Agricultural Water Management 247 (2021) 106736

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Lessons from local governance and collective action efforts to manage irrigation withdrawals in Kansas

Gabriela Perez-Quesada *, Nathan P. Hendricks

Department of Agricultural Economics at Kansas State University, Manhattan, KS, USA

ARTICLE INFO

Handling Editor: Dr Z. Xiying

Keywords:
Ogallala aquifer
Collective action
Local governance
Irrigation
Aquifer depletion

ABSTRACT

This study evaluates four groundwater management plans to increase the understanding of how local governance and collective action can be effectively implemented to manage irrigation withdrawals in Kansas. The results of our analysis demonstrate five key lessons that highlight the challenges of collective action efforts to manage common-pool resources in a developed country setting. First, the four management plans generally follow Ostrom's design principles for collective action. However, there are important areas—particularly boundaries and allocations definition—where the management plans could be improved to better align with Ostrom's design principles. Second, a majority of farmers agree that action is needed to reduce the rate of aquifer depletion but management plans have not substantially reduced water use. Third, management plans that allow for voluntary participation have not received more support than those that require mandatory compliance, perhaps due to the classic free-rider problem. Fourth, there is no clear evidence that heterogeneous benefits from management explain support within a management area. Fifth, groundwater users generally perceive that they have an acceptable level of information. Our analysis highlights the significant challenges facing successful collective action efforts to manage water in the USA. and that the efforts are most likely to be successful when they are small-scale, mandatory, and involve users in the formation process.

1. Introduction

The High Plains Aquifer (HPA) in the central United States—also known as Ogallala Aquifer—is one of the largest aquifers in the world. The aquifer underlies portions of eight states from South Dakota to Texas. This area is one of the primary agricultural regions in the country where land use is dominated by irrigated agriculture. However, extraction of groundwater at rates that exceed natural recharge has led to persistent aquifer depletion, particularly in the central and southern portions of the HPA (e.g., Scanlon et al., 2012; Steward and Allen, 2016; McGuire, 2017).

This unsustainable path of groundwater extraction is especially true in western Kansas where the agricultural economy critically depends on the Ogallala aquifer. Steward and Allen (2016) project that by 2060 under a business as usual scenario, only 18% of the original aquifer saturated thickness will remain in west-central Kansas and 27% in southwest Kansas. The impact of reductions in water use on future aquifer level has some uncertainty. Steward et al. (2013) estimate that reducing water use by about 80% is needed to sustain the aquifer while Butler et al. (2016, 2018) estimate that a reduction of only 21–33% would sustain the aquifer in western Kansas.

Local governance institutions that collectively manage the aquifer have been developed in Kansas as a potential solution to promote water conservation. For example, Drysdale and Hendricks (2018) find that farmers in Sheridan County in northwest Kansas substantially reduced groundwater extraction by forming a Local Enhanced Management Area (LEMA) to impose a restriction on themselves. Drysdale and Hendricks (2018) note that this LEMA had the broad support of the local irrigators based on records from meeting minutes. In this paper, we study the design and support for four different local management efforts in Kansas, including the Sheridan County LEMA.

The conventional theory of the commons states that even though users would benefit from collectively managing the aquifer, each user has an incentive to not participate in collective management. Managing a common-pool groundwater resource is particularly difficult because it is not observable and it is hard to understand its boundaries (Meinzen-Dick, 2018). However, there exists significant empirical evidence showing that users might cooperate to design, implement and monitor

* Corresponding author.
E-mail addresses: gperezq@ksu.edu (G. Perez-Quesada), nph@ksu.edu (N.P. Hendricks).

https://doi.org/10.1016/j.agwat.2021.106736
Received 8 July 2020; Received in revised form 29 December 2020; Accepted 2 January 2021
Available online 24 January 2021
0378-3774/

rules for the appropriate use of the resource and to avoid the tragedy of the commons (Ostrom, 2002). In this context, Ostrom (1990) proposed eight design principles that facilitate collective action. The empirical studies of these principles are challenging due to the complexity of the common-pool resources and data scarcity to perform statistical analysis (Smith, 2016). Instead, most studies use qualitative analysis of case studies to evaluate the design principles (e.g., Cox et al., 2010; Baggio et al., 2016).

Another related perspective is that collective action and management rules regarding common-pool resources emerge when their social benefits exceed their social costs and transaction costs (Demsetz, 1967). Coase (1960) recognized that transaction costs to adopt new institutional rules could be high and that they could affect users' willingness to participate in collective action. More recently, Ayres et al. (2018) find that transaction costs associated with defining and enforcing property rights limit agreement on groundwater rights or management plans even in critically overdrafted basins. Cody et al. (2015) show how reduced transaction costs enable irrigators in San Luis Valley of Colorado to create a Groundwater Subdistrict to collectively reduce groundwater use.

The objective of our study is to increase the understanding of how local governance and collective action can be effectively implemented to manage irrigation withdrawals in a developed country context. We need to better understand under what conditions irrigators support groundwater management plans, and how current governance could be modified to facilitate collective action to manage the aquifer. We consider collective action and local governance concepts in a complex setting where groundwater users, government agencies and other stakeholders interact to obtain common objectives. It is typical that self-governed systems where resource users are actively involved in designing collective management plans, also include rules made by local, regional, national, or international authorities (Ostrom, 2002). Smith et al. (2017) and Shalsi et al. (2019) show how irrigators working together with government agencies improved groundwater management and resource conditions.

To accomplish our objective we evaluate four collective management plans that are either proposed or recently implemented in Southwest (SW), Northwest (NW), and in Wichita County (WC) of Kansas. This evaluation is based on the eight design principles proposed by Ostrom (1990). We also analyze key variables, such as aquifer conditions or user heterogeneity, that affect groundwater users' willingness to support collaborative local management. Our study provides insights to the scientific community, water managers, and policymakers about the prospects for users to successfully manage common-pool resources in a developed country.

2. Policy background for the study region

The State of Kansas adopted the prior appropriation doctrine in 1945 which embodies the concept of first in time, first in right. Prior appropriation requires groundwater appropriators to obtain a permit from the state engineer to extract water. The permit authorizes the annual amount of water that can be extracted and the place of use. The date that the permit is authorized defines the priority of the right, with older rights having seniority. This system of priority is relevant under water scarcity conditions. If pumping by a junior water right holder impairs the ability of a senior water right holder to exercise its right, then the junior can be required to reduce withdrawals.

