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The importance of fit in groundwater self-governance

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Landon T Marston^{1,*} , Sam Zipper² , Steven M Smith³ , Jonah J Allen³ , James J Butler² ,
Sukrati Gautam⁴ and David J Yu^{4,5,6}¹ Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24061, United States of America² Kansas Geological Survey, University of Kansas, Lawrence, KS 66047, United States of America³ Department of Economics and Business, Colorado School of Mines, Golden, CO 80401, United States of America⁴ Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47907, United States of America⁵ Department of Political Science, Purdue University, West Lafayette, IN 47907, United States of America⁶ Center for the Environment, Purdue University, West Lafayette, IN 47907, United States of America

* Author to whom any correspondence should be addressed.

E-mail: lmarston@vt.edu

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1. Introduction

The primary use of groundwater globally is for irrigated agriculture. In many heavily-stressed aquifers, sustaining water resources requires shifts in management practices, with reductions in pumping often being the only viable option to diminish groundwater decline rates (Deines *et al* 2019, Butler *et al* 2020). Broadly, strategies to reduce pumping can be classified as *top-down*, in which rules are specified by a centralized governance organization, or *bottom-up*, in which the irrigators themselves develop and implement a strategy to sustain groundwater resources (Serra-Llobet *et al* 2016). Top-down approaches often struggle with buy-in from the affected irrigators and can lead to distrust between governing agencies and irrigators (Serra-Llobet *et al* 2016, Molle and Closas 2019). As a result, there is a growing impetus to develop bottom-up, community-based groundwater management systems to sustain water resources and avoid the imposition of top-down approaches (Smith *et al* 2017). While bottom-up governance of groundwater commons may offer a solution to slow or reverse groundwater depletion, there are few successful examples of such systems in large, industrialized agricultural settings and it is unclear what lessons learned from these settings are transferable to other heavily-stressed aquifers.

We argue that 'fit' to the unique social and environmental contexts of an area is the key to developing bottom-up governance systems that are effective, resilient, and adaptable. This notion of fit, also referred to as the problem of fit (Folke *et al* 2007),

means alignment between local contextual conditions and the governing rules on how people use and manage a resource. Designing governance arrangements that reflect local ecological dynamics and community attributes is key to sustainable governance of common-pool resource systems (Wijnen *et al* 2012, Ostrom 2009, Kiparsky *et al* 2017). On a macro level, consideration of such contextual conditions can also lead to diversity in rule designs that enhance adaptability and, thus, system-level resilience in the long-run (Brown 2003). Effective governance solutions to the deteriorating groundwater systems may also depend on solving such problems of fit.

Examples of bottom-up groundwater governance are more commonly found where a groundwater resource is shared by a limited number of small-holder farmers in developing countries (Wijnen *et al* 2012, Molle and Closas 2019). Legal, institutional, and social barriers often impede collective groundwater governance among numerous large-scale, industrialized farming operations in developed countries (Kiparsky *et al* 2017, Shalsi *et al* 2022). Nonetheless, water scarcity and new regulations have prompted farmers from California (Kiparsky *et al* 2017) to Australia (Shalsi *et al* 2022) to explore new means of water management where they have control of their own water future. Here, we highlight two examples of groundwater self-governance in the United States, which may offer general lessons for similar areas. We demonstrate that the fit of the governance rules with local conditions in these two study areas contributes to the effectiveness, resilience, and adaptability of these socio-environmental systems.

2. Self-governance of groundwater commons

There are two general forms of formal bottom-up groundwater governance: market-based approaches that use financial incentives or penalties and command-and-control approaches that set restrictive limits on pumping (Molle and Closas 2019). Hybrid systems, such as quotas with price limits or fees with a hard-pumping cap, are also possible. While neither governance system is intrinsically better than the other, the alignment of governance rules with the unique local environmental, socio-economic, and political contexts may cause an area to be more likely to adopt and find success with a given approach. Market-based and command-and-control systems can offer many of the same benefits. The assessment of pumping fees (market-based) and tradable, but restrictive, water-rights (command-and-control) can both increase farm values in different settings (Ayres *et al* 2021, Gebben and Smith 2022). If not overly prescriptive, both systems encourage a diversity of responses from irrigators, such as changes in cropping choice, irrigation technology, irrigation rates, or irrigated area, to lower the aggregate costs to meet the overall aims of the governance system.

While similar in many ways, market-based and command-and-control approaches each exhibit unique features which potentially fits with specific social-environmental contexts. We focus on two examples in the western United States—the Sheridan-6 Local Enhanced Management Area (SD-6 LEMA) in Kansas (command-and-control approach) and the San Luis Valley in Colorado (market-based approach)—to illustrate the alignment of socio-environmental context with bottom-up groundwater governance rules (figure 1). The two case studies are informed by review of the peer-reviewed literature for the study areas, semi-structured interviews of farmers and groundwater managers within both areas, and a systematic analysis of their governance documents.

