators respond to reduced allocation limits by reducing groundwater extraction. Importantly, as an allocation is reduced, there is some evidence that even producers that are

1 In 2018, the maximum fee is set at $10/irrigated acre.

2 The University of Nebraska 2017 Real Estate report (Jansen, 2017) estimates a statewide average per-acre cash rental rate of $39 ($170) for dryland (gravity irrigated) cropland, respectively.

unconstrained at the new allocation will reduce their water use. This suggests that allocations may be an important mechanism for reducing regional groundwater pumping even when set at levels that do not bind on all water users.

Under the Kansas Water Appropriation Act of 1945, Kansas uses prior appropriation to establish groundwater allocations; the lowest priority in periods of shortage or overdraft is assigned to the most recent pumper. However, recent regulatory changes allow groundwater users to establish Local Enhanced Management Areas (LEMAs) with a majority approval by the affected users. Under a LEMA, all landowners are legally obligated to follow new regulations. All irrigation wells in Kansas are required to have a flowmeter installed, and the state requires annual reporting of pumping. Water use is self-reported, but there are penalties for tampering with the meter or falsifying water use reports. One example is the Sheridan 6 LEMA, which covers a portion of GMD 4 in Northwest Kansas. In this case, the irrigators in the district voted to reduce groundwater allocations of all irrigators by 20 percent, but also allowed for some additional flexibility to shift water use between years during a five-year period. The initial allocation period was 2013 to 2017, and the LEMA was recently extended for another five-year period (2018 to 2022) (Guerrero et al., 2017). The area was successful in reducing pumping by 20 percent, and the remaining allocation from the 2013 to 2017 period will be carried over to the new period. The program has been sufficiently popular that irrigators in other parts of GMD 4 are in the process of developing a GMD-wide LEMA.

Another regulatory tool that was developed in 2015 in Kansas is a Water Conservation Area (WCA). While a LEMA requires approval of a majority of landowners in the affected area, a WCA can be developed with a single landowner or a group of landowners and imposes no restrictions on nonparticipants. WCAs provide a voluntary mechanism for individual producers or groups to initiate water conservation measures, which may benefit from state subsidies or cost sharing, directly with the state, thus bypassing GMDs. As of February 2018, 12 WCAs have been established in Kansas (one additional WCA is pending).[1] Several of the WCAs have functioned as water transfer schemes, as allocations have been moved between irrigated parcels within the WCA. The expanded use of LEMAs and WCAs suggest that the ability for local users to manage themselves is more politically feasible than state-mandated restrictions in Kansas. New evidence (e.g., Golden and Liebsch, 2017; Mieno et al., 2017; Smith et al., 2017; Drysdale and Hendricks, 2018) suggests that these regulations do reduce groundwater extraction below the status quo (no regulation) level. However, further research must be done to determine if the behavioral changes are sufficient to achieve long-term aquifer protection.

Many of Nebraska's NRDs have developed water allocations. In many cases, there is greater flexibility in the means to implement allocation policy design in Nebraska than in Kansas. Depending on the NRD, this flexibility includes multi-year allocations, the ability to pool allocations from multiple fields, or to sell allocations to another landowner. Recent work (Kuwayama and Brozović, 2013; Palazzo and Brozović, 2014) suggests that tradable permits are an effective way to reduce the cost of complying with interstate compact requirements in the Nebraska portion of the Republican River Basin. For example, the Upper Republican NRD in Nebraska allows a landowner or manager to pool his or her allocations as long as the fields are within a "floating township".[2] The Central Platte NRD (CPNRD) also has several tools to increase flexibility for groundwater users. Irrigators are allowed to permanently transfer groundwater rights within some geographical constraints. Specifically, rights can only be transferred one mile west, but there is no limit on transfers that shift water use east. The reason for the unidirectional regulation is to limit the impact on streamflow depletion in the Platte River. Several other NRDs also operate groundwater transfer schemes with varying designs.

Groundwater taxes: Groundwater is a smaller proportion of total irrigation water in Colorado than in Kansas or Nebraska. However, certain basins face considerable uncertainty about future groundwater availability. A policy tool that is often recommended to reduce over-extraction is a volumetric fee on groundwater extraction (see

1 See http://agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/wca, accessed on February 20, 2018, for more information.

2 The Public Land Survey System (PLSS) in the United States defined six-mile squares when the Western United States was originally surveyed. A floating township has the same size, but the corner of the six-mile square is defined as the furthermost corner of the field. Landowners are also permitted to permanently transfer water rights from one field to another if the fields are within a floating township.