The system of priority has had a minimal impact on avoiding overlapping wells that lead to a significant drawdown in many areas (Edwards, 2016). Given the inability of the state to control the depletion problem, five Groundwater Management Districts (GMDs) were established in 1972. They have authority from the Division of Water Resources – Kansas Department of Agriculture (DWR-KDA), to act on the behalf of local water users. The board of directors is elected, local stakeholders with an interest in promoting regional economic welfare. The GMDs have developed management programs to improve the management of groundwater, such as well spacing requirements and closing the district to further drilling. But the GMDs had never restricted water use on existing wells before 2013.

In 2012, the Kansas legislature authorized Local Enhanced Management Areas (LEMAs). The LEMA is a tool that gives the board of directors of GMDs the authority to implement corrective measures for water conservation for a particular region. A LEMA must include clear geographic boundaries, corrective measures (e.g., limits on the amount of water pumped), compliance monitoring, and enforcement mechanisms. A LEMA may also allow other types of measures that provide flexibility in water use such as allowing trading of water right within the LEMA. The plan requires the approval of the GMD board of directors and the state's Chief Engineer. The approval process includes public hearings. The LEMA requires mandatory compliance of irrigators within the management area, even if the irrigator was not supportive of the LEMA. KDA monitors and enforces the LEMA.

Water Conservation Areas (WCAs) were authorized by the Kansas legislature in 2015. A WCA allows a water right owner or group of owners the opportunity to develop a management plan to reduce total withdrawals while allowing additional flexibility in the use of water. The WCA requires purely voluntary participation of irrigators and does not require approval by the GMD board, but must be approved by the Chief Engineer. WCAs may implement water restrictions among participants that are enforced by the state, but any water users can choose to be excluded from the WCA.

In this paper, we evaluate four cases of local governance and collective action efforts shown in Fig. 1 that are in various stages of development. In the Southwest (SW) region, local water rights owners in northern Finney and Kearny counties considered different ways to reduce the rate of decline in the aquifer. A steering committee was formed to propose options for a proposed LEMA. A survey was conducted by the KDA in 2017 to better understand irrigators' views towards a potential LEMA versus purely voluntary reductions in water use. The survey results were unfavorable towards a LEMA and no LEMA proposal in the area has moved towards implementation.

The second management effort that we evaluate is the district-wide LEMA in Northwest (NW) Kansas that began in 2018[1]. This district-wide LEMA sets a 5-year allocation for pumping, where the allocation is defined for each township (approximately 6 miles $\times$ 6 miles) in the district. The LEMA was ultimately approved and implemented in 2018 but was not without controversy. In June 2018, a group of water right owners petitioned for judicial review of the LEMA in district court to challenge the LEMA orders and the validity of its statutory provisions. The district court upheld the LEMA order in October 2019, but the decision may be appealed.

The third management area is the Sheridan 6 LEMA contained within the boundary of the district-wide LEMA in the NW region in a portion of Sheridan and Thomas counties. The Sheridan 6 LEMA's first allocation period was 2013–2017 and a new allocation was approved for the 2018–2022 period[2]. The allocation in the Sheridan 6 LEMA is more stringent than the district-wide LEMA, but only the more stringent allocation is relevant to farmers. Minutes from meetings of the Sheridan 6 LEMA indicate broad support for the plan, but we have no data on which individuals might not support the plan. Therefore, we only discuss this collective action effort when we evaluate the Ostrom's design principles. The impacts of the Sheridan 6 LEMA on producer irrigation decisions have been examined in detail by Drysdale and

[1] https://agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/local-enhanced-management-areas/gmd4-district-wide-lema

[2] https://agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/local-enhanced-management-areas/sheridan-county-6-lema

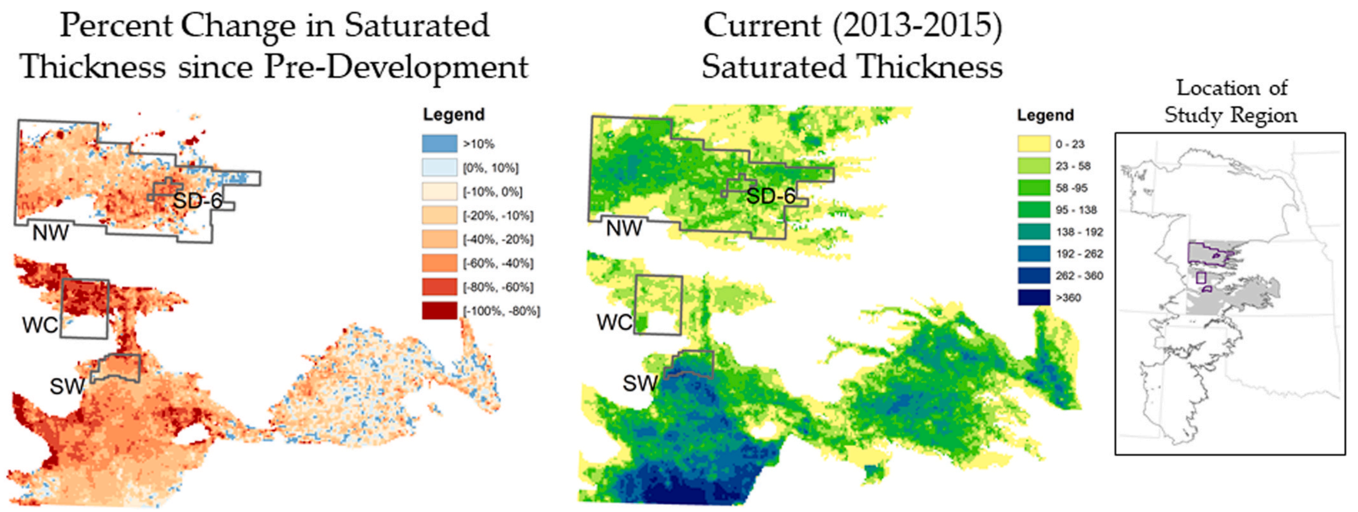

Fig. 1. Map of local governance and collective action initiatives. Note: The collective action initiatives that we study are abbreviated as NW = Northwest district-wide LEMA, SD-6 = Sheridan-6 LEMA, WC = Wichita County WCA, and SW = Southwest LEMA proposed in northern Finney and Kearny counties.

Hendricks (2018) and Deines et al. (2019).

