University of Nevada, Reno

Assessing Stakeholders' Perceptions of Water Sharing Arrangements in the South Platte River Basin

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Hydrology

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Abstract (276)

In snow-dependent river basins in the arid western US, irrigated agriculture accounts for most freshwater withdrawals, though rapid population growth is increasing urban water demand. In response to these trends, as well as to prolonged drought and aridification of the region, water markets have emerged to transfer water from agricultural to municipal use. Farms and rural areas may face adverse economic and social repercussions from permanent transfers, however. As an adaptation to these water markets, some areas are developing Water Sharing Arrangements (WSAs), which allow agricultural water users to transfer water intermittently or temporarily to non-agricultural uses while maintaining their water rights. This study uses semi-structured interviews with stakeholders representing competing water uses in the South Platte River Basin in Colorado to assess if and how WSAs can contribute to meeting both agricultural and urban water needs and where improvements can be made. Results suggest that, regardless of water use sector, stakeholders agree that WSAs can enhance opportunities to retain lands for agricultural production while supporting urban development. Further, stakeholders discussed concerns regarding the water court process for WSAs, and suggested more protection for water rights holders against the tenets of Prior Appropriation would ease apprehension. Stakeholders also advocated for increased collaboration and creativity of lease terms to encourage WSA participation. WSAs with these design features may improve overall water use efficiency while avoiding net economic losses, preventing the kinds of negative cultural and ecological impacts that typify buy-and-dry scenarios. These results contribute to extant literature on Prior Appropriation-based water markets by highlighting stakeholder preferences that can inform the development and use of WSAs.

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Introduction

In the arid western United States, where the Doctrine of Prior Appropriation (PA) remains the primary institution for allocating scarce water resources based on date of water right claim and amount allocated, competition for water is growing due to a variety of factors. Irrigated agriculture represents about 70-80% of freshwater withdrawals across this primarily snow-dependent region (Brewer et al., 2008; Dieter et al., 2015). At the same time the western U.S. has experienced steady urban population growth, with an increase of 9.2% alone since 2010, which increases municipal demand for water (U.S. Census Bureau, 2021; Schwabe et al., 2020). Climate change is now also impacting these snow-dependent river basins, resulting in more pervasive drought conditions, aridification due to less snowpack, earlier run-off, increased evapotranspiration, and reduced soil moisture (Zeng et al., 2018; Akbariyeh et al., 2019), which further reduce water supply. Together, these changing supply and demand dynamics exacerbate competition for already over-allocated water rights (Schwabe et al., 2020).

In response, water markets have emerged as a strategy for improving water use efficiency by reallocating water. Water markets, which require an established set of property rights to withdraw and use water on a continuous basis, involve the voluntary exchange of water resources between willing buyers and sellers and theoretically move these resources from lower-valued to higher-valued uses (Anderson et al., 2019; Leonard et al., 2019; Brevligieri et al., 2018). Since most freshwater withdrawals in the western U.S. support irrigated agriculture, water markets in this region have typically involved the purchase and permanent transfer of water rights out of agriculture, reflecting urban

population growth, growing environmental and recreation interests, and other changing water use priorities (Breviglieri et al., 2018; Schwabe et al., 2020). These permanent water transfers are assumed to lead to mutually beneficial outcomes for all parties when water moves from lower to higher valued uses (Howe et al., 1990). However, there are often a variety of negative social, economic, and environmental impacts to agricultural and rural communities where water is removed from previously irrigated land (Howe et al., 1990; Howe & Goemans, 2003; Marston & Cai, 2016; Dilling et al., 2019; Fei et al., 2022).

In attempts to mitigate the negative impacts of permanent water transfers, some western states have begun to experiment with new market strategies to move water to urban uses without harming agriculture. These *water sharing arrangements* (WSAs) are mechanisms that allow temporary agricultural water leases for other uses as an alternative to permanently drying up agricultural lands. Further, these types of arrangements provide added flexibility for agricultural producers and can aid in alleviating risk related to permanent acquisitions (Arellano-Gonzalez, 2021; Bjornlund, 2003). These arrangements can have a variety of structures, such as reservation fees for accessing stored water or annual leases of a set volume of water, which may lead to different benefits and drawbacks for the involved parties (Mahmoudzadeh Varzi & Grigg, 2019; Breviglieri et al., 2018).

Thus, the guiding research questions for this study are as follows:

1. *What types of water sharing arrangements are most desirable to water users and why?*
2. *How can the design of these arrangements be further improved to reduce negative externalities and enhance participation of all parties?*

These questions were investigated through a case study of the South Platte River Basin in Colorado, where water sharing arrangements are especially common, making it an exemplary critical case (Yin, 2009; Gerring, 2016). Further, the South Platte Basin is representative of many other urbanizing snow-fed basins in the western U.S., as it is historically, and remains an agriculturally dominant region that is experiencing rapid population growth in the face of shrinking water availability due to climate change (United States Department of Agriculture, 2017; CWCB, 2020; Rhoades et al., 2017). To answer these research questions, semi-structured interviews were conducted with various water users in the basin (n=28), and interview transcripts were qualitatively analyzed for content related to water sharing topics (Rubin & Rubin, 2005; Auerbach & Silverstein, 2003). Natural resource management decisions must be palatable to both stakeholders and policymakers in order to be successfully implemented; thus, this research contributes to the extant literature on Prior Appropriation-based water markets (e.g. Dilling et al., 2019) by providing primary data on stakeholder preferences that can inform the development and use of WSAs more broadly, as well as suggestions for how to mitigate some of their established drawbacks.

Literature Review

As climate-induced changes to water supply and watersheds persist, an array of climate adaptation solutions have surfaced, with water markets emerging as a popular choice for their flexibility and ability to encourage conservation and reveal information about alternative water uses (Koebele et al., 2021; Anderson et al., 2019). Climate adaptation solutions consist of tools that help communities and regions adjust to environmental pressures by increasing flexibility and their capacity to withstand these pressures (Anderson et al., 2019). Water markets are such a tool and are designed to improve water use efficiency by permitting the voluntary exchange of water resources between willing buyers and sellers, from lower-valued to higher-valued uses (Leonard et al., 2019). Higher-valued water uses often include domestic water use, power generation, and mining, whereas lower-valued uses typically refer to irrigation for less-productive farmland and/or lower-valued crops (Schwabe et al., 2020; Arellano-Gonzalez et al., 2021). Different institutions exist for facilitating water markets; with the Doctrine of Prior Appropriation (PA) being the predominant, seniority-based institution for allocating water use in the western U.S. (Leonard & Libecap, 2019). It establishes and defines property rights surrounding individual water use associated with the priority order of land claims, quantity that may be used, and purpose of use (Leonard & Libecap, 2019), allowing for the development of permanent water markets in the region, which are also referred to as formal or traditional markets (Bjornlund, 2003; Easter et al., 1999).

Though these traditional water transfers can be useful, they often result in less-than-optimal outcomes for agricultural producers, rural communities, and the surrounding

natural ecosystems through a practice called “buy-and-dry”, which occurs when water resources are permanently decoupled from agricultural lands (Howe et al., 1990; Marston & Cai, 2016; Fei et al., 2022). Impacts of buy-and-dry include the large-scale loss of irrigated lands, high rural unemployment, depreciating land values, and a shrinking local tax base, which may lead to the loss of local basic public services in rural areas, such as schools and health clinics (Dilling et al., 2019; Howe & Goemans, 2003; Mahmoudzadeh Varzi & Grigg, 2019). Because rural economies rely on banking, wholesale, and retail support services related to agricultural production, the loss of agricultural enterprises diminishes rural community vitality (Howe & Goemans, 2003; Thorvaldson & Pritchett, 2006). Further, ecological impacts include the degradation of water quality and habitat to support diverse wildlife species (Lund & Israel, 1995; Zhuang, 2016), as well as the loss of open spaces that contribute to the aesthetic value of rural places (Howe et al., 1990). Some municipalities have attempted to mitigate these impacts in places where they purchase water with “lease-back” programs, in which excess water purchased from the agricultural sector is leased back to irrigators (Mahmoudzadeh Varzi & Grigg, 2019; Taylor & Young, 1995). Aridification and prolonged drought, however, may prevent this strategy from being viable in the long term as cities grow into this excess supply.

