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Designing Groundwater Markets in Practice

Lessons from three California groundwater basins

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In many areas of the western United States, groundwater reserves have been and are increasingly overdrawn. When surface water supplies from rivers, reservoirs, or lakes are low, farmers often extract and use more groundwater from underground aquifers. Issues resulting from groundwater overdraft—such as increased energy costs to pump, domestic drinking water wells going dry, land subsidence, and saltwater intrusion—are leading regulators to consider pumping restrictions to stabilize water tables. Allowing trade of limited pumpable water can cut the costs of achieving sustainable management dramatically.[1] By trading allocations, pumpers with lower-value water uses can benefit from curtailing or ceasing pumping and selling their allocations to higher-value uses. Farmers and municipalities can compensate their neighbors for making conserved water available, thereby allowing scarce water to flow to its highest-valued uses.

Managing groundwater optimally, however, isn't quite so simple because groundwater is spatially interconnected—in other words, groundwater extracted in one location can affect groundwater resources elsewhere in the same basin. Surface water and groundwater are also hydrologically connected, meaning that pumping near a stream could affect streamflows at the surface.[2] Thus, groundwater extraction in one

Highlights

- Groundwater is spatially interconnected, which means that pumping in one location can have direct, unintended impacts on third parties that are different from the impacts of pumping in other locations.
- As a result, the development of groundwater markets requires careful accounting and design to balance gains from trade with the costs of uncompensated third-party effects.
- In California, several groundwater markets have emerged that attempt to address these challenges, providing lessons for the development of other groundwater markets.
- Solutions such as designating distinct trading zones or setting geographic trading restrictions can leverage existing information about the resource to reduce third-party effects, but they may also create barriers to trade that constrain market activity.

location can have unintended and uncompensated adverse impacts on the environment that may be different from impacts incurred in another location from the same amount of extraction.[3] Pumping that has no apparent impact at one site, for example, could dewater a wetland if pumped from elsewhere in a basin.[4] Regulators in groundwater basins are challenged to formulate and design market institutions that maintain flexibility with limited information about the potential effects of a new spatial distribution of pumping.

Given these realities, three prerequisites for an effective groundwater trading program include 1) developing a water budget to inform accounting, 2) establishing an initial allocation of groundwater pumping rights to groundwater users within a management area, and 3) addressing the differential impacts that groundwater pumping can have within a single basin. A water budget that accounts for groundwater and surface water interactions is foundational to the development of a market and any rules to mitigate unintended environmental consequences. Such a budget should also be coupled with an understanding of the water demands of various users, including for environmental purposes. The water budget determines the cap on the aggregate amount of water that can be extracted, constraining extraction to match the sustainability goals of the basin. The initial allocation of groundwater rights determines the baseline distribution of pumping, which can change if and when trades occur.

To address the fact that pumping has varying impacts depending on where it occurs in a basin, economists have proposed trading programs that assign trading ratios that adjust the volume of groundwater trades by multipliers to account for spatial consequences.[5] These types of policies are intended to maximize overall well-being, balancing the gains from trade with the mitigation of location-specific, third-party impacts of pumping.

This policy suggestion, however, abstracts away from the real-world costs of collecting information about each source's unique impacts, which could prove substantial. Instead, others have proposed simpler market rules, such as designating smaller trading zones within a basin or setting geographic trading restrictions.[6] While these more streamlined market rules may be easier to implement, they add additional barriers to trade that can constrain market activity.

In this policy brief, we discuss the relevance of these issues to California groundwater management and provide lessons for groundwater managers in other states. Addressing the spatial impacts of groundwater trading is a particularly timely concern in California, where groundwater markets are emerging under the Sustainable Groundwater Management Act. We provide background on this legislation and draw upon three case studies at various stages of development and implementation to assess how unintended third-party consequences are currently being recognized and addressed. We conclude by highlighting important trade-offs in the design of these mechanisms.