The fourth management area that we consider is the WC WCA[3]. Some water rights owners in WC voluntarily joined together to create a plan to reduce water use with a collective desire to sustain their community by conserving groundwater resources. A small group worked together to create the plan and then recruited water users in the county to voluntarily join the effort. WC is in a portion of the aquifer that is highly depleted with little saturated thickness remaining (Fig. 1).

One management effort that we do not analyze in detail, given that we do not have a measure of support, is the 2014 proposed district-wide (GMD 1) LEMA in west-central Kansas. The proposal was for a six-year allocation where the allocations were defined as 20% reduction from historical use. The board of directors decided to put the GMD 1 LEMA up for a vote by water right owners, even though the legislation does not require a vote of water users. The LEMA proposal did not receive a majority of votes and was not implemented. We know the vote count in each county, but not the vote of each water user. WC is within GMD 1 and the WCA was proposed after the failure of the GMD 1 LEMA.

3. Data

In each case study, we have a measure of support for the management plan across different users except for Sheridan 6 LEMA. In the SW area, we have results from a survey conducted by KDA in 2017 to elicit feedback about a potential LEMA. The cover letter was signed by the manager of the GMD and it was stated the results of the survey would be shared with the local steering committee and the GMD board of directors. Therefore, while the survey is a stated preference survey, it has strong consequentiality so that users have an incentive to respond honestly (Vossler et al., 2012). The survey was mailed to all water users within the proposed LEMA boundary. There were 70 survey responses returned from 465 water users, for a response rate of about 15%.

In the NW area, we do not have information on which users supported the district-wide LEMA, but we do have information on some users who actively opposed the LEMA. In particular, we collect the names of the individuals or entities that filed a lawsuit to challenge the legality of the district-wide LEMA. We also obtained data on the allocations of each water right under the LEMA from KDA. A limitation of these data is that there are likely individuals that opposed the LEMA but did not participate in the lawsuit. However, it is still insightful to examine if the characteristics of those filing the lawsuit differed systematically from the rest of the water users.

In the WC area, we collected the names and water right numbers that voluntarily enrolled in the WCA from the WCA Agreements that were posted online. These data are unique because they represent revealed preferences on willingness to participate in a voluntary management plan.

For all three of these datasets, water right numbers are available which allow us to match them with data from the Water Information Management and Analysis System (WIMAS). The WIMAS data contain information for each water right on attributes of the water right (e.g., priority date), historical use, and location. In Kansas, all water rights are required to report their water use. We also merge hydrologic data obtained from Kansas Geological Survey to the WIMAS data at the section level as defined by the Public Land Survey System (PLSS).

We also supplement the data above with qualitative data. We reviewed groundwater users' testimonies from public meetings held in the process of approving the district-wide LEMA in GMD 4. We also reviewed the documents that define the management plans and meeting minutes for the district-wide LEMA, Sheridan 6 LEMA and WC WCA since there are formal documents to define the rules in these areas.

4. Methods and analytical framework

We evaluate the four cases following the eight design principles for long-term institutions for collective action proposed by (Ostrom, 1990). We also identify factors that affect the irrigators' willingness to participate in collective action to effectively manage the aquifer. The key issue is to understand how resource and user attributes affect the perceived benefits and costs. Following Ostrom (2002) we observe that each groundwater user (i) compares the net benefits under the old rules (BO) with the expected benefits under the new rules (BN):

$$D_i = BN_i - BO_i,$$

where D_i is the user's incentive to support the new rules. If $D_i > 0$ for some users, then they consider three costs: initial costs of time and effort spent organizing and agreeing under the new rules ($C1$); short-term costs of operating in the new conditions ($C2$); and long-term costs of monitoring and maintaining new rules ($C3$). Hence, user i will invest time and effort to implement new institutions if the incentive to change exceeds the sum of the expected costs:

$$D_i > C1_i + C2_i + C3_i.$$

[3] https://agriculture.ks.gov/divisions-programs/dwr/managing-kansas-water-resources/wca

In our setting, irrigators are extracting groundwater from a shared aquifer. Expected benefits under the old rules (*BO*) reflect the stream of profits under the existing prior appropriations doctrine. Expected benefits under the new rules (*BN*) of reduced allocations could be larger than under the old rules if the allocations correct the spatial externality of pumping on neighboring wells. Under the new rules, the farmer could sacrifice some profits in the short run for greater profits in the long run. The difference in expected benefits (D_i) could differ across groundwater users due to aquifer and soil conditions. For example, areas with greater hydraulic conductivity and lower recharge have greater expected benefits from management (Edwards, 2016). Areas with too large of a saturated thickness may also have smaller gains from management because the negative impacts of excess depletion are not imminent and areas with too small of a saturated thickness may also have smaller gains from management because there is little aquifer to preserve (Foster et al., 2017). Differences in expected benefits could also differ across users due to different preferences. For example, users may also differ in how they discount future benefits. Some users may value preserving the lifestyle of farming for future generations more than others.

Costs of management are also likely to differ across users. Users likely differ in their willingness to organize or attend meetings where the new rules are discussed (i.e., $C1$ differs across users). Contracting costs arise during the initial phase when users negotiate the new rules, and when these costs are high users are less likely to agree on pumping controls (Ayres et al., 2018). The public good nature of the collective action efforts and the existence of significant differences in the perceived benefits and costs of the users imply that $C1$ is endogenous. For instance, users who have a large benefit from management (i.e., a large D_i) may be willing to invest more time and effort in organizational efforts (i.e., a larger $C1_i$) to overcome non-contributors and provide the management system. In the short-term, irrigators must learn and adopt new strategies to use less water for production ($C2$). The cost of managing these new operating conditions might differ across irrigators given different production costs and farm characteristics. The costs of monitoring and maintaining the new rules ($C3$) is fairly low in our setting because governance structures are already in place to monitor and enforce the new rules. All irrigation water rights in these regions are required to have meters and report their water use to the state annually.

5. Main lessons

To organize our discussion of results from evaluating these four case studies, we highlight five main lessons. Each lesson is supported by either quantitative or qualitative analysis with the available data.

Lesson 1. The four management plans generally follow Ostrom's design principles for collective action, but there are some weaknesses in the design for a complex system.

Design Principle 1: clearly defined boundaries

Clearly defined boundaries should state who can access the resource and which users are subject to the rules of the management plan. The Kansas Water Appropriation Act requires groundwater users to obtain a right to extract water so that the users of the resource system are clear. Both the LEMA and WCA plans establish clear geographic boundaries which help users to understand which water rights are subject to the management plan and what their allocations would be under the plan.

