

Coordination in water resource management: the impact of water rights institutions

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Abstract

This paper considers how water rights laws can shape the ways water providers coordinate when devising conjunctive water management programs. Conjunctive water management is a particularly useful tool for analyzing water management coordination because it involves certain physical and organizational complexities that may facilitate the need for coordination. It takes advantage of the natural storage capacity of underground aquifers for the storage of surface supplies during high flow seasons, allowing for recovery of those supplies when surface flows are limited. This paper compares conjunctive management programs across Arizona, California and Colorado. It identifies the distinct types of coordination associated with conjunctive water management programs across these states and shows that these forms of coordination depend upon the larger institutional setting governing rights to water resources.

Keywords: Conjunctive water management; Coordination; Institutions; Water industry; Water rights

1. Introduction

Coordination across individual water users, private water companies, local and regional jurisdictions, indigenous communities and nations can be vital to the optimal use of shared water resources (Blomquist & Ostrom, 1985; Benvenisti, 1996; Kenny, 1997; Wolf, 2000). The institutional arrangements governing rights to water resources are also known to shape the choices that are available to water providers for managing water supplies (Anderson *et al.*, 1983; US ACIR, 1991; Knox *et al.*, 2001). Water rights institutions can include the rules, regulations and policies that communities and organizations establish to control the acquisition, use and distribution of water. This paper attempts to identify how water rights institutions influence the decisions to coordinate the management of water resources using a study of conjunctive water management programs in California, Arizona, and Colorado.

Conjunctive water management is an appropriate method to study the relationship between water

rights and coordination because it involves physical complexity that may require inputs from multiple water providers or may affect multiple jurisdictions (Blomquist *et al.*, 2001). In general, conjunctive management relies on the storage of excess surface water flows in underground aquifers, which can then be recovered when surface supplies are scarce. Often conjunctive management projects rely on artificial recharge to store water underground. Recharge can occur by allowing water to seep underground through constructed ponds on overlying land or streambeds, or by injecting water directly underground (Bookman-Edmonston Engineering, Inc., 1979). Stored water can then be extracted by pumping groundwater in times of drought. Conjunctive water management can also occur by importing surface water into areas that are reliant on groundwater in order to reduce groundwater pumping during peak surface flows. This allows basins to refill naturally so they can then be pumped at times when surface supplies are low. Conjunctive water management is known to be a more cost-effective and environmentally sensitive method of water supply management than many alternatives (Jaquette & Moore, 1978; Thorson, 1978; Trelease, 1982; Fisher *et al.*, 1995)¹. For example, when water providers can alternate between surface water and groundwater supplies to meet peak demands, they do not have to pay for adding additional surface storage and delivery systems. Using stored groundwater during dry seasons can allow water providers to leave more water in streams to meet non-consumptive needs. Hence, an analysis of conjunctive management can also highlight the types of organizational and institutional arrangements that are associated with improved water resource management.

The data for this paper come from a 1997–99 study funded by the National Science Foundation and Environmental Protection Agency that compared institutions and conjunctive management projects across California, Arizona, and Colorado²; states that have similar water supply and demand settings while exhibiting variation in their institutions governing the rights to acquire, store and distribute water resources, particularly groundwater (Blomquist *et al.*, 2001). California, for example, has the most decentralized approach to groundwater governance among the three states, relying on local governments and court adjudications to determine groundwater usage rules. Arizona's approach to establishing groundwater institutions has come quite recently from the state legislature, which implemented policies in the 1980s and 1990s to quantify rights to groundwater supplies and recognize rights to store water underground. Colorado has used both state laws and locally defined rules governing surface water as the basis for establishing groundwater rights institutions.

This paper thus compares the divergent institutional arrangements governing rights to groundwater in

¹ For example, according to the California Department of Water Resources (1994) the estimated cost of storing surface water in reservoirs is about \$800 per acre-foot of water, whereas storage through conjunctive management costs about \$150 per acre-foot.

² See National Science Foundation & Environmental Protection Agency Water and Watersheds Program Grant #R824781. This study utilized a survey of water providers in the three states to collect various data on the organizations participating in projects, the type and purpose of projects they provide, the costs and performance of these projects and the rules that govern the implementation and monitoring of projects. In Arizona, the NSF/EPA study surveyed the population of 42 conjunctive management projects that held State permits, as of 1997–98. In California, since no central source of data on conjunctive management in the state exists, the NSF/EPA study conducted a cluster sample among California's 450 groundwater basins and then contacted water providers in the sample basins to identify conjunctive management programs. To identify projects in Colorado, the study used a cluster sample of water districts, based on the State Engineer's five major watershed divisions. Legal research on each state's water policies, statutes, regulations and case law affecting water supply management supplemented the survey.

these states and evaluates how these institutions relate to the extent of coordination used in conjunctive management programs within each state³. In order to better understand the importance of groundwater rights institutions relative to conjunctive management, the following section begins with a consideration of the dilemmas that face water managers engaging in conjunctive management. It then moves to an examination of conjunctive water management in California, which has the longest history of conjunctive management among the three states, to consider how the state's locally defined groundwater water rights institutions influence the practice of conjunctive management. It also describes how the institutional settings that facilitate conjunctive water management in Arizona and Colorado differ from California. The third section of the paper looks at individual conjunctive management projects in each state and identifies how coordination is used when rights to groundwater are quantified. The paper concludes by examining what these findings imply for policymakers concerned with facilitating the use of programs like conjunctive water management.

