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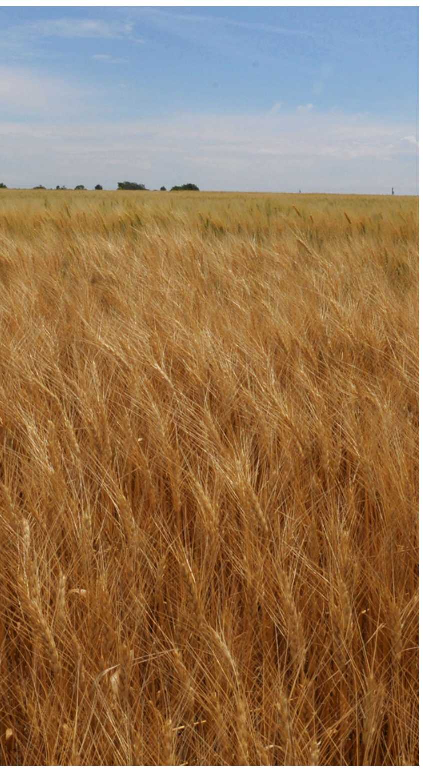

WEF
Western Economic Forum

Letter from the Editor:

The Agricultural Sector is increasingly complex, especially in the areas associated with the interaction of the biological, ecological and economic systems and disciplines. WEF focuses on issues with relevance and/or importance to the Western United States. To this end, the WEF provides a forum for economists in the western U.S. to participate in such discussions with articles related to food, farms, ranches, resources, institutions, communities and other related topic areas.

Authors are invited and welcome to email article submissions to WEF Editorial Team Leader Matt Stockton, or any of the co-editors at any time, and are encouraged to discuss ideas for articles with editors prior to submission as appropriate. Submissions will only be accepted in MS WORD, with at least two recommendations for potential referees including their contact information. Authors should generally follow the formatting guidelines for the Journal of Resource and Agricultural Economics, http://www.waeaonline.org/publications/jare/submission-guidelines).Articles should be approximately 2,500 words (maximum 3,500) and there is no fee for submission or publication. Generally, articles cover any issue related to natural resources and agriculture, including but not limited to farming, food, policy, community, stakeholders, or the ecosystem with relevance to the western United States. The articles should be written to appeal to the audiences described above. The work is expected to be original, professional and defendable based on current scientific standards. Articles should generally be understandable to any practicing economist and to other professionals with a working knowledge of the issue being focused upon.

Editorial Staff

The future of water management in the west

By Dana Hoag[1] and David Zilberman[2]

Water is one of the major constraints for agricultural development in the West. While there are common themes, each state faces its own unique problems. In the first issue of the revised Western Economics Forum we asked a group of prominent economic scholars from seven western states to discuss the future of water management in the West. Our focus is on providing scholars and practitioners with perspectives on how economics can help society better manage water, especially when it comes to the costs and benefits of (in)flexibility in water institutions.

Dr. David Zilberman and Ben Gordon from University of California, Berkeley, view water policies in the West within a historical context and much of their story applies across the West. Water and agricultural policy evolved through four stages from the 1850s to today. To encourage development, early settlers were granted rights to divert water, but trading in water was restricted. Water development was pursued through water district, state, and federal projects until the 1970s. Development solely for economic returns was phased out in a fourth stage, which the authors call the "conservation and environmental era," when policies shifted toward more balance between financial returns and the environment. Technologies that utilize water use efficiency allow coping with increased competition and reduced supplies.

Dr. Frank Ward, Dr. Brian Hurd and Sarah Sayles from New Mexico State University explain how economics can guide policymakers in water management and conservation. People state that they want water conservation, but water conversation practices may be expensive. Conservation may be desirable from a social perspective, but not affordable privately. Economics can help policymakers spend limited public funds for the public good. The authors show how water trading and banking, transboundary aquifer sharing, and headwater flow capture can all help with climate stress adaptation and improve water use efficiency.

Dr. Gregory Torell and Dr. Reid Stevens from Texas A&M University emphasize issues of water planning associated mostly with surface water management. They use the major 1990s drought in Texas to discuss how the state water plan had to evolve to meet the state's needs. While top-down policymaking was complemented

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with significant bottom-up decision making in 1997, that was not enough. The authors explain that the regions needed to explicitly include the linkage between supply and demand through prices when considering strategies. This inclusion would allow more regional flexibility and use a more holistic approach to water management.

Dr. Jonathan Yoder from Washington State University looks at the economics and politics of groundwater. He argues that "judicial innovations in Washington State…drive legislative, administrative, and private institutional innovation." In particular, he shows how a State Supreme Court decision on criteria for exempting wells from permitting in 2016 led to political gridlock. The decision required counties to prove water availability before issuing well permit exemptions for building homes in rural areas. Yoder looks at the potential economic impacts of the original legislation and showed that, by changing the way counties accounted for water use from exempt wells, the state overcame gridlock.

Dr. Bonnie Colby and Ryan Young from the University of Arizona offer a unique way to reduce political gridlock when reconciling water rights among multiple users. They give an interesting account about how Native Americans have found innovative ways to use their water rights to resolve regional water management issues. Negotiated settlements with tribes that result in water trading have helped urban interests in Arizona, and elsewhere, enhance long-term water supply reliability and improve the financial situation of various tribes.

Dr. Karina Schoengold and Dr. Nicholas Brozović from the University of Nebraska-Lincoln explain how groundwater use can be more effective when users can adapt their choices to local conditions rather than follow only top-down policies. Farmers tend to be skeptical about regulations, but they have been effectively implemented when those regulations are designed locally. The suboptimal outcomes of top-down regulations are both a result of rigidity and lack of inclusion.

Finally, Dr. Dana Hoag, Dr. Chris Goemans and Tony Orlando suggest that water managers are challenged by conflicting regulations and policies of water use and quality. Regulations cannot be written in isolation; policies for water use and water quality need to be made more complementary. Through a current example in Colorado, they demonstrate how complex and overwhelming it can be to manage water to meet multiple objectives when some tradeoffs will be necessary. They also show how economists can work with other sciences to make it easier for local stakeholders and decision makers to understand the tradeoffs in front of them.

California water: the present and looking to the future

By David Zilberman[1] and Ben Gordon[2]

Introduction

During a span of two centuries, California transformed itself into the leading agricultural and economic state in the United States. Much of this transformation has been the result of water resource management. The northern and eastern parts of the state are relatively water-rich. The southern region of California, to a substantial extent, is a desert but has climatic and biophysical conditions that are appropriate for agricultural production. Not to mention, the coastal area is very hospitable to humans. The state's transformation relied heavily on diverting water to areas where the lack thereof was the limiting condition to growth. This article overviews the historical development of the California Water System, beginning with the policies that initially drove its expansion, followed by an overview of the environmental consequences that drove the more recent policies of conservation and environmental protection. The drivers that have allowed for increased productivity during limited expansion, as well as some perspective for the future will also be discussed.

Expansion of Water Resources Era

The history of water use and management in California (Table 1) can be divided into four phases. The first stage, 1820-1890, is early settlement. The Gold Rush provided the impetus for a large migration to California and to the diversion of water for hydraulic mining, and then to growing urban areas associated with it. At the same time, farming started in order to supply settlers with basic foods, and then expanded during the latter half of the 19th century. Early water rights systems (e.g. riparian rights) constrained the movement of water among regions. However, the introduction of the prior appropriations water rights system in the American West provided the

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legal foundation for water diversion. The basic principles behind it are: (i) first-in-time, first-in-right and (ii) use it or lose it. This system, as well as homesteading policies, were instruments that enhanced settlements (Zilberman et al 2017).

The second stage, 1890-1930, is local water projects. Early investment in water diversion for agriculture was accomplished through collective action of farmers organized in water districts (Mercer and Morgan 1991). Many of these districts were near the Sierras. Agricultural settlements in the Northern Central Valley were rainfed, while early agricultural settlements in the southern part of the Valley relied on groundwater. The settlements in Southern California received a major boost in 1913 with the completion of the Los Angeles Aqueduct that brought in water from the Owens Valley. The water supply for the San Francisco Bay Area was enhanced by the large Hetch Hetchy Project completed in 1934.

The third stage, 1930-1970, is federal water projects. While in the initial stages, government provided support for water projects through enabling legislation. During this third stage, the government actually constructed water projects. Three of the major water projects in California are the Colorado Aqueduct, Central Valley Project (CVP), and California State Water Project. The major California water projects are depicted in Figure 1.

Year	Legislation	Notes
1855	Prior appropriation rights established	See *Irwin v. Phillips*
1868	Reclamation districts authorized	
1870	CA Fish Act (and subsequent Fish and Game code section 5937)	Principle of minimum flow requirement (amended in 1880 and 1915 Flow Acts)
1902	Federal Reclamation Act	Federal funding for water projects & dams
1913	Raker Act	Authorizes Hetch Hetchy Dam
1928	Boulder Canyon Project Act	Allocated Colorado River flow among states
1930	First State Water Plan created	5-year updates to state of water resources and management
1933	Central Valley Project (CVP) Act	Updated in 1992
1945	State Water Resources Act	Creates Water Resources Board to coordinate development & inventory of water resources
1956	Department of Water Resources launched	Brings together 52 previously independent agencies
1969	Federal Environmental Protection Act	Establishment of EPA
1969	Clean Water Act (Porter-Cologne)	Establishes water quality standards
1970	Endangered Species Act	
1983	Economic & Environmental Principles & Guidelines	Implementation studies for water and related land resources
1992	CVP Improvement Act	Changes in CVP for protection, restoration and enhancement of fish & wildlife
1994	Bay-Delta Accord (CALFED)	Funding and mechanism to develop multi-stakeholder water quality and management plans
2014	Sustainable Groundwater Management Act	Establishes districts to attain sustainable groundwater aquifers by 2030

Table 1: Timeline of major events affecting California water history.

Figure 1: California Water Projects (Source: Dennis Silverman, UC Irvine[1])

Conservation and Environmental Protection Era

The fourth stage, 1970-present, is intensification and environmental considerations. As the California economy and its agricultural sector has grown, the demand for expansion of water supply has increased. At the same time, some of the negative side effects of water extraction have prompted a significant shift in policy. First, the establishment of the Environmental Protection Agency in 1970 and a series of acts including the Clean Water Act of 1972 and the Endangered Species Act of 1973 created a legal environment for the protection of wildlife and reduction of pollution. In California, the State Water Resources Control Board oversaw monitoring water quality and enforcing water quality standards. Furthermore, it became clear that political economy considerations were leading to over investment in water projects (Reisner 1993). The government began requiring the use of cost-benefit analysis for Federal projects based on criteria established by the Water Resources Council (WRC 1983). These criteria explicitly recognized the environmental benefits of water use as well as the multiple costs of diversion and groundwater extraction. In the 1950s and 1960s, there were plans to divert water from the Eel and other northern rivers to the agricultural heartland of California. Following the new policies, the construction of big dams and reservoirs drastically slowed, with the last major dam (New Melones Dam) completed in 1979.

Public investments have since been diverted to projects that increase the safety of existing water conveyance facilities and protect the environment (including water to protect endangered species). The Kesterson Crisis of 1985 illustrates the importance of environmental considerations in California agriculture. The Bureau of Reclamation established wetlands to drain agricultural waterlogging to the Kesterson Reservoir in the heart of the San Joaquin Valley. However, the water had a high concentration of selenium and harmed migratory birds. The Bureau of Reclamation threatened to cut water supply to Central Valley contractors unless the issue was remedied. The threat led to changes in land use practices including buildup of evaporation ponds, adoption of drip irrigation to reduce runoff, and even diversion of land away from agriculture (Dinar and Zilberman 2012). Similarly, the multi-agency CALFED Bay-Delta Program was established to maintain reliability and quality of the Delta

1 http://sites.uci.edu/energyobserver/2015/04/28/california-water-projects-feeding-southern-california/

water, provide protection for the Delta ecosystem and protect against invasive species, and strengthen the levees on the Delta.

The constraints on availability of new sources of water in California for agriculture have led to a growing emphasis on increased water productivity (further discussed below). Since the 1970s, water use, especially in agriculture, has been revolutionized by adoption of innovative technologies and changes in land use. While California agriculture has grown substantially, its water use has stabilized.

Many of the reforms in California water use were in response to drought conditions. California agriculture responded to the drought between 1987-91 by fallowing land that had been used to grow low-value crop, increasing reliance on groundwater, and adopting modern technologies. However, in 1990, California introduced a water bank to allow owners of water rights north of the Delta to sell those rights to farmers in the south. This water trading reduced the production of rice, but allowed for sustained growth of high-value, perennial crops. The CVP Improvement Act recognized environmental use as a beneficial use of CVP water, diverted 10% of CVP water to environmental uses, and allowed CVP agricultural contract holders to sell their water rights on an annual basis to non-agricultural users (Zilberman et al 2002). Sunding et al (2002) compare adaptation mechanisms to reductions in water rights to CVP agricultural users. They find that water trading reduces the cost of adaptation by 50-75% compared to proportional reduction in water allocation to CVP water users. This is consistent with other findings of the literature that show transition from water rights to water trading increases economic efficiency and leads to adoption of improved practices (Schoengold and Zilberman 2007).

California responded to the recent severe drought of 2012-2016 by reducing agricultural acreage and increasing reliance on groundwater extraction. Howitt et al (2014) and Medellin-Azuara et al (2016) suggest that despite reductions in production, California agriculture was able to sustain, and even grow, its revenues during the drought mostly due to high commodity prices. However, during the drought, groundwater aquifers were significantly depleted, reducing water quality and availability to some regions. It became apparent that continued reliance on groundwater extraction was unsustainable, and the state passed its first Sustainable Groundwater Management Act in 2014 that requires monitoring and sets limits on groundwater pumping. This Act will require the establishment of groundwater management districts that will be responsible to establish mechanisms to attain sustainable groundwater aquifers by 2030. Bruno (2018) suggests that attaining sustainable targets will be much more cost effective using trading mechanisms rather than direct control.

Based on the California Water Plan, Mount and Hanak (2014) display applied water use in California between 1998 and 2010, as shown in Figure 2. Approximately 80 million acre-feet (MAF) of water are used annually in California, ranging from 61 to 104 MAF. Agriculture accounts for 40% of applied water and 10% of the urban sector, with environmental uses accounting for the remaining 50%. The figure suggests that while most of applied water in the north goes to the environment, the majority of applied water goes to agriculture in the Central Valley, and to urban uses on the coast.

The main sources of applied water annually are (i) streamflow that varies significantly with average of 31 MAF, (ii) water projects averaging 26 MAF, (iii) groundwater extraction averaging 18 MAF, and (iv) other sources such as reuse, recycling, and seepage, averaging 15 MAF. These figures need to be adjusted for the recent drought, and for the gradual growth of desalination projects and the reuse of wastewater.