While the boundaries of the management plans are clear, they are not without controversy. The boundary proposed for a LEMA in the SW area was defined by aquifer conditions and natural hydrologic boundaries. However, 55% of the survey respondents indicated that they did not agree with the proposed LEMA boundary. Most of those who did not agree with the boundary wrote comments that the entire GMD should be included instead of only the small region.

In the NW area, the proposed district-wide LEMA has definite boundaries for the allocations defined by townships within the district. Using township boundaries for the allocations was one of the most frequently discussed points during the public hearings. Those testifying in opposition to the plan argued that the boundaries were not hydrologic and that more analysis was required to better define the boundaries. Some also argued that township boundaries were too crude and smaller areas were required to sufficiently consider the difference in aquifer conditions within the GMD.

The Sheridan 6 LEMA is contained within the boundary of the district-wide LEMA in the NW region, but the Sheridan 6 is more restrictive than the district-wide LEMA. The boundaries of the Sheridan 6 LEMA, as well as the process by which they were defined, were extensively discussed by GMD 4, Kansas Geological Survey (KGS), and local stakeholders during the public hearing. Before the idea of a Sheridan 6 LEMA was conceived, the boundary had been defined by the GMD to define a high-priority area based upon sound and well-developed hydrologic data. Therefore, water users did not have to negotiate the boundary definition by themselves.

In general, a challenge with defining boundaries is that the aquifer does not have strict boundaries due to lateral flows of the groundwater. The management plans in the NW and SW areas create situations where a user on one side of the road may have allocations that significantly reduce water use while a user across the road does not have stringent allocations even though they both have similar aquifer conditions. Allowing the allocations to vary in a spatially smooth manner could help alleviate these concerns, but a disadvantage is that a spatially smooth algorithm is not likely to be as transparent.

There is a tradeoff in using hydrologic versus political boundaries. On the one hand, defining boundaries based on hydrology (e.g., a boundary of an aquifer) implies that changes in water use within the management area have minimal hydrologic impact outside of the area so that there are small externalities. But the hydrologic boundary may not align well with how people interact with each other. An advantage of defining boundaries based on political boundaries (e.g., a county) is that there are other governance and social systems already operating that can be utilized to coordinate water users. A disadvantage of using political boundaries is that aquifers do not follow political boundaries so there will by hydrologic externalities.

Design Principle 2: congruence

The second design principle implies that the benefits should be proportional to the costs imposed by the rules across users and the rules should be based on local conditions (Ostrom, 2002). In other words, the rules should be viewed as fair.

The LEMA proposal in the SW area states that water right owners will be provided a 5-year allocation. The steering committee set a goal of reducing water use by 11% and defined three alternative allocation options: (1) limit water allocation to 85% of recent historical average annual water use (2006–2015), (2) limit water allocation to the minimum of 90% of recent historical average annual water use (2006–2015) or 58% of the water right annual authorized quantity or (3) limit all water allocations to 50% of their water right annual authorized quantity.

Table 1 shows the survey results where water users were asked to rank their preferences of the allocation options. Of the 30 usable responses to the question, we can observe that defining allocations based solely on authorized quantity was the least popular (10%). But there is pretty even split between the other two options. Some written comments on the survey stated that they did not like reductions based on historical

Table 1
Preferred option for calculating LEMA allocations in the SW area.

	Percent of water users
Option 1	47
Option 2	43
Option 3	10
Other methods	34

use because the options supported the wrong attitude of "use it or lose it." Moreover, we could not find a clear correlation between the most preferred option and the higher allocation.

Roughly 34% of users in the SW area stated that they preferred an alternative method to the three listed. Most of the comments among these respondents can be summarized as follows: use a different set of years to determine historical use, use a smaller percent reduction in water use from authorized quantity, or use a uniform allocation across all water rights. One thing that is clear from the survey is that there is no broad agreement about how to define allocations.

The district-wide LEMA in the NW area defined allocations based on a township's average rate of depletion and net irrigation requirement for corn[4]. The allocation for each township differs by precipitation (regions with less precipitation receive larger allocations) and by the rate of aquifer depletion (regions with slower rates of depletion receive larger allocations). However, the allocations were questioned during the second public hearing, and also by those irrigators who are filing a lawsuit against the LEMA. They mostly argue that the implementation of the LEMA ignores prior appropriations doctrine and could constitute a "takings" of a property right. Some testimonies also argued that the allocations should be even more localized to the section level (1 mile × 1 mile) rather than township level (6 miles × 6 miles).

One sign of a lack of congruence would be if those users that filed the lawsuit were the ones facing the most stringent allocations. This does not seem to be the case. Table 2 shows that only 9% of the water rights that filed the lawsuit have an allocation that is more 10% of a decrease from their historical water use—a similar proportion among those that did not file the lawsuit. Somewhat surprisingly, 82% of the water rights have an allocation greater than historical water use among those that filed the lawsuit.

In the Sheridan 6 LEMA case, all water rights were provided with 55 in. per authorized acre for the five year LEMA period. Authorized acres were defined as the maximum number of acres irrigated in a single year between 2007 and 2010. Irrigators could use their 55 acre-inch allocation with flexibility as needed, using more water in dry years while saving water in wet years when full irrigation is not needed. They could also seek temporary transfers of allocations between water rights within the Sheridan 6 boundary. An advantage of the Sheridan 6 LEMA is that the region is relatively small so all users face roughly the same hydrologic, soil, and climatic conditions. The similarity of conditions within the region was conducive for a simple uniform allocation of 55 in. per authorized acre.

The allocations in the WC area define an allocation for each well over a seven year period that is based on a percent reduction from use for the period 2009–2015. Those that enrolled in the WCA committed to reduce water use by roughly 30%. An advantage of this method is that everyone is required to reduce their water use by the same percent, which some view as "fair." Another reason for people to promote a reduction based on historical use is that it implicitly accounts for differences in aquifer conditions that affect well capacities (i.e., the rate at which water can be extracted). If every user is extracting the maximum possible based on their well capacity, then reductions from historical use simply reflect differing aquifer conditions. However, concerns are also raised that reductions from historical use penalize voluntary water conservation in the past and promote a mindset of "use it or lose it."

Table 2
Decrease in historical water use under the district-wide LEMA allocation.