2. The relationship between basin-level coordination and water rights

Since conjunctive water management involves taking surface water supplies and storing them underground or relying on underground water supplies when surface flows are low, it is logical that, when groundwater resources are shared as a common pool, water providers may lack assurances that stored underground water will be available in times of need. This is because the use of common-pool resources can lead to problems of over-appropriation or lack of supply maintenance since it is difficult to exclude users from extracting available resource units (Ostrom, 1990). As such, coordination among individuals is often essential for successfully managing common-pool resources over long periods of time (Ostrom, 1990; Tang, 1992; Ostrom *et al.*, 1994; Baland & Platteau, 1996; McKean, 2000). In the absence of larger-level institutions, such as centralized regulation or well-defined property rights, it may be necessary for groundwater users to coordinate to devise rules in order to encourage programs like conjunctive water management that are designed to sustain resources for future use.

Coordination among a group of groundwater users may arise in an effort to establish rules that limit (a) the quantity of the resource that any one user can appropriate, (b) the time or location of resource use that is available to appropriators, or (c) the type of technology that can be used to harvest the resource (Ostrom *et al.*, 1994). When individuals want to assure that common-pool resources will be maintained, they often devise rules that require users to fund, or provide labor and supplies, in order to maximize resource productivity (Ostrom *et al.*, 1994). Where common-pool resources are managed successfully, such institutional arrangements are likely to be clearly defined around resource boundaries (Ostrom, 1990). The State of California demonstrates how an absence of groundwater rights have encouraged these types of coordinated efforts among groundwater users over the past half-century and how such efforts are associated with conjunctive water management. Arizona and Colorado, on the other

³ The focus on groundwater rights institutions is also due to the fact that conjunctive management projects are organized at the groundwater basin level. While surface water is a necessary component of conjunctive management programs, the groundwater basin is the unit where appropriators store water. So rights to groundwater are likely to determine the degree to which water providers have assurances over the storage and recovery of that water. Furthermore, little variation exists in surface water rights in the southwestern United States since most states rely on the prior appropriation doctrine, which establishes rights to surface water based on the timing of beneficial use.

hand, provide examples of how state-imposed property rights can eliminate the need to coordinate across all users of a groundwater basin in order to establish conjunctive water management programs.

2.1 California: basin-level coordination in the absence of groundwater rights

Coordinated self-governance to resolve dilemmas associated with groundwater use has occurred in a number of groundwater basins in California (Blomquist & Ostrom, 1985; Ostrom, 1990; Blomquist, 1992). California does not have a statewide statutory provision that limits rights to the use of underground aquifers and an open-access situation is encouraged by the state's recognition that property owners have the right to pump groundwater that lies under their land. In the absence of local coordination, many of these basins have become over-appropriated. California's Department of Water Resources estimates that groundwater overdraft averages about 1.46 million acre-feet per year (California Department of Water Resources, 1998). Sustained overdraft has resulted in land subsidence throughout large areas of the state, leading to a substantial loss of basin storage capacity. In California's coastal basins, such as the Coastal Plain of Orange County and the Salinas River Valley, over-pumping has led to the intrusion of saline ocean water into the freshwater basins.

In response, groundwater users, municipalities and local water agencies in some basins have formed "special purpose districts", one of the most common forms of local government in the United States, around basin boundaries to manage shared groundwater supplies. For example, between 1945 and 1959, members of Los Angeles' West Basin and Central Basin water associations formed municipal water districts to import supplemental water to their respective basins. Then these districts formed an overlapping Central and West Basin Water Replenishment District in the 1950s to finance and operate recharge projects to prevent seawater intrusion along the coast and to raise water levels in the two basins (US ACIR, 1991). Such districts can regulate groundwater pumping or provide funding mechanisms for groundwater management (California Department of Water Resources, 1998). In other basins, water users have come together through courts to adjudicate rights to water, and then appoint basin "Watermasters" to monitor and administer these agreements (Blomquist, 1992). In a number of basins, multiple water agencies that share a common groundwater basin have devised coordinated agreements known as AB 3030 Plans, which are local rules authorized by the State of California to promote long-term management of groundwater resources (California Department of Water Resources, 1998). The formation of these locally devised institutions involves extensive long-term coordination in order for local water providers to agree on rules governing appropriation and maintenance of shared resources⁴.

The emergence of these institutions around basin boundaries is particularly important for facilitating conjunctive water management programs in California. As evidence of this, the conjunctive water management study identified 34 conjunctive management programs in 13 of 70 sample basins, all of which operate under locally coordinated institutional arrangements devised around basin boundaries, such as special districts, court-adjudicated basins with Watermasters and basins where overlapping jurisdictions established AB 3030 groundwater management plans (Heikkila, 2001). As further evidence of the importance of basin-level coordination in the development of conjunctive management programs,

⁴ These forms of coordinated local governance are tied to California's tradition of "home-rule" governance. This means that local governments have the authority to organize and devise policies to resolve local problems, with little interference from the state. California's home-rule system provides multiple opportunities to devise institutions that address local problems facing a community of water users, particularly in the case of groundwater (Blomquist, 1992).

the study also looked at basins that have county or municipal ordinances governing groundwater use. Unlike the other local forms of groundwater institutions, these ordinances are not devised around basin boundaries. Thus, the study showed that these ordinances, because they cannot control all potential users in a basin, are not associated with the use of conjunctive water management unless another form of coordinated agreement is operating across basin boundaries (Heikkila, 2001). Moreover, even in some areas of the state where water demand is high and the physical infrastructure for conjunctive management exists, conjunctive management is not found unless some basin-level institution is present (Heikkila, 2001; Blomquist *et al.*, 2001).