Water sharing arrangements (WSAs) attempt to address some of these problems while continuing to use the broad principles of water markets. WSAs have been identified and defined using diverse terminology throughout the existing literature. For example, WSAs have also been termed informal water markets (Bjornlund, 2003; Easter et al., 1999), alternative transfer mechanisms (ATMs) (Dilling et al., 2019; (Mahmoudzadeh Varzi &

Grigg, 2019), spot market leases (Characklis et al., 2006; Ghosh, 2019), and temporary water transfers (Mooney & Kelley, 2022). Though the terms for WSAs may differ, each of these share a relatively similar definition. In the context of this paper, WSAs are defined as water *transfers which are temporary and attempt to mitigate the negative socioeconomic and ecological impacts of removing water from previously irrigated land by keeping land in production and allowing agricultural producers to retain all or a portion of their water rights* (Mahmoudzadeh Varzi & Grigg, 2019; Dilling et al., 2019). Deaton and Lipka, 2021 offer a different definition of WSAs that focuses on moving water resources among municipalities and between tribal nations and municipalities; however, the definition presented here is in alignment with that of Mahmoudzadeh Varzi & Grigg(2019), Dilling et al. (2019), and Mooney & Kelley (2022).

Several types of WSAs exist, including flex markets, interruptible supply agreements (or options markets), municipal-agricultural water-use sharing, spot markets, water banking, and water cooperatives, with deficit irrigation and rotational fallowing being components of these arrangements (Dilling et al., 2019; Mahmoudzadeh Varzi & Grigg, 2019; Ghosh, 2019; Characklis et al., 2006). Table 1 provides definitions for these terms. Mahmoudzadeh Varzi & Grigg (2019) recognize that WSAs feature two main components: 1) the ability to reduce the amount of agricultural consumptive water use and 2) the ability to facilitate temporary water transfers from agricultural to non-agricultural uses. In other words, the first component of a WSA requires the irrigator to develop a strategy to reduce their consumptive use, making water available for transfer to non-agricultural uses. The second component involves legal, political, and economic

processes that facilitate this transfer of water. Deficit irrigation and rotational fallowing make up the first component of a WSA, whereas flex markets, interruptible supply agreements, municipal-agricultural water-use sharing, spot markets, water banking, and water cooperatives comprise the second component (Mahmoudzadeh Varzi & Grigg, 2019).

Table 1. Types of Water Sharing Arrangements and their description. *Irrigation Reduction Technique

Type of Water Sharing Arrangement	Description
Deficit Irrigation*	Deficit irrigation occurs when farmers under-irrigate their entire farm, rather than fallowing an entire plot of land. These savings can then be used for water transfers. Irrigators must be compensated for reduced yields resulting from less irrigation. This method of reducing consumptive water use in agriculture is often used in municipal-agricultural-water-use-sharing (Mahmoudzadeh Varzi & Grigg, 2019; Dilling et al., 2019; Fereres & Soriano, 2006).
Rotational Fallowing*	Rotational fallowing occurs when farmers fallow a single plot of their land each year in order to fully irrigate a different plot of land. These plots are rotated out each season, and water savings are used for transfers (McMahon & Smith, 2011). Under these arrangements, irrigators must be compensated for reduced yields and often the costs associated with revegetating fallowed lands (Mahmoudzadeh Varzi & Grigg, 2019; Dilling et al., 2019).
Flex Markets	Flex markets typically occur between municipal or industrial users and environmental users. These water sharing arrangements involve changing the beneficial use of senior water rights to include environmental instream flow and restoration in order to facilitate trade (Dilling et al., 2019).
Interruptible Supply Agreements (Options Market)	These WSAs involve a lessor (an agricultural user) charging a lessee (non-agricultural users, often municipal or industrial) an upfront fee to have water in reserve and available during drought years. The lessee is then charged an additional fee upon the actual withdrawal of water (Characklis et al., 2006). Typically, farmers fallow fields under these arrangements, but deficit irrigation can also be used to supply water to the lessee. Interruptible supply agreements can have short-term contracts (i.e., 5 years or less) or long-term contracts (i.e., 20+ years) (Mahmoudzadeh Varzi & Grigg, 2019; Dilling et al., 2019).
Municipal-Agricultural-Water-Use-Sharing	This WSA is aptly named as it occurs between agricultural and municipal water users, with often flexible and varied terms. The goal of this type of arrangement is to ensure that continued irrigation occurs, as opposed to interruptible supply agreements which often require fallowing. Deficit

	irrigation can occur in these arrangements and municipalities typically fund or support agricultural producers to upgrade or implement water conservation irrigation technologies (i.e., sprinkler and drip irrigation), so that water savings can be used for transfers (Dilling et al., 2019).
Spot Markets	Spot markets refer to the immediate lease of a water resource for a short period of time, typically during a seasonal drought (Characklis et al., 2006). Spot markets occur in states like California and Texas, but may be less feasible in other states, depending on the institutional capacity in place to facilitate temporary water trading (Ghosh, 2019).
Water Banking	Water banking allows agricultural users to retain their water rights while selling a portion of their total expected volume to other users, usually allowing farmers to continue irritating (Ghosh et al., 2014). Typically, this WSA requires physical storage (i.e. a surface reservoir) where the portion of water banked can be held and transferred temporarily to other users. Water held in banks is typically a portion of a water user's historical water right (Dilling et al., 2019), as opposed to surplus or augmentation supply. Volumes can be traded as credits, such as an available share within a ditch company, and are typically administered through a central authority (Singletary, 1998; Singletary & Narayanan, 2003; Mahmoudzadeh Varzi & Grigg, 2019). Water banking has shown success in primarily shares-based or correlative water rights systems but can cause apprehension among priority-based water rights systems due to the long-term dependence on and established security of holding senior water rights (Mahmoudzadeh Varzi & Grigg., 2019).
Water Cooperatives	Water cooperatives are a type of water banking that relies on surplus augmentation credits that can be traded or transferred to optimize water use in an area (Mahmoudzadeh Varzi & Grigg, 2019; Dilling et al., 2019). Physical storage is not a necessity of this type of arrangement, but rather if a water user does not use all their augmentation credits in a given year, they can be transferred to another user in need of credits. This terminology was developed in Colorado to describe the Northeast Colorado Water Cooperative (Mahmoudzadeh Varzi & Grigg, 2019).

While continuing to work within the same market-based framework that has become familiar to water users throughout the region (Koebele et al. 2022; Ghosh, 2019), WSAs are theorized to offer several purported benefits over permanent water transfers (Dilling et al., 2019; Mahmoudzadeh Varzi & Grigg, 2019; Brewer et al., 2008). Many water users in the western U.S. are generally amenable to water markets as a reallocation strategy because they can preserve PA as a property rights institution, allowing water right holders to maintain some level of autonomy, as opposed to government-mandated

curtailments or use restrictions (Marston et al., 2022; Goemans & Pritchett, 2014). While many water users support the utility of PA in its clearly defined system of property rights which are essential to functioning water markets, its 'use-it-or-lose-it' tenet enforcing the forfeiture of unused water rights can create challenges to leasing water temporarily (Koebele et al., 2022). WSAs are designed, however, to address this tenet, with many western states having passed legislation that allows water rights holders to temporarily transfer a portion of their allocated water without the risk of losing their entire water right (Cal. Wat. Code § 1725; ORS § 540.570; 85-2-427, MCA).

Additionally, WSAs can provide increased flexibility for agricultural users to continue farming under uncertain water supply conditions, as opposed to permanent acquisitions, while making additional supply for other water use sectors available. Rather than selling a water right, irrigators engaged in WSAs can gain additional income in dry years while discontinuing or adapting farm operations for a season, alleviating some of the financial risk associated with determining whether to part with a water right completely (Arellano-Gonzalez, 2021; Bjornlund, 2003). Further, WSAs may help to mitigate the previously mentioned economic and ecological impacts of permanent water transfers by keeping agricultural lands in production, at least to some degree, which helps to retain the local tax base in rural areas necessary to support public services (Howe & Goemans, 2003; Thorvaldson & Pritchett, 2004), and avoid degradation of ecosystems and water quality (Lund & Israel, 1995; Zhuang, 2016). Additionally, municipalities are increasingly looking to obtain additional water supply as their populations grow (Schwabe et al., 2020; Characklis et al., 2006; Brewer et al., 2008). For many water utilities in the western

U.S., it is crucial to secure a consistent and reliable water supply for consumers. The municipal sector is thus focused on expanding their water rights portfolio, spurring their participation in available water markets (Characklis et al., 2006).