Hrozencik et al., 2017 for a case study from Colorado). While taxes are often considered a political non-starter, a recent example from Colorado shows that this is not always true. After the 2002 drought, groundwater levels in the San Luis Valley, located in Southern Colorado, declined significantly creating an issue with depletion of connected surface waters. Local users created several subdistricts to address the problem, and most have chosen to use volumetric fees (Cody et al., 2015; Smith et al., 2017). In contrast to relatively low occupation taxes in Nebraska and the Republican River Basin of Colorado, the San Luis Valley Subdistrict of the Rio Grande Water Conservation District imposed volumetric pumping taxes of up to $75/acre-foot. Recent research on the price elasticity of groundwater demand would suggest that this tax would be high enough to induce large reductions in water use (e.g., Hendricks and Peterson, 2012; Pfeiffer and Lin, 2014; Mieno and Brozović, 2016). Recent analysis of groundwater extraction in Subdistrict 1 (Smith et al., 2017) suggests that the tax has been an effective tool in reducing groundwater extraction relative to the case with no tax. The reduction has been largely on the intensive margin (groundwater applied per acre) and not the extensive margin (total acres irrigated with groundwater). However, some caution is needed in evaluating this result as most producers in the affected subdistrict pay much less than the maximum amount, and many pay no volumetric charge because of how stream depletion offsets are calculated. One possible explanation is that the introduction of the fee signaled the need to take water conservation seriously to producers, whether they were directly impacted by the fee or not.

Lessons Learned from Policy Innovation and Implications for the Future

Local and stakeholder input into groundwater policy is widespread and effective

Groundwater management decisions across the High Plains Aquifer show that local irrigators, as decision makers, are sometimes willing to regulate themselves to protect the aquifer and extend the useful life of groundwater resources. Examples include allocation limits in the URNRD (Mieno et al., 2017), irrigation fees in Colorado's San Luis Valley (Cody et al., 2015; Smith et al., 2017) and the Sheridan 6 LEMA in Kansas (Golden and Liebsch, 2017; Drysdale and Hendricks, 2018). All these examples show that producers, when allowed to design regulations that are acceptable locally, are often willing to do so. Dozens of conversations with producers throughout the region provide evidence that they are not solely concerned with short-term profits, but also with sustaining irrigated agriculture for the future.[1] However, they are also skeptical of regulations imposed by outside authorities. Thus, continuing and expanding the ability of individual groundwater management areas to determine how to meet groundwater conservation goals is most likely to be effective at achieving those goals. This means that if state authorities wish to limit groundwater pumping and protect the sustainability of regional aquifers while imposing minimum economic burden, they can ask the community of pumpers to establish a preferred method. However, the state would require this method to reduce total documented pumping by a targeted amount and demonstrate that their method is achieving the pumping limitation goals.

Behavioral and signaling impacts of policy are important

While evidence has shown that local regulations are effective at reducing groundwater use, the behavioral changes that lead to this reduction are less obvious. Anecdotal evidence suggests that one of the reasons that the URNRD has been successful in regulating groundwater use is that they established allocations in 1980, long before there was external pressure to do so. The allocation levels have consistently been set to be binding only on the most water-intensive producers, although they have been reduced multiple times over the years.[2] Thus, one goal of the allocations is to encourage producers to adopt established practices that assist with managing groundwater use (e.g., irrigation scheduling, soil moisture probes, drop nozzles on center pivots).

1 Personal anecdotes from the authors.

2 Personal communication with URNRD staff.

Conclusion

Negative impacts of agricultural groundwater use are becoming a great concern worldwide, and the High Plains Aquifer of the United States provides a range of examples on the potential of alternate mechanisms to reduce excess depletion. Groundwater management areas in Colorado, Kansas, and Nebraska are experimenting with locally-developed water conservation tools, both voluntary and regulatory, using an array of management options (e.g., taxes, allocations). Considerable heterogeneity exists in how each groundwater management area has chosen to design policy. Results show that locally-led policy change can be effective at reducing groundwater extraction, where effectiveness is defined as a reduction in groundwater extraction, relative to the status quo of no regulation. However, it is unclear the extent to which observed results are due to the signaling aspect of a management tool, and how much is due to true imposed economic and production constraints. It is likely that both mechanisms operate to some extent, with geographic variations. Importantly, the policy implications between the two mechanisms are different. The first suggests that farmers use policies as an incentive to learn how to be more efficient with groundwater use, such as by using scheduling tools or soil moisture probes. The second suggests that farmers have measurable decreases in profit and/or yield, and a loss in producer surplus due to the regulation. Further research is necessary to determine which explanation is consistent with observed outcomes, and which combination of mechanisms is most likely to lead to improved aquifer conditions given local hydrologic, economic, and institutional context.

References

Best, A. "Making the Ogallala Last," Colorado Foundation for Water Education (2014). Available: https://www.yourwatercolorado.org/cfwe-education/headwaters-magazine/archive/305-headwaters-magazine/headwaters-fall-2014-eastern-plains/703-the-ogallala

Brozović, N., and Richael Young. "Design and implementation of markets for groundwater pumping rights" (2014) in *Water Markets for the 21st Century: What Have We Learned?* (eds. K. Easter and Q. Huang).

Cody, K.C., S.M. Smith, M. Cox, and K. Andersson. "Emergence of collective action in a groundwater commons: irrigators in the San Luis Valley of Colorado." *Society & Natural Resources* 28, no. 4 (2015): 405-422.