The Sustainable Groundwater Management Act of California

In 2014, California revolutionized its groundwater management practices by passing three bills, collectively called the Sustainable Groundwater Management Act (SGMA). Until the act's passage, most groundwater in the state was an open-access resource, with any overlying landowner practically able to extract as much water as they could put to "reasonable and beneficial" use on their land. Lacking incentives to limit extraction apart from the costs of pumping, groundwater users had little reason to conserve the resource. The result was often long-term drawdown, as is common throughout the western United States, with costly side effects such as land subsidence and seawater intrusion.

SGMA contains many pieces, but the core of the policy mandates the creation of new local groundwater authorities known as groundwater sustainability agencies, requires those authorities to develop plans to achieve sustainability over the next two decades, and grants additional powers to those authorities

that enable the enforcement of the plans. This rapid development of dozens of sustainability plans induced by SGMA, many of which propose developing groundwater markets, makes the California context especially fruitful for studying how market design handles environmental concerns in practice.

SGMA defines sustainability as avoiding the "significant and unreasonable" occurrence of six "undesirable results": 1) persistent drawdown, 2) reductions in storage capacity, 3) saltwater intrusion, 4) degradation of water quality, 5) land subsidence, and 6) depletion of interconnected surface water. Of these, surface water depletion is most tightly linked to ecosystem challenges, with impacts on wetlands, streams, rivers, and lakes. Declines in groundwater levels can also affect vegetation and alter water temperatures and flows vital for the maintenance of spawning or rearing habitat for native fish.[7]

California groundwater sustainability agencies have a great deal of leeway in designing management schemes to avoid the six "undesirable results," with few prescriptions in the law itself for how these goals must be achieved.[8] Many basins in California are large, and most basins that face sustainability mandates have multiple new agencies that are required to coordinate their plans. Drafts of sustainability plans released so far reveal significant variation in proposed management strategies. Some focus primarily on funding groundwater recharge projects, which seek to divert stormwater or wastewater back into underlying aquifers. Others consider various demand management projects, ranging from extraction fees to pumping restrictions. California law prevents groundwater agencies from modifying the common law system of water rights, but new management tools authorized under SGMA allow agencies to set and enforce volumetric pumping allocations and enable the trading of those allocations.[9]

Many submitted management plans do not clearly differentiate between which management actions will be pursued and which are merely on the table. Of the 107 currently submitted plans, 50 mention the possibility of setting allocations, and 17 of those are definite about it.[10] Among all plans considering allocations, 31 are also considering a trading scheme. Most existing plans are still pending state approval. While the prevalence of allocations and trading in current submissions demonstrate that groundwater markets will be a key facet of California groundwater management moving forward, it may be the case that concerns over potential third-party impacts from groundwater trading—and how to deal with them—are impeding more widespread adoption of this policy instrument.