WSAs are not a perfect solution to competition over limited water supplies in the western U.S., despite these numerous purported benefits. One of the primary issues that persists with WSAs, and in all PA-based water markets, is high transaction costs, or the costs associated with trade (Howe et al., 1990; Womble & Hanemann, 2020). That is, transaction costs associated with legal and administrative processes for transferring water arise for all types of water markets (Womble & Hanemann, 2020). WSAs can vary in terms of their administrative processes, depending on the state in which they occur. For example, Nevada's State Water Engineer is generally the primary authority that approves water transfers in this state (Koebele et al., 2022; Colby, 1988); however, a special water court administers the trade of water resources in Colorado (Thorson, 2016; Womble & Hanemann, 2020). In many states, however, transfers are evaluated based on whether they will cause third party injury to downstream users (Brewer et al., 2008; Leonard et al., 2019). As opposed to permanent transfers or diversions which are easier to quantify, temporary transfers can take longer to approve and administer as the third-party impacts of temporary or intermittent diversions are more complicated to measure (Dilling et al., 2019; MacDonnell 2015). The costs of having the potential impacts of a temporary water right transfer evaluated, and the potential impact its temporary diversion might have on downstream users, may be very high (Colby et al., 2014; Banks & Nichols, 2015).

Another drawback of temporary transfers is that agricultural producers may perceive that the true costs or risks associated with reducing irrigation, even for one growing season, are not adequately reflected in the price offered for temporarily leased water (Taylor & Young, 2005; Dilling et al., 2019); and it has been suggested that agricultural financial risk be integrated more accurately into the negotiated prices for temporary transfers (Mooney & Kelley, 2022). Municipalities may struggle to pay these prices, however. That is, municipalities are typically rate-payer funded and may not be able to invest substantial amounts in water leases without increasing user rates, creating a barrier to municipalities participating in WSAs (Dilling et al., 2019). Moreover, despite there being legislation protecting users from the "use-it-or-lose-it" tenet in most states, agricultural users are often concerned they may ultimately forfeit their water right if they engage in a temporary transfer over a period of consecutive years (Dilling et al., 2019). In California, Montana, Oregon, and Washington, conservation of an allocated water right is protected and can be used for temporary transfers (Cal. Water Code § 1021 & 1024; ORS § 540.523 & OAR 690-380-0010; 85-2-415, MCA; Wash. Admin. Code § 173-166-080), whereas in states like Colorado, only historical consumptive use can be transferred, which is difficult to measure, contributing to a persistent concern regarding water forfeiture in this state (Dilling et al., 2019; CO. SB 06-1124, 2006). Additionally, physical water conveyance and storage infrastructure can also play critical roles in whether WSAs are successful. With the goal of WSAs being to preserve water for agricultural irrigation and create more flexibility for a range of water users, if infrastructure is lacking and new reservoirs and pipelines are needed, water users may be less likely to engage in a temporary transfer that is not large enough to support the costs

of additional infrastructure necessary to facilitate the transaction (Dilling et al., 2019; Howe & Goemans, 2004).

Overall, due to the temporary nature of WSAs, there is potential for these market mechanisms to mitigate the social, economic, and ecological drawbacks of permanent transfers (Mooney & Kelley, 2022). It is important to analyze which WSA designs will work best through stakeholder engagement, however, which is the goal of this study.

Methods

This research investigates the desirability of WSAs and their potential improvements through a case study of the South Platte River Basin, located in northeastern Colorado. Case studies permit the thorough analysis of a particular topic in a case-specific context which can reveal themes or other important information more broadly applicable to the subject (Yin, 2009). This study area is unique in that it provides a sufficiently diverse portfolio of WSAs, with several being established over the last decade (CWCB, 2020). However, it is also broadly demonstrative of other arid snow-fed river basins in the western U.S. in that it is primarily an agriculturally dominant basin that experiences pervasive drought conditions and minimal rainfall during the summer months; it also experiences ongoing urbanization, in cities like Denver and Fort Collins, similar to other areas throughout the region. In the following sections, the study area and justification for this selection are described, followed by the data collection and analysis methods used for this research.

Description of Study Area

From its headwaters at about 14,000 feet, where it originates as snowpack in the Mosquito Range of the Central Rocky Mountains, the South Platte River's course is about 480 miles across Colorado's northeastern plains, with its lower portions stretching into Wyoming and Nebraska (see Figure 1). The basin receives varied annual precipitation forms and amounts depending on altitude (lows being less than 15in) along with temperatures that can reach 100^{o}F during the summer seasons (Dennhey et al., 1998). The river supplies water to a variety of uses including irrigated agriculture, municipal and industrial use, as well as environmental in-stream flow for habitat restoration and recreation (CWCB, 2015). Irrigated agriculture remains an important economic driver in the basin, with Weld County being the top agricultural producing county in Colorado (generating over $2 billion in total sales of agricultural products in 2017) and the 8th top-producing county in the U.S. (United States Department of Agriculture, 2017). Additionally, the basin includes the counties of Larimer, Morgan, and Adams which are also among the top 10 agricultural-producing counties in Colorado (United States Department of Agriculture, 2017). Conversely, rapidly growing cities, such as Fort Collins, Denver, and Aurora, have led to municipalities competing with agricultural water use in the basin. The state of Colorado has projected to nearly double its municipal demand to about 401,000 AF by 2050 (CWCB, 2010). Moreover, climate change, including increased wildfire frequency and scale, has further strained the basin's water resources bringing water quality and water scarcity concerns to the forefront of the South Platte River Basin's water resource management challenges (Rhoades et al., 2017). For these reasons, the South Platte River Basin provides an excellent study location, as it

demonstrates critical challenges involving water resource management, while also leading the western U.S. in its experimentation with WSAs (Dilling et al. 2019).

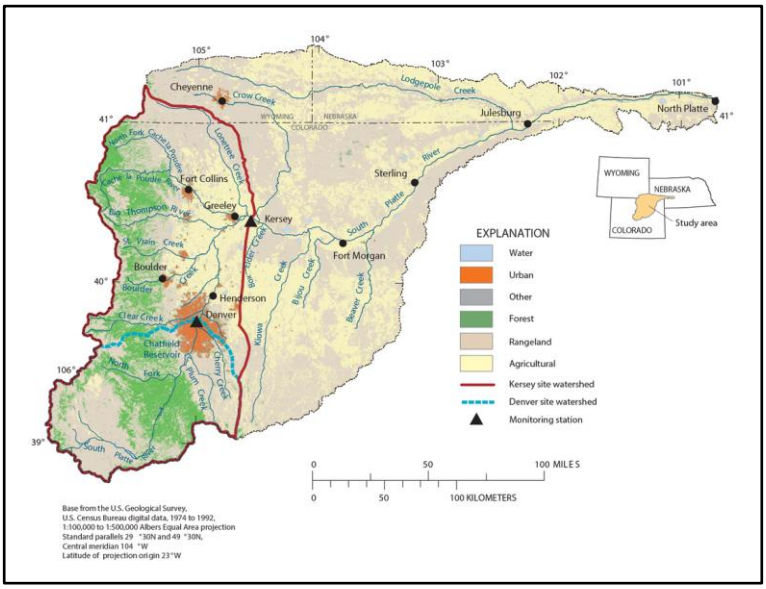

Figure 1: Map of South Platte River Basin, organized by land use type from USGS (Dennehy et al., 1998).

Part of the reason why Colorado is leading the nation in experimentation with WSAs is due to the Colorado Water Plan. The 2015 plan called for up to 50,000 acre-feet of water to be transferred from agricultural to municipal and industrial uses through WSAs, previously called ATMs, by 2030, and the most recent plan also includes goals to expand WSAs (CWCB, 2015; CWCB, 2023). The state has made available numerous resources to facilitate these transfers, including grant programs as well as several public agencies and non-profit organizations available to provide information and/or partner on WSA development and performance evaluation. Colorado House Bill 14-1333, for example, authorized $4 million to fund pilot lease-fallow projects, in addition to funding water banking and flex market feasibility studies (CWCB, 2015; CO. HB 14-1333, 2014).

Further, Colorado is unique in that it has a water court system dedicated to permitting and prohibiting water transfers and change cases (Thorson, 2016). Most WSAs are permitted through the water court only if a historical consumptive use (HCU) baseline is established for an individual water right. Once this baseline is established, an irrigator can adopt technologies to conserve water which can then be used in water transfers (Mooney & Kelley, 2022). Return flows must remain the same, however, which can lead to concerns regarding third-party injury and risk regarding water forfeiture, potentially making some WSA designs more attractive and legally feasible than others in the South Platte Basin. Given the impetus for establishing WSAs in Colorado, this research will provide relevant information regarding stakeholder perceptions of preferable WSA designs which can be implemented both within and outside of the study area.

