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A role for water markets in enhancing water security in the western United States?: Lessons from the Walker River Basin

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ABSTRACT

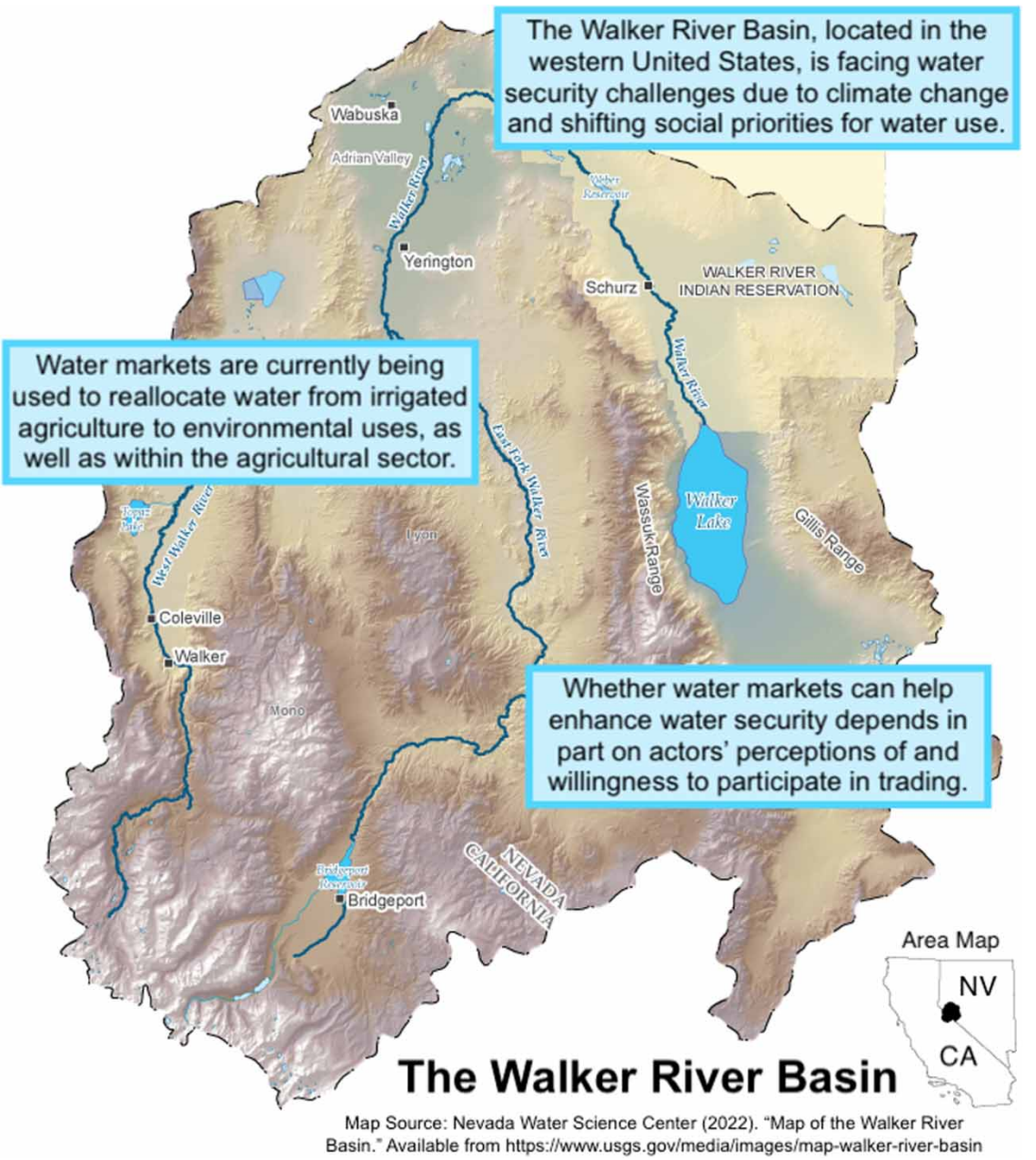
In many semi-arid, snow-fed river systems, climate change is shifting the timing and quantity of streamflow; at the same time, changing water use priorities are introducing additional demands on water supplies. These dynamics challenge water security across the globe. Water markets – economic instruments used to reallocate water via voluntary trade – may be used to adapt to these changes, though their implementation remains limited. To understand how water markets may enhance water security in the western United States, we assess diverse actors' perceptions of water allocation institutions broadly, as well as their preferences for different water market designs, in the empirical context of the Walker River Basin. This 4,200-square mile watershed, located on the California-Nevada border, exemplifies many key regional water management challenges. Through an analysis of 30 in-depth interviews, we find that actors across sectors desire changes to traditional water allocation institutions, preferably at the local level, and view markets as an acceptable tool for reallocation. Despite identified legal and social challenges, markets that facilitate temporary water trading are generally preferred. While limited to the context of a single basin, these findings provide lessons for designing water markets to enhance water security in basins regionally and beyond.