Market Design in Practice

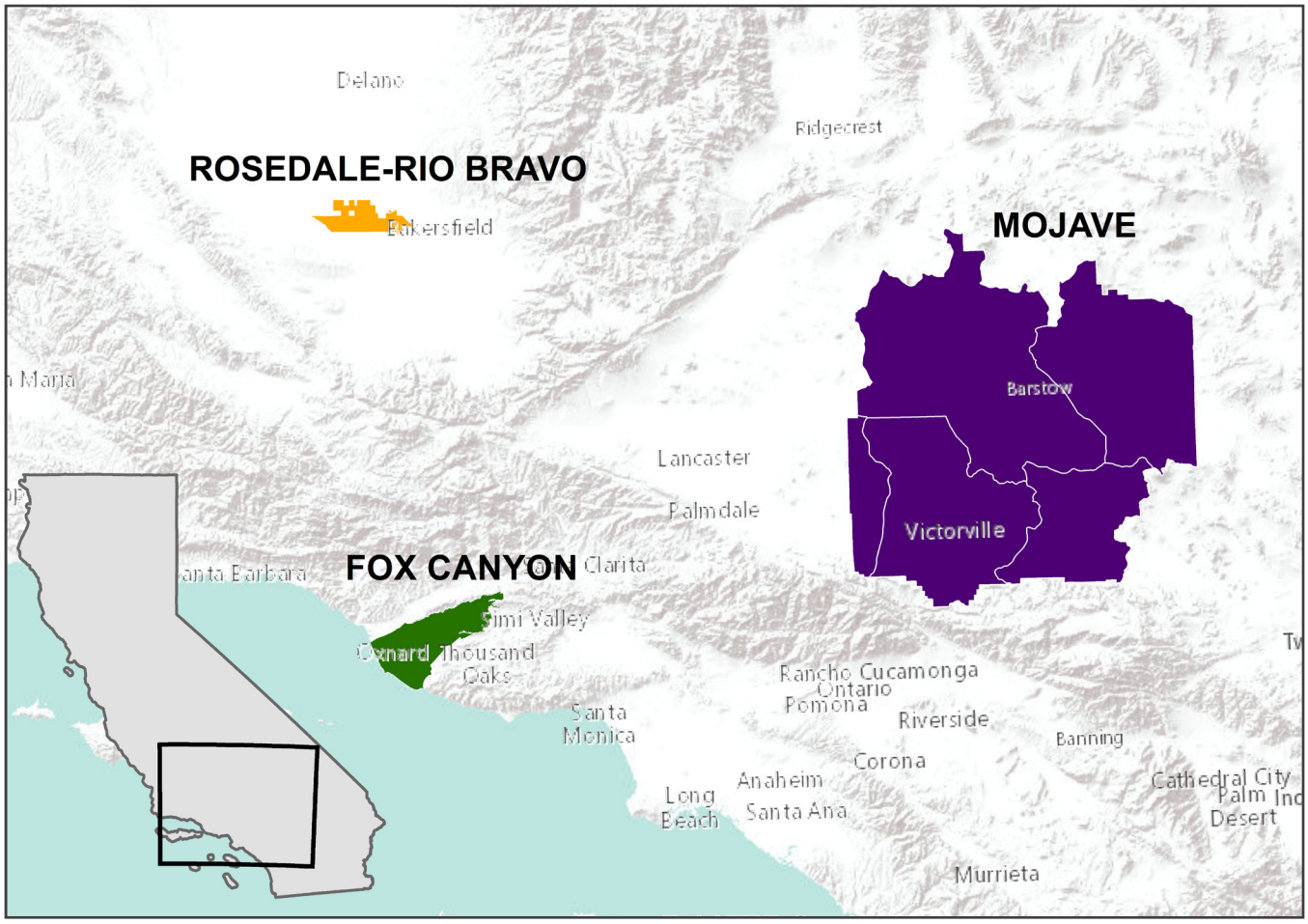
We draw upon three case studies at various stages of development and implementation to evaluate how third-party impacts of groundwater trading are being addressed in practice. First we consider the Mojave Basin in Southern California, which began trading in 1996, before the passage of SGMA and after a long and costly adjudication process.[11] Next, we discuss environmental protections in the Fox Canyon groundwater market, SGMA's first active groundwater market. Groundwater management had been ongoing in Fox Canyon prior to SGMA, so groundwater users in the basin were able to implement a groundwater market more quickly, having built upon prior data collection, trust, and governance. Finally, we consider a market currently being developed by Rosedale-Rio Bravo Water Storage District (Rosedale), which has yet to begin trading. Rosedale, like many other local agencies under SGMA, is coordinating basin-wide water budgeting activities to inform groundwater allocations and has established an open-source water accounting platform that can serve as the foundation for a future water trading program.

Mojave Basin

The Mojave Groundwater Basin resides along the north side of the San Bernardino Mountains in Southern California, just north of the eastern portions of the Los Angeles metropolitan area and in one of the driest areas in North America. Throughout much of the 20th century, more or less unconstrained groundwater pumping led to a precipitous

Figure 1

Map of Southern California Groundwater Management Case Studies



Three case studies at various stages of development and implementation—the Mojave Basin, the Fox Canyon groundwater market, and the Rosedale-Rio Bravo Water Storage District—help illuminate how third-party impacts of groundwater trading are being addressed in practice.

decline in the groundwater table. From 1990 to 1996, the Mojave's groundwater pumpers negotiated a settlement that set total limits on extraction and allocated pumping rights to individual users and municipalities. This adjudication of water rights laid the groundwork for a market to emerge that includes several hundred users.