2.1. Command-and-control approach: Sheridan-6 Local Enhanced Management Area

In Northwestern Kansas, a group of irrigators has self-organized to design groundwater management rules intended to ‘reduce decline rates and extend the life of the aquifer’ (SHPA6 GWC 2012) and, by extension, their livelihood. The boundaries of the 255 km² SD-6 LEMA were based on a fit between physical and social conditions—the LEMA encompasses an area with a high degree of groundwater depletion and a shared public interest to extend the life of the aquifer. Around 70 irrigators within the LEMA developed a conservation plan that restricted five year groundwater (no surface water is available)

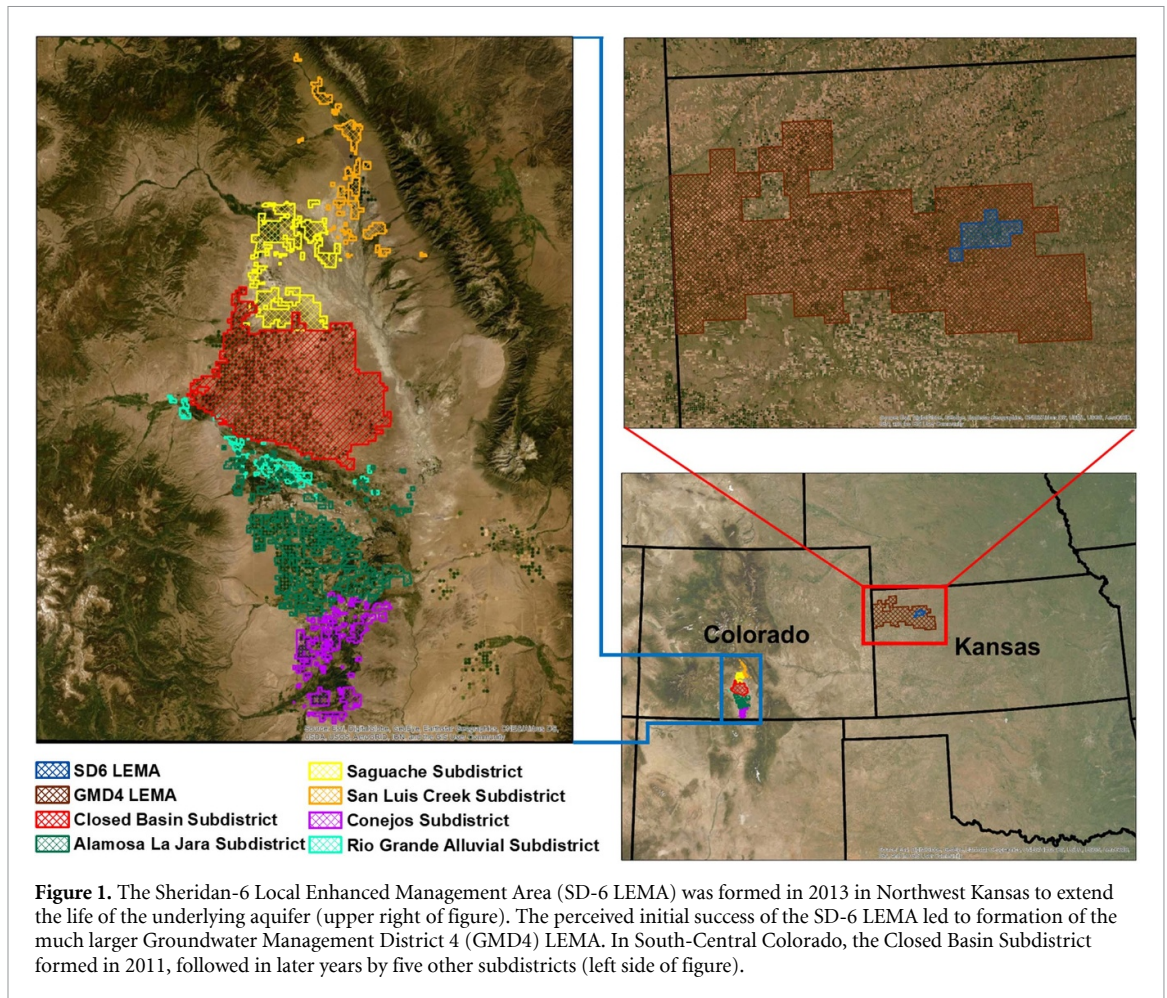
applications to 55 inches (139.7 cm) -a 20% reduction from pre-self-governance application rates. The plan is supported by the state water agency, which monitors pumping and applies fines (\$1000 for each day exceeding pumping limit) and suspension of water rights (up to two years for exceeding pumping limits by over 4 acre-feet) as penalties for noncompliance (Drysdale and Hendricks 2018).