Key words: Allocation, Markets, Scarcity, Security, Trading, Water

HIGHLIGHTS

- Climate change is increasing water scarcity in many semi-arid, snow-fed river basins.
- Competition over water resources challenges water security in the western United States.
- Water markets reallocate water via voluntary trading among water right holders.
- Understanding actor perspectives on water allocation institutions and market design can inform the development of markets that enhance water security.

GRAPHICAL ABSTRACT



Map Source: Nevada Water Science Center (2022). "Map of the Walker River Basin." Available from https://www.usgs.gov/media/images/map-walker-river-basin

INTRODUCTION

In many semi-arid, snow-fed river basins around the world, climate change and shifting water use priorities are exacerbating competition for scarce water resources (Barnett *et al.*, 2008; Mankin *et al.*, 2015; Schilling, 2018).

These dynamics challenge water security, defined as 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economics' (Grey & Sadoff, 2007, pp. 547–548).

In the western United States, among other water scarce regions, political actors have begun experimenting with approaches for reallocating water to enhance water security. Among the most prominent of these are water markets, defined as economic instruments that facilitate voluntary transfers of water, typically with the goal of improving water use efficiency (Chong & Sunding, 2006; Marston & Cai, 2016). However, the broad implementation of water markets in the western U.S., like other areas around the world, has been limited (Ghosh, 2019; Schwabe *et al.*, 2020), due in part to uncertainties around their local feasibility and social acceptability (Wheeler, 2021; Zheng *et al.*, 2021). Indeed, without incorporating considerations of regional context into market design, water markets are unlikely to be implemented widely or in ways that impact water security (Gerlak *et al.*, 2018). Governments and other organizations must therefore understand the perceptions of key actors in the water sector in order to assess the practical feasibility, desirability, and impacts of various market designs.

To contribute to this understanding, we analyze diverse actors' perspectives on water marketing in the empirical context of the Walker River Basin, which spans the California-Nevada border in the western U.S. This basin is characteristic of other regional basins in that its water supply originates as winter snowpack and is used primarily for irrigated agriculture. Additionally, the basin is experiencing shifts in the timing, and potentially volume, of streamflow, as well as growing demand for water uses that were not historically recognized, such as environmental restoration. There are also multiple water markets currently in place in the Walker River Basin, making it an ideal case to explore actors' perceptions of different market designs.

Through 30 in-depth interviews with actors from key sectors in the Walker River Basin, including agriculture, environment, tribal, government, and research, we assess community perceptions of (i) traditional and alternate water allocation institutions, including water markets; and (ii) different water market designs. We expect that having some level of dissatisfaction with traditional water allocation institutions may make actors more supportive of the establishment of water markets; however, we also expect actors' preferences for different market designs to vary based on their own values and experiences.

After introducing the practical and theoretical contexts and methods for this study, we present our results and discuss implications for water management in the western U.S. and beyond.

Water allocation and trading in the western U.S.

The predominant institutional framework for water allocation in the western U.S. is prior appropriation (PA), a doctrine established in the mid-19th century to encourage economic development and prevent water speculation (Burness & Quirk, 1979; Tarlock, 2000). Under PA, water is allocated based on priority, meaning that those first to establish claims to water have the highest priority rights to use that water. When appropriated rights exceed available water supplies, water deliveries are curtailed based on the priority date of the right, meaning that 'senior' right holders with earlier claims are typically more water secure than their 'junior' counterparts.[1] A water right also defines the source of water, or the amount that can be legally diverted annually, and the place and purpose of use, which must be deemed 'beneficial' (Schilling, 2018). Historically, most beneficial uses were consumptive, meaning that water had to be diverted from a stream and used elsewhere, such as on agricultural lands. PA also dictates that a water right holder must use their full allocation or risk forfeiture. While

[1] The extent to which priority-based curtailment occurs in practice may vary, given informal water trading, hydrologic projections, and other political and management concerns (Tarlock 2000); however, a foundational level of water security is associated with more senior water rights in the western U.S.

intended to discourage water speculation, this 'use it or lose it' rule has been criticized for incentivizing overuse by individuals seeking to maintain their full water right despite lower water needs (Tarlock, 2001).

While irrigated agriculture has been, and remains, the dominant water use in the western U.S., water is increasingly sought for other uses, including municipal and industrial development and 'instream flows' to support environmental preservation and recreation (Smith, 2019; Lane & Rosenberg, 2020). At the same time, climate change is increasing uncertainty around water availability (Dettinger *et al.*, 2015; Li *et al.*, 2017). These dynamics have led scholars and managers alike to investigate ways to more efficiently and equitably manage scarce water supplies. PA allows water rights to be bought and sold as real property, and for the place and purpose of use to be transferred, as long as no harm (i.e. no net loss in water) occurs to other users on the system (MacDonnell, 1999). This characteristic has facilitated the development and use of market-based water reallocation mechanisms to cope with water supply and demand changes (Anderson *et al.*, 2019; Koebele *et al.*, 2021).