The groundwater market in the Mojave is one of the most active in the American West. Every year since 1998 more than 20,000 acre-feet of water have been transacted on the spot market, accounting for between 15 and 20 percent of annual pumping in the basin. Permanent transfer of pumping rights is also common in some areas. The market has delivered economically meaningful benefits to groundwater users; a recent analysis estimates benefits of almost $500 million.[12]

This robust market activity occurs alongside various design features aimed at addressing spatial pumping impacts. Some of these design features affect foundational market rules, such as who can trade with whom. Most enable discretionary activity by either the third-party administrator (the "watermaster") or other entities to address impacts. In some cases, these features have benefited the environment by improving overall groundwater conditions, while others specifically target ecological improvements. We consider three examples below.

In many cases, smart design of groundwater markets will depend upon the hydrogeologic characteristics of the resource. The Mojave adjudicated area, encompassing more than 3,400 square miles, shares interconnected groundwater resources, but some areas are more connected than others. The market is broken into five administrative subareas, and trading across subarea boundaries requires watermaster approval. These constraints reduce the risk that trades into one subarea could upset local hydrologic balance and ultimately affect the inflows from, or outflows to, other adjacent subareas.[13]

Furthermore, the Mojave agreement defined obligations between subareas each year, which are estimated by the watermaster to ensure that any changes in pumping in one subarea that might impact water level conditions in another are addressed. The agreement established subsurface flow conditions between subareas, and one surface water obligation. Subsurface and surface flow obligations require the upstream Alto subarea to guarantee flow to the downstream Centro subarea (to be determined in a geographic area between the two subareas). If total flows from an upstream subarea are insufficient, users in the upstream subarea must purchase "make up water" or otherwise offset the impact.

Beyond attempting to stabilize long-term water tables in the region's groundwater subareas, the new regime also defined groundwater level thresholds along the Mojave River. These were designed in part to maintain sufficient groundwater availability for riparian vegetation that is important for endangered species. Groundwater levels at these sites are regularly monitored, and if they fall below certain thresholds, the watermaster can disburse resources from the Biological Resources Trust Fund, an account financed by small fees on pumping (less than $1/acre-foot in 2019-20) to purchase pumping entitlements or implement other activities. In many cases, these funds are used by the California Department of Fish and Wildlife to undertake conservation projects; for example, a two-year, $30,000 project removed groundwater-intensive invasive species (tamarisk, a shrub) from the floodplain in 2019-20. The funds are only available for projects inside several specially identified zones (totaling several dozen square miles), highlighting the importance of mitigating particularly high pumping damages in this area.

Finally, the market allows for voluntary purchases of water rights to address local pumping impacts. When one party is significantly impacted by another's pumping and well-defined rights to said pumping exist, negotiations among affected parties to reduce those impacts may prove sufficient. In 2001, the Department of Fish and Wildlife did just that with a property adjacent to Camp Cady, a restoration site it owns within the Mojave River floodplain. By purchasing the neighboring parcel and associated water rights, it was able to not only reduce nearby pumping by 90 percent but also use the balance of the acquired rights for irrigation of riparian vegetation. The improvements at Camp Cady have supported natural revegetation and resident and migratory bird species.

Management of spatial impacts in the Mojave includes a portfolio of approaches that reflect varying needs to trade off the complexity of management rules with a need to target the most important impacts. In cases where the number of impacted parties is small, market transactions help to resolve disputes, while the risk of reduced flows between subareas—affecting hundreds of parties in ways difficult to measure—was successfully resolved using a mixture of foundational trading restrictions and offset mechanisms. Meanwhile, the independent market administrator has leeway to use funds from local pumpers to address impacts in easily identified areas where the costs of declining groundwater tables would be high. Together, these approaches provide a basic structure to control important spatial impacts and flexible opportunities to address new ones as they arise; moreover, they do so in a way that allows for extensive, mutually beneficial trading to continue.