Data Collection and Analysis

To study stakeholder perceptions of WSAs, a set of 28 semi-structured interviews were conducted with various stakeholders in the basin (Rubin & Rubin, 2005). While semi-structured interviews follow a set of pre-developed questions, the researcher can ask follow-up questions or pursue topics more thoroughly for clarity (Rubin & Rubin, 2005). Several stakeholder groups were selected for interviews as they were determined through literature review and knowledge of water users in the basin to be the most relevant and engaged water market participants in the area. Water rights holders, water managers, and other representatives from organizations and entities involved with water use in the basin were recruited from the following groups: agriculture (AG), municipal and industrial (MI), environmental (ENV), government (GT), and research or other (RO). No federally

or state-recognized Native American tribal water users or reservation lands are located within the basin, and agriculture and municipal providers make up the majority of water rights holders in the South Platte River Basin. Government entities and environmental groups work tangentially with water users to manage water resources, watersheds, and water allocations, with the state of Colorado being the only entity allowed to lease water rights for in-stream flows. The research or other category consisted primarily of water experts working in academia or for water rights-related consulting firms. Thus, these groups comprise the most representative stakeholders in the basin. Table 2 shows examples of stakeholder groups and the number of interviews conducted per stakeholder group in this study.

Table 2: Number of interviews completed by water use interest stakeholder groups.

Stakeholder Group	Stakeholder Examples	Completed Interviews	Declined Interview/ No Response
Agricultural (AG)	Farmers and ranchers, irrigation districts, and ditch companies	6	8
Government (GT)	Water conservancy districts, local, state, and federal policy makers	8	15
Municipal/Industrial (MI)	Urban water purveyors, utilities, and industrial water users	6	8
Environmental (ENV)	Watershed and river advocates, wildlife-protection NGOs	5	9
Research/Other (RO)	Research scientists, water consultants	3	3
Total		**28**	43

Snowball sampling techniques were used to expand this purposive sample and secure additional interviews until saturation of information and common themes occurred (Rubin & Rubin, 2005). An email invitation was sent to all participants with a short description of the study, and all interviews were conducted via Zoom video conferencing software. All interviewees consented to be interviewed and the University of Nevada Reno's Institutional Review Board approved interview questions, data collection protocol, and data analysis and reporting procedures. The interview questionnaire developed by the authors (Supplementary Appendix A) covered topics regarding water supply availability, management strategies, and participation in or knowledge of existing water rights transfers or WSAs in the basin.

Each interview was then recorded, transcribed, and coded using qualitative data analysis techniques. NVivo Qualitative Analysis Software was used to thematically organize transcribed text into codes based on an *a priori* codebook created by the authors (see Supplementary Appendix B for full codebook), in order to more systematically analyze the unique narrative data collected (Auerbach & Silverstein, 2003; Glaser & Strauss, 1999). Codes represent repeating ideas that were demonstrated within and across transcripts (Auerbach & Silverstein, 2003). The majority of the codes were created and organized into the codebook prior to data analysis as this research was part of SNOWPACS, a larger, interdisciplinary project focused on western water management. This allowed the authors in this study to collaborate with a broader team of researchers and draw on existing empirical data about stakeholder perceptions of water trading programs in other basins. Some grounded theory was used to add codes to the codebook

during analysis, as additional repeated ideas were induced from the data (Auerbach & Silverstein, 2003). An example of a code is provided in Table 3.

Table 3. Example of code used for analysis derived from the codebook.

Example Code	Code Description
SECURE	Stakeholders participate in water rights transfers because they want to increase water security (for development, etc.)

To establish intercoder reliability and reduce bias, the first interview was coded by all authors, and the lead author coded the remaining transcripts (Auerbach & Silverstein, 2003). Any coding discrepancies or uncertainties were resolved through discussion and consensus involving all authors. For this study, codes regarding various stakeholder sentiments around WSAs were grouped into several themes and theoretical constructs. A theme consists of several similar codes, or repeated ideas, grouped together, and theoretical constructs refer to groups of themes that are related and exemplary of or build upon existing literature (Auerbach & Silverstein, 2003). For this study, themes regarding stakeholder mentions of existing or proposed WSAs, reasons for stakeholder participation in WSAs, stakeholder perceptions of water markets generally, as well as stakeholder suggestions for improving water transfers were analyzed and ultimately led to the development of three theoretical constructs, presented in the Results section below. These constructs consist of the i) perceived benefits of WSAs, ii) perceived drawbacks to WSAs, iii) and stakeholder suggestions to improve WSAs. Though no interview questions were specifically asked about what stakeholders perceived to be the benefits and drawbacks of WSAs, their experiences to date and suggestions for improvement

quickly grew as a focal point, eliciting these three constructs. See Figure 2 for a sample conceptual diagram of how codes and themes are used to develop a theoretical construct, using the perceived benefits of WSAs as an example.

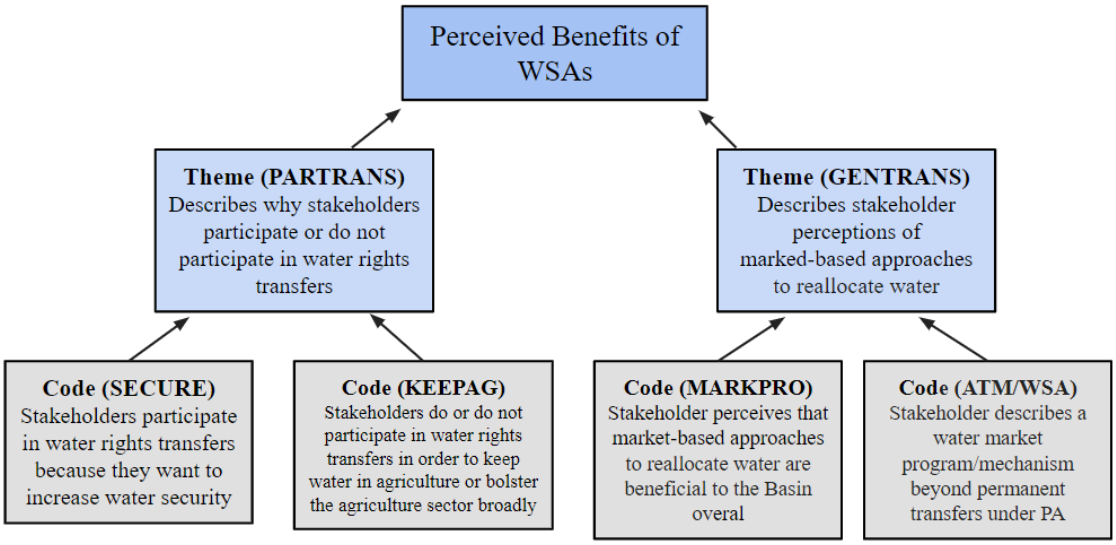

Figure 2. Conceptual diagram illustrating a few codes and themes used to create the "perceived benefits of WSAs" theoretical construct. This is not a comprehensive diagram of all codes and themes used to develop this construct, but rather an example of how the qualitative analysis process works. The theoretical construct is listed at the top as the broadest descriptive category, with the themes being listed in the middle, and codes listed at the bottom as they are the most specific concept.

The quotes in the following section are derived from various interviews and are illustrative of the most common benefits, drawbacks, and suggestions for improvement as discussed by stakeholders. To show that data come from various interviews, identifiers were created representing the interviewee's water sector (i.e., AG for agriculture) and assigned a random number (i.e., AG_01). This ensures anonymity among interviewees while allowing an accurate portrayal of stakeholders' sentiments towards WSAs.

Results

The Perceived Benefits of WSAs

Table 4 summarizes the three major benefits of WSAs identified by stakeholders. While agricultural producers discussed the benefits of WSAs more often than other stakeholders (as will be discussed further in the following section), the benefits of WSAs were indeed mentioned by interviewees in each water use sector. There was general consensus among stakeholders that WSAs are generally working as they are intended in that they help avoid buy-and-dry scenarios, promote the economic vitality of rural and agricultural communities, and efficiently move water across sectors.

First, stakeholders across several sectors (agriculture, environmental, and government) identified the ability of WSAs to prevent buy-and-dry as a major benefit. As demonstrated by the quotes in Table 4, stakeholders discussed the importance of keeping water in agriculture and agreed that WSAs help mitigate the negative consequences of permanently moving water from irrigated land to other uses. Specifically, a few stakeholders mentioned that WSAs can help avoid the negative ecological impacts of drying farmland, such as creating dust patches, raising temperatures in areas where fields were previously irrigated, and reducing habitat for wildlife. Several interviewees also referred to buy-and-dry scenarios that happened in other basins and explained how devastating it was for those rural communities economically. Thus, the desire to avoid the same fate by participating in WSAs was a prevalent sentiment in the interviews.