Every conjunctive management program the study identified in California was associated with the presence of an institution that involved local coordination at the scale of groundwater basin boundaries and no conjunctive management programs were found in locations that lacked such institutions. Basin-level institutions clearly help resource users control the common-pool problem associated with groundwater use. In some California basins, this means assigning water rights through, for instance, court adjudications. In others, it means devising new local governments or agreements among existing governments at the basin level with the authority to assign rules to limit pumping and monitor groundwater use. Of course, the existence of these coordinated arrangements does not mean that water providers will automatically engage in conjunctive management. For instance, three of the sample basins in the study with AB 3030 Plans and two of the basins with overlying special districts in the sample had not engaged in conjunctive management projects as of 1998 (Heikkila, 2001). Moreover, the physical conditions of the basin, such as storage capacity and permeability of soils, and access to supplemental surface water supplies also play an important role in the decisions to engage in conjunctive management (Blomquist *et al.*, 2001). Still, the survey of Californian basins and conjunctive management programs strongly supports the view that the absence of state-assigned groundwater rights inhibits the establishment of conjunctive management programs, except where basin water users coordinate to establish institutions that govern groundwater extraction and use.

2.2 Arizona and Colorado: how groundwater rights preclude basin-level coordination

Arizona and Colorado water users do not face the same need for basin-level coordination to facilitate conjunctive water management as found in California. In California, conjunctive water management is found where local water providers have devised basin-level institutions to govern the use of groundwater. Projects in Arizona and Colorado, on the other hand, emerge under institutional settings where the state has defined and quantified rights to groundwater. Arizona and Colorado also have state-imposed rules governing the coordinated use of groundwater and surface waters through storage or augmentation. As a result, conjunctive management in Arizona and Colorado does not depend upon groundwater institutions that control appropriators within particular basins.

In Arizona, a series of recent state-devised laws have been passed that have preempted the need for local water users to come together and devise their own basin-level rules, as they have in California. Prior to 1980, landowners were not limited in the amount of groundwater they could pump⁵. As growing urban and agricultural regions began to rely more heavily on groundwater in the mid-1900s, the state began to recognize in the 1970s that many of its most productive groundwater basins were, or would

⁵ Prior to 1980 the “reasonable use” doctrine, derived from English common law, governed Arizona’s groundwater. This doctrine treats water percolating through the soil as belonging absolutely to the owners of the soil.

soon be, overdrafted. In response, the legislature passed the 1980 Arizona Groundwater Management Act, which quantified groundwater rights in five “Active Management Areas” (AMAs) where the state’s major groundwater basins are used most heavily. In 1986, the Arizona legislature passed the Groundwater Storage and Recovery Projects Act, establishing rights to recover surface water that is stored in underground aquifers through artificial recharge, later amended as the Underground Water Storage, Savings and Replenishment Act (see Ariz. Rev. Stat. §45-651; §45-801). Under the Act, private individuals and public agencies can apply for permits to store water underground and receive credits from the state for future recovery of that water.

Other important state-sponsored institutional changes came about in the 1990s in Arizona to further secure the availability of the state’s groundwater supplies. These changes focused on pushing water providers to rely more heavily on Arizona’s allotment of Colorado River water (delivered through the Central Arizona Project) and to use this water to sustain groundwater supplies. For example, the Arizona Department of Water Resources, charged with administering the 1980 Groundwater Management Act, established assured water supply rules in 1994. Under these rules new domestic developments must obtain a certificate demonstrating they have an adequate supply of water for 100 years. A portion of this water can come from groundwater but the remaining water must come from renewable sources. Typically these renewable sources are obtained through membership with the Central Arizona Groundwater Replenishment District, created in 1993 as a subdivision of the Central Arizona Water Conservation District, which owns and operates the Central Arizona Project. Another way the State of Arizona encourages entities to secure groundwater supplies is through the Arizona Water Banking Authority. Created in 1996, the Water Bank contracts with water providers to store Arizona’s surplus Colorado River water allotted through the Central Arizona Project.

Arizona’s institutions governing groundwater ensure that entities can store and later recover water without the fear of other entities using those supplies. They also encourage providers to protect water supplies long-term by engaging in storage and recovery and working with replenishment districts and the Arizona Water Banking Authority. As such, Arizona’s institutional arrangements that quantify rights to groundwater and establish permits to store and recover water in aquifers have facilitated the use of conjunctive water management. In fact, all of the 42 conjunctive management projects that the study identified in 1998 operated within one of the Active Management Areas where groundwater rights are assigned. Moreover, while California’s experience with conjunctive management has spanned over 50 years in areas of the state where local water users have devised institutions to manage over-pumping, Arizona witnessed a rapid development of conjunctive management projects only since the early 1990s after the state began to implement policies that limit groundwater use and provide incentives to store water underground for future use.