	Did not file lawsuit (%)	Filed lawsuit (%)
No decrease	80	82
0–10%	11	9
More than 10%	9	9

Design Principle 3: collective choice arrangements

The third design principle refers to the relationship between the governing system and users. In particular, users should be able to participate in making and modifying the rules. The involvement of water users in the process of making policies or management plans is essential to the overall acceptance of the policy's implementation and results (Guerrero et al., 2008; Shalsi et al., 2019; D'Agostino et al.). Moreover, users face lower transaction costs when they have a significant level of autonomy to create and modify institutional arrangements, and to enforce the rules (Ostrom, 2009).

The SW area has conducted informational public meetings to share information about the proposed LEMA, and they also post information on a website[5]. The survey carried out in the SW area that we use in this paper was another tool to collect irrigators' opinions on potential solutions to the declining aquifer.

In the NW area, two rounds of informational meetings were held before the board of directors officially submitted the district-wide LEMA proposal to the state. As part of the legal process of approving the LEMA, two public hearings were held[6]. From the testimonies of the second public hearing in the NW area some irrigators expressed that they did not have a sufficient level of involvement in the creation of the LEMA proposal. They argued that the board of directors did not represent water right owners thoughts and that the board made little effort to involve water users in the process. Some water users stated that they were not aware of the specific details contained in the plan because of the incomplete information and poor quality of the public informational meetings. The process for the district-wide LEMA in the NW area is in contrast to the Sheridan 6 LEMA. For the Sheridan 6 LEMA we find a record of 13 meetings beginning in November 2008, where all water users in the area could participate and help influence the final plan. A formal LEMA proposal was not submitted until July 16, 2012.

In the WC area, irrigators voluntary decide to participate in the management plan. The WCA rules were formed by a sub-group of local water users. However, it is unclear to us how much input from the broader users was sought and whether or not the proposal was modified as a result of such input.

Design Principle 4: monitoring

Successful collective management requires regular monitoring of resource conditions and user behavior. There already exists a robust set of monitoring wells throughout the region to monitor aquifer conditions. In all four cases, monitoring of water use is already occurring under the current legal framework because users are required to annually report their water use to KDA to ensure that they did not exceed the authorized pumping. In all four areas, users are required to have meters to give an accurate accounting of water extracted and all management plans rely on metered water use to monitor allocations.

Design Principle 5: graduated sanctions

The fifth design principle is that sanctions or penalties should depend on the seriousness of the violation. We see a stark contrast in the penalty structure of the WCA in the WC area to the district-wide LEMA and Sheridan 6 LEMA in the NW area (Table 3). The sanctions in the WC area follow the design principle as the penalty increases according to the severity of the violation. Intuitively, the penalty is calculated per acre-

[4] A map of the allocations per authorized acre can be accessed at http://gmd4.org/

[5] https://kfl2017.weebly.com/meetings.html

[6] The objective of the initial hearing is to determine that three necessary conditions hold: there exists a need for water conservation; the public interest requires corrective controls provisions; and the geographic boundaries are reasonable. The second hearing addresses the corrective controls. The Chief Engineer makes a decision whether to approve the LEMA proposal after the hearings or could return the plan to the GMD to incorporate recommended revisions.

Table 3
Management plan sanctions.

Violation	Extent of violation	Monetary penalty ($)	Civil penalty
Panel A: WCA in WC area			
Failure to submit required information	First	1000	None
	Second	3000	None
	Third	10,000	Suspension of the water right
Excessive use of water-1st violation	0.01–5.00 AF	500/AF	None
	5.01–10.00 AF	1000/AF	None
	≥10.01AF	1500/AF	None
Excessive use of water-2nd violation	0.01–5.00 AF	1000/AF	None
	5.01–10.00 AF	2000/AF	None
	≥10.01AF	3000/AF	None
Excessive use of water-3rd violation	≥0.01AF	10,000/AF	Suspension of the water right
Panel B: NW LEMA and Sheridan 6 LEMA			
Exceeding total allocation	<4 AF	1000/Day	None
	≥4AF	1000/Day	2-year suspension of the water right

Note: AF = acre-feet.
Sources: Wichita County WCA Management Plan and GMD 4 LEMA Order of Designation.

foot exceeding the allocation. All monetary penalties are remitted to the WCA board of directors which could use those funds only for water conservation and community improvements. It is the board of directors who notify a WCA participant of any alleged violation in the WCA.

In contrast, the penalty matrix for the NW LEMA and Sheridan 6 LEMA is less graduated and less intuitive. In the WCA, suspension of the water right only occurs after the third violation. In the NW LEMA and Sheridan 6 LEMA, a suspension occurs on the first violation if the violation is greater than 4 acre-feet. To put this into perspective, average historical pumping in this region is 157 acre-feet, so 4 acre-feet is a relatively small violation. Setting the penalty in dollars per day of violation is also much less intuitive than a simple dollars per acre-foot penalty. The penalty of $1000 per day of violation is derived from the maximum penalty under the Kansas Water Appropriation Act. It also seems that the penalties under the LEMA are paid to KDA and may not be used for water conservation efforts in the NW area.

Design Principle 6: conflict-resolution mechanisms

Conflicts and disagreement about how to interpret a set of rules to manage a common-pool resource arise easily (Cox et al., 2010). Therefore, it is necessary to establish a mechanism to resolve conflicts. The district-wide NW LEMA and SD-6 LEMA provide an appeals process regarding eligible acres and the water allocation. In the case of the WCA in the WC area, there were three options for a farmer to determine "historical use." First, they could simply use the seven-year historical average. Second, they could exclude years with zero from the calculation. Third, they could conduct a flow test to determine the rate at which water can be extracted times 135 days. The three options provided some flexibility in determining the allocated quantity rather than only a single rule.

Design Principle 7: minimal recognition of rights to organize

Design Principle 7 states that external government agencies do not challenge the right of local resource users to create and organize their own institutions. The LEMA and WCA statutes passed by the state of Kansas were critical in providing the legal support to organize and develop recognized plans. These statutes were also critical for initiating collective action efforts in Kansas and serve as a model for other states.

Design Principle 8: nested enterprises

Design Principle 8 applies when common-pool resources are components of a larger system. In Kansas, the lateral flow of groundwater is relatively slow so aquifer depletion is a localized problem. However, the region is all connected as a part of the High Plains Aquifer. Nested enterprises allow small groups of users to have influence on rules within their region, but these small groups are nested within larger organizations. The Sheridan 6 LEMA, WC WCA, and SW LEMA are all composed of a relatively small group of users with similar resource concerns that are organized within a larger GMD that are under the DWR-KDA. The exception to a nested enterprise is the NW district-wide LEMA where the rules were established by the GMD board of directors without the formation of small groups to influence rules within their respective regions of the GMD.