This foregrounds the second benefit discussed by stakeholders: the ability of WSAs to promote economic vitality in rural and agricultural communities under changing social and hydrologic dynamics. When buy-and-dry is avoided, farmers are able to continue irrigating, helping small, agriculturally reliant economies avoid massive changes. Further, when agricultural water right holders can trade water in some years, especially those in which a drought or other event may reduce agricultural production (Arellano-Gonzalez, 2021), agricultural users are "made whole" economically. Without WSAs, an irrigator would have to consider whether to forgo any profits from farming that season or perhaps even sell their water right permanently. WSAs, however, allow farmers to decide whether they want to lease the whole of their water right for a season, earning income in the interim, or lease a portion of their water right and continue farming a smaller plot of land, allowing for additional flexibility to continue earning some on-farm and off-farm income that may otherwise be lost. Furthermore, because WSAs are temporary and it is unlikely that a majority of users in a single community will all lease their water in one year, businesses and services that support agriculture in rural communities, and contribute to the local tax base, do not suffer in the way they might if an area underwent large-scale permanent water transfers. At least one interviewee in each of the agricultural, governmental, environmental, and research sectors mentioned how WSAs contribute to economic gains in rural and agricultural communities and increase flexibility for agricultural producers during drought years.

Third, all sectors had at least one interviewee discuss the ability of WSAs to effectively reallocate water from agriculture to other water use sectors, showcasing that relevant

stakeholders perceive WSAs as achieving the goal of creating flexibility in water management. Across sectors, many interview participants agreed that as urban populations in the South Platte River Basin grow, the need to transfer water to municipal uses will grow, and WSAs will play an important role in efficiently facilitating this reallocation. Using WSAs to meet demands may look different across sectors, however. Municipalities championed WSAs as an effective way for water providers to obtain an additional emergency supply if portfolios are relatively developed. However, they are hesitant to rely on WSAs for primary supply due to reliability challenges, as will be discussed further in the next section. On the other hand, participants from the energy sector were in favor of engaging in WSAs for all kinds of water supply, as their operations don't necessarily require the same degree of reliability as a municipality, making the flexibility of WSAs attractive to them. Additionally, some stakeholders even mentioned the potential for WSAs to provide additional water supply for environmental purposes, though transfers for these purposes may be somewhat limited by Colorado water law (CO. HB 03-1320, 2003).

Table 4. Stakeholder-Identified Benefits of WSAs

Theme	Stakeholder Group that Identified Theme	Quote
WSAs help avoid buy-and-dry scenarios	AG, ENV, GT	"I think generally, [water sharing arrangements] are a great thing to avoid the buy-and-dry model that we've seen. I think the reality is development is coming to the Front Range…it's increasing every day. And anything that can be done to preserve agriculture is a good thing. So, if that means a [water sharing arrangement] where [water is leased to a municipality] a couple years out of 10, the fields are fallowed and the water goes for a

		municipal use…that certainly is better than 10 years out of 10." (AG_04) "The slogan here is 'sharing the water to save the farm.' So, the more partnerships we have with local municipalities where we're sharing that water, and let's say a municipality has an agreement with 10 producers on a ditch system, and they pull a little bit of water off one farm each year, that's helping everybody because there's a disincentive for [that municipality] to go and buy and dry farms." (ENV_02)
WSAs promote the economic vitality of rural and agricultural communities and create flexibility for farmers to manage water in drought years	AG, ENV, GT, RO	"[A specific WSA] changed the attitude of our farmers' willingness to do a deal with other users. They treat their water more as a commodity, and that's what I've been trying to teach them…you don't always have to use your water to grow corn or hay, or whatever you might do with…produce in our area. You can look at it as if I could get more by leasing some of this water to someone else, then maybe I can farm a few less acres or maybe not irrigate my alfalfa a fourth time, or whatever it may be." (AG_03) "It's also a way to keep that money in that local system, you're paying some of those producers. It's a diversification of income for them and that water is still staying in the system." (ENV_02). "I've always contended if you can keep [some of] the water on that land and keep that farm active…you still have a farmer who is actively engaged [and] producing in the community. That water is tied to the community, that market value is tied to the community. You're buying inputs, you're buying tractors or buying corn seed and buying fertilizer, you're producing something, so that means they're selling it in the local economy. So, you have economic growth, you have economic stimulus because of that." (AG_05)
WSAs help users meet water demands across sectors	All Sectors	"In a community like [ours where] we have less growth left…we're maybe in a position where we can start looking at [WSAs], where we're really just trying to top [water supply] off with emergency supplies…it doesn't have to be perpetual, we could get into like a 10-year rotating agreement" (MI_01) "...there's a lot of potential for [the energy sector] to participate in [WSAs]. For instance, the wind is blowing today, and so our [energy] generation is down. How can we decouple our water demand, or our water supply, from our reduced demand, and then retime it or deliver it to another user in a predictable way, so that they can use it?... So that's something I'm working on

		with the electric utility piece of that." (MI_05) "So, I see a tremendous value and a tremendous opportunity for these types of leases or for these types of [WSAs] to keep water in agriculture…while still meeting the demands of municipalities." (AG_05) "...on the Arkansas, there have been times where Parks and Wildlife has been able to enter into leases on a short term basis during just particularly dire flow conditions with willing irrigators who maybe they already got their first cut in and they were willing to forego a second and sell that water instead for that one season [for environmental uses]....I know the [Colorado] Water Trust has done a fair bit of that in the Yampa Basin as well. Not as familiar with a lot of that in the South Platte basin, doesn't mean it hasn't happened." (AG_04).

The Perceived Drawbacks of WSAs

Although there was a relative consensus among stakeholders that WSAs are largely achieving what they were designed to do, several drawbacks to these arrangements were identified by stakeholders across sectors. Table 5 describes the most commonly mentioned drawbacks of WSAs, including a lack of physical infrastructure for transfers, difficulties in reaching an agreement on lease prices, residual uncertainties surrounding the political institutions of WSAs and how they will impact agricultural livelihoods in the long term, and the inability of WSAs to provide long-term water security for municipalities.

First, several stakeholders from the government and research/other sectors stated a lack of physical infrastructure (either conveyance or reservoir storage) as a major barrier for utilizing WSAs. In particular, it may be infeasible for a transfer to occur among users

who are not in close geographic proximity. Some temporary infrastructure in the form of gravel ponds exists for downstream users to temporarily store water upstream for use by others, but this can limit the size of a transfer. Further, investing in new infrastructure dedicated to supporting temporary water transfers may not be cost-efficient.

Moreover, the price of water leases remains a significant barrier for both agricultural producers and municipalities to engage in WSAs. Agricultural producers discussed that prices commonly offered for yearly leases do not compensate irrigators for the lost revenue associated with halting or reducing operations for a growing season. As a result, agricultural users often seek higher prices than municipalities are willing to pay. At the same time, while the municipal sector generally has more available cash-on-hand than irrigators to engage in water markets, their rate-payer funding structure may prevent them from spending large amounts of money on a lease, especially if it is only for the short term (generally just a year but this applies to 5-10 years as well). Municipal water leases and purchases are reflected in domestic water use bills, and thus several municipal stakeholders mentioned the difficulty of being able to meet the water lease prices desired by agricultural producers. Additionally, because the market value of water is subject to volatility, several stakeholders mentioned the hesitancy of the agricultural sector to engage in longer-term WSAs (20 years or more) at fixed prices, as their water may be worth much more in the near future. Additionally, agricultural producers are concerned about locking their heirs into longer-term arrangements, given that they may want to use or sell that water right in the future.

Additionally, although several WSAs within the South Platte River Basin have been in place for more than 20 years, there are stakeholders who remain concerned that WSAs conflict with the fundamental tenets of Prior Appropriation (PA). For example, there are concerns that WSAs do not fully protect lessors against the threat of water right abandonment and forfeiture or that changes in diversions associated with WSAs are not monitored well enough to protect downstream users who rely on return flows from injury. Water right forfeiture and abandonment have long threatened water security for irrigators in the western U.S., and though many states have drafted and/or passed legislation to protect against this tenet in order to encourage conservation, PA has governed and acculturated water use in the region for so long that many water rights holders are still hesitant to change their water use behaviors. This sentiment was evident in our interviews, despite recent legislation passed by the state of Colorado to protect WSAs against the use-it-or-lose-it tenet. The law states that a water right will not be considered abandoned if it is part of "(1) a Federal land conservation program, (2) a water conservation program, (3) a land fallowing program, or (4) a water banking program" (CO. SB 05-133, 2005). Though this list of exclusion criteria seems comprehensive, it does not specifically mention agricultural water protection rights or interruptible supply agreements, which likely contributes to stakeholder uncertainty regarding the outcomes of WSAs in the long run.