As in Arizona, Colorado’s water rights institutions preclude the need for coordinated action at the groundwater basin level where conjunctive management appears. Conjunctive water management in Colorado emerged out of the State’s strict enforcement of quantified water rights (Gregg *et al.*, 1991; Blomquist *et al.*, 2001). Since Europeans began mining and farming in Colorado in the 1800s, Colorado has governed surface water under the doctrine of prior appropriation, which means that those water users who put water to beneficial uses at the earliest point in time have priority rights to their share of water⁶. In the 1960s, increasing groundwater use, heavy agricultural water demands and over-appropriated

⁶ In 1882, the Colorado Supreme Court asserted the dominance of the prior appropriation doctrine for allocating the State’s water (Vranesh, 1987).

surface flows led to conflicts between groundwater and surface water users. Since surface water was appropriated before groundwater in Colorado, most such groundwater users obtained junior water rights in Colorado. This meant that surface water users would be entitled to their full share of water before tributary groundwater users could pump.

In 1965, the Colorado Legislature passed the Groundwater Management Act that established a framework for governing groundwater and directed the State Engineer's office, the agency responsible for administering water rights, to address the conflict between tributary groundwater and surface water (Radosevich *et al.*, 1976). The Colorado legislature later assisted the State Engineer in resolving the conflict between groundwater and surface water users by passing the 1969 Water Rights Determination Act, which encouraged the integration of well owners under the same prior appropriation system as surface water users. This act, however, provided flexibility to allow tributary groundwater users to continue to pump water without injuring surface water rights holders. It allowed the State Engineer's offices to devise rules requiring groundwater users to replace surface flows in the State's two most heavily populated and appropriated river basins, the South Platte and the Arkansas, both of which flow into the arid eastern plains from the Rocky Mountains (Schlager, 1999).

The Colorado State Engineer's office devised rules for the South Platte River basin in the early 1970s, known as "Augmentation Plans", to cover water they deplete from surface flows. The plans must identify the quantity, time and location of stream depletions, as well as the source of water that will be available to the river at that time and place. Groundwater users in the South Platte typically meet the obligations of these plans by acquiring supplemental surface water supplies in the off-season and then recharging the aquifer so that sufficient surface water is available when surface water demands are high. Thus, Augmentation Plans provide flexibility in the use of tributary groundwater by allowing groundwater to be pumped in times of need in exchange for replacing that water with other sources later in the year when surface flows are scarce. In essence, the Colorado State Engineer's Office authorizes groundwater users to engage in conjunctive water management through Augmentation Plans.

Unlike the South Platte River basin, however, groundwater users in the Arkansas River basin did not at first respond to the tributary groundwater crisis by adopting augmentation. Instead, the State Engineer's office in this basin approved a set of rules regulating well pumping to three days per week in 1973. Problems persisted between groundwater users and surface water users under these rules, however. In the early 1990s a US Supreme Court case between the States of Colorado and Kansas finally forced Colorado to ensure that sufficient stream flows would be available to meet an inter-state river basin compact between the two states. The State Engineer's Office in the Arkansas basin responded to the case by devising rules to allow tributary groundwater users in the basin to develop "Replacement Plans", which are similar to Augmentation Plans in that they fully replace each out-of-priority stream depletion caused by pumping at the time and point of injury. Conjunctive management programs then emerged in the mid-1990s in the Arkansas basin under these Replacement Plans. However, instead of recharging water into the aquifer directly, as is found along the South Platte basin, well owners have organized various private/non-profit associations to purchase or lease rights to surface water. This surface water is delivered into the stream over the course of the irrigation season to replace the water depleted by well pumping.

Since the State of Colorado has addressed water rights conflicts through Augmentation Plans in the South Platte River basin and Replacement Plans in the Arkansas River basin, it is not surprising that conjunctive water management has emerged most prominently in these two areas of the state. The conjunctive management study found all of its 42 conjunctive management projects within the sample

of Colorado water districts in the South Platte and Arkansas River basins⁷. The majority of these projects were identified in the South Platte River basin, accounting for 39 of the 42 projects identified in a sample of water districts across each of Colorado's water basins. In the South Platte basin, all 39 projects are designated for some form of direct recharge. These direct recharge projects comprise about 58% of the water used for conjunctive management in the sample of Colorado water districts, averaging 74,260 acre-feet per year. These results concur with state water diversion records showing that the South Platte River basin accounted for nearly 84% of Colorado's augmentation and recharge diversions between 1994 and 1998 (Colorado Division of Water Resources, 1998). Since the Division Engineer's rules in the Arkansas basin did not require groundwater users to devise Replacement Plans until 1996, the three projects identified in this basin have operated for only a few years. Yet, two of the three projects combined provide an average of 34,000 acre-feet of water per year to replace out-of-priority groundwater pumping.