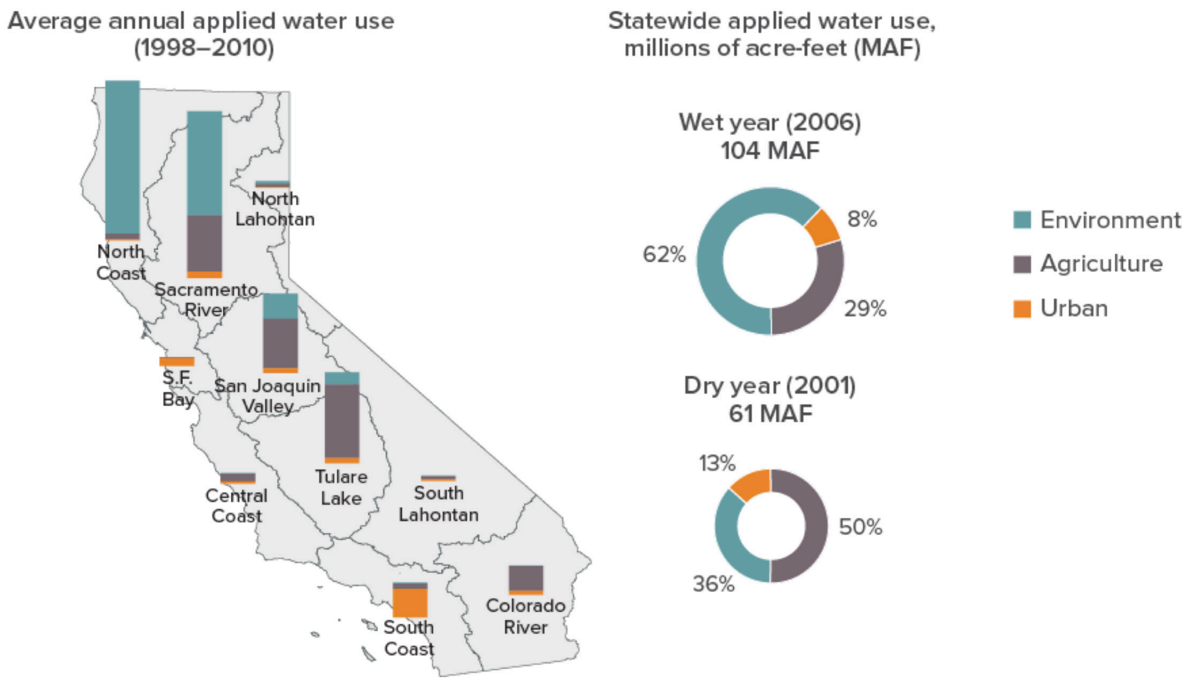

Figure 2: Applied water use in California: 1998-2010

Water Productivity in Agriculture

There were three drivers behind the changes in agricultural productivity during the era of limited expansion of supply and stricter environmental constraints: technological change, changes in consumer demand and environmental regulations. Caswell and Zilberman (1985) suggest a gap exists between applied water and effective water (utilized by crops). Water use efficiency, which is the ratio of effective to applied water, is dependent on land quality and technology. For instance, it is lower for sandy than heavy soils, and is lower for flood versus drip irrigation. Adoption of modern technologies tends to increase yields, may save water and reduce residue/runoff. However, modern technology is costlier. Furthermore, modern irrigation may increase efficiency by improving the timing of irrigation. As a result, farmers will adopt modern technologies for high-value crops, when water price is high or increasing and within regions of lower land quality.

Historically, California relied on furrow and flood irrigation. Sprinkler irrigation was introduced in the 1940s, and mostly adopted on fruit and vegetable fields. Drip irrigation was introduced in the late 1960s and primarily adopted by avocado growers with steeply-graded soil in Southern California. After a slow start, adoption of drip irrigation expanded significantly during the droughts of 1976-77 and 1987-91. It moved throughout the state from high-value fruits and vegetables to lower-value crops (on a per acre basis). The diffusion also benefited from implicit collaboration between manufacturers that improved the technology and University Extension services that modified production systems to accommodate the technology. This led to the large-scale adoption of drip irrigation for processing tomatoes. While in 1980, less than 5% of irrigated agriculture used drip and low-pressure irrigation. By 2010, the figure rose to 40%. Flood and furrow irrigation declined over time, and by 2010 was below 40% (Taylor and Zilberman 2017). The adoption of drip also allowed for the application of fertilizers and pesticides through irrigation systems. This was correlated with more sophisticated irrigation scheduling, frequently using the California Irrigation Management Information System (CIMIS). The estimated net annual benefit from the adoption of drip irrigation is approximately $700 million (Taylor, Parker and Zilberman 2014).

The adoption of advanced irrigation technologies benefited from the expansion of the acreage of high-value fruits and vegetables. Increased consumer demand, both domestically and internationally (especially in Asia) occurred as a result. Kuminoff, Sumner and Goldman (2000) show that the acreage of high-value crops, including fruits, nuts and vegetables, increased from 2.1 million acres (27% of total acreage) to 4.1 million acres (48%) between 1964 and 2002.

The Future

California's water system is likely to face multiple changes in the future due to several drivers. First, the expected impacts of climate change may include migrating weather (e.g. Los Angeles weather may migrate to San Francisco, Napa Valley may face much warmer, drier weather), which may require either significant adaptation, or even migration of crops. For example, some of the wine grape industry may need to shift to northern regions. Already, farmers in California are using different technologies to reduce temperatures during critical parts of the year. For example, pistachio growers are using clay dust to reduce tree-level temperature to increase the likelihood of blooming that requires sufficient period of low temperature (Trilnick, Gordon and Zilberman 2018). Relocations in response to climate change will require investment in water infrastructure. Climate change may lead to increased likelihood of drought, which in turn may require improved water resource management over time. However, climate change may result in declining snowpack, which today serves as intra-seasonal water storage. The increased likelihood of drought, and declining snowpack, will require increased storage capacity and investment in conservation efforts. While it seems that conservation and storage are substitutes, they may be complements when the increase in water-use efficiency due to conservation increases the incremental value of storage. Xie and Zilberman (2018) illustrate the possibility of complementarity of conservation and storage in the context of California agriculture.

A second driver is economic growth and increased concern for environmental amenities. These factors are likely to increase the demand for water. A third driver can be met by this demand , which is improvement in technologies that can increase water supply. California is already reusing brackish water, but much below the level of reuse achieved in Spain and Israel (Dinar, Pochat and Albiac-Murillo 2015). California is also venturing into the use of desalinated water along the coast. Desalination remains expensive, but its cost is declining and is likely to be a competitive source of water in some coastal regions. Desalination is energy-intensive, so the use of fossil fuel-based energy production may make the technology less desirable in the long-run. Given the solar exposure of coastal regions in California paired with California's research and innovation capacity, one possible avenue to address this problem is long-term investment in research that will utilize solar energy for desalination of both seawater and brackish water. Development of a viable desalination capacity may lead to significant modification of California's water system. Urban regions may become less dependent on water conveyance from inland regions. Thus allowing this water to be used for environmental and other purposes, and possibly reducing the cost of water overall. For example, San Francisco is surrounded by water and can use desalinated water, allowing the restoration of the beautiful Hetch Hetchy Valley, and even capturing the value of the environmental amenities it generates.

While much of the discussion in this article focuses on water quantity, water quality regulations are playing a significant role in California agriculture. For instance, protection of fish and other wildlife led to restriction of water transfer through the Delta and are a major cause of the consideration of Delta Tunnels.[1] There is room for further economic research on the implications and merits of the tunnels compared to alternatives (e.g. increased desalination capacity). Enforcement of nutrient-load standards in water as well as the high cost of production have led to reallocation of dairy farms from Southern California to the Central Valley, and now from California to other states, including Idaho and New Mexico.[2] As we look to the future, we may see California's livestock industry decline as a result of both stricter quality standards and the introduction of animal-free meat and milk technologies, many of which are based in California. These changes may reduce overall demand for water and may shift water demand from crops like alfalfa to other feedstocks used for animal-free meat production or other water-consuming activities (e.g. aquaculture, marijuana, recreational activities). Research on water will need to continue to adapt to the changes in California's economy, environment and technologies.

1 Project description: https://s3.amazonaws.com/californiawater/pdfs/Draft_Final_DCE_Agreement_Combined.pdf

2 See table: https://hoards.com/article-13240-cows-continue-to-congregate.html

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Water currents in New Mexico: A global reach

By Frank A. Ward[1], Brian H. Hurd[2], and Sarah Sayles[3]

Abstract
This article describes a series of water issues and policy choices for adapting to climate-stressed river and stream systems. It addresses issues that are important both in New Mexico and internationally for which economic analysis can inform and guide ongoing policy debates. Economic analysis is needed both in New Mexico and overseas to guide plans for efficient, equitable, and sustainable water use and for reducing costs of adapting to climate-stressed river and aquifer systems. Special attention is given to three current water issues in New Mexico: climate-stress adaptation through water trading and banking, adaptation through transboundary aquifer sharing, and adaptation through headwater flow capture. All three of these measures face design and implementation challenges both in New Mexico and internationally for adapting to growing evidence of climate-stressed river systems.

Introduction
Growing populations worldwide, rising international needs for food security, climate stress on river systems, and increased economic value of water both in and out of irrigated agriculture continue to challenge water policymaking in New Mexico and other dry regions of the world (Brouwer, Rayner, and Huitema 2013, de Bruin et al. 2009, Jeuland and Whittington 2014, Taylor et al. 2013). These problems challenge attempts to sustain overall economic prosperity, protect key ecological assets, and secure economic welfare of the world's poor who bear a disproportionate share of climate-stressed water supplies and who are often unable to adapt to increased water scarcity when it occurs. Irrigated agriculture is the world's largest water user in dry regions. In addition, by use of conventional methods to measure the economic value of water, irrigated agriculture produces low marginal economic values of water compared to values in competing sectors (Ward and Pulido-Velazquez 2008).

Water resources sustainability for farms, cities, and the environment face numerous drivers of change. These include: 1) agricultural practices and trends, especially increasing production of perennial tree crops such as pecans and greater reliance on groundwater of marginal quality for irrigation, with both quality and quantity

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implications; 2) urban growth and per capita usage, impacting land use, water demand and quality; 3) climate stress that affects both water supply, especially reduced snowpack in the headwaters and increased water demand through increasing temperatures and greater evapotranspiration demand; 4) and growing demand for environmental services such as riparian habitat for endangered species and environmental flows (Hargrove 2015).

New Mexico, a dry region in normal periods, sits on the front lines of challenges faced by the ongoing need to handle climate-stressed river and aquifers. In New Mexico, much recent water planning and policy design is based on a historical trend of 6 to 10 inches of precipitation yearly. New Mexico faces international treaty obligations to Mexico, federal requirements for protecting endangered species, delivery requirements for eight interstate compacts with other states, as well as numerous water development and allocation challenges within New Mexico's borders.

Water Policy Debates Informed by Economic Analysis	**Importance** (x: some, xx: more, xxx: most)	
	New Mexico	International
Adaptation measures for climate stressed supplies	xxx	xxx
Aquifer storage and recovery	xxx	xx
Basin scale modeling for policy analysis	xxx	xxx
Establishing or renegotiating interstate compacts	xxx	xx
Financing rural water systems	xxx	x
Investments in renewable backstop technologies	xxx	xxx
Managing stream-aquifer exchange	xxx	xx
Meeting growing urban demands and protecting irrigated agriculture	xxx	xx
Production functions analysis: water substitution for other inputs	xxx	xx
Reservoir storage development, restoration, or removal	xxx	xxx
Sustaining affordable water with growing demands	xxx	xx
Settling transboundary water sharing conflicts	xxx	xxx
Water conservation measures	xxx	xx
Water supply portfolio management among diverse sources	xxx	xxx
Design and operation of water trading and banks	xx	x
Irrigation infrastructure for environmental flows	xx	xxx
Mandated water conservation	xx	xx
Measures to protect environmental flows	xx	xxx
Safe minimum standard of reservoir/aquifer storage	xx	xxx
Shortage avoidance: demand reduction v supply expansion v both	xx	xx
Water importation measures	xx	xxx
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Economic v financial performance of solar desalination	x	xxx
Economics of water recycling and reuse	x	x
Financing irrigation infrastructure restoration	x	xx
Managing the energy-water-food nexus	x	xxx

Table 1: Waterpolicy Debates

Table 1 ranks by importance many water policy challenges inside New Mexico and internationally for which economic analysis can offer important insights to inform policy debates. The ranking of issues inside New Mexico is qualitative. This can be seen based on our experience working with stakeholders in recent years, and on our assessment of gains in discounted net present values from resolving the conflicts. For the international assessments, the rankings are more limited. They are based entirely on those few places in the international world where the authors have traveled to consult on water issues. That scope is limited to these basins: Murray Darling, Jucar (Kahil et al. 2016), Jordan (Ward and Becker 2015), Tigris-Euphrates, Amu Darya, Nile, as well as several headwater basins in Afghanistan (Acquah and Ward 2017).

While the table is mostly self-explanatory, several policy debates are attention-grabbers that compel the need for economic analysis. The search for sustainable water conservation measures is a good example. For instance, ongoing surveys of irrigators in Southern New Mexico, West Texas, and Northern Mexico since late 2015 continue to reveal a widespread interest by growers in water conservation. Most have expressed a commercially-motivated interest in maintaining farming income while using less water, unless water conservation could threaten the safety of a water right based on historical beneficial use. Conserved water risks interpretation as water use that failed the test of beneficial use.

Water conservation debates face a paradox: when asked directly, most people in New Mexico and worldwide state they favor water conservation. Yet many methods of conserving water are expensive compared to the value of water saved (Ward, Michelsen, and DeMouche 2007). In other words, the cost of substituting other inputs for water to reduce water use are more expensive than the economic value of the water saved by the substitution. For example, conservation can occur by converting from urban grass landscape to xeriscape, converting from flood to drip irrigation, deficit-irrigating crops, shifting into water conserving crops, and taking irrigated land out of production. All these measures reduce water applied, but it takes a careful economic-hydrologic analysis to discover the few that are economically attractive (Ward and Pulido-Velazquez 2008).

Water conservation can be mandated by public declaration or enactment. Still, somebody must pay for its implementation, and the mandated requirement needs to be enforced, which also incurs a cost. Least cost measures to protect environmental flows of rivers and streams are another ongoing debate in New Mexico (Fernald et al. 2015, Ward et al. 2006) as well as internationally. Recently, billions of dollars have been spent in Australia for irrigation infrastructure improvements with the intent of making more flows available for the environment. However, in many of the sub basins of the Murray-Darling, little if any additional environmental flows have been made available (Loch et al. 2012). Subsidies of irrigation infrastructure can reduce water applied. Although, even if applications are reduced, it is not always clear that more water is available for the environment or other uses (Ward and Pulido-Velazquez 2008).

Several measures can promote water conservation. For example, partial root zone drying (PRD) is an irrigation method that could promote conservation by using alternating, directed-water applications to produce a staged, simultaneous, wet/dry cycle between both halves of a root system. In turn, a drought response will be stimulated, even as the plant receives adequate amounts of water to sustain photosynthesis. PRD has increased water-use efficiency and improved yields in some plants. However, to date there has been no research-grade work on its physical or economic potential for PRD pecan production, an important commercial crop in New Mexico (Othman et al. 2014). Urban water studies in New Mexico have also received attention for conservation opportunities. Measures that have been investigated include low-flush toilets, low-flow showerheads, subsidies of water saving appliances, and conversion from turf to xeriscape (Gutzler and Nims 2005).

Adaptation to Climate Stress Through Water Trading and Banking

Considerable interest has been expressed in New Mexico since 2010 in the development of practical water trading arrangements, such as implementation of water banks as a measure to move water to higher-valued uses for handling water shortages when they occur. When practiced, water banking typically involves forgoing water deliveries during some periods, then banking either the right to use the banked water in the future or saving it for someone else to use in exchange for a cash price or an in-kind delivery of water or other assets. Water's productive use increases when there is adequate surface or groundwater storage capacity to permit the water transfers to occur. A water bank can allow a water stakeholder group to meet long-term policy goals, often handed down by state legislation or court order, while still protecting their local water, water rights, agricultural economies, endangered species, and more. This is often accomplished by creating a financial instrument that allows one water user to give up their short-term claim to the water in exchange for compensation with no loss of their long-term water right.

Two studies of farmers in the region downstream of Elephant Butte Reservoir conducted at New Mexico State University have found that the farmers of the region are interested in designing a water bank to prepare for future shortage. A survey from 2008 (Hadjigeorgalis 2008) asked 168 farmers a set of short, directed questions. The results indicated that more than 80% expressed interest in short-term water transfers with long-term rights protections, such as a water bank, could provide. An ongoing, intensive study, for which we are currently conducting hour-long, one-on-one farmer interviews, has reached similar conclusions. To better design a water bank that will meet the specific needs and goals of the region, we conducted an analysis of the water banking literature. From this work, the need for a theoretical framework by which to better analyze the success or failure of real world water banks has become clear.

The best framework would allow us to analyze water as a common pool resource, ground our findings in the localized economic uses and management of resources, and provide a comprehensive structure for analysis. Ostrom's Eight Principles for Managing Common Pool Resources (Ostrom 1993) provided that framework, and also furnished us with a rigorously-researched, organizational scheme by which to elaborate upon the reasons for success of existing water banks. Having seen little application to describe common property management in a western country, we believe analysis through this framework would offer insights on water bank design.

Long-running banks with economic or goal-based success have several characteristics in common. They have strong ties to localized needs and economies, and they closely follow the model established by Ostrom with few exceptions. To illustrate, the Idaho State Water Bank has been through several well-documented changes in its nearly 50 years of operation, reflecting the kind of flexibility and localized control that Ostrom's principles dictate. The Kansas State Bank naturally evolved to include specific rules for localized use in different hydrologic regions covered by the bank. The rules included local monitoring, penalties for non-compliance administered locally, and a strong conflict resolution mechanism. These water bank examples are mapped against Ostrom's Eight Principles in Table 2.