Water court requirements to approve WSAs are also varied, which further contributes to uncertainties regarding their use. In Colorado, interruptible supply agreements and agricultural water protection rights (i.e., rights that allow 50% of an agricultural historical

consumptive unit [HCU] to be used for other uses) are approved by the state engineer through an administrative process and do not need to go through water court for a decree change (CWCB, 2020). Arrangements that rely on rotational fallowing, however, are subject to water court proceedings, which require HCU measurements for each parcel. This verification process is costly and time-consuming, and once completed for a decree change, HCUs cannot be re-measured (CO. SB 15-183, 2015). Undertaking this measurement and verification process may be cost-prohibitive as well as potentially libelous for some users, as HCUs are an average derived from plant water use in a variety of dry and wet years, so they may not accurately reflect an irrigator's true consumptive use. Thus, quantifying an HCU may be risky for farmers given that it may be determined to be less than the legally appropriated water duty associated with their water right. Because of this, stakeholders in our study often mentioned their apprehension to engage in WSAs due to these legal processes and requirements.

Lastly, as mentioned in the previous section, municipal water users less often discussed benefits associated with WSAs. This is primarily due to the inability of WSAs to provide secure, long-term supplies for municipal users. Consequently, municipal participation in WSAs may be stunted due to the disparity between the municipal need for a long-term supply to support reliable taps for consumers, and the short-term availability of water through WSAs. As such, many municipal interviewees suggested that water providers who are more supply-secure may be willing to use WSAs to acquire emergency supplies. Municipal stakeholders seeking larger and more reliable water supply for their growing communities may instead prefer "lease-back" agreements, where they permanently

purchase water rights from agricultural users and lease surplus water back to irrigators, "*as a way to support local ag" (MI_02).* Although the intent of a municipality that engages in these lease-back programs is to continue to support agriculture, these transfers violate the fundamental aspect of WSAs to keep water rights in agriculture and therefore cannot be viewed as an improvement upon WSAs. Moreover, lease-back programs may be viewed as a way to simply prolong inevitable buy-and-dry scenarios, as municipalities will grow to use any surplus water and no longer have water available to lease to irrigators. The willingness of municipalities to engage in creative arrangements is encouraging and discussed further in the following section, yet the ability of WSAs to provide water supply security for the municipal sector remains a notable drawback.

Table 5. Stakeholder-Identified Drawbacks of WSAs

Theme	Stakeholder Groups that Identified Theme	Quote
Lack of physical water conveyance and storage infrastructure	GT, RO	"There's physical infrastructure…political infrastructure, and there's financial infrastructure…I believe it's fair to say that [WSAs] and interruptible supplies… are complicated by the fact of the infrastructure that's available to do it…. Who's going to make the investment… if it's only for a short period of time? Most entities would invest in infrastructure because they have a perpetual obligation. But if you have this 10-year lease, why would you make that kind of investment?...It is a limiting factor, and it's part of why you don't see more and more of that in Colorado, or in this discussion on the Platte." (GT_06a) "I've always said that the reason that a lot of these… [WSA]s don't happen is more infrastructure… and agreement driven. I mean, it needs to be between a willing water provider, municipality, [and] a group of farmers who agree on the same terms, the price, the length of the contract, and then you have to be able to get water from point A to point B and treat it…and you have to convey it, move it. So, there's a lot of pieces that need to be done before you do a lease…I think infrastructure is a key to

		making those work." (GT_03) "In dry years leasing around you nearby is something that can happen, it doesn't happen as much as it should, but where the water is probably the most valuable and there's a lot of opportunities [is upstream]. It's much more difficult to move it up and use it upstream…exchange potential is a really big deal. That limits a lot of what happens." (RO_03)
Difficulties of competing sectors to agree on water lease prices	AG, GT, MI, RO	"...the true cost is, according to ag users, much more than municipal users think it is" (RO_03) "I would say the crux of [WSAs] in terms of getting more of those projects off the ground has basically been how to get the financials to work for both the producer and the city. So, there's kind of perverse incentives when it comes to [WSAs]. A producer doesn't want to get locked into a long-term water-sharing arrangement, typically, because they're concerned that they might miss out on fluctuating commodity prices, and their water lease might be less valuable to them than if they were actually actively farming in a given year….The other part of that is they might not want to put any limitations on their heirs…so if they're nearing retirement and say [a producer has] the city knocking on the door interested in a [long-term WSA], well, what we've actually seen is the producer saying, 'No, I'm not going to lock my kids into a 30-year lease agreement, I want to make sure that they have the option to sell the asset at its full value" (GT_01) "One of the issues with [WSAs] is that many farmers seem to think that the cities have kind of endless pockets of cash, and [farmers] would ask for a lot of money. But the city…is a nonprofit governmental agency, we operate at cost. And the money that we're spending is our rate-payers' money. It's our citizens' money. So, we can't just spend tons of money because somebody else wants it." (MI_06) "We get some farmers interested (in leases), and the price isn't right, or, we did have a municipality offer to lease water on [a] six out of twenty years lease, but in this area, the water might be worth $50,000 today, and in six months, it's worth $70,000. So why would I sign up when it's worth $50,000 when the price is changing so drastically? And so, we found that to be the major hindrance to [WSAs], it was just the market is so hot" (AG_06)
Uncertainties regarding the political institutions of WSAs and their long-term impacts	AG, GT, MI, RO,	"From an agricultural user standpoint…one of the concerns that was out there is if you go to court to change your water for a [WSA] use, [and] you decide to rent it a couple of years to someone like [a water conservancy district], [but] then you want to take it back on the farm to irrigate…then you get…monthly volume limitations that were defined in

		that court case, in that decree…change. So, it kind of ties your hands when you want to put it back on the farm." (GT_07) "When you go to water court and transfer your water right… it has to go through the water court process, [and] the water users in the state of Colorado are very comfortable that [because of this] you're not injuring anyone else in [a] transfer…non-injury is the criteria. When you do [an interruptible supply agreement] just for a year [or for 3 out of 10 years]…you don't have to go through water court [and] there's a lot of ag users who are still concerned that their interests are not being taken care of downstream. And I think that that's likely true, or potentially could be true…because [producers and their neighbors] are not convinced that the process protects the river downstream and other water users." (RO_03)
WSAa provide less long-term security for municipalities than permanent transfers do	All sectors	"But I'm not aware of very many municipalities that will accept temporary water rights for issuance of taps. Because when we issue a tap, we are guaranteeing to serve that in perpetuity [and a WSA is only temporary]." (MI_02) "We don't personally do any [WSAs]. I understand them. I get them. They're a pretty hard sell. Well, it's a really good idea, [but] from the water provider perspective, it's a really hard sell. Primarily because when you issue a water tap to a house, you've committed I'll say forever. But [WSAs] many times aren't forever. I think there's definitely a place for them, but we just haven't done any." (MI_04)

Stakeholders' Suggestions for Improving WSAs

In conjunction with the drawbacks stated above, stakeholders suggested changes they believe will improve the facilitation of and participation in WSAs. Table 6 identifies three common suggestions: i.) receiving increased public funds to support WSAs, ii.) streamlining the water court process to homogenize requirements for temporary transfers and clarify the outcomes of decree changes for WSAs, and iii.) creating an even greater culture of collaboration in which WSAs are developed. These suggestions speak directly to the identified drawbacks described in the previous section.

First, a lack of physical infrastructure and disagreements on water pricing led several stakeholders to advocate for public funding to help municipalities and other stakeholders pay irrigators' desired water prices and invest in necessary conveyance infrastructure. When it comes to funding transfers, it was generally accepted among actors from various sectors that agriculture would not be responsible for bearing the costs associated with WSAs and that those in need of the water (i.e. municipal and environmental actors) should pay for infrastructure that supports temporary transfers: *"We're trying to look more at projects that are in partnership with other water users and if there are ways that we can improve their infrastructure and its reliability, while also creating some environmental benefit at the same time, where we can really create win-wins." (ENV_04).* However, because funding is not always available in these sectors, many stakeholders advocated for more public funding for WSAs. This funding may come from the state, for example, given that Colorado's previous water plan encouraged the large-scale use of WSAs and provided some funding for users looking to engage in them.