The development of state-sponsored institutions that secure rights to groundwater in Arizona and Colorado, in effect, address the demand dilemmas that Californians face in using an open-access groundwater basin. These dilemmas can include over-appropriation and lack of basin maintenance if institutions do not exist to facilitate coordination among all water users (Ostrom *et al.*, 1994). Individual appropriators in these settings are less likely to store water underground for future use if there is no guarantee that other water users will not consume their water. Open-access settings, without basin coordination, can impede the development of conjunctive management because water users cannot be assured that they can store or replenish water for the future without others using the water (Blomquist *et al.*, 2001). This appears to be the case in California. In Arizona and Colorado, however, this preliminary examination of the states' institutional arrangements and conjunctive water management programs indicates that basin-level coordination, such as California's creation of AB 3030 Plans or special water districts, is not necessary for facilitating conjunctive management. In Arizona and Colorado, the states have imposed institutional settings that eliminate the need for all individual water users in a basin to come together to coordinate their management efforts. These state-imposed institutional arrangements, including quantified water rights, recharge rules and Augmentation Plans, ensure that appropriators can use, store and recover conjunctively managed water without the threat of losing that water. This helps to explain why conjunctive water management is now as widespread in Arizona and Colorado as in California, despite the fact that conjunctive management has a history in California that is decades longer (Heikkila, 2001; Blomquist *et al.*, 2001).

3. Coordination in the presence of well-defined property rights

If state-imposed groundwater institutions in Arizona and Colorado have controlled demand dilemmas within groundwater basin boundaries, why would we find any coordination used for providing conjunctive water management? One of the reasons why jurisdictions choose to coordinate the provision

⁷ Two of the seven major river basin divisions in Colorado did not have adequate groundwater supplies for conjunctive management and were excluded from the sample. The districts sampled in the remaining three divisions of the State Engineer's office did not have active conjunctive management programs. However, some conjunctive management may be occurring in those districts that were not included in the sample.

of a particular public service is that the fluctuating demands can be met more efficiently when multiple jurisdictions are available to participate in the production of a good or service (Oakerson, 1999). For example, a municipality may choose to contract with other government agencies and/or private firms for the production of all or parts of a service, such as water treatment (US ACIR, 1987; Ostrom & Ostrom, 1991). Service providers can also coordinate with other jurisdictions when they lack adequate inputs or facilities to supply emergent needs or meet fluctuating demands. The availability of alternative supply arrangements allows officials to “seek changes in multiorganizational arrangements that enable them to do more for less” (Oakerson & Parks, 1988, p. 108). In addition to providing flexibility to meet fluctuating demands, multiple producers and suppliers encourage cost efficiency because they can take advantage of economies of scale. For example, in the water industry, municipal and agricultural providers typically contract with various types of water wholesale districts. In most cases, wholesalers can deliver water across multiple jurisdictions at a lower cost than if the municipality paid for the infrastructure and delivery alone.

In relation to conjunctive water management, agencies may choose to coordinate their efforts to provide aspects of conjunctive management services that affect multiple jurisdictions overlying a basin. Examples of such efficiency-enhancing coordination include joint funding or coordination of inputs, such as surface water or recovery wells, which are needed to develop a conjunctive management program. Similarly, jurisdictions involved in a conjunctive management project may choose to rely on temporary agreements with alternative surface water suppliers in order to adjust to fluctuating flows in natural resources or to serve changing public demands for water. Therefore, the purpose of coordination in the management of water resources is not necessarily predicated on the need for resolving a problem of appropriation that faces a group of water users.

How then can we distinguish between the forms of coordination that occur for the purposes of producing a conjunctive management project from the forms of coordination that we see in California, where water users get together to devise new institutional arrangements that control groundwater use? To address this question, this section presents project-level data on the number and types of organizations participating in conjunctive management projects in each state. In considering how the organizations operating conjunctive management differ across the three states, this section further clarifies the ways in which groundwater rights impact the forms of coordination used among water providers.

3.1 Coordination in Arizona's conjunctive management projects

In Arizona, where the state has quantified rights to water resources in Active Management Areas, various water providers coordinate for the purposes of producing projects. Among the 42 projects identified in Arizona as of 1998, some 36 organizations coordinated the production or operation of projects. Coordination for the purposes of funding projects happened in four of Arizona's projects, or 10% of the cases. Organizations work together most often to produce projects through water storage and acquisition, as 20 out of 42 projects in the study had at least two organizations participating through water storage permits. The average number of entities holding water storage permits in Arizona's conjunctive management projects, as of 1998, was 2.4 per project. Of the 20 projects with multiple water suppliers, the average number of organizations involved per project was 4.4. Some 15% of the projects were permitted with more than four water suppliers per facility. In addition, two projects involved multiple organizations during the construction phase of the recharge facility, one project had multiple

organizations participating in facility maintenance and five projects had multiple organizations participating through recovery well permits⁸.

One reason why Arizona's projects involve coordinated arrangements for water storage and recovery is that such arrangements can offer flexibility in meeting fluctuating demands for water customers. Furthermore, providers of conjunctive management projects may choose to organize projects to take advantage of cost-savings afforded by the use of multiple organizations for surface water delivery systems, some of which may have greater economies of scale in surface water delivery infrastructure. As evidence of how coordination in Arizona's projects may be used for project cost-efficiency, Table 1 shows that the average number of production participants per project in Arizona increases with project size, as measured by project storage capacity. Extensive coordination, involving more than just a couple of organizations, occurred only in a few large-scale projects. Yet these projects account for a significant portion of the underground storage capacity within Arizona. For example, the Granite Reef facility, which has a permit to store up to 200,000 acre-feet of surface water underground per year, has received funding and water supplies from nine different organizations.