Importantly, the GMDs were established within the larger legal system of prior appropriations. Therefore, a LEMA or WCA cannot increase the water right allocations of any water right and priority can still be exercised. If a LEMA provides allocations greater than a water right's annual authorized quantity, then the authorized quantity is binding rather than the allocation. Senior water right users are also still legally entitled to the ability to file an impairment complaint against neighboring junior water rights under the priority system.

Lesson 2. A majority of farmers agree that action is needed to reduce the rate of aquifer depletion but management plans have not substantially reduced water use, with the exception of the Sheridan 6 LEMA.

As table 4 shows, most irrigators believe that groundwater should be conserved through some type of management plan. Based on the survey results in the SW area, we can observe that 88% of water users and 92% of water rights support the LEMA or would participate in a WCA, but no action has been taken yet. A particular challenge is that only 53% of water users and 33% of water rights supported the LEMA, making it difficult to justify moving forward with the LEMA. No large WCA has occurred in the region even though 69% of water users and 81% of water rights said they would participate in a WCA. This is perhaps because of the free-rider problem of voluntary agreements and the survey had little consequentiality in terms of participating in a WCA that could have created hypothetical bias. So although many users in the region support management to reduce water use, no reduction has been achieved in the SW area since the LEMA has not been implemented (Table 5).

In NW, the district-wide LEMA was implemented in 2018 but some of the irrigators filed a lawsuit against it. At least 5% of water users and 7% of the water rights in GMD 4 oppose the proposed district-wide LEMA since they filed the lawsuit. Admittedly, we do not have a great measure of how many water users supported the district-wide LEMA, but at least relatively few were willing to join the lawsuit. GMD 4 implemented its district-wide LEMA, but we find that the allocations only reduce water use by 2.2% compared to historical water use (2009–2015) in the district (Table 5). In contrast, Drysdale and Hendricks (2018) find that the

Table 4
Measures of support by region.

Measure of support	Percent of Water Users	Percent of Water Rights
Panel A: SW (42 users, 219 rights)		
Prefer LEMA, would participate in WCA	36	23
Prefer LEMA, would NOT participate in WCA	17	10
Prefer WCAs, would participate in WCA	33	58
Prefer WCAs, would NOT participate in WCA	2	1
No action is needed	12	8
Panel B: NW (837 users, 2215 rights)		
Did not file lawsuit	95	93
Filed lawsuit	5	7
Panel C: WC (284 users, 742 rights)		
Did not enrolled in WCA	91	93
Enrolled in WCA	9	7

Table 5
Group size and expected percent reduction in actual water use.

	Number of water rights	(%)
SW LEMA	614	0
District-wide LEMA	2215	2.2
Sheridan 6 LEMA	185	26
WC WCA	742	4.5

Notes: Reductions are calculated as follows: SW LEMA is 0 because nothing was implemented; district-wide LEMA is calculated by comparing historical average water use to allocations for each water right; Sheridan 6 LEMA is estimated by Drysdale and Hendricks (2018); and WC WCA assumes a 29% reduction among the water rights that participated.

Sheridan 6 LEMA decreased water use by 26% (Table 5).

As we already mentioned, a district-wide LEMA in west-central Kansas was proposed in 2014 by the GMD 1. The LEMA proposal failed because users in most of the counties voted against the LEMA. However, in WC, a majority of water users (62%) supported a LEMA based on the votes. Even though a majority of water users in WC supported a management plan little conservation has occurred so far (Table 5). The low reduction in water use is because the participation in the voluntary WCA only includes 9% of the water users and 7% of the water rights.

Lesson 3. Management plans that allow for voluntary participation have not received more support than those that require mandatory participation.

According to our results in Table 4, more water users prefer a LEMA (53%) than a WCA (35%) in the SW area. And as stated previously, the willingness to participate in a WCA may be overstated in the survey given the evidence from revealed preferences that a large WCA does not exist in the region today. The preference for mandatory can be seen more clearly in Wichita County where 62% of water users voted for a mandatory plan (LEMA), but only about 9% of users enrolled in a voluntary plan (WCA). The failure of the WCA in WC to get sufficient enrollment has led to current discussions about forming a LEMA in WC (not the entire GMD) for a five year period 2021–2025[7].

Lesson 4. There is no clear evidence that heterogeneous benefits from management explain support within a management area.

Table 6 shows how aquifer conditions differ between those water users that support or oppose management plans within each management area. Hydraulic conductivity is a measure of the rate of lateral flows of the aquifer. Areas with larger hydraulic conductivity are expected to have larger benefits from management. We find the expected sign in WC that is statistically significant, but the opposite signs in the SW and NW, where NW is also statistically significant. There are no significant differences in the rate of aquifer depletion (i.e., the change in saturated thickness) or current saturated thickness. We would expect benefits from management increase with well density. Only in the WC area we observe that density of wells is significantly larger among those that support. Therefore, we find no systematic differences in aquifer attributes based on whether irrigators support management.

While aquifer conditions within the management area are not related with support, it could be that these management areas are forming in areas where the gains from management are largest in general. For example, saturated thickness levels in NW fall within the range of depletion estimated by Foster et al. (2017) where farmers obtain higher benefits from water conservation efforts.

Table 7 shows how the characteristics of the irrigators differ between those who support and those who oppose the management efforts in each area. The first row of each panel shows the average water right number of each group, where a smaller water right number indicates a more senior water right. We hypothesize that more senior water right holders are more likely to oppose the management plan because they can protect their right based on seniority and none of the management plans differentiate allocations by seniority. However, the results do not support this hypothesis since the difference is not statistically significant for any area and those opposed are more junior on average for the SW and NW areas.

The second row of each panel shows the intensity of irrigation (i.e., the amount of water applied per acre). In the SW and NW areas, the difference is the opposite of expected—users who apply more water are more likely to support management—but the differences are not statistically significant. In the WC area, those that enrolled in the WCA historically used significantly more water than those that did not enroll. This makes sense in the WC area because the allocations in the WCA are defined as a percent reduction from historical use so larger water users received a larger allocation.

The third row in each panel shows total acres irrigated for the water user (i.e., a measure of irrigated farm size). Those that filed the lawsuit in the NW area manage significantly more irrigated acres, but we get the opposite result for SW and WC areas. When we analyze the SW region, we find that farmers who oppose the LEMA are on average larger than those who support it. Farmers who oppose the LEMA manage on average 937 irrigated acres while those who support it manage on average 501 irrigated acres. However, farmers who oppose the WCA are smaller than those who support it. They manage on average 453 and 1276 irrigated acres, respectively. Therefore, we can observe that either in SW and WC areas, farmers who support management plans that require voluntary participation (WCA) are on average larger, in terms of irrigated acres,

Table 6
Comparison of aquifer's attributes between support and opposition.