Additionally, to combat the issues of institutional uncertainties related to water court and the politically charged task of moving water out of agriculture, stakeholders across sectors encouraged streamlining the water court approval process to make it easier for participants wanting to engage in WSAs. Specific legislative or political changes were not cited, but the biggest concern of stakeholders was focused on the risk of losing water through the process of quantifying HCUs for decree changes. Thus, many interviewees advocated for more protection for irrigators when transacting a decree change for WSA

use, in the instances where it is still required under Colorado water law. It was also suggested that municipalities help irrigators financially navigate this process, a feat that would be more easily achievable with the public funding mentioned previously.

Finally, though stakeholders did not provide explicit suggestions that target the issue of municipalities' need for long-term security, all stakeholder groups did encourage collaboration and creativity in the development of temporary transfers to better meet the dynamic water needs of all sectors. Moreover, the general attitude of the municipal sector towards WSAs was positive, despite the noted drawback of lack of water security: "*We would be happy to do [WSAs] to work with farmers to lease water, where it makes sense"(MI_06).* Some municipal stakeholders even mentioned various creative arrangements in which they would be willing to engage, such as financially helping farmers switch crops potentially to produce food that can be used for local consumption in public school systems and leasing water from these farmers in drought years. Collaboration was a frequently mentioned component by stakeholders for its ability to foster arrangements that provide the maximum benefits for all parties involved.

Table 6. Stakeholder-Identified Suggestions for Improvements to WSAs

Theme	Stakeholder Groups that Identified Theme	Quote
More external funding for WSAs	ENV, GT, MI	"I believe there needs to be an input of external money. If the state or the counties want to see preservation of irrigated ag, there has to be an external form of money, whether that's state severance tax or a mill levy. Municipal providers can't do it on our own" (MI_02)

		"...longer term, there's a lot of transaction costs associated [with WSAs], along with just the cost of the water itself and ensuring that whoever is providing to, say, a farmer that's fallowing for a year or a season is compensated appropriately. But there may be opportunities if we're creative about it, for [these WSAs] to also create environmental benefits, and that in turn could mean that funding from licensed dollars and anglers… or environmentally focused, federal stewardship programs under the farm bill could play a role in helping fund some of those transactions…So I think there's room for some creativity on that." (ENV_04) "just more federal funding for water sharing programs" (GT_01)
Streamline the Water Court approval process. Many stakeholders	AG, GT, RO	"In Colorado, the water court process is so incredibly difficult, expensive, and risky. [WSAs are one] example of [a type of short-term water transfer where] people are hesitant to [engage] because of the unintended consequences of a diminishment of their ultimate water right…So if there were a way to streamline processes like [water court], with no risk to the water right owner, I think that would go a long way." (AG_04) "...going through water court is such a big expense and risk, because you never know how much water you're going to get out of [a change case] and the cost of it. And I don't think farmers right now have the resources to do that. So…it's going to have to…be a joint partnership, where a municipality is going to say, 'We'll work with you to get through the water court process, [if we are] able to have first right of refusal for that water'...because they're the people that have the staff…that can go through the water court process and do it" (AG_01)
Create a culture of collaboration and creativity of WSAs	All Sectors	"We were trying to encourage water planning [for municipalities]...that if [their] water supply is mostly stable [to put] the very top, the last 5%, of [their] water supply…in a sharing [arrangement] with agriculture. Because [they're] only going to need that 5% in extreme years to provide water to [their] ratepayers.'" (RO_02) "We're trying to figure out a way that we can partner with the farmer, so it's not just a lease, but it's a partnership. So they have less risk, and [our city] gets some of the [agricultural] production. So, in the years where food is produced, [our city] gets some of that

		food. And in this case, what's been grown on the farm…[is] eggs, milk, and sugar…then we can take that food and either inject it into our school systems or inject it into our food banks so that the farmer reduces their risk. They still profit, but [the city] is injecting money… into the farming operation, and then…[the city] gets some of that food, which goes then to help…food insecurity issues. And on the years where [our municipality] needs the water, the farm is fallowed, and we would pay the farmer to lease that water." (MI_06) "Having that better understanding of both sides [agricultural and municipal], I think we can move forward [to create] some cooperative agreements that would work." (AG_01)

Discussion/Conclusion

Understanding how climate adaptation solutions like WSAs can be designed to create optimal outcomes for participants is critical for responding to climate-driven shifts to water supply. Through a case study of stakeholder perceptions of WSAs in the South Platte River Basin in Colorado, this study conducted a qualitative assessment of the state of WSAs and provided insight into potential ways to improve them. According to stakeholder perceptions, WSAs are generally performing as they are intended, though they are not a perfect solution; however, there are several viable avenues for improvements going forward.

Many of the findings in this study mirror that of previous literature (Dilling et al., 2019 and Mahmoudzadeh Varzi & Grigg, 2019), primarily in that stakeholders see the benefits of WSAs in mitigating adverse effects of buy and dry, yet challenges persist regarding time and costs associated with seeking transfer approvals in water courts, lack of

sufficient water conveyance and storage infrastructure, determining and negotiating a fair market price for water, and uncertainty surrounding temporary trades. Stakeholders also voiced concern that temporary arrangements may meet the needs of agricultural producers while failing to meet the long-term security needs of municipalities, potentially reducing the number of willing lessors. This study also advances the extant literature by eliciting the perspectives of stakeholders who are actually involved in WSAs, whether as current or potential lessors, lessees, regulators, or water managers in basins where WSAs exist. Information on stakeholder perceptions is necessary for the success of all water markets, as the effective use of markets as a policy tool requires the direct participation of water users. Thus, qualitative interview data obtained from water users across sectors is a strength of this study.

Further, as discussed in the results section, there were many suggestions for improving WSAs primarily by increasing public funding to support water transfers, simplifying the water court transfer approval processes, and further promoting a culture of collaboration among competing water users for WSAs to occur. Increased public funding through state agencies, like the Colorado Water Conservation Board (CWCB), was encouraged and may be useful in strengthening participation in WSAs in the future. In previous years, the CWCB helped to fund WSAs as part of the Colorado State Water Plan. Continued funding of this kind is recommended to aid water users in engaging in the water court process, meeting desired water rights prices, and constructing necessary conveyance and storage infrastructure. Federal funding may also be helpful in further implementing WSAs, yet it is worth noting that water users may be reluctant to participate in federally

funded water projects due to the inherent nature of water rights as a “private good” (Hargrove & Heyman, 2020). There has also been pushback against federal funding on the grounds that local water issues are often much more complex than what large federal projects may anticipate (Kenney, 1997; Diaz-Kope & Morris, 2022).

Additionally, streamlining the water court process and ensuring adequate protection for water rights holders to engage in temporary transfers is necessary for the widespread implementation of WSAs. Water forfeiture due to enforcement of the “use-it-or-lose-it” tenet is a major concern of water users, thus creating a space where water users feel safe to engage in transfers is imperative for large-scale adoption of WSAs. With added security regarding these transfers, a culture of collaboration and creativity may be able to develop more freely. If stakeholders have less apprehension engaging in these types of transfers, coupled with greater transparency around establishing price and transfer terms (Colby et al., 1990), arid areas in need of water reallocation may progress in their ability to implement water trading.

Lastly, it is important to note that there are some limitations to this study and further research on the topic is encouraged. This study was conducted during an extended drought period (about 20 years, with some wet years breaking up the drought), which can increase stakeholders' participation and involvement in studies like this, as natural resource managers are likely to adapt management practices after drought has occurred sequentially over a few years (Sterle et al., 2019). Additionally, though there was diverse stakeholder participation in this study, ongoing water management issues related to the

Colorado River compacts were a deterrent for a few stakeholders, as they were hesitant to speak on water-related topics due to the contentious policy decisions being made for such a major water resource in the area. Further, this study could have included more stakeholder perspectives, such as those from federal policymakers and additional scientific researchers. Moreover, though there are no state or federally recognized Native American Tribes in the basin, Tribal water users are a major stakeholder in many basins in the western U.S. and should be included in further research on water trading. Finally, as more examples of WSAs are becoming available across the western U.S., it is also suggested that comparative studies incorporating examples from other states also be conducted to assess how WSAs are working beyond a single case study.

Overall, this study highlights the importance of stakeholder-driven research and provides important information on WSAs and temporary transfers more broadly, which are emerging as an important water reallocation strategy in the western U.S.

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Supplementary Appendix A

SNOWPACS Interview Questionnaire: Summer 2021-Summer 2022

Introduction: brief introduction of interviewer(s), project; review consent form; any questions?