Fox Canyon Groundwater Management Agency

The Fox Canyon Groundwater Management Agency (GMA), a Special Act District created in 1982, manages a 183-square-mile wedge of Ventura County, California. Due to its proximity to the ocean, groundwater pumping in this area has led to seawater intrusion into the underlying aquifer, where saltwater enters into freshwater wells. Issues of seawater intrusion dating back to the 1950s led to the establishment of the agency. Early local groundwater management included reporting on levels of groundwater extraction, a practice that is still not widely adopted throughout the state today.

Now acting as a groundwater sustainability agency under SGMA, the Fox Canyon GMA developed and implemented a groundwater trading scheme for the Oxnard Basin in Ventura County, in conjunction with California Lutheran University and the Nature Conservancy. The Fox Canyon groundwater market began trading as a pilot in 2020. The speed at which the market was developed is largely attributable to the fact that local management was in place long before SGMA.

Building upon a previous foundation of local governance, data collection, and water accounting, the Fox Canyon GMA was able to establish a groundwater market under SGMA that includes protections for the environment. Two special management areas were designated in the basin's groundwater sustainability plan to ensure protections against seawater intrusion and overuse. As a part of the market's rules, the special management areas were given directional trading restrictions whereby pumpers in those areas are restricted from buying pumping rights from those located outside, so as not to increase pumping within the special areas. They can sell the right to pump groundwater to those outside or trade with others within the special management area.

The Fox Canyon GMA recognizes that trades can create cones of depression and concentrations of pumping in certain areas that can inadvertently reduce surface water flows, with negative environmental impacts, and that market rules may need to adapt over time.[14] At the end of the pilot market's first year of trading, nearly 200 acre-feet of groundwater pumping rights were transferred out of the two special management areas, demonstrating that the approach reduced pumping around sensitive resources.

Rosedale-Rio Bravo Water Storage District

The Rosedale-Rio Bravo Water Storage District is located within Kern County, at the southern end of California's San Joaquin Valley. The district participates as one of 16 member entities within the Kern Groundwater Authority, an entity tasked with coordinating SGMA-related activities between its members. Rosedale's management area covers approximately 75 square miles.

The district's groundwater sustainability plan outlines several projects and actions, including a water accounting framework that establishes allocations and develops a web-based water supply accounting database that allows the district and its landowners to track water usage. It also includes a water charge demand reduction strategy, that, if needed, would assess a fee based on the volume of water used over and above a designated amount to prevent overdraft.[15] Further, Rosedale's plan highlights that water transfers will be considered.[16] As a component of the water accounting framework project, Rosedale has worked with Environmental Defense Fund to co-create an open-source water accounting platform that has billing and trading components that can be enabled when the district determines there is a need for this functionality.[17]

Rosedale's plans equip landowners with several tools to manage water resources in response to SGMA. The water accounting platform is designed to enable water managers and farmers to develop accurate water budgets and facilitate water trading. Recognizing the need for basin-wide coordination, accounting, and management strategies, the platform was developed using open-source code so that other areas of the Central Valley that face similar water challenges can leverage and adapt the

Irrigation well and pump in San Joaquin Valley, California. © Water Alternatives Photos

platform. Rosedale has also been an early adopter of satellite-based evapotranspiration data provided by OpenET to measure consumptive water use and is making this data widely accessible to landowners through the accounting platform.[18]

The platform will also integrate an open-source groundwater modeling decision-support tool. It will allow water managers and stakeholders to model trading scenarios to better understand the potential impacts of water transfers on groundwater levels and water users within basins, which can inform rules that address impacts to communities and the environment.

Lessons Learned and Policy Implications

The value of water markets stems from their ability to flexibly reallocate scarce water from lower-value uses to higher-value uses. When it comes to groundwater management, allowing trade of pumping allocations can generate gains that buffer the costs of groundwater cutbacks. However, groundwater is a spatially interconnected resource; pumping in one location can have direct, unintended, and uncompensated impacts that are different from the impacts of pumping in other locations. Certain restrictions or controls may be needed to mitigate these differential impacts. Yet market restrictions

hinder the ability of buyers and sellers to flexibly reallocate, reducing the economic gains from trade. As a result, the development of groundwater markets requires careful accounting and design to effectively balance gains from trade with avoidance of uncompensated third-party effects. Groundwater management agencies under SGMA that are not currently considering markets out of concern over third-party impacts may look to these case studies for practical solutions.