	Support	Opposed	Mean Diff.
Panel A: SW			
Hydraulic conductivity (ft per day)	67	80	−13
Change in saturated thickness (2003–2013) (ft)	−30	−25	−5
2014 saturated thickness (ft)	174	152	22
Density of wells (2 miles radius)	27	28	−1
Panel B: NW			
Hydraulic conductivity (ft per day)	78	89	−11*
Change in saturated thickness (2003–2013) (ft)	−9	−8	−1
2014 saturated thickness (ft)	73	68	5
Density of wells (2 miles radius)	13	12	1
Panel C: WC			
Hydraulic conductivity (ft per day)	82	73	9*
Change in saturated thickness (2003–2013) (ft)	−8	−7	−1
2014 saturated thickness (ft)	27	25	2
Density of wells (2 miles radius)	20	17	3*

* Mean difference significant at 5% level of significance.

Table 7
Comparison of users' attributes between support and opposition.

	Support	Opposed	Mean Diff.
Panel A: SW			
Water right number	8894	10,105	−1211
Historical intensity of irrig. (in)	14	13	1
Historical total irrigated acres	851	352	499
Panel B: NW			
Water right number	20,493	22,684	−2191
Historical intensity of irrig. (in)	13	13	0
Historical total irrigated acres	331	704	−373*
Panel C: WC			
Water right number	13,119	13,051	68
Historical intensity of irrig. (in)	14	11	3*
Historical total irrigated acres	452	238	214*

Note: Intensity of irrigation and total irrigated acres are the averages of 1991–2014 period.
* Mean difference significant at 5% level of significance

[7] See http://www.gmd1.org/lema.html for more details.

than those who oppose them.

Lesson 5. Groundwater users generally perceive that they have an acceptable level of information.

It is important to have information available at a low cost about the aquifer and the consequences of any proposed management plan. When users do not share a common understanding of the resource system it could be difficult to agree on a collective management plan. The expected costs of collective action are lower when users have a common understanding of the resource's characteristics and how their actions affect each other (Ostrom, 2009).

The survey in the SW area asked if users have sufficient knowledge and understanding of the local aquifer conditions and their own groundwater use to make an informed response to the LEMA proposal. Of the 43 usable responses to the question, 72% said they have sufficient knowledge. Examining the written comments following this question did not indicate any common concerns about a lack of information about the resource.

GMD 4 in the NW area conducted two informational meetings in each county before the board of directors approved a formal LEMA plan to inform users about the proposal. These meetings allow users to discuss the plan and exchange information as part of the development process.

Public informational meetings were also held before the WCA in the WC area began and the governance of the WCA requires annual meetings of the membership to update their water management policies. These public meetings provide an opportunity for users to develop a common understanding.

6. Discussion and conclusions

Lesson 1 analyzes how well collective action efforts in a developed country context align with Ostrom's design principles. We find that the management plans are in general consistent with the design principles, but there are important areas where the management plans could be improved. The boundaries of management areas could have a better hydrologic rationale that is understood by water users. Allocations could have smoother differentiation at boundaries to avoid equity and hydrologic externality concerns.

The method of assigning allocations is especially controversial and deserves substantial discussion among users to determine a method that is deemed fair by a majority of users. A suggestion is that GMDs could conduct surveys to better understand the method of assigning allocations that is preferred by most users. Public meetings are useful, but the discussion is often dominated by a few individuals and may not reflect the majority view. Transaction costs associated with finding agreement on the rules might explain why many regions have struggled to effectively adopt restrictions to manage the aquifer. A small group (i.e., the board of directors) using feedback from a survey to construct a management plan could reduce these transaction costs yet allow users to feel like they had input.

Lesson 2 shows that even though a majority of farmers agree that action is needed to reduce groundwater use, minimal reductions have been achieved so far. Only the Sheridan 6 LEMA achieved a large reduction in water use. The NW district-wide LEMA implemented a plan that results in little reduction in use—perhaps to avoid opposition to a more stringent plan. The SW area achieve no reduction in use because they could not get sufficient support to implement the LEMA. And, the WCA in WC achieved little reduction in use because few water rights enrolled.

The smaller scale of the Sheridan 6 LEMA compared with the other plans might facilitate agreement by users on boundaries, allocation rules, monitoring, and enforcement. As the management area becomes larger in scale, it is less likely that groundwater users effectively communicate, coordinate, and interact to develop a plan to manage the aquifer. Therefore, we suggest management plans may be more effective if they use separate plans within a district based on the localized input of users.

We also observed that users need significant involvement in the formation process of a management plan. A practical suggestion is to elicit feedback from as many users as possible. This can slow the time to implement a plan and require substantial effort by leadership, but increase support for the management plan among users. It will also be important to study the changes in profitability in areas that have implemented more stringent restrictions. Reducing uncertainty about the change in net benefits from reduced water use could increase support for management plans. Specific information about how the management plan is likely to impact aquifer levels could also increase support.

From Lesson 3 we learn that management plans that allow for voluntary participation have not received more support than those that require mandatory compliance. A barrier to getting sufficient voluntary participation in a WCA is the well-known free rider problem. Farmers decide to not participate in the WCA to obtain benefits from the collective efforts of others without contributing to the costs. Mandatory compliance is necessary to address the free rider problem. It is especially interesting to note that after the lack of enrollment in the WC WCA, users in the same region have pursued a mandatory LEMA that is in the process of approval at the time of this writing. If approved, the WC LEMA is expected to decrease water use by roughly 25%. This lesson suggests that purely voluntary collective action efforts are not sufficient in a developed country context, so local governance is required to make significant improvements in resource conditions.

Lesson 4 states that there is no clear evidence that heterogeneous benefits from management explain support within a management area. Support for management differed across users within the same system and we could not find a clear set of characteristics of those users who support or oppose each plan. Unobserved factors like ideological differences are likely to explain why some users support the management plans and other do not. Therefore, policymakers cannot look only at differences in biophysical characteristics as explaining differences in support, but also need to understand the underlying ideological differences of users. And if seeking to garner larger support, they need to try to appeal to some of these different ideological preferences. An important area for future research is to measure some of these differences in demographics and ideology.