Ostrom's Eight Principles for Managing Common Property Resources Applied to Water Banking			
Principle (Ostrom 1993)	**Idaho State Water Bank**	**Central Kansas Water Bank**	**Texas State Water Bank**
1. Clearly defined boundaries.	✓	✓	**X**
2. Congruence between rules and locality.	✓	✓	**X**
3. Collective choice arrangements.	✓	✓	✓
4. Monitoring.	**X**	✓	**X**
5. Graduated sanctions.	**X**	✓	**NC**
6. Conflict resolution mechanisms.	✓	✓	**X**
7. Recognition of organization's rights.	✓	✓	✓
8. Nested enterprises	✓	**NC**	**NC**
Key: has characteristic (✓), lacks characteristic (X), unclear (NC)			

Table 2: Ostrom's Eight Principles for Managing Common Porperty Resources Applied to Water Banking

In contrast, the Texas State Water Bank has met numerous barriers in its short life. Although water is available for transfer, a brief investigation of the water listed on their web site as available in the marketplace shows the bank's important limitation: water is available in unconnected basins with little transferability. The state of Texas covers multiple topographies, climates, and types of water storage/delivery, separated by vast distances. This disconnection combined with the size of the state and Texas' different standards for surface and groundwater rights makes oversight difficult.

While research is ongoing, it appears at this early stage that Ostrom's Eight Principles are likely to provide guidance on the design of workable and practical water banking or trading arrangements for moving water to higher values when shortages occur. As a result, the effective cost of adapting to climate-stressed river systems will be reduced. In New Mexico, new long-term goals for water could be imposed by court decisions, legislation, or climate change. We conclude that designing a water bank to meet such goals, both in this region and elsewhere, using these principles has a greater chance to succeed.

Adaptation to Climate Stress Through Transboundary Aquifer Sharing

Sources of freshwater in Southern New Mexico suitable for municipal, industrial and agricultural uses are scarce. Additional population and economic growth and development will require either the transfer of water from existing, primarily agricultural uses, and/or procurement and development of costlier alternative sources. Beneath one thousand square miles of the desert sands of Southern New Mexico, far West Texas, and the northern state of Chihuahua, Mexico lies an estimated 65 million acre-feet of fresh to mildly brackish groundwater (Hawley 2017).

The Mesilla Basin (figure 1) is a valuable reserve of available water that is poised to be more heavily- used to serve domestic, agricultural, and industrial users across the region. Putting a conservative value of $50/acre-foot reveals an in-situ value for the aquifer more than $3.25 billion. Water values have been described for this region in existing studies (Ward et al. 2001, Hurd and Coonrod 2012), indicating this valuable regional asset can assist in providing important and sustaining services broadly across the community of users.

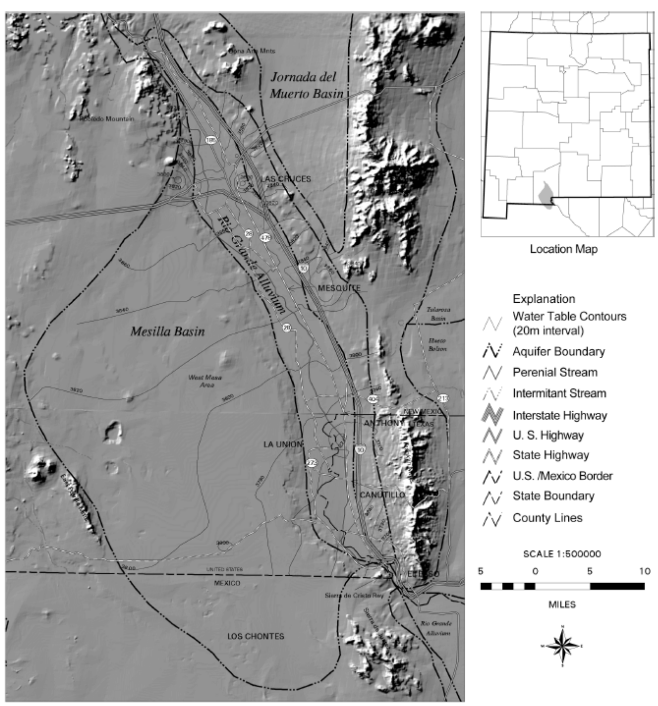

Figure 1: Shaded-relief index map of the Mesilla Basin area of Southern New Mexico and adjacent parts of Texas and Chihuahua showing extent of modeled basin-fill (Santa Fe Gp) and Mesilla Valley aquifer systems. Source: Hawley, Kennedy, and Creel. 2001, Figure 7-2.

Historically, a lack of management, cooperation, and oversight regarding access and use of this shared virtual 'trust-fund' can be seen. There is no treaty or governing agreement concerning sharing or joint management of the aquifer. Control and access is left to each of the three governing jurisdictions, states of Texas and New Mexico, and the federal government in Mexico. Indeed, shared-governance is further complicated by legal conflict and an on-going assertion by Texas that New Mexico pumpers are diminishing surface flows, in alleged violation of the Rio Grande Compact (New Mexico Office of the State Engineer 2018).

Recent changes on both sides of the US- Mexico border have accelerated pumping rates and contributed to rapidly falling water tables. North of the border, persistent drought coupled with significant institutional changes in 2008, has seen Mesilla Valley irrigators rely more heavily on pumping as their primary water source. In 2008, an accord was struck between the two US irrigation districts who share the surface waters of the Rio Grande Project. The settlement offered Texas irrigators directly downstream of New Mexico in the El Paso Water Conservancy District No. 1 a greater share of released project waters in exchange for affirming the groundwater pumping of New Mexico irrigators in the Elephant Butte Irrigation District. In effect, New Mexico irrigators exchanged their surface access for groundwater access as their primary water source in meeting their irrigation demands. This change improved surface reliability to Texas farmers and relieved New Mexico farmers from on-going legal threats from the Texas district. Moreover, it afforded New Mexico irrigators with a reliable and highly controllable water source.

Figure 2 illustrates effects of the settlement on groundwater levels from 2004 - 2015. The dramatic fall in the water table shows the extent to which Mesilla Valley farmers realized the opportunities of greater reliance on groundwater. These effects were especially pronounced because of the enduring drought that continued to affect the region. As a result, yields and production of most crops in the Mesilla Valley remained high or exceeded average levels in spite of the drought (New Mexico Department of Agriculture 2016).

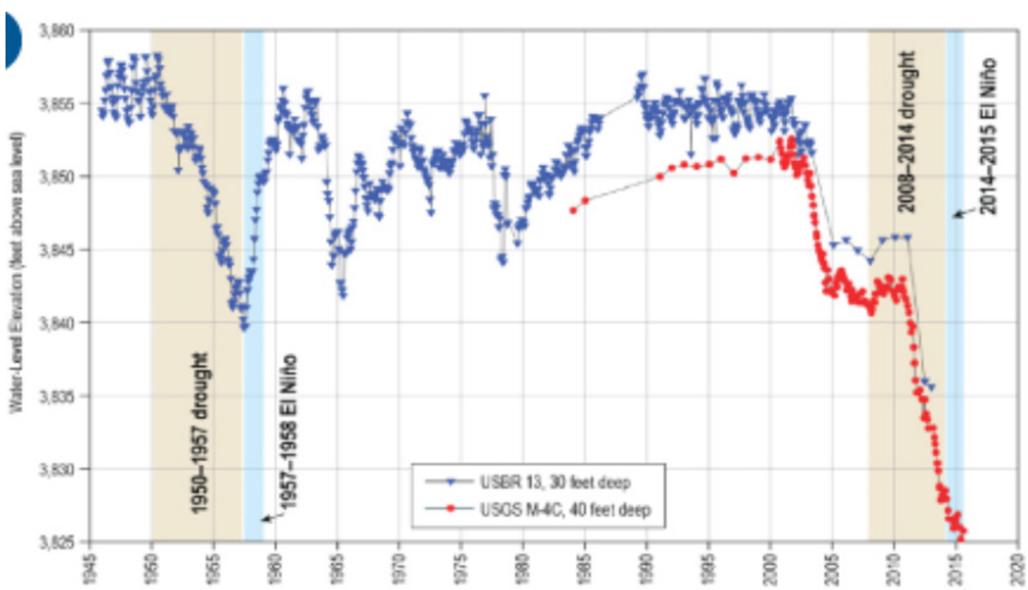

Figure 2: Water Table Trends in the Mesilla Basin (1946-2015)
Source: New Mexico Institute of Mining and Technology

South of the border, the changes have been even more dramatic and potentially consequential for users across the region. Beginning in 2010, Ciudad Juárez (a city of over 1.3 million) began drilling from 23 wells and pumping about 20 thousand acre-feet of water annually from the Mesilla Basin (on the Mexican side the aquifer is the Conejos-Médanos). This is about as much as the nearby city of Las Cruces, New Mexico pumps annually. The result has been an estimated drawdown of three feet per year in the aquifer below the well field just south of the border (Villagran 2017).

Economic development in the region is needed, on both sides of the border. Many residents live in at-risk and disadvantaged communities that lack access to safe and reliable water-services. Furthermore, these communities are vulnerable and ill-prepared to cope with growing risks of severe drought and climate change. The potential is high for mismanagement and misuse of this vital aquifer. This 'trust-fund' resource, for which insights for improved management could come from Ostrom's eight principles described earlier. Without rules, the stage is set for the unfortunate cooperative over-use and misguided exhaustion of this valuable resource, just as with any trust-fund account in rivalrous competition in the absence of rules and constraints.

Adaptation to Climate Stress Through Headwater Storage Capacity Development

Increased use of water for agriculture in support of protecting food security for growing populations is a growing issue worldwide. At the headwaters of the Lower Colorado Basin in New Mexico, the Gila River runs through very dry country. One of many remarkable historical events illustrates the point: Three German prisoners of war during WWII planned to escape to Mexico by taking their hastily assembled boat down the Gila River, then to the Colorado, and then into Mexico. It was a fine plan except for their ignorance of the Gila, which appeared as a wide blue river on their map. It turned out to be a dry streambed (Moore 2006). All were caught.

Continued evidence of climate stress at the headwaters of the Gila River New Mexico, in the Lower Colorado River Basin, raised interest in reservoir development as an old method with new possibilities under the Arizona Water Settlements Act of 2004. If developed, that new storage would increase water supply reliability. Like most other proposals for handling climate-stressed river systems, economic review takes on a vital role. These challenges are elevated in the face of climate stressed water supplies and growing demands for environmental flows in the Gila Basin, one of the last basins in the United States without storage developments at the headwaters. Climate-stress adaptation measures by farmers in this region include fallowing land, altering cropping patterns, elevated groundwater pumping, reservoir capacity expansion, reduced scale of acreage, and continued production of crops like cattle forage that can handle unreliable water supplies. Farm and urban water users in this basin have lived with a long history of high fluctuations in water supply producing a history of flooding as well as the need to adapt by producing low-valued crops that can handle unreliable water supplies, thus pointing to the need for an assessment of an investment in expanded storage capacity.

Recent work conducted by researchers at New Mexico State University reviewed the economic performance of storage reservoir development near the headwaters (Ward and Crawford 2016). A mathematical programming model was developed to predict irrigation patterns and potential farm income under two reservoir development scenarios. The first scenario was a status quo development plan with no new storage capacity. The second investigated additional storage capacity under which several existing institutional and technical barriers to producing higher-valued crops were removed.

That analysis found that storage capacity expansion in the basin's headwaters could lead to a higher-valued mix of irrigated agriculture combined with a more sustainable economic value of farm livelihoods. Results of that work show that compared to the first scenario, the second increased regional farm income by 30%. Some of the counties in that study would achieve farm income gains exceeding 900% relative to base levels.

The analysis found that added storage would be most economically attractive when technical and institutional barriers facing the region's irrigated agriculture are overcome. Important constraints that need to be dissolved include poor transportation capacity, small production scale, weak access by farmers to up-to-date information, limited capacity to bear risk, low levels of management skills, low and unreliable labor supply, and limited scale of food processing capacity. Removing most or all these barriers can elevate the economic value of additional irrigation capacity development in the Gila. Results of this work provide guidance to policy makers, farm managers, and water suppliers. All carry the burden of securing additional farm income and urban use benefits, protecting water and food security, and enhancing rural economic development in New Mexico as well as in dry places internationally faced with the need to adjust to climate-stressed water supplies. Similar analysis supporting policy debates of handling the food-water-energy nexus is ongoing worldwide (Bazilian et al. 2011, Conway et al. 2015, Ringler, Bhaduri, and Lawford 2013, Siddiqi and Anadon 2011).

Conclusions

Ongoing evidence of climate-stressed water supplies in many of the world's dry regions, including New Mexico, elevates the importance of finding low cost adaptation measures. The desire on the part of many of New Mexico's stakeholders to protect an acceptable amount of water in irrigated agriculture while ensuring enough affordable water is available for growing cities, is an important institutional requirement.

A core question posed by this article is how can water be managed so that the three competing sectors — agricultural, urban, and environmental — can simultaneously thrive in this stressed water system in both New Mexico and in the world's arid regions. New Mexico exemplifies an important category of agricultural water sustainability challenges. It is an arid to semi-arid river basin relying on conjunctive use of surface water and regional groundwater to sustain irrigated agriculture. Significant areas of the Western United States face similar challenges as do other intensively-used desert-river basins around the world.

This article has presented water lessons learned from New Mexico with international application. It has presented a series of water issues important both in New Mexico and internationally for which economic analysis can inform important debates over policy design and implementation. Economic information is essential information needed to guide efficient, equitable, and sustainable water futures for reducing the cost of adapting to climate water stress. The article gave special attention to three ongoing water issues in New Mexico: water trading, US-Mexico aquifer management, and capture of headwater flows to protect future water use when needed. All of these continue to face implementation challenges in the face of growing evidence of climate-stressed river systems.

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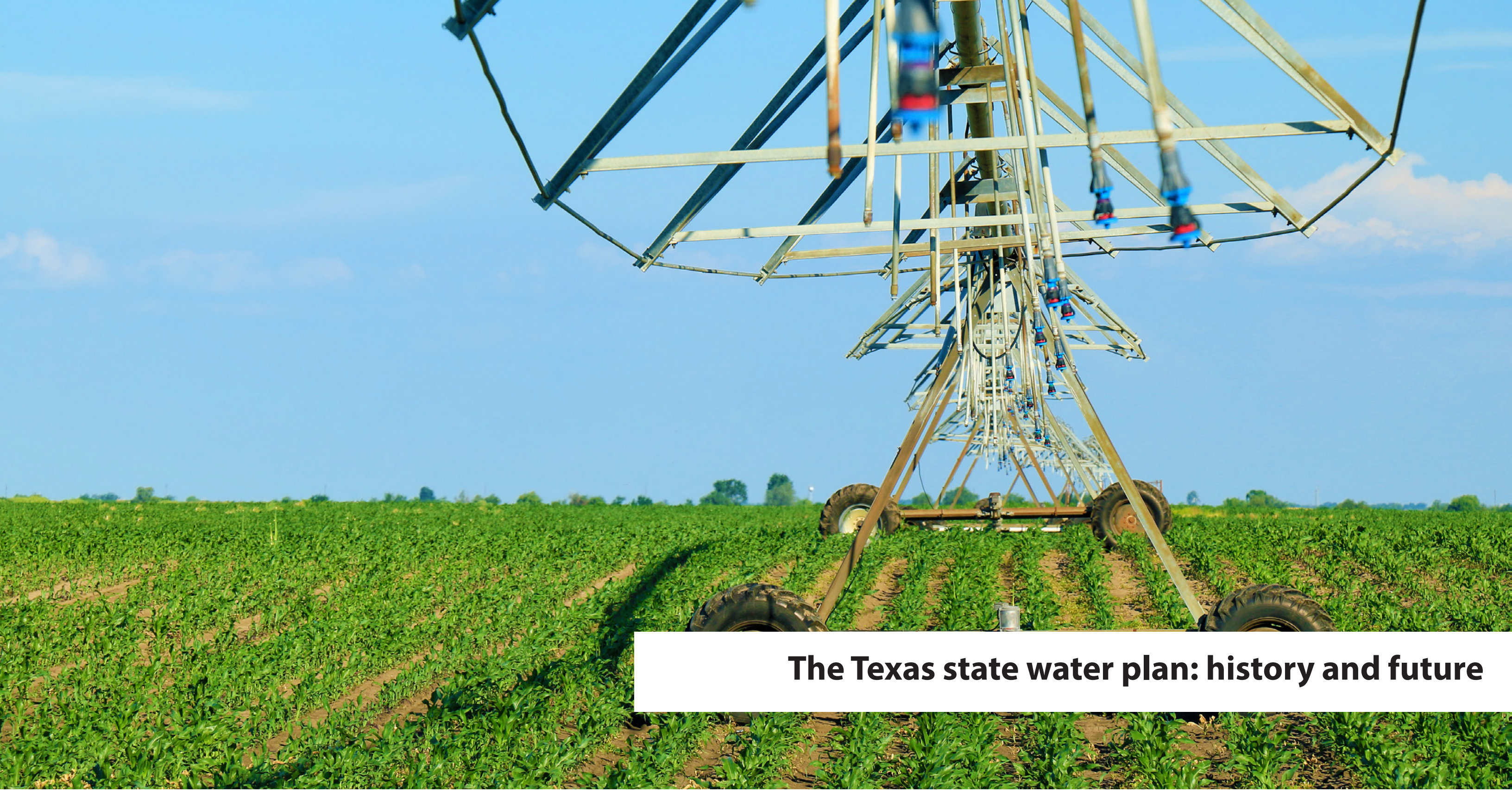

The Texas state water plan: history and future

By Gregory Torrell[1] and Reid Stevens[2]

Abstract
The severe Texas droughts of the 1950s prompted the development of a comprehensive planning framework to guide the state's water policy and investments. The Texas State Water Plan has been regularly updated since the first plan in 1961 and has developed into a system of regional water plans that define the statewide strategies to mitigate the impact of future severe droughts. In this paper, we describe the history of the Texas State Water Plan, some of its shortcomings, and provide recommendations for its improvement. We recommend that the plan include linkages between demands and supplies, allow for flexibility in regional planning, and expand its scope to allow a more holistic approach to water management.