The SD-6 LEMA began operation in 2013 and results to date indicate that it has been successful: groundwater pumping has decreased by approximately 30% (2013–2020 period and controlling for climatic conditions) and water level declines have significantly diminished, all while maintaining producer profit (Golden 2018, Deines *et al* 2019, Butler *et al* 2022). There is continued support for self-governance, and the LEMA was renewed in 2017 after the initial five-year period ended; it is likely to be renewed again later this year. These successes, however, were under relatively ideal weather and commodity-market conditions. It is unclear how the LEMA will fare under less-ideal conditions. Nonetheless, the initial success of the LEMA has motivated the formation of similar self-governance institutions throughout northwestern and west-central Kansas, including the Groundwater Management District 4 LEMA that is 40 times larger in both spatial extent and number of irrigators. Questions regarding the transferability of these governance rules between places remain.

2.2. Market-based approach: San Luis Valley subdistricts

Excessive groundwater depletion has decreased connected surface water supplies in Colorado’s San Luis Valley. The infringement on senior surface water rights gave the state engineer a legal justification to reduce water use. The credible threat of state intervention, as well as a sense of shared responsibility, motivated irrigators in the San Luis Valley to create six groundwater management subdistricts (based on hydrologic features) to govern their water resources. They aimed to use ‘economic-based incentives’ as an alternative to ‘state-imposed regulations’ to promote sustainable irrigation (RGWCD 2009). Sustainability for many of the irrigators meant long-term environmental, financial, and community well-being.

The Closed Basin Subdistrict, the first and largest subdistrict to form, introduced a \$45 per acre-foot groundwater pumping fee in 2011 as a market-based incentive to conserve water. The fee option was chosen due to a need to generate revenue to buy and deliver water, or another agreed upon payment (e.g. cash or hay), to surface water right holders that were impacted by groundwater pumping. Furthermore, fees are assessed and used by the local



water conservation district to subsidize the fallowing of irrigated cropland to help bring the system in balance. Many of the approximately 500 irrigators in the Closed Basin Subdistrict have a portfolio of surface water rights and groundwater wells, meaning they are being harmed in some instances just as they are causing harm to others. Furthermore, irrigators can use surface water to recharge the aquifer and receive credits to offset their groundwater pumping. It has proven difficult, however, to establish a fee that induces the needed water conservation: the pumping fee has incrementally increased from \$45 to its current rate of \$150 per acre-foot, with plans to increase to \$500 per acre-foot by 2023. Irrigators typically apply over 1.5 feet (45.7 cm) of water per irrigated acre, though this varies by crop and irrigator.

The rules set by the Closed Basin Subdistrict aim to increase groundwater storage to 1980 levels, i.e. restoring roughly 800 000 acre-foot (~ 1 billion m^3). To achieve this goal, irrigators in the Closed Basin Subdistrict use market-based incentives (i.e. groundwater pumping fee) to reduce aquifer overdraft instead of the command and control measures seen in Kansas (i.e. five year pumping limits). The other subdistricts in the San Luis Valley (figure 1) are adopting similar rule structures through their own self-governance, though with smaller fees (less than

\$30 per acre-foot). The Saguache Subdistrict, similar to the Kansas SD-6 LEMA, is set to impose a reduction on historic pumping (30%) to avoid the financial burden of a large fee and to ‘put it right’ in an equitable way [Saguache Subdistrict interviewee].

It is still premature to assess the long-term effectiveness of the groundwater governance systems in the San Luis Valley. While pumping fees initially reduced water use in the Closed Basin Subdistrict by a third (Smith *et al* 2017), most of the gains in aquifer storage were wiped out in a single drought year (2018) with diminished recharge and increased pumping. The other five subdistricts have only been operational for a few years or less. While most irrigators we spoke with felt action needed to be taken to make the system ‘sustainable’, there was less agreement upon the means to achieve sustainability (in contrast to Kansas where there was greater consensus). The complexity of the hydrologic system, including both surface and groundwater, and the preexisting water right system may have contributed to the divergence of opinions, since this increased heterogeneity in the socio-environmental system led to more uneven outcomes among irrigators. Some large senior water right holders say the community-based rules are unnecessary and that the prior appropriation doctrine should be strictly followed. Other irrigators,

Table 1. The three measures of appropriate fit of bottom-up groundwater governance systems.