Solutions such as trading zones with restricted or unilateral trading between zones, as seen in Mojave and Fox Canyon, respectively, economize on the information that groundwater agencies must gather. They also provide a relatively simple trading scheme for market participants. Trading activity from the Mojave also illustrates the value of users themselves devising local solutions. In cases where the number of bargaining parties is small—such as across neighboring parcels—informational requirements are lower, and it may be simplest for parties to contract for reduced pumping as a solution. Though lacking the complete information required of the ideal theoretical solution, market design and activity observed in practice can effectively address salient spatial impacts associated with trading while facilitating trades.

Since SGMA requires the avoidance of undesirable results, designing trading programs that address impacts to the environment will not only be good practice, it will also be necessary. Even though the act passed nearly eight years ago, many local agencies continue to struggle with how to collect, coordinate, and make available water-use data to inform actions within user groups and across larger basins. Accurate, trusted accounting systems are critical to inform water decision-making and in facilitating the development of groundwater trading programs across California and elsewhere.

Similar to previous data collection efforts in Mojave and Fox Canyon, groundwater sustainability agencies in California will be able to leverage the information required under SGMA to inform spatial considerations for groundwater market design. Management tools like those being developed in Rosedale can enable additional granularity in managing the differential consequences of groundwater trades, especially in areas where pumping is spatially concentrated. In June 2021, Environmental Defense Fund, the California Water Data Consortium, the California Department of Water Resources, and the State Water Resources Control Board, along with several local agencies, including Rosedale, launched a partnership to further expand and scale the water accounting platform with an eye toward supporting water trading programs into the future.[19] Other technological advances in groundwater monitoring could further expand the agencies' administrative capacity to oversee groundwater markets.

Conclusion

In California, many local agencies are developing groundwater trading programs under SGMA. The case studies explored in this report illustrate how several groundwater markets in California are currently balancing the gains from trade with avoidance of third-party effects in the presence of unintended spatial consequences.

The vast majority of California's groundwater sustainability agencies that are exploring groundwater market feasibility have not yet determined practices for avoiding or mitigating the potential unintended consequences of spatially reallocating groundwater extraction. Policies designed to address third-party impacts need to take informational requirements into consideration while defining impact thresholds that are objective, measurable, and tied as clearly as possible to pumping. Solutions that encourage interaction among affected parties will be the most likely to lead to beneficial outcomes.