Introduction
State-level water planning in Texas has its roots in the reaction to the massive droughts of the 1950s, which continue to be the basis of comparison for all other droughts in the state. Some effects of those droughts were short-lived: overgrazed pastures were more susceptible to noxious weed invasion, agricultural losses were worse than those during the Dust Bowl Era, and 244 of Texas' 254 counties were declared federal disaster areas (Burnett, 2012; Nace & Pluhowski, 1965; Wythe, 2011). In other areas, the legacy of the 1950s drought has left Texas permanently changed: the number of reservoirs more than doubled from 1950 to 1970, and the number of farms and ranches fell by nearly 100,000 between 1950 and 1960 (Wythe, 2011).

Beginning in 1961, plans for meeting future water demands were developed at the state level by the Texas Water Development Board (TWDB), an agency created near the end of the drought in 1957 (Wythe, 2011). From the first plan in 1961, the Texas State Water Plan (TSWP) has evolved in scope and methodology. In 1997, the Texas Legislature created a new process by which plans would be developed. The previous "top-down" approach,

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which used state-level water use projections to determine regional needs, was replaced with a "bottom-up" method, where local stakeholders create regional plans for their water needs. Currently, the state is broken into 16 water planning regions. Each planning region is tasked with determining current and future water supplies, demands, and drought contingencies. Each planning region consults with an engineering firm to assess current and future water supplies and demands as well as prepares recommendations and plans for future water management strategies and investments. These regional plans are compiled into a state-wide document that describes the water plan for the state for the next 50 years. This process is repeated every five years, and the latest plan was adopted on May 19, 2016 by the Texas Water Development Board.

Texas experienced a water supply shortfall in 2011 that plunged most of the state into severe drought. The most damaging impacts during the 2011 shortfall rivaled those of the 1950s drought and did not fully abate until 2015. This caused the 2012 TSWP to receive increased attention from policymakers and the press. Two conclusions from the TSWP were the focus of attention. First, Texas would face a gap between supply and demand of 8.3 million acre-feet (10.2 km^3) of water by 2060. Second, the overall cost of meeting water supply strategies would be $53 billion.

These headline-grabbing conclusions led to the passage of House Bill 4, which created the State Water Implementation Fund for Texas (SWIFT) and the State Water Implementation Revenue Fund for Texas (SWIRFT). SWIFT and SWIRFT are designed to finance revolving loan programs for water infrastructure and conservation projects, as well as requiring the 16 regional water planning groups to prioritize water projects in their regional plans through ranked ordering. Voters approved Proposition 6 in November 2013, enabled by House Bill 4, which authorized $2 billion to be drawn from the Texas Economic Stabilization Fund to fund SWIFT.

The TSWP has changed substantially throughout the course of its over 50-year life. This evolution has moved the TSWP towards a system that is more responsive to local issues, allows decision-making under clearer criteria, and creates a funding mechanism for municipalities, counties, and others to borrow at low interest rates to undertake capital improvement projects. While the history of the TSWP has largely been one of maturation, the water planning process lies at a crossroads--its ability to anticipate and continue to provide for the changing needs of Texas citizens. In the rest of this article, we will describe some of the challenges that the near future holds for this plan.

Demand Forecasts

One of the most common critiques of the TSWP is that it has consistently over-stated future water demands (Figure 1). Since 1968, the demand projections have, on average, been 18.1 percent above actual consumption. This upward bias in demand projections is consistent for all but one of the TSWPs. The 1990 TSWP produced projections that underestimated observed water consumption. Indeed, the demand projections used in the TSWP perform worse than a simple naïve prediction where it is assumed that current trends in water use continue. The problem of increasingly inaccurate projections over time is common, particularly in projections of water demands (Bijl, Bogaart, Kram, de Vries, & van Vuuren, 2016). The phenomenon has come to be called "porcupine graphs" by some commentators due to the distinctive shapes of these projections when compared to realized outcomes (Herberger, Donnelly, & Cooley, 2016, p. 6; Cox, 2010).

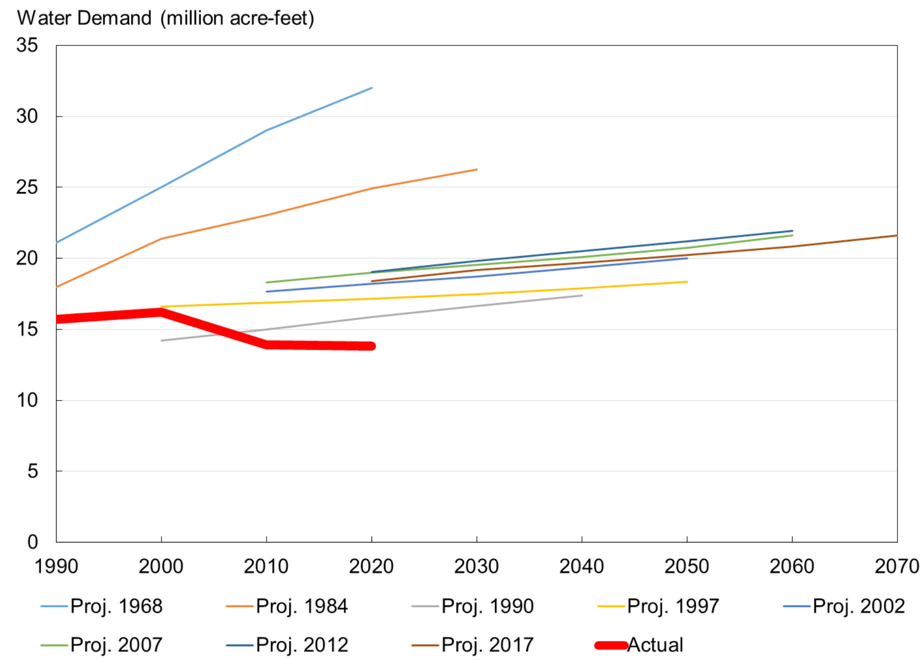

Figure 1: Texas Water Demand Projections

The consistent overestimation of demand by the TSWP is a fact that deserves attention and thought. This is true because of the importance of water demand forecasting in determining the need for supply side maintenance, i.e. for infrastructure building and conservation programs to meet those demands. Currently, demand projections are intended to capture a worst-case scenario by forecasting dry year consumption. However, this may ignore the fact that infrastructure and policies are maintained, and have a cost, in both good and bad water years.

The demand forecasts are estimated by taking population growth predictions and multiplying the current demands by forecasted per capita consumption. The estimates of per capita consumption used are based on a historical dry year by user group, which are adjusted downward slightly for municipal users. This downward adjustment is due to federal and state laws that determine water-use efficiency in fixtures and appliances. Similar to the projections of total water consumption, the projections of per capita water use in past TSWPs have typically overestimated per capita use (Figure 2). In a sense, the per capita water demand forecasts used in the TSWP are an extrapolation of peak demands under drought conditions, with expected population growth. This methodology contains the assumption that water use during dry years is indeed the correct target for the future. However, drought management can be most effective at reducing water use during these dry years, as municipal use is often higher during drought conditions, due to the increased lawn and garden watering during these times. History shows that a third or more of municipal water use during dry periods is used for lawn and garden use (Anderson, Miller, & Washburn, 1980; Kjelgren, Rupp, & Kilgren, 2000).

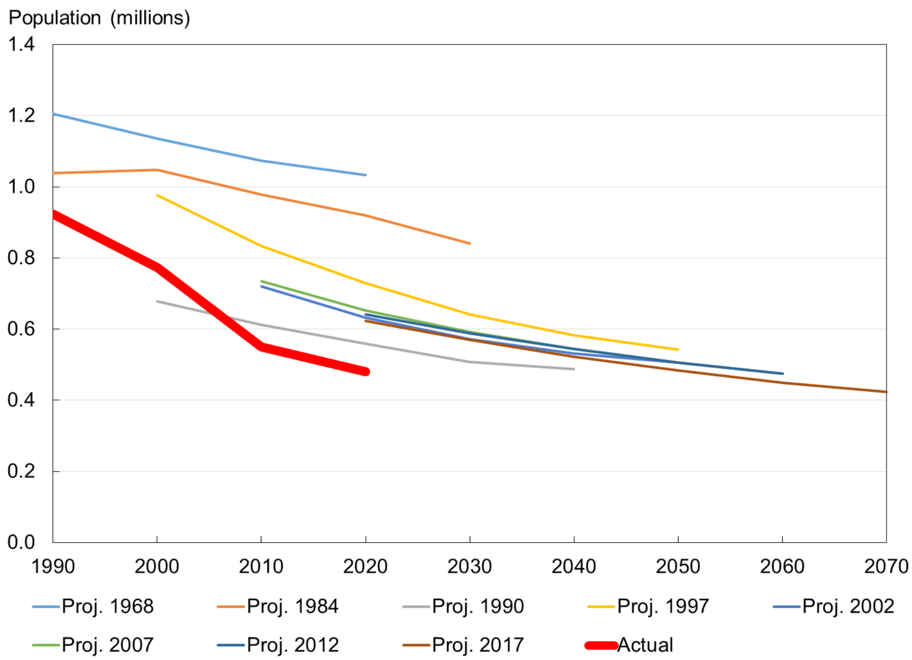

Figure 2: Texas Per Capita Water Use Projections

One area that is not accounted for in the demand projections is a reduction in per capita use that is endogenously precipitated from policy and infrastructure changes. Increasing the costs to water users, changes in attitudes about water use, and conservation campaigns may be able to reduce, delay or eliminate the need for some large water supply projects (Olmstead & Stavins, 2009). Even if the need for water supply projects is taken at face value, and it is assumed that some of these projects will be undertaken, the TSWP fails to encapsulate the effect that these projects will have in increasing costs of management strategies and capital building, resulting in price increases. Water utilities cannot maintain fixed prices in the face of increasing capital costs indefinitely. Meta analyses of the price elasticity of demand for municipal water have shown that a 10 percent increase in the marginal price of water in the urban residential sector can reduce demand by about 3 to 4 percent in the short run (Espey, Espey, & Shaw, 1997; Dalhuisen, Florax, de Groot, & Nijkamp, 2003). Comparable price elasticities have been estimated for other sectors (Ziegler & Bell, 1984). This means in aggregate, even moderate changes in real prices can be as effective as a suite of infrastructure projects.

The viability of using price as a tool to manage water shortages can be strengthened by promoting it. Utilities are often hampered by pricing that disincentivizes utility-wide conservation efforts. In many municipalities, a decline in water use (water conservation) may result in a larger reduction in revenues than in water delivery costs. This is because some utilities charge large marginal prices relative to the share of marginal costs to total costs. Were utilities able to price in a manner where fixed and marginal charges are proportional to fixed and marginal costs, this would reduce the issue. Pricing in a proportional manner has the secondary benefit of giving municipalities the ability to use scarcity surcharges as water becomes scarcer. Policy innovations like this are low cost and effective. Options in pricing such as this are not considered in the TSWP in its current form as a method to promote reductions in water demand.

Supply Modeling

In the current TSWP, when any given water management strategy as well as any associated new water infrastructure projects are considered, strategies are chosen. The TSWP selects strategies using the following criteria: 1) quantity of new water supply provided by each strategy; 2) reliability of the supply under drought of record conditions; 3) cost of the proposed new supply; 4) impacts of each strategy on water quality and natural resources. Each regional water planning group determines a prioritized list of projects for their own region, and these prioritized lists are compiled for the state. These projects and strategies form the basis for the proposed manage-

ment strategies for ensuring adequate water supplies to meet the projected demands.
Several issues arise with this approach, and the first relates to the previous section. Spending on management strategies and infrastructure are not assumed to influence water prices within the TSWP framework. As a result, the back-and-forth relationship that exists between costs, prices, and price elasticity of demand is ignored. In this case, breaking the linkage between demand and supply is likely to cause an overstatement of not only demand, but also the demand-supply gap that exists given current and proposed management and water infrastructure. Consequently, this causes an overestimation of the infrastructure needed to meet demand.

A more accurate approach to determining the impact of management strategies on the demand-supply gap would be to acknowledge that each proposed management strategy alters the costs of providing water. As a result, prices charged to customers become altered which ultimately changes quantity of water demanded. Even a methodology as simple as levelized costs (net present value of the costs of one unit of water over the expected life of the project) of each proposed asset could serve as a proxy for the average price that the asset would require to break even, and thus each proposed asset's impact on price.

A related issue on the supply side is the timing and magnitude of proposed management strategies and infrastructure projects. The current 2017 TSWP shows that the needed outlay of funds to meet the proposed supply side projects will cost $63 billion in capital costs, with more than 40 percent of those outlays to occur within the next decade. Related to the previous section, these are financial supports sought to meet demands that have been historically overestimated and may not emerge or be delayed for decades. This is further exacerbated by the lack of a proper demand-supply linkage in the current process. Given the uncertainty about future water needs, it would be advantageous for the TSWP to account for the option value of delaying investment and waiting for more information. Because SWIFT is a revolving loan program, these outlays of capital will be repaid by revenues from the borrowers' customers, raising water rates and potentially disincentivizing conservation if demand falls short of projections.

A Move Towards Flexibility and Scenarios
The state can improve the TSWP by increasing the flexibility of its scope, vision, and frequency of preparation at the regional level. More regional flexibility may produce a better water plan, reduce the risk of misallocation of funds, and could be a more robust water plan.

The demand projections are based on water use patterns during dry years and lean towards the worst-case scenario. As a result, the TSWP produces single "headline numbers". These single numbers are easily understood by the press and policymakers but provide little flexibility. However, a more realistic approach to water planning would provide the ability for regions to expand their analysis to consider varying scenarios. Modeling that includes varying scenarios allows for simple "what-if" analyses over a range of potential outcomes, rather than aiming for a single goal that may not describe future conditions. Such planning adds complexity to the analysis performed at the regional level, but allows for robustness in water planning, which would lend credence to plans that "make the cut". Particularly, this is important because management strategies and infrastructure projects are often an either-or prospect. Once an infrastructure project has been undertaken, there is often little ability to return to a world before its existence, particularly in dam construction or aquifer pumping strategies.