In contrast, just over half of the conjunctive management projects in Arizona involve only one organization (and no interorganizational coordination), but these projects tend to be small, accounting for less than 10% of total water storage capacity in the State. Municipalities are responsible for 68% of projects produced by only one participant (15 of the 22). Seven of the projects managed by single organizations operate under private water companies or private utilities. These organizations all have rights to, or contract for, their own sources of surface water and have rights to pump groundwater in their Active Management Areas. This reliance on single-project producers demonstrates that Arizona water users can produce small-scale projects on their own, where they have relatively easy access to surplus surface water supplies and storage facilities. In addition, they do not have to coordinate across

Table 1. Project-level coordination in Arizona.

Permitted storage quantity ^a (acre-feet per year)	No. of projects	Average no. of project participants	% of total state storage capacity
<10,000	24	1.2	7%
10,000 to 99,999	13	2.9	25%
100,000 to 200,000	5	6.2	68%
All projects	42	2.3	100%

^aMean project storage capacity = 25,616 acre-feet.

Table 2. Organizations participating in conjunctive management in Arizona.

	No. of organizations	No. of projects
Municipal water agency/department	13	25
Special districts (irrigation /water)	12	14
Private corporations/utilities	9	6
State-sponsored special districts (Water Bank and CAWCD)	2	18

⁸ Recovery well permits are not designated to any particular facility in Arizona. Instead, they are designated to organizations that store water at facilities, which can use credits to recover stored water at any of their permitted recovery wells in their Active Management Area.

all water users in the basin in order to gain assurances that the water they store underground can be recovered without interference from other water users.

Examining the types of organizations involved in conjunctive management projects also helps explain how coordination is used in Arizona. As can be seen in Table 2, various types of organizations in the Arizona water industry participated in conjunctive management projects. None of these organizations were devised around basin boundaries. Most were either sub-basin entities, such as cities, special districts or private utilities, or state agencies, such as the Central Arizona Water Conservation District or the Arizona Water Banking Authority. Coordination in Arizona thus does not involve the establishment of basin-scale organizations such as those observed in California.

3.2 Coordination in Colorado's conjunctive management projects

In Colorado, where the state has integrated tributary groundwater rights with surface water rights, water providers also commonly work together to produce conjunctive management projects. As in Arizona, the participants in these projects are not organized around groundwater basin boundaries. Nearly half, or 20, of the 42 Colorado projects identified in the 1998 study involved multiple organizations. The highest number of participants in the Colorado sample was four organizations per project. Among the 42 projects in the sample, the average number of organizations per project was 1.6. As shown in Table 3, all of the projects in the sample districts using under 10,000 acre-feet of water per year included an average of 1.5 organizations, but the four projects over 10,000 acre-feet averaged 2.25 organizational participants.

Coordination across organizations in the Colorado sample is found most frequently among the direct recharge projects in the South Platte basin, where multiple organizations sometimes shared the same direct recharge facilities. For example, an irrigation district, state agency and non-profit organization all store water in one direct recharge site. In most coordinated conjunctive management projects in this sample, however, individual organizations contracted with one or two private water companies or individuals either to use land for recharge or to lease water as a stream replenishment source. Unlike special irrigation districts, which operate as public entities authorized by the state, private water companies are formed as corporations for member irrigators. The private or non-profit irrigation companies and irrigation districts fund conjunctive water management through fees paid by its members, who are required to comply with Augmentation Plans. They use these funds to acquire supplemental water supplies and to develop recharge sites. For instance, the use of private well-owner associations to develop conjunctive management programs has been common throughout the South Platte basin since the 1970s. Two well-owner associations that engage in conjunctive management, but were not involved in the projects in the districts sampled in the conjunctive management study, are the

Table 3. Project-level coordination in sample districts of Colorado.

Average project water use ^a (acre-feet per year)	No. of projects	Average no. of participants
<1,000	18	1.56
1,000 to 9,999	20	1.50
10,000 to 25,000	4	2.25
All projects	42	1.60

^aMean water use per year = 3122.5 acre-feet.

Central Colorado Water Conservation District and the Groundwater Appropriators of the South Platte. These organizations were devised in the 1970s to cover thousands of wells under temporary plans of augmentation in the South Platte basin (MacDonnell, 1988).

In the Arkansas basin, two organizations operating Replacement Plans during the study contracted with multiple entities to provide surface water for indirectly recharging pumped groundwater. The Arkansas Groundwater Users Association participated with two municipalities for most of the 24,000 acre-feet of water that it uses for conjunctive management. The Colorado Water Protection and Development Association leased about 10,000 acre-feet per year of water from a local municipality and from a water conservancy district for its project. These two organizations are both private associations of well owners, covering approximately 1800 wells. The third organization operating a conjunctive management program in the sample districts of the Arkansas basin was the Lower Arkansas Water Management Association, which owns all of its replacement water, equaling about 14,000 acre-feet per year and covers about 640 wells. These three organizations managed Replacement Plans for a combined total of nearly 3000 wells and over 900 individual members. They are not the only water users associations that organize Replacement Plans in the Arkansas basin. However, they are the largest organizations. According to State Engineer records, 14 organizations submitted Replacement Plan applications in 1998, among which were four other water user associations (Bagentos, 1998). These four organizations each covered about 30 wells, on average.