Water markets aim to reallocate water via the voluntary trade of water rights. They depend on differences in the marginal value of water across water uses and sectors to incentivize trade, which typically results in the movement of water to its highest valued uses (Schwabe *et al.*, 2020). Water markets have been used in the western U.S. to transfer water among users in the agricultural, municipal, industrial, and environmental sectors, with most water being moved within or out of the agricultural sector in these transactions (Jones & Colby, 2010; Ghosh, 2019; Smith, 2019; Lee *et al.*, 2020). Although PA has historically supported permanent transfers (sales) of water rights, some markets also facilitate temporary water transfers (leases) that allow the water right holder to retain their water right asset despite use elsewhere (Hansen *et al.*, 2014; Colby & Isaaks, 2018).

While some water markets in the western U.S. have seen robust trading activity (Debaere & Li, 2020), water trading generally remains thin. For instance, the volume of trade from 1987 to 2008 in Arizona, California, Colorado, Nevada and Texas annually represented only 5–15% of total diversions (Grafton *et al.*, 2012). Schwabe *et al.*'s (2020) more recent analysis of trading activity in Texas, California, and Arizona found that the volume of water transferred is only 2–4% of the total water used in each state and that trading activity actually declined during California's most recent drought (2012–2015) despite rising market prices. Factors such as water conveyance infrastructure limitations, difficulties with acquiring information necessary for transfer approvals, and uncertain property rights can also increase the costs of trade and decrease market activity, especially around temporary leases (Jones & Colby, 2010; Womble & Hanemann, 2020). Yet, some studies find leases to be more prominent than sales (Schwabe *et al.*, 2020), and many scholars view leasing as a promising tool for responsive and adaptive water management under changing supply and demand conditions (Libecap, 2018; Anderson *et al.*, 2019).

Much work remains in assessing how water markets can be designed to overcome the challenges described above to enhance water security in the western U.S. A key part of this work includes using participatory and collaborative research methods to understand the perceived opportunities and obstacles associated with water markets by potential actors who are involved in or can influence water trading, as well as their preferences for different market designs, in their local context (Grafton *et al.*, 2020; Singletary *et al.*, 2022).

METHODS

This study analyzes local actors' perceptions of the need for alternative water allocation institutions, including water markets, as well as their preferences for different market designs, within the Walker River Basin. We first describe this empirical context, followed by our data collection and analysis methods.

Empirical context

The Walker River Basin is a closed basin that covers roughly 4,270 square miles in California and Nevada (see graphical abstract for a map of the basin). The headwaters are located in eastern California, though approximately 75% of the basin's drainage area is in west-central Nevada. Across these states, the Walker River supplies water for irrigated agriculture, several rural communities, three Native American reservations, state-managed recreational areas, and aquatic and riparian habitat before terminating in Walker Lake.

Water law in the Nevada portion of the basin, the primary focus of this study, is broadly governed under PA by the Nevada Division of Water Resources (Nevada Division of Water Resources, 2021). However, a 1919 federal decree divided the Walker River's surface flow among 151 users and established water rights for the Walker River Paiute Reservation. In the same year, the Walker River Irrigation District (WRID) was formed to oversee 235,000 acres of water-righted lands, including 80,000 irrigated acres, and to manage water delivery infrastructure in the basin's two major agricultural valleys (Bryan, 2018). The Walker River Decree has since been amended to incorporate newly adjudicated rights and establish seniority for the Walker River Paiute Tribe, who continues to engage in litigation to expand their irrigated acreage (DePaoli, 2016; Puglielli, 2019). The amended Decree also created the Walker River Commission and the U.S. Board of Water Commissioners to oversee its administration by an appointed Federal Water Master.

During the 1930s, two reservoirs, Bridgeport and Topaz, were constructed in the upper Walker River Basin to store spring runoff for use later in the irrigation season by non-tribal irrigators who hold 'storage water rights' (Horton, 1996). In addition to these reservoirs, the basin contains substantial groundwater resources, including primary groundwater rights that are standalone rights appurtenant to land and supplemental groundwater rights designed to augment Decree rights in water-short years (Carroll *et al.*, 2010).

Critically, over a century of upstream diversions has reduced flows to Walker Lake, shrinking its surface area by half and reducing its volume by 90% (Walker Basin Conservancy, 2022). Walker Lake's ecological health has declined as a result (Sharpe *et al.*, 2008), severely impacting local wildlife, including a fishery that supports a threatened cutthroat trout population and an important migratory bird habitat (Allander *et al.*, 2014). These changes have negatively affected the region's tourism and recreation economy (Eiswerth *et al.*, 2000), causing local governments and environmental advocates alike to demand water be transferred out of irrigated agriculture to maintain and restore Walker Lake. Like other basins in the western U.S., climate change has also exacerbated water management issues in the Walker River Basin, causing more variable snowpack volumes, earlier snowmelt, and higher air temperatures, in addition to extended drought (Barnett *et al.*, 2008).

