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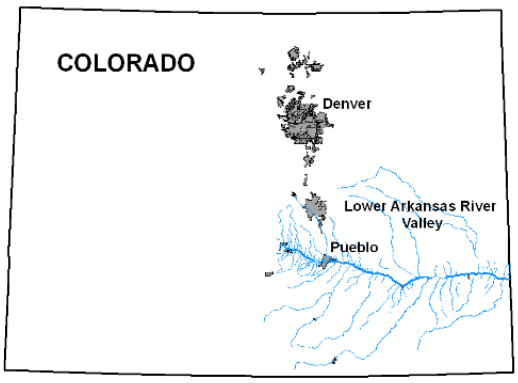
attempting to solve complex problems in ecosystems is growing. Despite this awareness, progress has been slow due to entrenched private interests and often disconnected local, state and federal policies.

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.

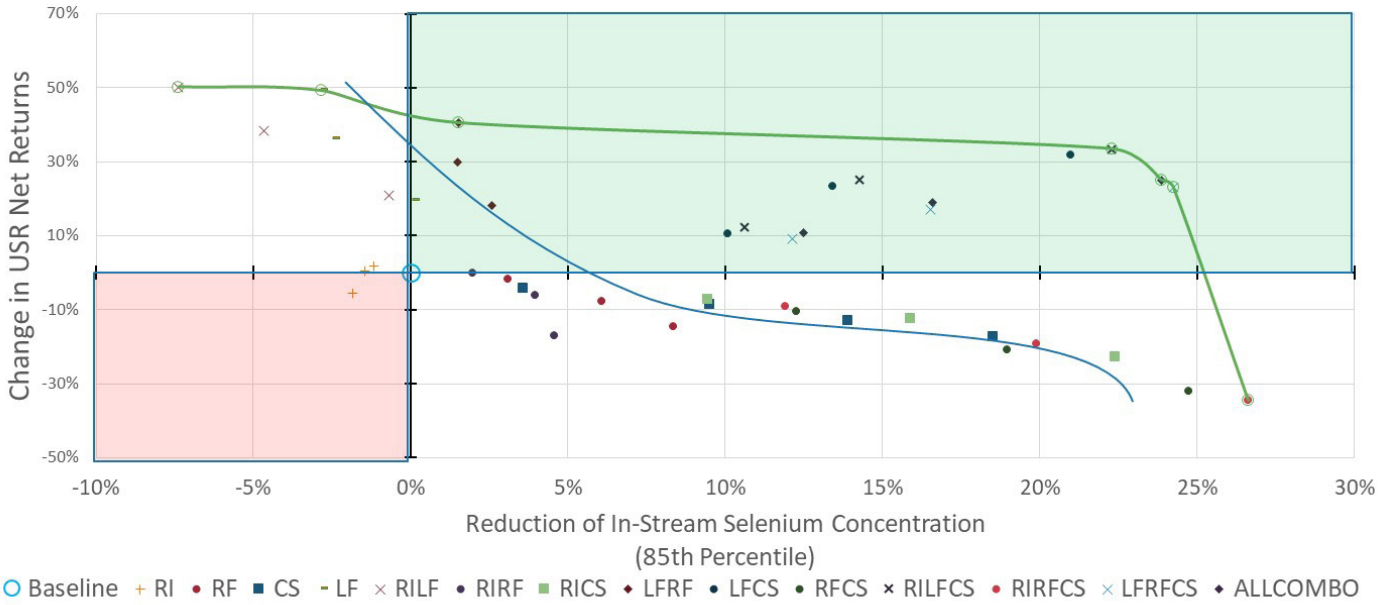


Figure 1: Changes in total net returns from crop production in the study region and resulting selenium concentration in the Arkansas River compared to a baseline (no best management practices) and various combinations of four best management practices: reduced irrigation (RI), lease fallow (LF), canal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