Consider, for example, changes in climate or realized population growth that may alter the value of the construction of a new dam. If atmospheric water demand increases due to increased temperature, the value of the dam may be decreased in comparison to an aquifer storage strategy. Although, if realized population growth is lower than predicted by the TSWP, the construction of the dam may come to be an unnecessary expense. The TSWP's singular goal of minimizing the predicted demand-supply gap does not give planning groups a framework to explore the value of water infrastructure under plausible alternative scenarios. Rather than focusing the analysis on a single, dry-year projection, the TSWP could be the source of a set of likely scenarios for the long-term planning. Freedom to consider more complex scenarios on both the demand and supply can be used to create a probability-weighted criterion for proposing management strategies and infrastructure investments.
The TSWP is focused on managing the demand-supply gap 50 years into the future. While this type of medium- to far-term planning is crucial with a resource as critical as water, in some regions, a 50-year plan may be the wrong focus. Texas is vast and diverse, with some regions that are more dynamic in terms of population and land

use change, water supply and its stresses, resulting in varying water management challenges. Consider the unexpected water needs of unconventional oil and gas producers in Texas since the late 2000s. This increase in water demand, especially in the sparsely populated Permian Basin, could not have been anticipated even a few years before the shale boom. For much of the state, a more flexible focus on the near term would be more relevant. Allocating limited resources to meet predicted water demand in 50 years may be inefficient when those same resources could be used to meet unanticipated water needs in the short run.

In a similar vein, where regions currently experience little change in the 5-year period between TSWPs, flexibility in the frequency of preparation for the regional water plan can be a welcome prospect. Each region has a limited budget for developing the regional water plan. Were regions flexible in the frequency of regional plan preparation, the time regions would save could be spent on more detailed study and more accurate water planning. The current 5-year time frame between water plans renders this prospect impossible.

Holistic Water Planning

The final area we will discuss is the scope of challenges addressed in future TSWPs. The TSWP is born from a response to severe drought. Preparation for future drought is the focus of the current planning system. While planning for drought is critical, the TSWP has reached a point in which it would be beneficial to incorporate other goals related to water planning. Namely water quality, inter-regional planning, and a comprehensive statewide flood plan.

For instance, it is not clear whether the TSWP is a collection of individual regional water plans, or a cohesive statewide water plan. The TSWP is prepared at the regional level, allowing for direct stakeholder input and the incorporation of local knowledge and concerns. However, the plan has evolved away from a document that defines a comprehensive statewide plan for water management. This is noted by conflicts between regions in the state water planning process.[1]

The issue can be illustrated by a recent example related to flood management, specifically the 2017 flooding in the Houston area due to Hurricane Harvey. Early estimates of the damage caused by the storm were cited up to $108 billion (Quealy, 2017). The TSWP does not currently include a specific task for regional planners to determine a comprehensive flood plan, nor how to manage water quality issues that can result from flood events. In this example, potential gain may exist in both water storage for drought conditions and flash flood mitigation in a project that considers aquifer storage of storm water.

While holistic planning is more complicated and costly to produce, the bottom-up approach of the TSWP provides the needed informational transfer to the state government, policymakers, and water managers to make it possible. This shift in focus could be a gradual goal for the TWDB and could be started at the regional level.

Conclusion

In response to severe droughts in the 1950s, Texas began regularly publishing a state water plan to guide state water policy. The TSWP is a collaborative, good-faith effort by state agencies, stakeholders, academics, and other experts which include projections of future population, water demand, and water supply. Though this plan has evolved since the first plan was published in 1961, its important influence on regional water planning necessitates consideration of additional elements in order to increase its value to Texas.

A principal component of the TSWP is the water demand projection. While the projections of water use within the plan are intended to capture and plan for the worst-case scenario, the current planning process says little about other conditions or scenarios. The demand estimates used most often overshoot actual demand by an average of 18 percent. Also, the common demand estimates have a much higher error rate than simple trend forecasting. As a result, a major critique that the TSWP has faced is that it justifies investment in water infrastructure that exceeds the actual needs because water projections exceed actual demand in most years. This cri-

1 Region C in Northeast Texas proposed the construction of a reservoir. At the same time, Region D to the east and downstream of Region C included specific language opposing the reservoir. The conflict led to a court case, which determined that it is not clear from statute how TWDB should interpret the term "interregional conflict", nor how it should operationalize resolving such conflicts. Definition by statute and a clear definition of how the TSWP defines, plans for, and meets water management goals is a need for the plan.

tique has merit. The demand projections are not a traditional forecast which attempts to minimize forecast error. Rather, the demand projections are the result of an exploratory model which assumes a worst-case outcome in the water market. While this may be a useful scenario to consider, it is not the only relevant scenario for water infrastructure investment. We suggest that the incorporation of other likely scenarios in the analysis would allow for a more flexible and robust plan.

From our perspective, a key shortcoming of the TSWP is the implicit assumption that spending on water management infrastructure does not impact water prices. By leaving out the relationship between water supply and water demand, the water plan likely overestimates the gap between projected demand and projected supply, resulting in a bias towards an over-estimate of the infrastructure needs over time.

We have three recommendations that we feel will help remedy these deficits and improve the TSWP. First, explicitly include the linkage between demand and supply through price mechanisms when considering proposed strategies for water supply. Secondly, allow regional flexibility over the period for which projections are made. Plans currently include a 50-year water demand and supply forecast. For some regions, focusing on a nearer term may be more critical. For other less dynamic regions, the ability to perform more detailed analysis with limited budgets may be welcome. Third, expand the scope of the water plan using a more holistic approach to water management. While drought was the initial focus, there are other areas that could be addressed that provide value to the citizens of Texas, including water quality, interregional water plans, and flood preparation.

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Fiscal gridlock over the budget in Washington state: The politics and economics of pouring exempt wells into the prior appropriations bucket

By Jonathan Yoder[1]

Abstract
Washington State has been in fiscal gridlock because a recent court case – the Hirst Decision (Hirst)--- would require counties to show legal availability of groundwater to issue permits for new rural residential wells that would be in connectivity with surface water. Many argued that this requirement would halt rural residential development in the state. This article examines the context and potential consequences of Hirst through an economic lens. For context, the characteristics of exempt wells and recent legal precursors are discussed. A qualitative assessment of the likely impacts of Hirst and the conditions that might alleviate its effects is provided, followed by potential institutional innovations that may emerge because of or in response to Hirst. These developments in Washington State illustrate some of the complexities of exempt wells common to many of the Western United States.

Prologue: *When this article was written, the State had been operating with no capital budget since June 2017 because of legislative negotiations over a consequential Washington State Supreme Court decision that could limit rural residential development due to concerns over groundwater impacts. A bill was passed in January 2018 as a legislative response to the court decision, which then allowed the state capital budget to be passed. The text of the article has not been changed in response to the recent passage of the new bill, but an epilogue provides a brief description of the bill and its potential implications.*

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Introduction

Washington State and the Pacific Northwest are facing many changes in water systems. Climate change will likely lead to smaller snowpacks in the Cascade Mountains, leading in turn to lower summer streamflow and irrigation availability. Despite growing population especially in the west side, municipal water demand is holding steady or declining in many places, but storm water runoff is impacting terrestrial water quality and Puget Sound. The Columbia River Treaty is up for renewal, potentially changing the dynamics of energy production, flood control, and fisheries management in the Columbia River Basin. Groundwater is declining in some aquifers, increasing in others, and groundwater nitrate levels in the central part of the state have led to recent court cases and regulatory response.

The most politically pressing water-related problem in Washington State right now is the effect of permit-exempt groundwater wells on surface water flows. In fact, the state of Washington has had no capital budget since June of 2017 because of political gridlock due to a potent 2016 State Supreme Court decision over permit-exempt wells. Permit-exempt wells are small-volume groundwater wells for which a full water right is not required, and are often issued as part of a building permit for rural residential property where no municipal system is available. Legal exception to appropriative rights for small-volume wells is common across the Western United States, but there has been longstanding and, in some places, mounting legal pressure to bring them more fully into prior appropriations systems.

Exempt wells can have consequential aggregate impacts on groundwater stocks. Where there is surface-groundwater continuity, exempt wells in sufficient numbers (like groundwater pumping generally) can lead to reduced surface water stream flows, affecting water availability for ecosystem services and surface water rights. Potential solutions to conflicts over exempt well use and its impacts are varied and often vexing (Bracken 2010, 2012); the foundations for what Vinett and Jarvis call a "Spaghetti-western water war" (Vinett and Jarvis 2012). This paper describes recent legal developments around exempt wells and conjunctive use in Washington State, examines the economic underpinnings and consequences of these developments, and discusses some related institutional innovations occurring in Washington State. The issue of exempt well effects on surface water spans multiple dimensions of water management. These dimensions include friction over qualitatively different forms of water rights, variability and uncertainty about surface-groundwater continuity, uncertainty and conflict over instream flow values, ecosystem services, the salmon and steelhead populations that they support, and the Native American treaty right that are tied to them. All these factors affect the law and economics of water. They play a role in where Washington State finds itself now as well as how water law and economics will evolve in the future. The Journal of Contemporary Water Research & Education Volume 148, Issue 1 (JCWRE 2012) is dedicated to exempt wells. These articles illustrate the scope and importance of exempt wells and their associated water management issues across the West. While this present article focuses on Washington State, its content echoes and illustrates the legal, regulatory, and economic content of the articles in that issue and its predecessors.

Washington State's Spaghetti Western

The State Supreme Court Hirst Decision (Hirst 2016) is used as a bargaining chip for the State Capital Budget. For the first time, it requires counties to show physically and *legally* available water in order to issue an exempt well for residential development. The *legal availability* aspect of the decision is the new monkey wrench, especially for county administrators who have never had to be concerned with water rights. As a result, these administrators find themselves required to assess local surface-groundwater continuity, and the likelihood that a small-volume well will impinge on existing surface water rights. Also, if no water is legally available, no development will be allowed. This is the potential consequence of Hirst that has led to legislative gridlock (Brunell 2017).

The Hirst Decision was preceded by a string of consequential State Supreme Court cases and regulatory changes in the last 20 years which illustrate some of the complexities. In 2009, the Washington State Department of Ecology imposed a moratorium on new exempt well development in upper Kittitas County on the eastern slope of the Cascade Mountains. The moratorium was in response to a petition on behalf of senior surface water rights holders and environmental groups concerned over instream flows (Cronin and Fowler 2012). Another court case brought and won by the Swinomish Tribe (Swinomish 2013) in the Skagit Basin in Western Washington contended that groundwater use, specifically from exempt well development, was affecting their treaty rights to sustained salmon habitat. The case resulted in a moratorium on exempt wells in the Skagit Basin.

An earlier State Supreme Court Decision, (Postema 2000), found that individually *de minimus* (trivial, effectively unmeasurable) impacts on existing water rights could preclude new water rights issuance.[1] Finally, the Foster Case (Foster 2015, Ecology 2018a) places tight restrictions on the allowable forms of mitigation that can be used against the effects of groundwater pumping. Basically, the potential impact of groundwater pumping on mandated minimum instream flows must be mitigated at the time, in the place, and in the form of the surface waterflow impact. In other words, there can be no "out-of-kind" mitigation. These rulings together are quite restrictive for mitigation options against exempt well use impacts.

Within this legal context, the Kittitas and Swinomish moratoria have led to very different outcomes and illustrate the range of possible Hirst consequences. In Kittitas, water banks developed quite quickly, allowing developers to purchase mitigation rights for rural property development requiring exempt wells. In contrast, no water banking has developed in Skagit after the Swinomish Decision, essentially halting well development. Looking forward, some claim that Hirst will halt rural residential development across the state (FixHirst 2017). Although there is reason to believe (the Kittitas water banks are a hint) that the consequences of Hirst will be more limited both at the intensive and extensive margin across the state.

Mitigation Markets. or Not.

The Kittitas moratorium caused consternation, transition costs, and ongoing transaction costs. As a result, a robust mitigation market has developed for much of the affected area, with myriad private and public water banks with a variety of prices (Ecology 2018c, Ziemer et al. 2012). Relatively low prices are charged for a mitigation right by the public (state and county-run banks) and relatively high prices are charged by private for-profit banks (Hall et al. 2016). Indeed, for most of the affected area, these water banks provide over-the-counter (easy to acquire) mitigation water allowing existing water rights to be transferred from relatively low-valued uses to highly-valued residential use. Therefore, water is available to support high-value development, but now developers (and subsequent homeowners) are paying existing water rights owners to move water use to new exempt wells.

No water market has developed in Skagit, ostensibly because senior water rights are not available to purchase for mitigation purposes. One might ask how there can be no senior rights to purchase if the moratorium is designed to protect more-senior water rights? First, there are senior agricultural irrigation and municipal water rights low in the coastal plain where agriculture and the major municipal areas exist. These water rights are not currently suitable for upstream mitigation due to the potential diminution of streamflow between the potential sale and upstream purchase points. Second, tribal water rights to which the Swinomish Decision applies are not likely transferable (Nyberg 2014, Palma 1980). Based on a complex body of legislative and legal rulings, treaty-based water rights to instream flows for the support of fisheries are either not transferable or transferability is questionable. Although, there is active leasing of tribal water with explicit and specific congressional authorization (Getches Wilkinson Center 2017, Anderson 2015, Nyberg 2014, Colby, Thorson, and Britton 2005, Storey 1988). Leased water is likely ineligible for exempt well mitigation, or at least much less practical than outright purchase as mitigation for permanent exempt wells. In a nutshell, the transferability of tribal water rights reserved for instream flows to support fisheries is questionable even if tribes were interested in such a transfer. In any case, this option does not appear to have substantively entered the discussion around the Swinomish Case in the Skagit.

How does this range of outcomes — from very active mitigation markets in Kittitas to no markets at all in Skagit —bode for the future of mitigation markets in the wake of Hirst? Statewide, senior surface water rights appear to be the most viable source for exempt well mitigation. As in many western states, these water rights are held and used in greatest volume for agricultural irrigation, largely due to historical water appropriation history during western development. Given that the value of water for agricultural use tends to be low relative to municipal and domestic use (Brewer et al. 2007, Brown 2006), it might suggest that existing senior irrigation rights might play a key role as a source for mitigation water.

However, irrigation rights tend to be seasonal, allowing water withdrawal and use only during the irrigation

1 For a summary of these cases and additional information about instream flow management (Ecology 2018b).

season, roughly from April through October. The Foster Decision discussed above requires that mitigation be a time and place-specific wet water "replacement" of groundwater pumping impacts. This means that the Foster Decision throws some cold water on the prospects for using senior irrigation rights as exempt well mitigation. In fact, the Washington State Department of Ecology, which is the regulatory authority for issuing water rights in the state, says that it cannot issue change of use that alters the season of use because of the Foster Decision. Further, the Department explicitly states that because of it, "There are few areas in the state where in-kind, in-time, and in-place mitigation water will be available." (Ecology 2018a). Given the relative scarcity of senior water rights other than those designed for agriculture, the Foster Decision may be quite constraining.

Consequences of Hirst

Hirst and its predecessors can be interpreted as an attempt to internalize or at least address an externality: one imposed by rural residential exempt well users on more senior water surface rights owners. The cases mean that the burden on senior water rights owners of showing harm has been shifted to a burden on prospective exempt well owners to show no harm to surface water rights owners. One version of a Coase theorem suggests that initial rights do not matter for efficient resource allocation if conditions are conducive to trade (Randall 1983). Water markets rarely, if ever, come anywhere near satisfying the necessary conditions for any version of a Coase theorem to hold. Therefore, one might expect initial rights to matter. Looking at Skagit, a failure of mitigation market development has already been demonstrated. Rajnus (2014) argues that the series of court cases leading up to Hirst impedes water markets and the state's and stakeholders' capacity to allocate water efficiently. It would require potential transactors to prove a negative --- that a transaction will not have even *de minimus* impacts on third parties. In doing so, he argues, these cases entrench the status quo against water reallocation across competing uses as demands change.

What is the net economic impact of the Hirst property rights switch when markets are ineffective at facilitating trade? This is difficult to answer quantitatively. For the sake of conjecture, suppose there are two sets of beneficiaries of the Hirst Decision who might have otherwise been harmed by exempt well development. The first set is composed of agricultural surface water diversion rights holders (who do hold most surface water rights by volume). The second set are beneficiaries from maintaining instream flows, such as Native American tribes who value fisheries and who collectively hold treaty rights for instream flows as fish habitat, and environmental stakeholders who receive ecosystem services or other benefits from instream flows. In principle, these benefits come at the expense of forgone residential development where legally available water cannot be shown and mitigation is not available.