One of the differences between Arizona and Colorado is that most of the organizations that provide conjunctive management in Colorado are private water companies or private well-owner associations, whereas most of the projects in Arizona involve municipal water departments or special water districts, which are forms of local government. Like Arizona, however, these organizations were not devised to coordinate the management of an entire groundwater basin, as found in California. The types of organizations that were participating in conjunctive management in the sample districts in Colorado are shown in Table 4. Nineteen of the organizations were private (private or nonprofit organizations, individual farmers or families), and eight were public (municipalities, irrigation districts or a state agency).

The extensive involvement of private organizations in Colorado's conjunctive management activities highlights a form of coordination that is somewhat unique to this State. This coordination occurs across individual groundwater users who are members of private water companies or well-owner associations, which are the primary providers and producers of conjunctive management projects. In Colorado, a number of private and non-profit organizations use membership fees of individual well owners to replace the stream flow augmentation obligations of their members. For instance, in the sample districts within the South Platte basin, the six principal organizations that provide conjunctive management projects had nearly 800 individual members as of 1998. These organizations essentially act as umbrella companies to fund the acquisition or leasing of surface water supplies and for developing and

Table 4. Organizations participating in conjunctive management in Colorado's sample districts.

	No. of organizations	No. of projects
Private or non-profit water companies	11	24
Private family/farm	8	12
Irrigation or water conservation districts	4	16
Municipal or state agency	3	3

maintaining recharge sites for individual members⁹. Similar to the inter-organizational coordination found in both Arizona and Colorado, these well-owner associations appear to help reduce some of the costs involved in engaging in conjunctive management, allowing the provision organizations to achieve greater economies of scale in the acquisition of surplus water (Blomquist *et al.*, 2001).

3.1 Coordination in California's conjunctive management projects

Although Arizona and Colorado exhibit distinct forms of coordination from the basin-level efforts in California, where the State does not assign groundwater rights, this does not mean that project-level coordination is not used in California. Project-level coordination also occurs in California's sample basins, but to a lesser degree. Moreover, projects only appear in the sample basins where overlying basin-level institutional arrangements are organized. Of the 27 organizations involved in conjunctive management projects in the sample basins, 16 were acting as project managers or the principal agencies for project funding. They included nine water districts/agencies, four irrigation districts, two county agencies/departments and one federal department. Therefore, 11 organizations were involved in the coordinated production of these projects, most commonly as water suppliers. Instead of supplying water to projects, a few of these organizations participated in conjunctive management by recovering and using water that is stored by project operators. Some organizations provided land or conveyance facilities needed for project operations. Table 5 shows the number of participants per project in the sample basins in California.

The types of organizations that were involved in the funding and production of conjunctive water management in the sample of California basins as of 1998, however, reflect the need for basin-level coordination and institutional development to engage in comprehensive water management programs. For example, the predominant type of organization involved in providing and producing conjunctive water management, according to the conjunctive management study, was a special groundwater management district/agency. Basin-level Watermasters, who are assigned to monitor pumping in basins where well owners have established groundwater rights through court adjudications, were also key participants¹⁰. Thus, project-level coordination did appear in the sample of California basins, even where basin-level institutions were the primary providers of conjunctive water management projects. Table 6 summarizes the types of organizations that participate in conjunctive management in the sample basins in California and their level of involvement.

⁹ The argument could be made that Colorado's well-owner associations, while private, are forms of water management "institutions", in that they make collective decisions, collect and disburse funds and impose rules on their members. As such, one may argue that these institutions are akin to the basin-level institutions in California because they encompass so many water users in the Arkansas and South Platte basins. The difference, however, is that Colorado's well-owner associations do not form to impose groundwater use rules on all water users operating in a shared groundwater basin. Moreover, multiple well-owner associations exist across Colorado's groundwater basins and their purpose is to acquire supplemental surface water supplies for their individual members.

¹⁰ In the sample of California basins, the Main San Gabriel Watermaster was participating in three conjunctive management projects in conjunction with three municipal water districts and the Los Angeles County Public Works Department. In another sample basin, the Hi-District Water Agency, appointed as Watermaster of the Warren Valley basin, was operating a conjunctive management program with the Mojave Water Agency, a State Water Project contractor.

Table 5. Project-level coordination in sample basins in California.

No. of participants per project ^a	Frequency	Percent of total
1	19	56%
2 to 4	13	38%
5 to 7	1	3%
8 to 10	1	3%
	34	100%

^aMean number of participants per project = 1.97 (st. dev = 1.5).

Table 6. Organizations participating in sample basins in California.

	No. of organizations	No. of projects
Special water districts/agencies	13	17
Irrigation districts	5	10
County water agencies/department	6	7
Federal agencies	3	5

4. Conclusion: comparing water rights and forms of coordination

The data on conjunctive management programs in California, Arizona, and Colorado help explain how the larger institutional setting governing rights to water resources relates to the forms of coordination used in the management of water resources. In California, coordination is important at the basin level to control resource use and ensure that water providers can invest in projects like conjunctive water management. The purpose of basin-level coordination in California is not necessarily to provide conjunctive water management. This form of coordination, through formal institutions, allows water users to limit groundwater pumping (e.g. in adjudicated basins), to monitor groundwater use (through Watermasters and some special districts) and to supply basin management programs or basin replenishment (special districts, AB3030 Plans and Watermasters). So, the coordination involved in providing these institutions allows water users to control basin-level boundaries and provide basin management without fear that other water users will consume stored water supplies or free-ride off replenishment efforts.