1.	<i>Effectiveness</i> , or the degree to which the groundwater governance system achieves the goals it sets forth (e.g. rule compliance and gain in aquifer thickness) while minimizing impacts that may eventually destabilize the socio-environmental system.
2.	<i>Resilience</i> , or the degree to which the governance system can tolerate a certain level of disturbance (such as drought or socio-economic shocks) and still function before the system structure and function breakdown and the system returns to an unsustainable state.
3.	<i>Adaptability</i> , or the degree to which the governance system has capacity to enact diverse responses—meaning a variety of proactive, preemptive, and reactive measures—that facilitate continual adjustment to and absorption of endogenous and exogenous challenges.

however, view community-based groundwater rules as more equitable than strict adherence to the prior appropriation system, stating, ‘If all the subdistrict does is spread the hurt around, well, maybe that’s only right’ [Saguache Subdistrict interviewee].

2.3. Case study comparison

The Kansas and Colorado case studies illustrate how local socio-environmental context can lead to different self-governance regimes to manage groundwater commons. Kansas, for instance, is only dependent on groundwater for irrigation, which may better fit with the command-and-control approach that requires clearly defined boundaries to monitor (Dietz *et al* 2003). Integrated groundwater and surface water systems have dynamic boundaries which are extremely demanding to monitor (Dietz *et al* 2003), potentially explaining why a market-based approach has been adopted in the San Luis Valley. Furthermore, per-acre revenues for irrigated crops in San Luis Valley are generally higher than in Kansas, suggesting a similar fee may not be affordable in Kansas. Irrigators in Kansas created flexibility in their water allocation rules by setting a five year pumping limit of 55 inches instead of limiting annual pumping to 11 inches to provide themselves greater operational flexibility to mitigate economic and climate variability. These socio-environmental conditions—hydrological connectivity, farm cropping patterns, and climate/economic variability—are but three examples of many that can shape rule designs, especially when arrived at through local collective-action.

3. Transferring local solutions to a global problem

What aspects of successful groundwater governance schemes can be transferred to other stressed aquifer systems is not well understood. The uncertainty around transferability of governance systems is a key challenge for developing groundwater conservation strategies in other settings. Although knowledge transfer across regions lowers barriers to establishing self-governance schemes, widespread application of similar rules may inadvertently undermine long-term

resilience by reducing institutional diversity (Low *et al* 2003, Bodin and Norberg 2005). This loss of diversity also increases the likelihood of a misfit between rules and unique social and environmental contexts of individual areas, a cause of many of the serious, recurring problems in natural resource use and management (Folke *et al* 2007, Ostrom *et al* 2007).

To evaluate the potential fit of a proposed management scheme to a local groundwater system, we propose that the governance scheme be evaluated on three axes: (a) effectiveness, (b) resilience, and (c) adaptability (table 1). The SD-6 LEMA, for example, has thus far been highly *effective* in that pumping reductions have exceeded targets and the water table decline rate has slowed, and shows hallmarks of *adaptability* in that individual irrigators used a diversity of approaches to reduce pumping, but due to relatively wet climate conditions since its implementation, its *resilience* to environmental shocks such as drought has not yet been fully tested (Deines *et al* 2019). However, the performance in 2020, the fourth driest year in the last 20, hints at resilience to drought. The Closed Basin Subdistrict, on the other hand, has shown initial evidence that it is effective (declines in water use and gains in aquifer storage during early years) and adaptable (changing pumping fees) but not resilient (all gains wiped out during drought).

To ensure a good fit, the effectiveness, resilience, and adaptability of a groundwater governance system should be evaluated separately for each setting where it has been implemented to ensure alignment with the local social and environmental context. Moreover, maintenance of diversity, which is regarded as a key principle for building resilience in complex systems, is critical. Analogous to the ecological literature which has shown that more biodiverse communities tend to have greater resilience to climatic shocks, the diversity of rules that emerge within and across communities in a region can make system outputs respond differently to a given disturbance, thereby enhancing resilience. In sum, developing sustainable groundwater management strategies requires new understanding of how the fit of rules with socio-environmental contexts

affects the effectiveness, resilience, and adaptability of linked social-environmental systems.

Data availability statement

No new data were created or analysed in this study.

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ORCID iDs

Landon T Marston  <https://orcid.org/0000-0001-9116-1691>

Sam Zipper  <https://orcid.org/0000-0002-8735-5757>

Steven M Smith  <https://orcid.org/0000-0002-9653-2663>

Jonah J Allen  <https://orcid.org/0000-0002-1209-4898>

James J Butler  <https://orcid.org/0000-0002-6682-266X>

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