Based on water bank prices in Kittitas and elsewhere in Washington State, water prices paid for rural residential development in private water banks ranged from about $30,000 per acre/foot consumptive use to over $130,000 per acre/foot consumptive use. The low end of this range is substantially higher than that for essentially all agricultural water uses (Hall et al. 2016, Part 2, p. 261, Yoo et al. 2013). This means that the Hirst Decision is a switch of rights away from a *de facto* right for a higher-valued use (residential use) to a lower-valued use (agriculture) when weak or no opportunity for a subsequent transaction exists. In other words, where markets do not develop for whatever reason, the Hirst Decision may trade one external cost imposed on irrigators for a larger cost imposed on rural property owners. As a result, potential exacerbation of inefficient water allocation might occur from a water value perspective. The benefits from instream flow maintenance are substantially more difficult to assess. They are an important basis for the satisfaction of treaty rights for tribes with economic and cultural fishing interests and rights. Also, they are an important dimension of other ecosystem functions and services whose valuation is difficult, but of which water markets are increasingly inclusive (Griffin and Hsu 1993, Murphy et al. 2009, Young and Loomis 2014).

Institutional Innovations in Washington State

Hirst became a bargaining chip ostensibly because it is taken to be a substantial threat to rural development. Rajnus (2014) argues that the judicial predecessors of Hirst hinder efficient allocation of water across competing uses in part due to high information costs over the burden of proof. Another hindrance is a failure of administrative capacity to adjudicate review requests. Further, Rajnus argues that even in the aggregate, exempt wells amount to a minuscule proportion of consumptive water use in most settings. The strict impairment standard arising from these cases amounts to a costly "symbolic action." Nonetheless, the Kittitas water banks (and others in the state) arose precisely because of exempt well moratoria. While information and associated transaction costs can be high, apparently, they can be overcome in some circumstances.

One thing seems clear: these judicial innovations in Washington State are and will continue to drive legislative, administrative, and private institutional innovation. The active Kittitas water banks are an example of innovative market development in direct response to legal change around exempt wells. Others include some flexible local water management arrangements such as under the Walla Walla Watershed Partnership, and legislative code in the form of RCW 90.90 (the Columbia River Water Management Program, 2006) intended to help "streamline review of water rights for mitigation and consultation purposes." In Skagit, while water banks have yet to develop in response to the Swinomish Decision, numerous mitigation strategy proposals have been examined. One proposal consisted of pumping water sourced from inchoate municipal rights low in the Skagit Basin via small diameter pipes for direct stream augmentation during low flow periods to satisfy minimum instream flow requirements (Brady et al. 2016). Yakima County is implementing what is being called a Groundwater Utility, in which the County is purchasing senior water rights satisfactory for exempt well mitigation. Conceptually, this practice is somewhat similar to a standard public water utility, charging a fee for connections and required metering, in addition to marginal consumption fees for the installation and use of individual exempt wells (Ferolito 2017a, Ferolito 2017b). Other counties are taking various different routes, including a "wait-and-see" approach.

The wait-and-see approach might be warranted. As of mid-January 2018, the state of Washington still does not have a capital budget because it is being used as a bargaining chip to find ways to "fix" Hirst. To date, it remains unclear how the budget impasse will be resolved, and how the solution will affect how exempt wells in water-constrained basins will be dealt with in the future. The legal developments leading up to and including the Hirst Decision will certainly change the institutional landscape within which the last holdout from the prior appropriations system — exempt wells — will be managed. In turn, rural residential development in Washington State will also be affected.

Epilogue: The Legislative "Fix" for Hirst

"An act relating to ensuring that water is available to support development" (Engrossed Substitute Senate Bill [ESSB] 6091) was signed into law on January 19, 2018. The act passed more than half a year after the capital budget failed to pass because of the impasse over the Hirst Decision.

The Hirst Decision would require counties to assure that legally-available groundwater was available to issue building permits reliant on an exempt well. However, the absence of a basin closure by Washington State's regulatory authority (the Department of Ecology) was found to be insufficient basis for allowing a new well. Thus, Hirst placed the burden of proof on counties to show water availability. Demonstrating burden of proof is a tall order, especially for groundwater.

The new bill removed this general burden of proof for allowing new wells, and in its place provides for and in some places requires the implementation of Watershed Preservation and Enhancement Committees (WPEs). These committees are charged with measuring and mitigating the effects of groundwater withdrawals on instream flows specific to individual watersheds.[1] The state will charge a fee of $500 per exempt well (current wells are grandfathered) and set aside $300 million over 15 years to support WPE streamflow enhancement planning and implementation. The bill also reduced allowable water use of domestic exempt well owners in some basins. In summary, the bill seems to reduce the potential restrictions on the development of Hirst, while providing a mechanism and funding basis for mitigating against the effects of continued exempt well development.

1 The author of this article is not a lawyer, ESSB 6091 is a complex bill. This summary is a relatively loose interpretation of the bill intended to provide a broad sense of primary implications for exempt well use. It is a far-from-complete description of the provisions of this bill. For additional analysis see Senate Committee on Agriculture, Water, Natural Resources, and Parks (2018), Washington State Department of Ecology (2018d)

As the concluding sentence of the main body of this article suggests, Hirst and its legislative response will indeed change the institutional landscape around water in Washington. The development of these WPEs, for example, may be a foundation for more robust local watershed-level management than currently exists in Washington State.

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WEF
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Tribal water settlements: economic innovations for addressing water conflicts

By Bonnie Colby[1] and Ryan Young[2]

Abstract
This article highlights examples of innovative approaches in regional water problem-solving contained in tribal settlements, providing readers with a sense of the possibilities that tribal participation brings to western water management. Many tribal settlements use economic incentives in ways useful to consider in a broader water management context. The article highlights economic components of several specific settlements and concludes by summarizing ways in the economic principles and incentives they illustrate can be more broadly applied in addressing water challenges. Figure 1 lists the tribal nations that are referred to in this article and shows the area where these tribes' reservations are located.

Introduction and Background

The role of Native American tribal nations in the western water arena has evolved over the past several decades. Tribal participation has evolved in many regions from primarily being viewed as a litigious threat to non-Indian water allocations, to negotiators and co-implementers of settlements that quantify tribal water rights and address regional water challenges (Deol and Colby, 2018). Along with other water management components in settlements, tribes are initiating innovations which incorporate economic incentives. Tribal nations have legal status as sovereign governments not ruled by state water law and able to enact their own regulations over water use, water quality and watershed protection. Tribal nations often have senior water entitlements that date back to the establishment of the tribal land reservation. These entitlements are more reliable during drought than junior rights held by non-Indian farms, industry and cities and this puts tribes in a unique position (Colby et al, 2005), and allows for innovations when crafting solutions to regional water problems.

Native American nations have legal entitlements to water resources, recognized by U.S. courts in 1908 when the Fort Belknap Indian Community in Montana was developing a reservation irrigation project. During dry periods, there was inadequate water for the tribal project, so the U.S. government sued upstream water users on behalf of the tribe in Winters v. U.S. (Colby et al, 2005, Landry and Quinn 2007). The Supreme Court recognized

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tribal nations have rights to use and manage water in order to fulfill the purposes of their land reservations. While tribes have strong legal entitlements to water, the quantification of those rights and provision of water supplies to tribal nations has been slow, costly and pain-staking, ongoing process.

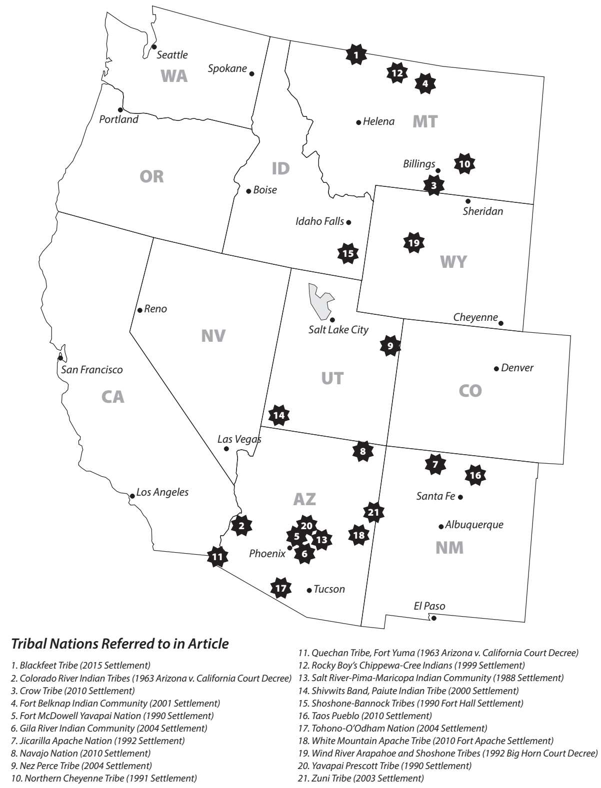

Figure 1 Locations of Tribal Nations Mentioned in This Article

A water settlement agreement typically involves negotiations between a tribal nation, federal agencies, states, water districts, and other water users in the area where the tribe is quantifying their water rights. Negotiated water settlements aim to resolve conflict among water users by allowing parties to specify water allocations, provide water supply assurances, and reduce litigation. Negotiated settlements with tribes have become an important part of western water institutions (Deol and Colby, 2018). Tribal water right claims are senior in priority to many water rights held by non-Indians, and so recognition and development of tribal rights threatens non-Indian water users that would be "bumped" downward in priority. This stark possibility provides impetus for negotiating settlement of Indian water right claims. Since the 1970s, over three dozen tribal water right settlements have been formalized in the U.S., with Arizona and Montana settlements accounting for a large share of these (see Table 1). The Montana settlements have focused on achieving mutual state-tribal advantages such as improvement in water management (Crow Tribe, Blackfeet Tribe), reservoir storage and dam safety (Northern Cheyenne Tribe), and domestic water supplies (Rocky Boys Chippewa-Cree Indians). In Arizona, urban interests have been motivated to collaborate on settlements in order to enhance their long-term water supply reliability through access to tribal water.

Negotiated settlements of tribal water entitlements produce a wide range of benefits, as compared to absence of a settlement and ongoing regional uncertainty and litigation over tribal rights (Colby, 2006). Settlements can contribute to addressing poor access to water resources for tribal communities and low income and high unemployment on tribal reservations, and provide some redress for historic injustices. Specific regional benefits include funding for new water projects and infrastructure improvements and improved collaboration between tribal and non-tribal water interests in addressing the water management challenges of their region. Economic development programs included in settlements stimulate local economies. Environmental provisions of settlements aim to restore streams, wetlands and other wildlife habitat that contribute cultural and recreational values along with other ecosystem services.

In addition to their many benefits, tribal water settlements are costly in both financial and water commitments. The federal government (and thus U.S. taxpayers) incurs significant financial obligations under most settlements, as do state governments, cities and other non-tribal water users. Commitments of water also are significant. Several Arizona settlements (Gila River Indian Community, Salt River Pima-Maricopa Indian Community) are based on the transfer of previously decreed water rights or on federal project water from non-Indian users to an Indian community. The amount of water quantified for tribes in settlements varies greatly. Entitlements of over 500,000 AFY are recognized for reservations in Montana, Utah, Nevada and Idaho. Other settlements—located in the arid Southwest—quantify tribal water at smaller annual amounts; 40, 000 to 100,000 being a typical range in Arizona and New Mexico. Some settlements involve very small amounts of water, but include important water and economic development funds: Yavapai Prescott Tribe (Arizona), 1,550 acre-feet per year, and Shivwits Band of Paiute Indian Tribe (Utah), 4,000 acre-feet per year.

The northern settlements are principally based on surface water sources, with groundwater included as a secondary source for reservation needs. Storage arrangements specified in settlements make smaller entitlements more reliable during dry years for tribal water users. The southern settlements rely on a more complex mix of water sources. Surface water is usually made available through an existing water development project, water from the CAP in most Arizona settlements. Due to heavy reliance on groundwater in the most populated areas of the state, Arizona settlements pay special attention to groundwater. Several Arizona settlements require tribal governments to place limits on tribal groundwater use in order to protect surface water rights that could be depleted by groundwater pumping. Some Arizona settlements add restrictions on non-tribal water users pumping water from wells located near the tribal reservation, in order to protect groundwater resources underlying tribal lands. These provisions create a buffer zone of additional protection not only for groundwater, but also for reservation streams and wetlands that rely on maintaining the elevation of the groundwater table.

State	Number of Tribal Water Rights Settlements	Number of Litigation Cases Quantifying Tribal Rights*	Total: Settlements Plus Court Decrees
Arizona	9	4	**13**
Colorado	2	0	**2**
Idaho	1	1	**2**
Montana	6	0	**6**
Nevada	6	0	**6**
New Mexico	6	1	**7**
Oregon	1	0	**1**
Utah	2	0	**2**
Washington	1	4	**5**
Wyoming	0	1	**1**
Totals	**34**	**11**	**45**

*This column refers to litigation cases with a final court decree quantifying tribal water rights, cases that are NOT part of a negotiated settlement process. In this column, litigation has been the primary process to quantify the tribal water entitlement. Most negotiated settlements (second column above) require an accompanying court decree as part of settlement implementation, and/or had earlier rounds of litigation prior to achieving a negotiated settlement.

Table 1 Western U.S. Cases: Quantified Tribal Water Rights (excluding California)

Tribal Innovations in Regional Water Management
Water transfers and exchanges involving tribes

Water transfers of various types are used to provide settlement water for on-reservation water needs, and to generate revenues for tribes from leasing their water. The opportunity to earn revenues by leasing out their water provides an important incentive signal to all water right owners. Lease prices give an indication of water values and can motivate improved water management practices and other measures that create "saved water" to lease. Farmers growing lower profit crops, in particular, are responsive to opportunities to lease water so long as laws protect the security of their water rights.

The settlement of Zuni Tribe claims in Arizona's Little Colorado River Basin involved purchase and retirement of surface water rights held under state law in order to restore streams and habitat on Arizona lands held by the tribe. In the Fort McDowell Yavapai Nation settlement (Arizona), a portion of the tribe's water supply comes from transfer of water previously held by irrigation districts. Arrangements for off-reservation leasing of tribal water are prevalent in Arizona settlements; which include complex agreements that allocate CAP water, surface water, groundwater, and treated effluent among Indian and non-Indian water users.

Exchanges among water sources can provide improved water supply reliability and a better match of water quality with water user needs. The Northern Cheyenne settlement involves exchanges among native surface flows and water stored in federal reservoirs to provide a reliable supply for the tribe. The water supply arrangements associated with the Navajo Indian Irrigation Project (NIIP), negotiated many decades ago, provide upstream surface water storage for reservation (and other nearby) water users in the Colorado River Basin.

In some cases, off-reservation leasing is a material part of the agreement, as in several Arizona settlements under which Phoenix-area cities lease tribal CAP water for 99 years. In Idaho, off-reservation leasing must occur through the state's water bank. The Fort Peck Tribes are authorized to engage in out-of-state marketing, but must first afford Montana state government an opportunity to share in the sale. States generally vigorously oppose interstate marketing of tribal water rights, believing this would disrupt carefully crafted interstate apportionments. The Jicarilla Apache Settlement and many Arizona settlements include prohibitions on interstate marketing.

In some basins, a tribe's full use of its reserved rights would disrupt non-Indian water users only in times of shortage and dry year water use contracts are attractive. The tribe agrees to share shortages with non-Indian water users rather than to exercise the full seniority of their right, protecting non-Indian water users during dry years. The Navajo Nation's agreement in the 1960s with proponents of the San Juan-Chama Project involves sharing shortages when flows are insufficient to satisfy both the San Juan-Chama Project and the Navajo Indian Irrigation Project. The Wind River Arapahoe and Shoshone Tribes and the State of Wyoming entered into a 1989 interim agreement for equally sharing surpluses and shortages in the basin.