Water markets in the Walker River Basin

Several water markets have been implemented in the Walker River Basin to meet agricultural and environmental water management goals under these changing water supply and demand conditions (Table 1). Two of these water markets are well-established and provide opportunities for permanent water transfers and temporary leases, primarily among agricultural uses. First, since water law was first codified in Nevada, permanent transfers (Table 1, Market 1) have been allowed pending no third-party injuries, as determined by the Nevada State Engineer's Office. The Federal Water Master and the U.S. Board of Water Commissioners are also involved in transfer approvals that affect the enforcement of the Walker River Decree. A second market facilitates temporary trading of 'storage' rights in the district's two major reservoirs among members of WRID, pending approval of the WRID board at its monthly meetings (Table 1, Market 2).

Recently, two additional water market arrangements have been implemented to increase flows to Walker Lake. These markets are funded by the 2005 U.S. Desert Terminal Lakes Program (Public Law 109-103, 2005), which authorized more than $500 million to the U.S. Bureau of Reclamation to support restoration efforts, including

Table 1 | Water markets in the Walker River Basin.

Water market	Type of transfer	Description of market and goals
1. Traditional Water Rights Acquisition	Permanent	Water rights may be purchased from willing sellers and permanently transferred to other land parcels, pending no third-party injury.
2. WRID Storage Water Leasing	Temporary	Storage water rights may be temporarily traded among water right holders within WRID boundaries, pending approval by the WRID Board of Directors, to increase flexibility in agricultural water use.
3. WBC Water Rights Acquisition Program	Permanent	WBC purchases agricultural water rights (and often, appurtenant land) from willing sellers and permanently transfers these for environmental instream flows to restore Walker Lake, pending no third-party injury. The WBC also revegetates formerly irrigated lands with native plant species to mitigate dust and soil loss.
4. WBC/WRID Stored Water Leasing Program (SWP)	Temporary	WBC temporarily leases storage water rights to enhance flows to Walker Lake, pending no third-party injury. The program was piloted in 2019, a water surplus year, and can run for two more (non-consecutive) years to assess its utility for increasing flows to Walker Lake.

funds for the National Fish and Wildlife Federation's (NFWF) use in the Walker Basin. NFWF created the Walker Basin Conservancy (WBC), a locally based non-profit organization, to implement the two new water markets. In the first, the WBC can purchase water rights from willing sellers and permanently transfer them to enhance environmental flows to Walker Lake, requiring approved changes in place and purpose of use (Table 1, Market 3). The WBC also works to revegetate the land from which the water was removed with native plant species to reduce negative impacts associated with drying historically irrigated lands. Additionally, in collaboration with WRID, the WBC administers a pilot Stored Water Leasing Program (SWP; Table 1, Market 4) in which storage water right holders can lease water to the WBC annually for Walker Lake restoration purposes. The SWP was authorized to run for three non-consecutive years, with the goal of collecting information to investigate the feasibility of a longer-term temporary leasing market for stored water.[2] As of 2022, the WBC has acquired 53% of the water needed to restore Walker Lake (estimated at 50,000 acre-feet per year of increased flows) through these combined programs (Walker Basin Conservancy, 2022), with a price tag of $76.7 million in federal funding (National Fish & Wildlife Federation, 2022).

Data collection and analysis

As part of a large, interdisciplinary project on western water management under climate change, we conducted 30 in-depth interviews (Dunn, 2005) with actors representing the major water-use sectors in the Walker River Basin – agriculture, environmental, tribal, government, and research – between May and August 2020. We sought to interview individuals who either (i) consume, deliver, protect, or manage a large quantity of water; (ii) may pursue litigation that impacts water management; (iii) possess expertise on issues pertaining to water markets and related water management issues in the basin; or (iv) maintain roles that influence systemic capacity to adapt. We initially identified these actors through a review of the secondary literature and recruited them to participate via an email invitation that included a one-page description of the research, as well as a link to the project

[2] At the time of data collection, the SWP pilot program had only been run once in 2019.

website where they could learn more about the project and investigators. We expanded our purposive sample using snowball sampling (Noy, 2008) until reaching a point of information saturation where no major new perspectives were heard and no additional subjects were willing to participate.

Twenty-five interviews were conducted using Zoom video conferencing software, three were conducted by telephone, and two were conducted in-person. Three interviews included two participants from the same organization, for a total of 33 participants.[3] The interview procedures were approved by the authors' Institutional Review Board, and all interviewees consented to participate. The interview questionnaire (Supplementary Appendix A) was drafted by the authors, with input from the broader research team.