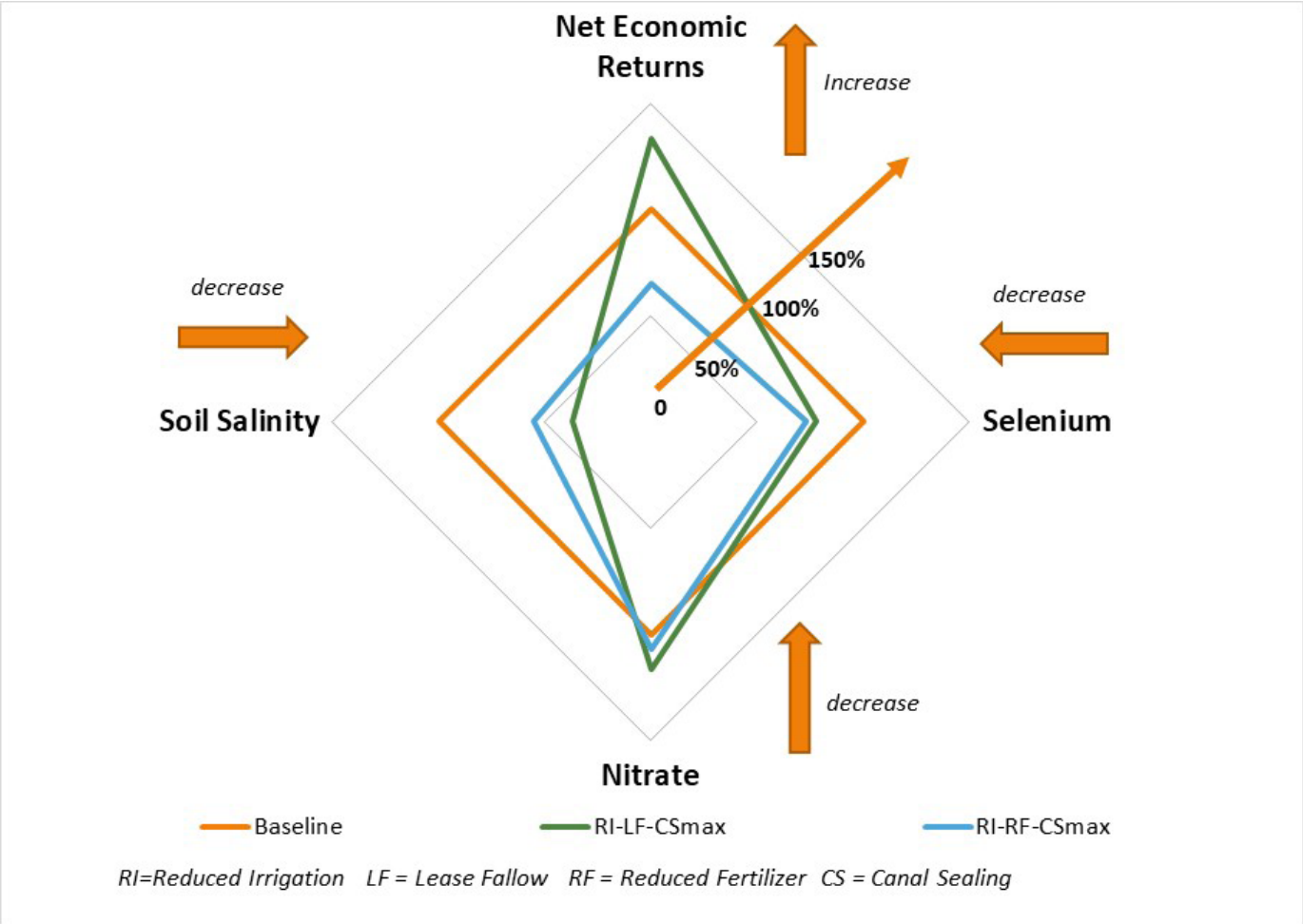


Figure 2: Impact of BMPs on four objectives: net returns from crop production, selenium and nitrogen concentration in the Arkansas River and soil salinity

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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