Drysdale, K. and N. Hendricks. "Adaptation to an Irrigation Water Restriction Imposed through Local Governance", Working Paper (February 2018).

Fishman, R., U. Lall, V. Modi, and N. Parekh. "Can Electricity Pricing Save India's Groundwater? Field Evidence from a Novel Policy Mechanism in Gujarat." *Journal of the Association of Environmental and Resource Economists* 3, no. 4 (2016): 819-855.

Golden, B. and K. Liebsch, "Monitoring the Impacts of Sheridan County 6 Local Enhanced Management Area Interim Report for 2013-2016" (2017), Working Paper.

Griggs, B., "Lessons from Kansas: A More Sustainable Groundwater Management Approach", *Water in the West*, (2014).

Guerrero, B., B. Golden, K. Schoengold, J. Suter, A. Stoecker, C. Goemans, and D. Manning, "Groundwater Laws Across the Ogallala Aquifer Region", *Colorado Water* 34(6): 12-16 (2017).

Hendricks, Nathan P., and Jeffrey M. Peterson. "Fixed effects estimation of the intensive and extensive margins of irrigation water demand." *Journal of Agricultural and Resource Economics* (2012): 1-19.

Hrozencik, R. A., D. T. Manning, J. F. Suter, C. Goemans, and R. T. Bailey. "The heterogeneous impacts of groundwater management policies in the Republican River Basin of Colorado." *Water Resources Research* (2017).

Jansen, J. "Nebraska Farm Real Estate Market Highlights 2016-2017", University of Nebraska-Lincoln, (2017).

Kansas Division of Water Resources. "Intensive Groundwater Use Control Areas", Kansas Department of Agriculture Fact Sheet (August 2009).

Kuwayama, Y. and N. Brozović. "The regulation of a spatially heterogeneous externality: Tradable groundwater permits to protect streams." *Journal of Environmental Economics and Management* 66, no. 2 (2013): 364-382.

Kuwayama, Y., R.K. Young and N. Brozović. "Groundwater scarcity: Management approaches and recent innovations" in J. Ziolkowska and J. Peterson (eds.), Competition for Water Resources: Experiences and Management Approaches in the U.S. and Europe, Elsevier, 480 p. (2016).

Maupin, M.A., J.F. Kenny, S.S. Hutson, J.K. Lovelace, N.L. Barber, and K.S. Linsey, "Estimated use of water in the United States in 2010"., U.S. Geological Survey Circular 1405, 56 (2014) p., https://dx.doi.org/10.3133/cir1405.

McGuire, V.L., K.D. Lund, and B.K. Densmore, "Saturated thickness and water in storage in the High Plains aquifer, 2009, and water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009" U.S. Geological Survey Scientific Investigations Report 2012–5177, (2012) 28 p.

McGuire, V.L., "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, (2017) 14 p., https://doi.org/10.3133/sir20175040.

Mieno, Taro, and Nicholas Brozović. "Price Elasticity of Groundwater Demand: Attenuation and Amplification Bias Due to Incomplete Information." *American Journal of Agricultural Economics* 99, no. 2 (2016): 401-426.

Mieno, T., J. Keeler, K. Schoengold, and C. Walters. "The impacts of water allocation limits on irrigation behavior", Association of Environmental and Resource Economists Summer Conference, Pittsburgh, PA (2017).

Palazzo, Amanda, and Nicholas Brozović. "The role of groundwater trading in spatial water management." *Agricultural water management* 145 (2014): 50-60.

Pfeiffer, Lisa, and C-Y. Cynthia Lin. "Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence." *Journal of Environmental Economics and Management* 67, no. 2 (2014): 189-208.

Richey, A. S., B. F. Thomas, M.-H. Lo,J. T. Reager, J. S. Famiglietti, K. Voss,S. Swenson, and M. Rodell (2015), Quantifying renewable groundwater stress with GRACE, Water Resour. Res.,51, 5217–5238, doi:10.1002/2015WR017349.

Scanlon, Bridget R., Claudia C. Faunt, Laurent Longuevergne, Robert C. Reedy, William M. Alley, Virginia L. McGuire, Peter B. McMahon. *Proceedings of the National Academy of Sciences* Jun 2012, 109 (24) 9320-9325; DOI:10.1073/pnas.1200311109

Smith, Steven M., Krister Andersson, Kelsey C. Cody, Michael Cox, and Darren Ficklin. "Responding to a groundwater crisis: The effects of self-imposed economic incentives." *Journal of the Association of Environmental and Resource Economists* 4, no. 4 (2017): 985-1023.

Wheeler, Sarah Ann, Karina Schoengold, and Henning Bjornlund. "Lessons to be learned from groundwater trading in Australia and the United States." In *Integrated Groundwater Management*, pp. 493-517. Springer, Cham, (2016).

Young, Richael K. and Nicholas Brozović. "Innovations in groundwater management: Smart markets for transferable groundwater extraction rights." *Technology and Innovation* 17 (2016), 219-226, DOI: 10.3727/194982416X14520374943220.

WEF
Western Economic Forum