All interviews were audio-recorded, transcribed, and coded using NVivo Qualitative Analysis software according to an *a priori* codebook developed by the research team (see Supplementary Appendix B for codes used in this analysis) based on the research questions and relevant literature. The coding process allows for complex, narrative data to be sorted into thematic categories so they can be analyzed more systematically (Glaser & Strauss, 1999). Three authors collectively coded one interview to ensure reliability and consistency and to reduce bias; then, one author coded the remainder of the interviews. Questions that arose during coding were discussed by all researchers and resolved through consensus. Coded data were analyzed using constant comparative analysis, a technique used to identify themes, patterns, and relationships in qualitative data (Miles *et al.*, 2013), such as patterns in actors' perceptions within and across sectors.

Here, we analyze coded data from questions about interviewees' (i) perceptions of current water allocation institutions, including if and where change is needed; and (ii) preferences around existing water markets in the basin. When illustrative quotations from interviews are provided to substantively demonstrate the data associated with detected patterns in our Results and Discussion section, each quotation is marked with an alphanumeric ID that signifies the interviewee's sector (Table 2) and a randomly assigned interview number (i.e. AG_01) to demonstrate that data were derived from different interviews. This approach allows for reporting of de-identified responses in a way that protects subject confidentiality while bringing interviewees' voices to the fore.

Table 2 | Interviews by actor sector.

Sector	Actor examples	Interviews conducted	Declined or no response
Agriculture (AG)	Irrigation districts, non-tribal farmers, and ranchers	10	6
Environment (EN)	Conservation organizations, water purveyors, watershed restoration, and wildlife protection advocates	6	1
Tribal (TR)	Watershed restoration and wildlife protection advocates, farmers, and ranchers	4	3
Government (GT)	Federal and state policymakers and water law administrators, river/reservoir operations, and land/water management personnel	9	6
Research (R)	Scientists, watershed modelers	1	0
Total		30	16

[3] Interviews with more than one participant were analyzed as a single interview with multiple speakers, as there was no way to disentangle the unique views of each participant.

RESULTS AND DISCUSSION

Perceptions of water allocation institutions

Given the changing water supply and demand dynamics in the Walker River Basin, we asked interviewees for their perspectives on current PA-based water allocation institutions in the basin, including whether they perceive the need for any revisions or changes, at any level, that could help enhance water security. A general theme heard from at least some actors is that PA is outdated, at least in some respects, and may need to be adapted to effectively reallocate water under changing water supply and demand conditions:

> 'In my opinion, why are we working in the 1800s? It's because people don't want to give up what they want… and that needs to be solved. (EN_06)'

> 'We probably need [a] more defined process for… what people's water rights are… Right now, it basically just goes off how things have been operated for the last 90 years or more. (TR_01)'

At the same time, interviewees from all sectors noted that substantially modifying the PA system of water rights would be exceedingly difficult due to its historical embeddedness and complex evolution, including through contentious litigation spanning decades. This perspective was summarized most vividly by government actors tasked with administering water rights:

> 'Anytime you touch water law, it's extraordinarily complicated. There's lots of points of view and strong, strong opinions, and… it's just difficult. (GT_06)'

> 'Changing those laws is not an easy process… you've got a 100-plus years of water law in place that, you make one change, [and] you have to recognize there's a ripple effect that goes back 100 years. (GT_03)'

Given these challenges, it is unsurprising that interviewees generally focused on potential changes to water allocation institutions at the state or local (basin) level. At the state level, interviews mentioned the desire for improved coordinated management of surface water and groundwater, improved groundwater use monitoring, and increased communication and transparency among water managers and users. At the basin level, interviewees suggested a variety of potential modifications to the Walker River Decree. For instance, some environmental actors suggested that the Decree could be modified to allocate water to environmental flows for the restoration of Walker Lake as a beneficial use, despite its historical exclusion:

> 'I think there's a governmental duty that was… defaulted on or simply not recognized and never fulfilled, which was to take a more balanced, holistic approach to the water system. And so, I think that, if necessary, there is an appropriate role for the Decree Court to play in taking a look at different ways of managing the water rights and water flows. (EN_07)'

However, similar to the above discussion about modifying PA, multiple interviewees reinforced the general political impracticality of 're-opening' the Walker River Decree, primarily because of anticipated resistance from agricultural water users who 'are really worried about unintentional consequences from opening up those doctrines' that historically prioritized their water uses (GT_01). However, some agricultural actors still suggested revisions to the Decree, such as increasing their flexibility to irrigate earlier in the season to match changing snowmelt timing and overcome challenges associated with limited water storage capacity:

> 'For irrigators, it would be advantageous to be able to set [the irrigation season start date]… according to what the water forecast is for the season and to try to… rig it, if you will, for the maximum yield for the irrigators. (AG_02)'