START RECORDING

1. Can you please describe how you are involved in managing (or using) water in the South Platte Basin?
    a. How long have you been doing this?
    b. Where (geographically in the Basin) do you manage water?

2. What are the most important kinds of water management (or use) decisions you need to make each year? (e.g. crop fallowing, curtailment of water use, contracts, etc.)
    a. When do you need to make these decisions?
    b. What information or costs are most important for you to consider when making these decisions? (e.g. costs, projected water availability, reservoir levels, water/agricultural market prices, legal or regulatory factors, models, etc.).
    c. How certain do you need to be in the information in order for it to be useful?

3. What changes have you noticed in water supply *or* demand over the course of your work in the South Platte Basin?
    a. How do you think these changes will play out over next 25 years?
    - Prompt: physical changes (e.g. snowpack/melt has changed), human changes (e.g., more diversions/people, changes in agricultural markets/societal values, diversification of uses to M&I/environment, oil & gas production).

4. Scientists suggest that, in the future, surface water flows throughout the western U.S. will stay the same or decrease depending on local precipitation, but snowmelt runoff will occur 2-4 weeks earlier and cause a large reduction in streamflow during May-July. What impacts, positive or negative, do you think these changes will have in the South Platte Basin?
    a. What changes do you anticipate in water supply in the future?
    b. Who do you think these changes will impact most and why?
    - Prompt: Are there particular types of water rights that are more impacted?

5. In response to the changes you have observed in water supply, have you (or others you know) implemented any changes to the way you manage or use water? Do you think they have helped meet your needs?

   a. If no changes: why do you think policies/plans haven't been implemented yet?

   - Agriculture prompts: changes in conveyance infrastructure (lining ditches or laying pipes), irrigation technologies (e.g. drip irrigation, soil moisture monitoring and irrigation scheduling), cultivation practices (no-till, dryland, indoor ag), crop choices, storage, using reclaimed water, exit strategy?
   - Environment prompts: changes in water rights acquisition, water management/ delivery, storage, agriculture land reclamation programs, conservation practices?
   - M&I prompts: Changes in water rights acquisition and water management/delivery, efficiency/re-use plans, using reclaimed water?

6. Next, we'd like to hear your perspective on existing water trading and transfer programs. Specifically, we're interested in market programs for Colorado-Big Thompson units within Northern Water's boundaries: **1) permanent sales/transfers; 2) annual rental market, including the Regional Pool Program (lease unused water for next year, allocated via sealed bids), 3) Carryover Capacity Transferability Program (CCTP), to trade carryover capacity related to the Annual Carryover Program (ACP).** [discuss each program]

   a. Why do people participate in this program? What keeps people from participating?
   b. Is there a favorable or unfavorable view of the program?
   c. Is there anything you think could improve the program?
   d. Are there any other water trading programs we should know about/discuss?

7. Are there any other changes you think should be made to water management or policy to ensure sufficient water supplies going forward, whether at the district, basin, state or federal level?

   a. Is there anything that might impede these changes from occurring?

   - Prompt: existing allocation rules, a lack of information about markets and/or proving no injury, lack of coordination among water managers, issues pertaining to protection of private property rights and public trust doctrine, costs, other?

8. We'd like to ask you some questions about who you have worked with to address existing water management challenges:

   a. Who are the most important people or organizations you get water-related information from, or who you share information with?

b. Who have you worked with on creating or implementing plans or policies related to water management?

c. Have you engaged in any other specific water management programs in your basin? If yes, who else was involved?

d. Are there any other important individuals or organizations you work with that we should consider?

e. Is there anyone else you might work with in the future to cope with water challenges in the basin and why?

9. Given our discussion today, what kind of information would be useful for you to get from our project? Do you have any remaining questions about the project or comments about topics we didn't cover?

STOP RECORDING

10. Would you be willing to participate in this project in the future as either part of an advisory committee or through an online survey?

11. Would you be willing to participate in a 3-minute online survey being conducted by our external project evaluators about the research project?

12. Is there anyone else you recommend we interview for our study? If we choose to contact them, can we tell them that you sent us?

Supplementary Appendix B

Water Sharing Arrangements Thesis Interview Codebook

Coding Instructions:

- Coders should read through the full transcript prior to beginning coding.
- Coders should review the full codebook prior to coding.
- When coding, coders should:
    - Code all text relevant to a code, including any necessary contextual information around relevant text (complete sentences not necessary).
    - Code for a single group (highlighted) of supercodes at a time:
        - Ex: code the entire transcript simultaneously for the supercodes (and their subcodes) under the *Water Supply* group before moving on to the *Water Rights Transfers* group, at which point you should start coding at the beginning of the transcript again.
- Coders should assign Geography and Sector attributes to all cases when loaded into NVivo.
    - Ex: Assign "Upstream" Geography attribute and "Agriculture" Sector attribute for case associated with an AG stakeholder that is located in or has interest aligned with areas designed as "Upstream" according to the map below.
        - Metro: geography attribute assigned to the users highest on the river in the more urban area
        - Upstream: geography attribute assigned to users from Greeley to Sterling
        - Downstream: geography attribute assigned to users from Sterling to state

**** Blue text marks codes that were added to the codebook after initial analysis****

GROUP 1: Water Right Transfers

GENTRANS – describes stakeholder perceptions of marked-based approaches for water rights

- MARKPRO: stakeholder perceives that market-based approaches to managing and sharing water rights are beneficial to the Basin overall
- MARKANT: stakeholder perceives that market-based approaches to managing and sharing water rights are detrimental to the Basin overall
- INSECTOR: stakeholder perceives that water rights transfers within a given sector are beneficial to the Basin (e.g. ag to ag) but opposes water rights transfers across sectors.
- XSECTOR: stakeholder describes water rights transfers across sectors as either beneficial or detrimental to the overall Basin

- ATM: stakeholder describes a water market program/mechanism beyond permanent transfers under PA or within the C-BT share system

PARTTRANS – describes why stakeholders participate or do not participate in water rights transfers (permanent or temporary) outside of the C-BT market programs

- SOCPRESS: stakeholders do not participate in water rights transfers due to social pressure from their neighbors and/or peers in the community (e.g. 'selling out')
- GENCHNG: stakeholders participate in water rights transfers due to generational changes in their families or on their farms or ranches (e.g., no family member wants to continue farming)
- FINANC: stakeholders participate in water rights transfers due to financial gain from selling and/or transferring
- PRODCT: stakeholders participate in water rights transfers due to declines in productivity of agricultural land (including not regularly receiving enough water)
- ENVVAL: stakeholders participate in water rights transfers in order to support environmental restoration and protection
- ASSET: stakeholders don't participate in (permanent) water rights transfers because they want to maintain water rights as a long-term asset
- KEEPAG: stakeholders do or do not participate in water rights transfers in order to keep water in agriculture or bolster the agriculture sector broadly (may include preserving pastoral aesthetics)
- RTNFLW: stakeholders don't participate in water rights transfers due to concerns over affecting return flows
- SECURE: stakeholders participate in water rights transfers because they want to increase water security (for development, etc.)
- AUXILIARY: stakeholders participate in water rights transfers for auxiliary reasons (PR, compliments operations, etc.)
- LEGALP: stakeholder do not participate in water rights transfers because of limitations or barriers due to legal processes or requirements

GROUP 2: Water Policy Changes

STWATLAW – describes stakeholder's desired changes to state water law

- TRANSFER: changes are related to the flexibility of transfer mechanisms/rules (e.g. water courts need to be more flexible in allowing temporary transfers for ag to lease when optimal for them; munis should be able to transfer among themselves)
- COLLABPOL: changes are related to more collaborative work, collaboration amongst larger groups of stakeholders, or collaboration amongst new stakeholders
- NOCHANGES: changes related to state water law are not necessary

GROUP 3: Decision-making

COPINGACTIONS – describes actions that stakeholders take in order to cope with water supply changes and/or challenges

- INFSTRUCT: stakeholder increased reservoir storage or conveyance infrastructure (to engage in more transfers, to increase security during droughts)
- ACQUIRE: stakeholder acquires more water rights or engages in more transfers
- AUG: stakeholder engages or creates augmentation plan to mitigate groundwater pumping
- NEWPLAN: stakeholder engages in or creates a new plan to help deal with changes to water supply (drought resilience plan, conservation plans, stream management plans, etc.)
- RESTOR: stakeholder engages in or facilitates restoration of forests, watersheds, streams to mitigate or deal with changes to water supply

COLLAB – describes collaborations or partnerships among stakeholders to achieve shared goals