Finally, Lesson 5 indicates that groundwater users generally perceive that they have an acceptable level of information. This result does not mean that users have enough information. It only states that users perceive they have enough information. We cannot generalize this result beyond Kansas as different hydrologic systems have different levels of complexity. Additionally, we are not able to test if the users engage in collective action because they truly have a firm understanding of the aquifer conditions or if they are biased in their level of understanding and ability to make projections in the future. While users perceive they have enough information, there are still likely benefits from reducing uncertainty about the economic and hydrologic impacts of reduced water use.

This work analyzes collective action efforts in Kansas using a general framework from Elinor Ostrom's pioneering work. Our results provide valuable insights for policymakers in developed country contexts. We find that the complexity of the physical and social systems make it difficult to achieve successful collective action. However, there has been success in Kansas for efforts that are small-scale, mandatory, and involve local users in the formation process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by the US Department of Agriculture (USDA-NIFA 2017-67023-26276) and the National Science Foundation Research Traineeship (NRT) program (NSF 1828571). We thank the Kansas Department of Agriculture for access to the GMD3 survey data. We thank anonymous reviewers, Susan Metzger, participants at the Agricultural and Applied Economics Association annual meeting, and participants at the Governor's Conference on the Future of Water in Kansas for helpful comments.

References

Ayres, A.B., Edwards, E.C., Libecap, G.D., 2018. How transaction costs obstruct collective action: the case of California's groundwater. J. Environ. Econ. Manag. 91, 46–65.
Baggio, J.A., Barnett, A.J., Perez-Ibarra, I., Brady, U., Ratajczyk, E., Rollins, N., Rubiños, C., Shin, H.C., Yu, D.J., Aggarwal, R., Anderies, J.M., Janssen, M.A., 2016. Explaining success and failure in the commons: the configural nature of ostrom's institutional design principles. Int. J. Commons 10 (2), 417–439.
Butler, J.J., Whittemore, D.O., Wilson, B.B., Bohling, G.C., 2016. A new approach for assessing the future of aquifers supporting irrigated agriculture. Geophys. Res. Lett. 43, 2004–2010.
Butler, J.J., Whittemore, D.O., Wilson, B.B., Bohling, G.C., 2018. Sustainability of aquifers supporting irrigated agriculture: a case study of the High Plains Aquifer in Kansas. Water Int. 43 (6).
Coase, R.H., 1960. The problem of social cost. J. Law Econ. 3, 1–44.
Cody, K.C., Smith, S.M., Cox, M., Andersson, K., 2015. Emergence of collective action in groundwater commons: irrigators in the san luis valley of colorado. Soc. Nat. Resour. 28 (4), 405–422.
Cox, M., Arnold, G., Tomás, S.V., 2010. A review of design principles for community-based natural resource management. Ecol. Soc. 15 (4).
D'Agostino, D., Borg, M., Hallett, S.H., Sakrabani, R., Thompson, A., Papadimitriou, L., Knox, J., 2020. Multi-stakeholder analysis to improve agricultural water management policy and practice in malta. Agric. Water Manag. 229.
Deines, J.M., Kendall, A.D., Butler, J.J., Hyndman, D.W., 2019. Quantifying irrigation adaptation strategies in response to stakeholder-driven groundwater management in the US High Plains Aquifer. Environ. Res. Lett. 4, 044014.
Demsetz, H., 1967. Toward a theory of property rights. Am. Econ. Rev. 57 (2), 347–359.
Drysdale, K.M., Hendricks, N.P., 2018. Adaptation to an irrigation water restriction imposed through local governance. J. Environ. Econ. Manag. 91, 150–165.
Edwards, E.C., 2016. What lies beneath? Aquifer heterogeneity and the economics groundwater management. J. Assoc. Environ. Resour. Econ. 3 (2), 453–491.
Foster, T., Brozovi, N., Butler, A.P., 2017. Effects of initial aquifer conditions on economic benefits from groundwater conservation. Water Resour. Res. 53, 744–762.
Guerrero, B., Amosson, S., Almas, L., 2008. Integrating stakeholder input into water policy development and analysis. J. Agric. Appl. Econ. 40 (2), 465–471.
McGuire, V.L., 2017. Water-level and recoverable water in storage changes, high plains aquifer, predevelopment to 2015 and 2013-2015. U. S. Geol. Surv. Sci. Investig. Rep. (5040).
Meinzen-Dick, R., 2018. Tragedy revisited. Science 362, 6420.
Ostrom, E., 1990. Governing the Commons: The Evolution of Insitutions for Collective Action. Cambridge University Press, Cambridge, UK.
Ostrom, E., 2002. Common-pool resources and institutions: toward a revised theory. In: Gardner, B., Rausser, G. (Eds.), Handbook of Agricultural Economcs, vol. 2. Elsevier, pp. 1315–1339.
Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325 (5939), 419–422.
Scanlon, B.R., Faunt, C.C., Longuevergne, L., Reedy, R.C., Alley, W.M., McGuire, V.L., McMahon, P.B., 2012. Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. Proc. Natl. Acad. Sci. USA 109 (24), 9320–9325.
Shalsi, S., Ordens, C.M., Curtis, A., Simmons, C.T., 2019. Can collective action address the "tragedy of the commons" in groundwater management? insights from an australian case study. Hydrogeol. J. 27, 2471–2483.
Smith, S.M., 2016. Common property resources and new entrants: uncovering the bias and effects of new users. J. Assoc. Environ. Resour. Econ. 3 (1), 1–36.
Smith, S.M., Andersson, K., Cody, K., Cox, M., Ficklin, D., 2017. Responding to a groundwater crisis: the effects of self-imposed economic incentives. J. Assoc. Environ. Resour. Econ. 4 (4), 985–1023.
Steward, D.R., Allen, A.J., 2016. Peak groundwater depletion in the High Plains Aquifer, projections from 1930 to 2110. Agric. Water Manag. 170, 36–48.
Steward, D.R., Bruss, P.J., Yang, X., Staggenborg, S.A., Welch, S.M., Apley, M.D., 2013. Tapping unsustainable groundwater stores for agricultural production in the High Plains Aquifer of Kansas, projections to 2110. Proc. Natl. Acad. Sci. 110 (37), E3477–E3486.
Vossler, C., Doyon, M., Rondeau, D., 2012. Truth in consequentiality: theory and field evidence on discrete choice experiments. Am. Econ. J. Microecon. 4 (4), 145–171.