'…if we had a second, even small, reservoir, that would make the system efficiency go sky high… But… we can't afford a Ferrari [so] we'll keep driving our Chevy. (AG_08)'

In addition to potential Decree changes, actors from multiple sectors also emphasized that water trading, including through the types of markets already in place within the Walker River Basin, could be a feasible way to address water security issues under changing needs:

'I think having a fluid market for groundwater or surface water transfers is really important… If someone has a right and they're not using it, they should be looking to sell it permanently or lease it or sell it on a temporary basis to someone who can place it to beneficial use. (GT_02)'

'If you have a farmer that's not putting this field in and they want to give [water] to another farmer, as long as they work out whatever deal they're [going to] do and they sign off the transfer sheets, then we're allowed to transfer that water [within WRID]. (AG_01)'

However, interviewees from multiple sectors also noted challenges with water trading broadly, such as difficulties in verifying 'no third-party injury' or the potential for permanent degradation of fallowed agricultural lands – an issue particularly salient among tribal actors who participated in a previous experimental water leasing and fallowing program on their reservation that negatively impacted their lands:

'I think leasing… makes no sense… You can't let your ranch burn up and dry up and blow away and then think that… I'm [going to] put my water back on [the land]. Well, then you have no ranch left, everything went… downhill and is all… dilapidated or whatever, you can't just get it going, and the costs of that [are high]. (AG_01)'

'The [Walker River Paiute] Tribe went on a fallow program… [which] paid the [tribal] farmers not to irrigate… and it was a long time, because the country got really dry… the crops died, and trees dried, there was a real environmental [impact] – a lot of dust, and dry heat… But… it kept the farmers whole, money wise. (TR_01)'

In sum, actors across sectors generally perceived the need to modify traditional water allocation institutions to meet changing supply and demand dynamics, but they openly recognized the political obstacles to modifying PA. Many were supportive of changes at the state and local levels, which they perceived to be more feasible, though not free of challenges.

Perceptions of water market designs

To better understand actors' perceptions of water markets as a potential solution to water security challenges, as well as to assess their preferences around market design, we asked interviewees about the two newer water markets in the Walker River Basin (Table 1, Markets 3 and 4), which aim to increase flows to Walker Lake. These markets represent the greatest departures from traditional water allocation institutions while operating alongside them; thus, actors often compared traditional with newer water markets in their responses.

The WBC water rights acquisition market

Interviewees' responses were the most detailed – and most conflicting – in their discussions of the WBC permanent acquisition market (Table 1, Market 3). All environmental actors, as well as some tribal and government actors, described this market as a way to balance preserving the basin's historical agricultural economy with new or historically underrecognized demands (i.e. protecting natural resources and cultural values associated with Walker Lake), in turn increasing basin-wide water security. Some environmental and tribal actors also emphasized the WBC's focus on revegetating the agricultural lands from which they purchase and remove

water, and converting some of those lands to broader uses, such as a state park. Ideally, this strategy reduces 'buy and dry', a term used to capture the negative effects of permanently removing water from irrigated lands via traditional water rights sales (Table 1, Market 1):

> 'I think that management on the river is such that… you try and maintain the [agricultural] productivity level of the basin, and with conservation and other measures that you reduce the amount of water that is taken out to be used for that and… stabilize Walker Lake to a level that will maintain a fishery. (TR_01)'

> '[The WBC is] taking care of land – this isn't a 'buy and dry'… it's not just dust and weed abatement, [they're] completely restoring ecosystems… [they're] making sure that as [they] retire these ranches, [they're] teeing them up to completely recover to what the surrounding native ecosystems look like. (EN_04)'

> 'I think there [were] amazing things that were outcomes from [the WBC's permanent land and water acquisitions], like the East Walker [state park]. The acquisitions of those ranches and the ability to create a state park [where previously irrigated lands were] is really significant. (EN_01)'

However, environmental, tribal, and government actors all noted challenges for administering the permanent acquisition market, such as the extensive time and cost involved in negotiating deals with willing sellers, the legal challenges associated with acquiring the necessary approvals to actually transfer and deliver acquired water to Walker Lake, and the lack of adequate fiscal resources to operate the market at the scale needed for meaningful restoration efforts. Critically, some tribal actors also felt that the Walker River Paiute Tribe was left out of the decision-making and market design process, despite the fact that permanent acquisitions may impact their water rights. These comments suggest that while WBC's permanent acquisitions water market created some benefits for Walker Lake, the feasibility of administering it in the long term may be limited.