Endnotes

1. Ellen Bruno and Richard Sexton, "The Gains from Agricultural Groundwater Trade and the Potential for Market Power: Theory and Application," *American Journal of Agricultural Economics* 102, no. 3 (2020): 884-910.
2. Brian Venn et al., "Hydrologic Impacts Due to Changes in Conveyance and Conversion from Flood to Sprinkler Irrigation Practices," *Journal of Irrigation and Drainage Engineering* 130, no. 3 (2004): 192-200.
3. Economists refer to these spatially varying negative consequences as non-uniform marginal external damages. Third-party effects from groundwater trading may also arise for communities and other landowners with, for example, shallow drinking water wells. Our focus in this policy brief is on environmental considerations, but much of this discussion can also be applied to other types of third-party effects.
4. Contrast this with globally dispersing pollutants like carbon dioxide emissions, where a uniform tax or trading scheme could be appropriate. Regardless of the source location, all carbon emissions have the same impact on global warming because carbon is a global pollutant.
5. R. Scott Farrow et al., "Pollution Trading in Water Quality Limited Areas: Use of Benefits Assessment and Cost-effective Trading Ratios," *Land Economics* 81, no. 2 (2005): 191-205. Nicholas Muller and Robert Mendelsohn, "Efficient Pollution Regulation: Getting the Prices Right," *American Economic Review* 99, no. 5 (2009): 1714-39.
6. Nell Green Nylen et al., "Trading Sustainably: Critical Considerations for Local Groundwater Markets Under the Sustainable Groundwater Management Act," *Berkeley Law, Center for Law, Energy & the Environment* (2017) https://www.law.berkeley.edu/research/clee/research/wheeler/trading-sustainably/.
7. The Nature Conservancy, "Groundwater Dependent Ecosystems Under the Sustainable Groundwater Management Act: Guidance for Preparing Groundwater Sustainability Plans," (2018) https://groundwaterresourcehub.org/public/uploads/pdfs/GWR_Hub_GDE_Guidance_Doc_1-31-18.pdf.
8. The statute requires that the state step in and take over management if local groundwater agencies fail to achieve the outcomes required by SGMA.
9. As such, some sustainability plans have outlined a block rate scheme for pumping fees that would make pumping nearly free up to some defined limit, then prohibitively expensive thereafter. The water volume charged under the initial, cheaper block would be allocated among pumpers, who could then trade their volumes under that block amongst themselves. Though stopping short of instituting new property rights to a volumetric allocation, this system incorporates many of the design features of markets that enable them to allocate water efficiently. Eric Garner et al., "The Sustainable Groundwater Management Act and the Common Law of Groundwater Rights—Finding a Consistent Path Forward for Groundwater Allocation," *UCLA Journal of Environmental Law and Policy* 38, no. 2 (2020).
10. Groundwater Sustainability Plans can be accessed through the California Department of Water Resources SGMA Portal, available at: https://sgma.water.ca.gov/portal/gsp/status. Fifty-six percent of the groundwater sustainability agencies had a submission deadline of January 2020. More basins faced a deadline of January 2022.
11. In this context, "adjudication" refers to a court-led process to redefine (ground)water access rights by delineating volumetric entitlements. Historically in California, adjudication processes were initiated by resource users, with negotiations over final allocations facilitated and finalized by courts.
12. Andrew Ayres et al., "Do Environmental Markets Improve on Open Access? Evidence from California Groundwater Rights," *Journal of Political Economy* 129, no. 10 (2021): 2817-60.

13. For example, if cross-subarea trades increase pumping in one subarea, and the water table falls as a result, then subareas that typically receive inflows from that subarea may receive less and suffer a declining water table themselves.
14. Sarah Heard et al., "The First SGMA Groundwater Market is Trading: The Importance of Good Design and the Risks of Getting it Wrong," *California Agriculture* 75, no. 2 (2021): 50-56.
15. Rosedale-Rio Bravo Water Storage District, "2018 Engineer's Report in Support of Proposed Assessment Increase and Implementation of a Water Charge," GEI Project No: 1701276 (2018), available as "Appendix K – Engineer's Report" at https://www.rrbwsd.com/wp-content/uploads/2019/12/Appendices-E-K.pdf
16. Kern Groundwater Authority Groundwater Sustainability Agency, "Groundwater Sustainability Plan Chapter for the Rosedale-Rio Bravo Management Area," (2019): 80, https://www.rrbwsd.com/wp-content/uploads/2021/10/14.-4-2019-12-10-com.-RRBMA-GSP-FINAL-Chapter.pdf
17. Christina Babbitt, "A Craigslist for Water Trading? Learn How this New Water Management Platform Works," *Environmental Defense Fund* (2020) http://blogs.edf.org/growingreturns/2020/10/07/new-water-accounting-trading-platform-sgma/. For additional information on the Water Accounting Platform, visit: edf.org/waterplatformstory.
18. OpenET is a collaborative initiative that uses best available science to provide easily accessible satellite-based estimates of evapotranspiration (ET) for improved water management across the western United States. To learn more, visit: https://openetdata.org/faq. Satellite-based ET data is particularly well suited for Rosedale because the district brings in surface water, which is then recharged underground, and landowners then pump the groundwater. The district does not have the more complex, coupled surface water and groundwater pumping systems that many other basins have. In most hydrologic and geologic settings, additional information is needed to track water usage.
19. California Department of Water Resources, "State Water Agencies, CA Water Data Consortium and EDF Partner on Groundwater Accounting Platform and Data Standards," (2021) https://water.ca.gov/News/News-Releases/2021/May-21/Groundwater-Accounting-Platform-and-Data-Standards.

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