The Gila River Indian Community (GRIC) tribes have been practicing irrigated agriculture in central Arizona for over 2,000 years. In the late 1800s, non-Indian communities upstream of the GRIC reservation developed significant water usage that led to water shortfalls and sharp losses in tribal crop production. GRIC and other Arizona water interests developed the 2004 Arizona Water Settlements Act, which provides for an annual tribal water entitlement of 635,000 acre-feet. In 2012, GRIC and the Salt River Project initiated a water banking system to store over 2 million acre feet in aquifers underlying GRIC lands, with a system of long-term storage credits, 100 year leases, and dry year options to use the stored groundwater and tribal CAP water. The credits are easily traded, compatible with state water banking rules, incur no evaporation losses and are available for areas of high predicted growth. Buyers include cities, private water companies, mining companies and golf courses (Gila River Water Storage, 2013, (Woods, 2017). The tribe used money available through the water settlement to upgrade a dam so that it could divert water into the aquifer, which can hold 40,000 AF. The tribe is in the process of taking over operations of this recharge system and expanding it to replenish the aquifer more efficiently. This tribal water banking initiative highlights tribal roles in providing drought buffers to junior non-Indian water users through market mechanisms.

The Jicarilla Apache Nation, which governs a large reservation in northwestern New Mexico, crafted a settlement with leasing provisions specified to provide revenues from its water rights. The Tribe has implemented

10 long-term leases, supplying 32,000 AFY to off-reservation parties. This generates $3.5-$4 million in annual income for the tribe, with protections built into the contracts that provide for changes necessary for the tribe to develop new on-reservation uses (Nyberg, 2015.)

The Shoshone-Bannock Tribe quantified water rights in the 1990 Fort Hall Indian Water Rights Agreement. In 2014, the tribe entered into agreements with junior-water rights holders to address water supply shortfalls for non-Indian water users. The agreements include a tribally managed water bank and help address Snake River in-stream flow and groundwater replenishment needs that are of concern to water users throughout the area (Bovee et al, 2015).

Other innovations: storage, forbearance, improved irrigation, water for the environment, mitigating shortage risks

Provisions in tribal settlements are providing improved flexibility in water storage and use and new ways to address water shortage risks. Provision of water for environmental needs is a feature of many settlements. Table 2 provides examples of innovative features included in specific tribal water settlements.

Settlement Features	Examples in Specific Settlements**
Dry year options, shortage-sharing	Navajo Nation San Juan Chana Project agreement, White Mountain Apache, Shoshone-Bannock, Northern Cheyenne
Tribal forbearance of water development	Quechan
Stream and habitat restoration	Zuni Pueblo, Northern Cheyenne, Jicarilla Apache, Nez Perce
Exchanges among water sources	Fort McDowell, Salt River Pima-Maricopa,
Water Banking	Gila River Indian Community Shoshone Bannock
Provisions for managing future conflicts	Taos Pueblo
Off-reservation leasing by tribe	Northern Cheyenne, Fort Peck, Fort McDowell
Improved agricultural water management	Crow, Blackfeet
Restricting groundwater pumping to preserve aquifer levels, wetlands and streams	Zuni Pueblo, Gila River Indian Community

** Examples only, not an exhaustive list.

Table 2 Settlement Feature and Examples

The Nez Perce Tribe, with a 750,000 acre reservation in Idaho, settled their water rights claims to the Snake River in a 2004 agreement (U.S. Department of the Interior, Office of the Secretary, 2004). The settlement includes provisions to provide water to protect endangered salmon and steelhead fish species and specifies tribal responsibilities towards managing fish species and hatchery facilities (Idaho Water Resource Board, 2004). The Tribe has 200,000 AFY of stored water to manage flows to protect endangered fish. Settlement funds allow the tribe to acquire land, water rights, protect habitat, and pursue agricultural and water resource development (Idaho Water Resource Board, 2004).

As a part of settling litigation, in 2005 the Quechan Tribe (Fort Yuma Reservation) and Metropolitan Water District (MWD) of Southern California entered into an agreement that specified amounts of water decreed for the Fort Yuma (Quechan) Reservation. One unique component of the settlement, the Forbearance Agreement, specifies that if the tribe limits development of its water entitlement, MWD will pay the tribe for reduced water usage (Morisset, 2015). This suggests a pathway for tribes to earn revenues from their senior water entitlements without needing to incur the expense of building storage and conveyance facilities to withhold the water in order to extract payment from other water users. A pragmatic problem facing tribes who wish to lease their water is the lack of incentive for non-Indians to pay for tribal water they already are using without cost. This situation is prevalent because many tribes lack capital to develop new on-reservation irrigation and other water-intensive projects. The Quechan Tribe - MWD agreement indicates that motivated parties can find a way to pay for tribal forbearance, though agreements of this type are currently uncommon.

The Crow Tribe, with a 2.3-million-acre reservation in Montana, entered into a 2010 settlement which provides funding for new irrigation on the reservation, as well as for a Municipal, Rural, and Industrial water system to serve the communities. (U.S. Department of the Interior, 2012). The tribe has water allocation and storage for 300,000 AFY through Reclamation projects.

The Blackfeet Tribe governs a reservation in Montana spans 1.5 million acres. In 2015, the tribe, state of Montana, and the federal government agreed to the Blackfeet Water Rights Settlement Act of 2015, which adjudicated 800,000 AFY to the tribe, as well as $470 million for water-related projects (State of Montana Governor's Office, 2013). The projects include habitat protection, land purchases, community water systems, and irrigation upgrades (U.S. Department of the Interior, 2016). The tribe is upgrading their existing irrigation projects, initiating new irrigation projects, repairing the dam, increasing water storage and expanding clean water systems for drinking water access.

Taos Pueblo began negotiations in 1989 to identify and quantify it's water rights and a settlement was finalized in 2013 (Interstate Stream Commission/New Mexico Office of the State Engineer, n.d.) Under the agreement, the tribe can divert 2,215 AFY annually from the San Juan River and store it in Heron Reservoir. (Utton Transboundary Resource Center of University of New Mexico , 2015) The Pueblo continues to use the 315 acre-feet per year of groundwater presently withdrawn from its existing well fields. The settlement agreement requires the tribe to develop a water administration code that provides notice to water users in the Valley of actions taken on the Pueblo's rights (University of New Mexico Digital Repository, 2012). The tribal water code will specify a protocol for non-tribal users to object to uses of tribal water believed to threaten other water rights, with hearings and due process (University of New Mexico Digital Repository, 2012).

The White Mountain Apache Tribe has a reservation (Fort Apache Reservation) that stretches over 1.67 million acres in Arizona, with over 400 miles of streams (White Mountain Apache Tribe, 2011). In 2010, the Tribe settled a quantification of their water rights. They receive CAP water and other surface water (U.S. Department of the Interior, 2013), along with $200 million for creation of a clean water and $78.5 million to develop reservation fishing and recreational resources. The White Mountain Apache Tribe is building a dam to create a reservoir, building a water treatment plant, and developing water storage facilities (U.S. Bureau of Reclamation, 2013).

The Zuni Tribe has a reservation located in Arizona, near the Little Colorado River. They also have land in New Mexico, with a total land area of 450,000 acres (University of Arizona, 2016). The tribal lands in Arizona include a previously "lush riparian habitat, with springs, streams, and a sacred lake with religious significance to the tribe" (University of Arizona, 2016). Under the Zuni Tribe Water Rights Settlement Agreement, the land is being restored to its natural flow levels, which were diminished by non-Indian dams and water depletions (Arizona Department of Water Resources, 2014). The federal government, state of Arizona, and the Salt River Project collectively provided $26.5 million for restoration, including purchase and retirement of surface water diversions in the area (U.S. Department of Interior, 2004). Additionally, to help restore flows, a "Pumping Protection Agreement" included in the settlement restricts groundwater pumping by landowners in the protected area. Any new wells are limited in pumping capacity to 500 gallons per minute per section of land. (University of New Mexico Digital Repository, 2002)

Tribes are playing a key role in the Colorado River Basin System Conservation Pilot Program, which was initiated in 2014 by Reclamation and major municipal water interests to address shortage threats (Agreement, 2014). Funding for supply reliability projects comes from a combination of federal, municipal and foundation sources. Project water becomes a new category of "system water" that is stored in Lake Mead to avert hitting reservoir levels that trigger a shortage declaration with its cascade of negative consequences for junior water users. Three tribes (Colorado River Indian Tribes, Gila River Indian Community and Tohono O'odham Nation) with reservation lands located in Arizona are among the participants contributing "system water" in return for payment (USBR, 2018).

Summary and Implications for Western Water Future

Tribal governments exercise sovereign jurisdiction over their water entitlements and often possess the most senior water in their basins (the water last in line to be cut off during shortage). Since they are not governed by state water law, tribes have been able to tailor innovative water management tools to address tribal concerns as well as to accommodate broader water challenges in their regions. Many innovations have been developed as part of the dozens of tribal water settlement agreements achieved over the past several decades. Other innovative approaches have arisen to settle litigation cases or have evolved as part of collaborative problem-solving discussions involving tribes and non-Indian water users. Examples include new forms of water leasing, dry-year shortage sharing, aquifer banking as a buffer against drought, groundwater pumping restrictions to protect stream flows and wetlands, revamped operation of storage and delivery systems, new dispute resolution approaches and improved agricultural water management.

The role of economic incentives and tradeoffs is central in tribal settlements and tribal participation in regional water problem solving. The benefit of reduced uncertainty over unquantified tribal water entitlements is a key motivation for settlements, which allow all parties to better plan how to address water shortfalls and for their overall future water needs. Significant amounts of money and water are invested in implementing settlements. Water leasing, banking and exchanges provide price signals to water users that can motivate improved water management and conservation. The economic and cultural contributions of water dedicated to restore streams and wetlands are central in many settlements.

The western U.S. wrestles with severe drought, extensive wildfire impacts on watersheds, changing snowpack patterns and increased demand for water to sustain stream and wetlands and growing cities. Innovations made possible through tribal participation in regional water problem-solving are playing an important role in addressing these challenges.

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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

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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.

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Sustainable policies that align irrigation and water quality

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Abstract

Rules about water use in the West evolved independently from those meant to improve water quality. Sometimes rules governing use have a negative effect on water quality and vice versa. We look at the interaction of use and quality rules in the Lower Arkansas River Valley (LARV) in Southeast Colorado. The adoption of water-saving sprinkler irrigation systems has lagged behind adoption in similar regions. The lag is primarily because the LARV has unique use rules that require replacing water savings to the river when a more efficient system is adopted. At the same time, several studies have found that sprinklers can help with pollution problems from nitrogen, selenium and salinity. We show that economists, working with other sciences, can make sophisticated estimates about the impacts conservation systems. However, it is difficult to present those complex results in a way that helps stakeholders examine the options. An example is presented that allows farmers and others to compare the impacts of different conservation systems across multiple objectives in a simple and meaningful way. Researchers are now better equipped than ever to work with local stakeholders to evaluate conservation systems and address multiple objectives.

Introduction

A portfolio of policies is typically required to manage complex ecosystems. Identifying the optimal portfolio of policies requires an awareness of how different policies interact with each other. Another factor to consider is how the policies perform relative to the multiple objectives society wishes to achieve. Social welfare is diminished when individual objectives are ignored or the impact of one program on another (whether positive or negative) is not taken into consideration. Fortunately, awareness that multiple objectives must be considered when

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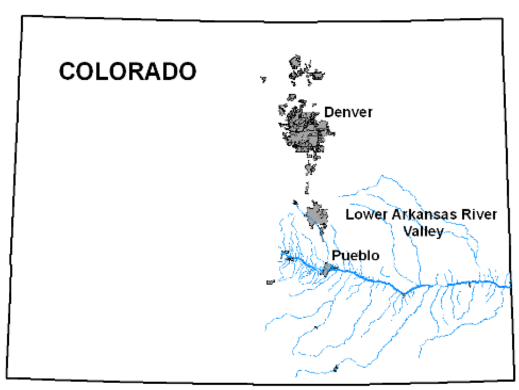
attempting to solve complex problems in ecosystems is growing. Despite this awareness, progress has been slow due to entrenched private interests and often disconnected local, state and federal policies.

The development of policies, regulations and stewardship practices governing water quality and water use serve as a good example. Traditionally, a divide has existed between efforts to improve water quality versus those aimed at improving the efficiency of water use. Much of this divide stems from the fact that water allocation laws were developed at the state level more than a century ago. Whereas water quality laws are based on federal guidelines rooted in the adoption of the Clean Water Act in the 1970s. Over time, policy development has increasingly reflected frictions between desires to improve water use efficiency in crop production and efforts to maintain or improve water quality. Often these frictions have made it difficult to implement sensible resource management decisions. Increasing scarcity driven by population growth throughout many arid areas has exasperated this divide. As competition for water increases, so does the need to reduce these frictions. This disconnect has meant that water quality policies might negatively influence water use and vice versa. In Colorado, for example, use rules that protect return flows to the Arkansas River limit the adoption of practices that reduce pollution because they alter water use (Sharp et. al, 2016). Policymakers are tasked with three, often competing, objectives: to maximize net returns, to reduce water use and to improve quality. All states in the West have improved the compatibility of water quality and use policies to simultaneously address these objectives. Yet, it is not always easy, and progress is often slow. Herein we look at one community where progress has been slow, the Lower Arkansas River Valley (LARV) in Colorado. The LARV is not unlike many communities in the West. Farmers cannot manage water without considering their impact on others. The linkages between their management and those impacts are increasing in dimensionality and complexity. We show the complexity and disparity of choices in front of the LARV community. Also, we provide a few examples about how economists work with other sciences to make choices with multiple objectives simpler to compare.

Water Quality and Quantity Issues in the Lower Arkansas River Valley

The Lower Arkansas River Valley is home to substantial irrigated agricultural production; about 200,000 acres were irrigated in 2014 to produce a wide range of crops from grains to specialty vegetables. Individual producers depend heavily on the ability to irrigate and irrigated agriculture is a key driver of the surrounding economies. However, studies have linked irrigation to elevated in-stream selenium and nitrate concentrations, as well as shallow, saline water tables (Seiler, Skorupa and Peltz 1999; Gates et al. 2002; Gates et al. 2009, Morway and Gates 2012). Rapid population growth along with dry conditions over the past 20 years have resulted in increased pressure for producers to reduce water use, either by reducing irrigated acreage or improving irrigation efficiency. Reductions in acreage are becoming increasingly unpopular due to the negative economic impacts decreasing production has on rural economies (Howe and Goemans, 2003). On the other hand, the adoption of new irrigation technologies and practices, designed to improve irrigation efficiency, is limited by existing allocation laws. The limitation is because the new technologies change return flows and threaten existing water rights holders in Colorado as well as downstream states. As is commonly the case, efforts to address these issues (e.g., via the adoption of new policies, regulations, or irrigation practices) have been hampered by a complex, and often conflicting, set of existing water quantity and quality laws.



Water Quantity Laws

Throughout much of the Western United States, the allocation of water *within* states is governed by the Doctrine of Prior Appropriation. Colorado is considered one of the "purer" forms of prior appropriation where water rights holders are guaranteed in perpetuity "… [t]he right to divert the unappropriated waters of any natural stream to beneficial uses" (Colo. Const., Art. XVI, Section 6 (2016)). Beneficial use is defined in statute "[as] use of that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the appropriation is lawfully made" (C.R.S. 37-92-103(4)). The list of "beneficial uses" has evolved over time. For example, the addition of in-stream flows to the beneficial use list, as means of preserving wildlife habitat and natural environment, in 1973 (C.R.S. 37-92-102(3)).

Prior Appropriation not only dictates who has the right to divert water, but also who gets "shut off" during periods of shortage. When available flows are insufficient to fulfill all water rights holders' demands, the prior appropriation system grants "… [p]riority of appropriation [to] the better right…" (Colo. Const., Art. XVI, Section 6 (2016)). Where "better" in this context refers to the "seniority" of the right, i.e. when the water was initially appropriated. Later claims on water rights are referred to as "junior" rights, which are only fulfilled in times of higher-than-average flows such as spring snowmelt and summer rainstorms, providing inconsistent, difficult-to-predict, and many times inconvenient surges of water. For perspective, the earliest decreed water right in the LARV has an appropriation date of 1859, and by the 1880s flows in average years were fully appropriated (Abbott 1985).