Agricultural actors overwhelmingly emphasized the permanent acquisition market's negative impacts to agricultural livelihoods, land productivity, surrounding rural communities, and the basin's pastoral environment. Many of these criticisms also questioned the reality of WBC's revegetation efforts:

> 'I understand the concerns for Walker Lake, but I have seen water removed from some very historic, highly productive ranches in Nevada. These ranches are not at the production level they once were… Employees and their families had to look elsewhere for work and most of the historic tradition has been lost. (AG_06)'

> 'Generation after generation has fought this… to make these valleys beautiful and green and open and pastoral-like… productive ground. I see now where they've taken over this ground for the WBC, and the tumbleweed is piled up so high that it literally comes over the top of the fence… It's heartbreaking from the understanding of how much work and how many lifetimes have gone into creating that environment, and now… it's gone. (AG_05)'

> '[The WBC] own[s] the farm west of mine. It is nothing but a fire hazard. It is so ugly. They were supposed to revegetate it… All the animals, they come where there's water, they come where there's greenness, they come where there's some willows, they come where there's some trees. [The WBC is] hurting our valley dramatically… (AG_08)'

Some agricultural actors even argued that Walker Lake is 'beyond saving', essentially suggesting that even if the WBC was able to acquire substantial water from willing sellers through the market, they would still be unable to achieve their management goals:

> 'Do I want to see Walker Lake, or any other terminus lake, go away? No… I just personally don't believe that that lake, long term, will be able to be saved. (AG_09)'

'You're not [going to] save Walker Lake because the [pollution] numbers have gone up. They have not gone down. And it's been a drying lake… (AG_08)'

Notably, a minority of agricultural actors expressed positive perceptions of, or at least interest in, the WBC permanent acquisition market. Some opined that generational changes were leading to a moment where a large amount of agricultural land might be retired, causing an increase in water rights available for sale in the basin. In this context, the market provided an opportunity for willing water right sellers to potentially benefit financially to a greater degree than they would by selling their water rights within the agricultural sector. Others focused on how the acquisition market creates options that increase flexibility in water management more broadly:

'The new generation is coming in… and they've seen their parents work themselves to death on these farms out here, especially these really rural types, and I don't think they really want to do that. So, I think… with the change in generation, you're getting some of that land being sold. (AG_05)'

'I believe that [farmers] see the acquisition program… in a perspective of… what can they get out of it… 'Do I have anything on my farm that is not productive that I can sell and put it over here [in Walker Lake]? (EN_05)'

'I'm all for [experimenting with the program]: try it out, sell some, let them buy some, let's work it out… Let's be a little flexible on a lot of this. (AG_04)'

The WBC/WRID stored water leasing program (SWP)

In contrast to the WBC permanent acquisition market, questions about the SWP (Table 1, Market 4) elicited less criticism from agricultural actors. Although the SWP is also designed to increase environmental flows to Walker Lake, both agricultural and environmental actors highlighted the potential financial benefits of leasing surplus storage water through this market, especially because leasing decisions could be changed annually to reflect water availability and agricultural market conditions:

'If a guy's got a really good water right or… some extra storage water maybe in a reservoir somewhere, and he was able to lease it out to have some supplemental income on his operation… I don't see any problem with that. (AG_06)'

Critically, environmental actors also described how the SWP, designed as a fairly low-risk 'demonstration' program, catalyzed a broader conversation between agricultural and environmental interests about water security solutions that could benefit both parties. However, the pilot market was run for the first time in a very wet year, which may have increased participation simply because individuals had more surplus water:

'[The SWP] caused interaction with the [WBC] and the [agricultural] water users, and for the most part it was favorable because they got paid for something that they had an abundance of at the time, and that water got to Walker Lake. So, Walker Lake benefitted from that. (EN_05)'

'…the leasing program went through, people participated… The folks that got their feet wet showed other farmers that it can work, and the water was delivered. Of course, there was excessive waters on top of excessive waters [in 2019], but those waters did not get delivered within the two [agricultural valleys], they did go to the benefit of the system all the way to Walker Lake. (AG_03)'

Criticisms of the SWP from across sectors concerned the challenges with administering the market, including securing a steady stream of public funding necessary to support it; the need to get information on water availability earlier to improve lessor decision making; and the need for a more reliable source of water, other than storage, to restore Walker Lake:

'My concern about that kind of a program is that I don't believe it's economically sustainable or viable as a long-term solution for the lake because it does require a substantial amount of money to be budgeted every year, in perpetuity, to pay for, or to induce people to temporarily transfer their water down to the lake for a year or for a couple of years at a time. (EN_07)'

'I think if they could do it in February or March… preferably before March 1 when the irrigation season starts, then I think that would be optimum for letting people decide. (AG_07)'

'It always seemed to me that they should be focusing on buying permanent water rights that will continue to… have water, actual water, that they can transfer to Walker Lake, because… these are just one-year programs and as soon as they run out of water… it's over, and that's $20 million gone and I'm not sure how much benefit there actually was to Walker Lake from it. (TR_02)'

Taken together, these data suggest that diverse actors are generally accepting of changes to water allocation institutions that rely on voluntary, market-based mechanisms to cope with local water security challenges, despite recognized challenges. Regarding market design, markets supporting temporary leases may be more palatable to diverse actors than permanent acquisitions, even if they are not the ideal mechanism for securing reliable water supplies for environmental purposes. Moreover, experimental markets, such as the SWP, can help to increase dialogue about broader water issues in the basin and potentially open the door for the development of more permanent programs in the future.

CONCLUSION

As water supply and demand dynamics change throughout the western U.S. and other semi-arid regions, many communities will face greater water insecurity. To alleviate this, we must critically assess existing and emerging water allocation institutions for their ability to meet the needs of diverse water users while reducing risk (Grey & Sadoff, 2007). Our analysis of actor perspectives in the Walker River Basin points to two key findings. First, most interviewees identified issues with PA as the dominant water allocation institution. However, interviewees were generally pragmatic: instead of seeking to dismantle and/or replace PA, most suggested that feasible and desirable changes were more likely to occur at the state and local level – such as the development and implementation of voluntary water markets. Second, despite a general acceptance of water markets as a water reallocation tool, actors' preferences for market designs diverged based on their water use values and experiences.

Agricultural actors in the Walker River Basin generally expressed a desire for more flexibility in water management under changing supply conditions, but they held mixed views on the two newer water market programs as mechanisms for achieving this. While some noted that the WBC permanent acquisition program provides a potentially lucrative means for retirement or exit from the agricultural industry, most agricultural actors expressed concerns about the long-term impacts of permanent transfers on the future of the basin's agricultural-based economy, as well as about the viability of restoring Walker Lake through the permanent acquisition and transfer of water. More agricultural actors preferred the SWP's temporary leasing arrangement, even though its primary goal is also restoring Walker Lake, because it is a pilot program that does not threaten to dry-up agriculture in the long-term while also creating a potentially lucrative opportunity for leasing surplus water.

Environmental actors supported both the permanent acquisition program and the temporary SWP as ways to meet their core goal of restoring Walker Lake. Although temporary storage water leases are comparatively less reliable than permanent acquisitions, many environmental actors expressed high levels of support for the SWP, in part because they recognized the substantial political and legal challenges associated with the permanent transfer of water rights to the environment. Some actors even suggested that the SWP was as much an effort to

begin overcoming these hurdles and building trust in the community around the provision of environmental flows as it was a way to actually get water to Walker Lake. Tribal actors were also generally supportive of both of the newer markets, despite irrigated agriculture playing a major role in sustaining their current livelihood, given the historical and cultural importance of Walker Lake. However, the usefulness of the SWP or any other leasing program hinges, to a great extent, on non-tribal agricultural actors' willingness to lease water in dry years, which are expected to become more frequent as temperatures warm in the region.

These findings affirm that agricultural actors maintain a major – and widely recognized – influence over water management in the Walker River Basin, as is the case in much of the western U.S., due to precedents set by historical PA-based water allocation institutions. They also suggest a firm commitment by actors across sectors to continue to manage water as private property, despite the recognition of interrelated water security challenges. Together, these findings highlight the importance of local input in the design and operation of water markets (Singletary & Narayanan, 2003), especially when long-standing water disputes and litigation are driving factors behind their development, as was the case in the Walker Basin. Developing knowledge and goodwill among competing actors via pilot programs, such as the SWP, may provide a potential path forward toward increased co-development of water market mechanisms.

Highly functioning water markets – in theory, those characterized by a clearly defined set of property rights – can improve information access and transparency around water pricing, while reducing transaction costs associated with water transfer approval processes to mitigate third-party injury (Libecap, 2018; Ghosh, 2019; Lee *et al.*, 2020). Our findings suggest that the markets in the Walker River Basin, based on these principles, may provide a feasible avenue for reallocating water and enhancing water security in the basin. More comprehensive inventories of basin hydrology, basin-scaled climate projections, and water supply forecasts can support the use of markets in places like the Walker River Basin (Carroll *et al.*, 2010) by improving agricultural actors' decision-making about water conservation and potential trading opportunities.

These findings also highlight the need for more context-sensitive, participatory research on the multiplicity of tradeoffs that agricultural users – as the primary sellers and lessors – must balance when making decisions to participate in different markets, as well as more in-depth studies of how elements of water market design may increase or decrease transaction costs for participants. There are also limitations of this research that should be considered in future studies. To fully understand the extent to which water markets can address challenges associated with water security amidst changing water supply and demand in the western U.S., more research is needed in larger semi-arid, snow-fed river basins that include greater municipal demand. Furthermore, while our sampling strategy aimed to recruit participants representing the primary water interests in the Walker River Basin, our sample may not be fully representative of the views of *all* actors, a limitation that was exacerbated by the COVID-19 pandemic. Despite these challenges, this study provides important insight into actor perceptions of existing and emergent water allocation institutions. It suggests that changing water supply and demand has the potential to spur changes in water management, such as through the implementation of water markets, that may enhance overall water security if their design is tailored to reflect local needs and preferences.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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