Water allocation *across* states is typically determined according to existing interstate compacts. More than 20 compacts exist throughout the West (Kenney 2002). In the case of the LARV, the allocation of Arkansas River flows between Colorado and Kansas is governed by the Arkansas River Compact. In 1902, the U.S. Supreme Court presided over a series of lawsuits filed between Colorado and Kansas (*Kansas v. Colorado* 1902; *Kansas v. Colorado et al*. 1907) and ultimately suggested an interstate compact. In 1948, a bilateral compact between the states of Colorado and Kansas was ratified, which created the Arkansas River Compact (C.R.S. 37-69-101 (1949)). In 1985, Kansas filed a complaint to the Supreme Court arguing that Colorado had failed to meet its compact obligations, resulting in $34 million in damages to Kansas (Littleworth 2008). To help prevent disputes of this type, Colorado and Kansas have since developed the Hydrologic-Institutional model (H-I), which simulates water use and return flows throughout the LARV. The model is used to help maintain compact compliance with a changing irrigation landscape.

The H-I model has become the basis for evaluating the impact on water quantity of potential changes in irrigation and delivery practices relative to existing irrigation improvement rules. In effect, the H-I model represents a use constraint to any irrigation improvements in the region.

Water Quality

Like most states, Colorado is also facing increased pressure to improve water quality. While currently, like most states, agricultural producers are relatively unregulated with respect to water quality impacts, farmers in the LARV face serious risks of becoming more regulated. Numerous water quality issues have been identified in the LARV. However, herein we focus our discussion on three water quality issues: nitrogen, salinity, and selenium (Gates et al., 2016; Miller et al. 2010). In the LARV, nitrogen is an issue primarily related to fertilization. In 2012, Colorado adopted Regulation #85 which established nutrient management standards for point source discharges, as well as the framework for nutrient trading programs (for both point source to point source, as well as between point and non-point polluters). At present, the standards are voluntary for agriculture. However, the legislation includes a provision that would allow the state to adopt control regulations specific to agriculture if sufficient progress is not made through the voluntary adoption of best management practices (BMPs).

Shallow, saline water tables represent a persistent problem throughout the LARV (Sutherland 2008, Gates et al. 2002). Houk, Frasier and Schuck (2004) estimated that salinity build-up and waterlogging costs producers on average about $68 per acre in Otero County. In the LARV, salinity is related to the transportation and application of irrigation water. Tailwater runoff and deep percolation from irrigation events elevate water tables, leading to salinity. Lowering water tables across the region, which could be achieved by replacing flood irrigation with high-efficiency sprinklers, could reduce losses in crop yields (Morway and Gates (2012).

Another environmental benefit that would be realized by reducing the water table is reduced selenium in the Arkansas River. Concerns about selenium originated in the 1980s with the discovery of contamination in the Kesterson National Wildlife Refuge in the San Joaquin Valley of California. Concentrations of selenium lead to bioaccumulation and waterfowl mortality (Nolan and Clark 1997). Selenium exposure to livestock can result in acute selenium poisoning (short-term exposure), or a chronic condition known as alkali disease (long-term exposure), both of which can lead to hair loss, hoof deformities, loss of appetite, lethargy, and death (Davis et al. 2000). Selenium, present in the bedrock under farms in the LARV, is oxidized into mobile species then transported to the surface water systems. Several studies in the region have found rates of selenium in the Arkansas River that are double or even triple of the state and Environmental Protection Agency standard of 4.6 micrograms per liter (Shultz, 2017).

Comparing the Impacts of the Adoption of Best Management Practices

A variety of studies have shown that the adoption of various land and water BMPs can be effective in reducing selenium and nitrate groundwater concentrations and mass loading into streams (Orlando, 2017; Shultz, 2017). The question becomes: what is the optimal combination given the multiple objectives of producers and policymakers in the LARV? A pair of master's theses, one in Civil Engineering (Shultz, 2017) and the other in Agricultural and Resource Economics (Orlando, 2017), recently showed how BMPs in the region impact water quality and economic returns. Specifically, the studies considered various combinations of the following four BMPs:

- RI: Reducing the amount of irrigation water applied to the crop.
- LF: Fallowing previously irrigated lands and leasing the water to municipal water providers (e.g., residential or industrial uses).
- CS: lining/sealing canals to prevent/reduce seepage.
- RF: Reducing the amount of fertilizer applied.

Each of these alternatives either directly or indirectly affects the quantity and quality of water in the river. The first three of these BMPs potentially alter the timing and quantity of water available to downstream users. The last two reduce pollutants in water delivered to the river. The cost-effectiveness of each BMP or combination of BMPs was analyzed using a linear programming economic optimization model (Orlando, 2017), coupled with output from a surface flow (MODFLOW-UZF) and reactive solute transport (RT3D-OTIS) model (Shultz, 2017). The combination of these models allows for a hydro-economic analysis of BMPs by identifying the tradeoffs between regional economic net returns and pollution abatement in local waters associated with various levels of BMP adoption. The model focused on 6 irrigation canals feeding about 40,000 irrigated acres producing 6 major crops. The goal of the analysis is to determine how constraints on irrigation decisions affect water quality, and how some of these limitations have been or could be overcome.

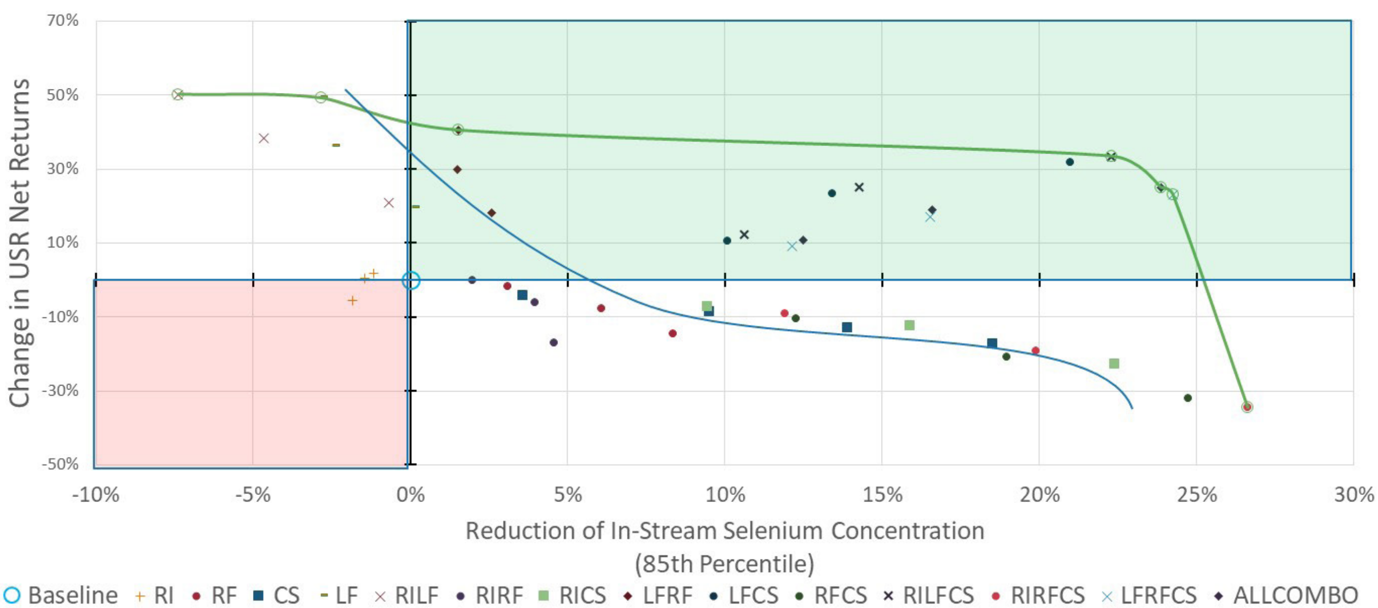


Figure 1: Changes in total net returns from crop production in the study region and resulting selenium concentration in the Arkansas River compared to a baseline (no best management practices) and various combinations of four best management practices: reduced irrigation (RI), lease fallow (LF), canal sealing (CS), and reduced fertilization (RF).

It easy to understand how people making decisions can become overwhelmed. Figure 1 illustrates the tradeoffs between just two objectives: total net returns to crop production in the study area and selenium concentration in the Arkansas River. The points in the graph represent outcomes for the BMPs (e.g. RI, LF, RF and CS) and combinations of those BMPs (e.g. LF and CS or RF and RI). The baseline is at the origin, and any point northeast of the baseline is preferred because it improves both income and pollution (green box). Any point to the southwest is worse in both dimensions. Points to the northwest improve income but make pollution worse and points to the southeast reduce pollution but also reduce profits. The blue line represents the standard downward slope that would be expected, where reducing pollution reduces returns. The green line represents the actual frontier of the tradeoffs. Figure 1 demonstrates how complex managing multiple objectives can be but is not fully described here; those interested will find more details in Orlando (2017).

Farmers in the LARV can increase returns and reduce pollution through some levels of lease fallow. The practice allows cities to lease water from a farmer and call on it 3 out of 10 years. In a recent pilot program in the region, lease rates were a little over $1,000 per fallowed acre, which is considerably higher than producing most crops (Lower Arkansas Valley Water Conservancy District (LAVWCD), 2016). This BMP option produces a win-win for the farmer, the environment and the city. However, the BMP option is not yet practical due to two different sets of rules governing use, one for cities and one for farms. The pilot program demonstrates a desire of some decision makers to move toward making those rules more harmonious.

After LF, the BMPs that best reduce selenium pollution at least cost involve canal sealing (CS). CS costs money, so the practice does not offer the ability to increase income while reducing pollution, but it reduces pollution at a lower cost than other BMPs. Canals can be sealed with the application of granular linear anionic polyacrylamide (PAM). PAM is a water-soluble polymer that, when applied in granular form to irrigation conveyance structures, has proven to be a cost-effective method of reducing seepage from the bottom and sides of unlined canals (Susfalk et al. 2008). Like the case with LF, the rules for quality and use are at odds. Farmers and ditch companies in the region have little interest in CS since, under current rules for use, the saved water seepage must be replaced at substantial cost. Conceptually, replacement water could be found in reservoir storage and released but thus far this has not been allowed due to uncertainty surrounding the impacts to downstream users and states. The results shown for CS in Figure 1 might therefore be of little value in the LARV unless they are used to leverage arguments to change the water accounting rules related to CS.

Stakeholders in the LARV need to weigh tradeoffs, which are delineated in Figure 1. However, Figure 1 ignores the effect of each BMP on the other two environmental concerns--nitrogen and salinity. Fortunately, there is a way to show all four objectives simultaneously using spider or radar graphs like that shown in Figure 2. The orange line is the baseline, where each objective starts at 100% of where it was before any BMPs were installed.

The blue and green lines represent two examples of BMPs. The green line, reduced irrigation-lease fallow-canal sealing (RI-LF-CS), increases net returns above the baseline, and reduces selenium and soil salinity from the baseline, but increases nitrogen pollution. The blue line, by comparison, reduces net returns from the baseline and does not do as well at reducing soil salinity, but is slightly better at reducing selenium and not increasing nitrogen. With this approach, local stakeholders can quickly see the tradeoffs presented by each BMP, making it easier to work toward the solutions that fit them best. And, perhaps equally important, only a handful of practices need to be graphed because they dominate other practices in at least one objective and are not inferior in any other. Out of the 44 combinations shown in Figure 1, only 7 needed to be graphed (Orlando, 2017).

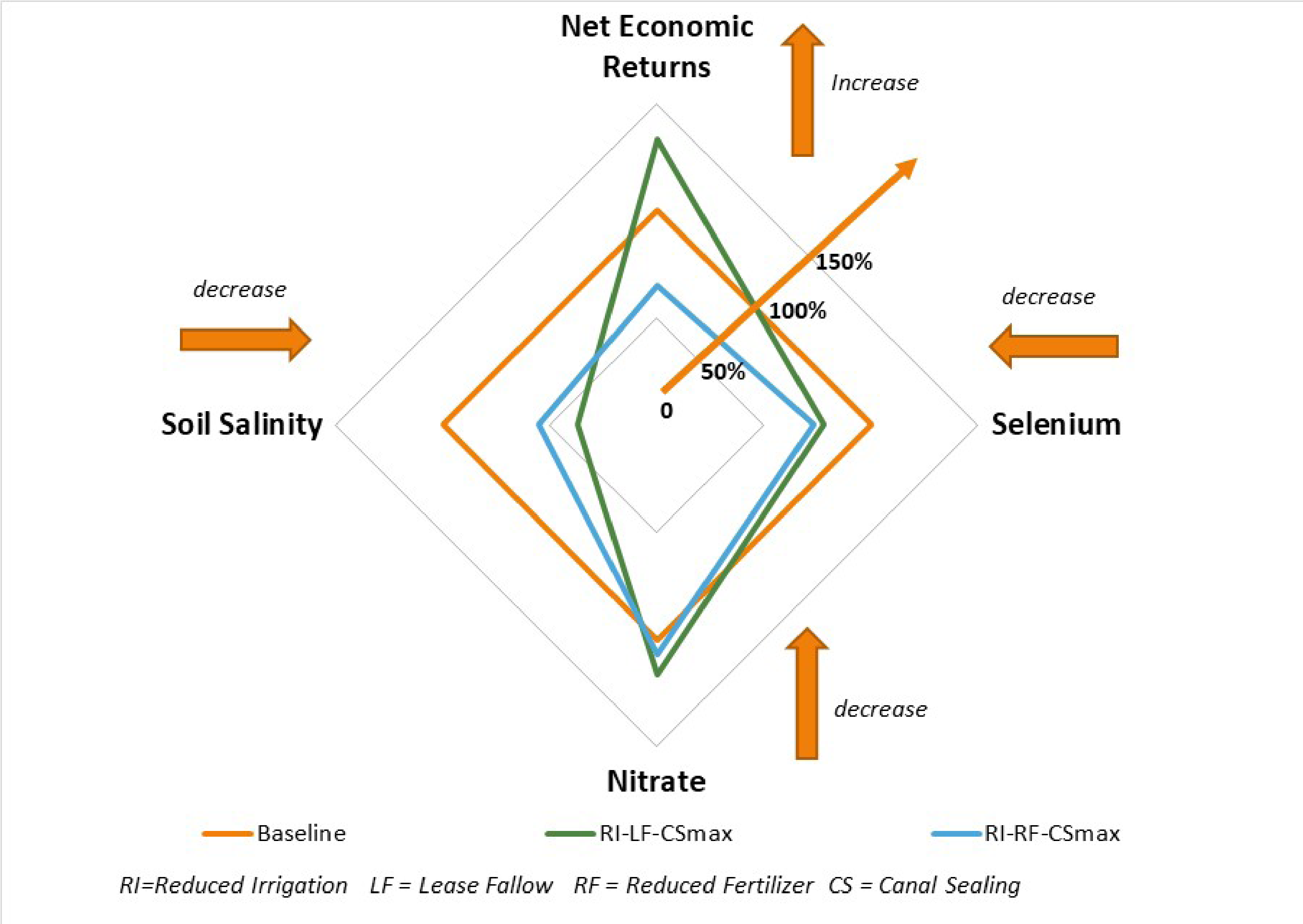


Figure 2: Impact of BMPs on four objectives: net returns from crop production, selenium and nitrogen concentration in the Arkansas River and soil salinity

Discussion

Managing water is very complex and managing water to fully meet multiple objectives is virtually impossible. Therefore, farmers must choose which objectives to prioritize. One of the most difficult problems that must be overcome is communication between researchers who know how to study the impacts and stakeholders who have to make final management decisions. Engineers and economists have made impressive gains in their ability to model impacts that might be realized by the implementation of different conservation practices. However, the answers are often very complex to display and interpret, as shown in Figure 1. Therefore, researchers have developed ways to make these tradeoffs easier to compare, like the radar graph presented in Figure 2. In the end, it is the local stakeholders that must choose which BMPs to adopt and on how to prioritize their objectives. The time and effort to do research is largely wasted if researchers cannot show these stakeholders what those tradeoffs are in a meaningful way.

By making it easier for local stakeholders and decision makers to compare the economic and technical implications of BMPs, they can focus on the social or community dimensions that are perhaps even more important than the technical details. Many factors will affect how local stakeholders weight each objective. For example, in the LARV, selenium levels are far above federally-allowable standards, but nitrogen is not, allowing farmers and other decision makers to focus on BMP combinations that are effective in reducing selenium concentrations. In addition, canal sealing offers a lot of potential, but use is limited under current regulations. Whether people feel that lawmakers would be willing to change rules about CS will likely affect whether they want to prioritize this BMP. Finally, while lease fallow can boost income and reduce pollution, it appears to be very limited in scope. All these factors will affect how people weigh the set of objectives, but local leaders need that information before these discussions can take place.

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