In Arizona and Colorado, where the state defines rights to groundwater, coordination is not organized at the basin scale. Coordination in these two states for the purposes of conjunctive water management occurs at the project level. Colorado is distinct because coordination occurs within organizations, which bring together hundreds of individual well owners to satisfy stream replacement obligations. These well-owner associations then operate projects or work with one or two other organizations to produce projects. Arizona and Colorado differ from California in that water providers do not need to coordinate their efforts to gain control of a basin before engaging in conjunctive water management. When project-level coordination does occur, it presumably helps minimize the infrastructure and operation costs of developing conjunctive management projects. Municipal water providers that want to engage in conjunctive management, for instance, can take advantage of the economies of scale provided by functionally specialized water wholesale jurisdictions. In other cases, irrigators that pump groundwater can acquire supplemental supplies from municipal suppliers with excess surface capacity to replenish groundwater supplies; or municipal providers may be able to use the storage capacity of irrigators that have large expanses of land overlying basins to save excess surface supplies for drought years.

The types of organizations that participate in conjunctive management and how they work together also provide evidence of the key differences between basin-level coordination and project-level coordination. In Arizona, municipalities are the most common organizations involved in conjunctive management. The State water bank and the Central Arizona Water Conservation District, which have jurisdictions across multiple counties, participate in nearly as many projects in Arizona as municipalities. Private organizations and non-profit groups, on the other hand, are most active in conjunctive management activities in Colorado. Where non-basin-scale organizations participate in conjunctive water management in California, they do so under basin-level groundwater governance institutions. In California, special districts are the most common organizations involved in providing and producing conjunctive management activities. These special districts often serve as basin-level governance institutions in California. In Colorado and Arizona, special districts also participate in conjunctive management activities, but these districts are formed generally as irrigation districts around a common group of water users and not around groundwater basin boundaries. This is because, in Arizona and Colorado, the state's establishment of rights to groundwater eliminates the need for all users of a shared basin to coordinate their activities in order to establish assurances that they can engage in programs like conjunctive water management.

Table 7 identifies the differences in the institutions governing groundwater across the three states, the organizations operating conjunctive management projects and the level of coordination associated with the provision of conjunctive water management.

The results of this analysis can offer important policy and management implications for regions struggling to manage scarce water supplies. First, this paper provides insights for water providers and managers interested in developing conjunctive management programs. It demonstrates that coordination across organizations is useful for producing water management programs since jurisdictions can take advantage of the options of overlapping providers and producers in a water industry. Such coordination can achieve economies of scale in producing projects or help meet

Table 7. Comparison of conjunctive management institutions, organizations, and coordination.

	California	Arizona	Colorado
Institutional setting			
Do local basin-level groundwater institutions exist?	Yes	No	No
Are groundwater rights quantified by the state?	No	Yes	Yes
Are rights to recharge and recover stored groundwater defined by the state?	No	Yes	Yes
Organizations providing conjunctive management			
Are organizations that provide conjunctive management designed around basin boundaries?	Frequently	No	No
Do sub-state governments, including municipalities and counties participate in conjunctive management?	Yes	Yes	Rarely
Do private organizations and individuals participate in conjunctive management projects?	No	Yes	Yes
Coordination			
Is basin-level coordination used to provide conjunctive management?	Yes	No	No
Is project-level coordination used to provide conjunctive management?	Yes	Yes	Yes
Is sub-project level coordination (within organizations) used for providing conjunctive management?	No	No	Yes

fluctuating demands with multiple water providers. Likewise, coordination is beneficial at the sub-project level in Colorado, allowing hundreds of well owners to acquire supplies of water for conjunctive management through a single organization. The evidence from each of the states discussed indicates that coordination is used to fund and produce many conjunctive water management projects, yet it is not a necessary precondition for producing conjunctive management where rights to stored water resources are secured.

Just as important, the results demonstrate that the ways in which governments assign rights to water influence the incentives that water users face for managing supplies. As shown in the cases of Arizona and Colorado, conjunctive water management programs were facilitated relatively quickly where rights to groundwater resources were clearly defined or quantified. Yet, simply assigning water rights is not enough to promote conjunctive water management. In Arizona, the state passed a number of laws that gave water providers further assurances of their rights to store surface water underground and receive credit for those supplies. The state also created institutional mechanisms to help entities conserve groundwater supplies by using renewable sources. Similarly, in Colorado, bringing groundwater users under the prior appropriation system used for surface water rights did not immediately encourage conjunctive management programs. The State had to establish a system of augmentation and replacement rules in the South Platte and Arkansas River basins that would allow surface and tributary groundwater users to both retain their rights without conflicts. Thus each of these states made some effort to adapt policies over time to their particular institutional and physical settings.

Another valuable policy lesson comes from considering the diverse local institutional alternatives found in California established for governing groundwater without state or regional intervention. The institutional arrangements that are associated with conjunctive water management in California highlight the importance of bringing together all entities within the boundaries of an open-access resource. Such coordination is vital for water providers to engage in conjunctive management in California. The benefit of such institutional approaches to manage water supplies is that they can address distinct physical and institutional problems at the basin level. The downside is that setting up the types of institutional arrangements common in California, such as adjudicated basins or special groundwater management districts, can be time-consuming and expensive. Also, without any state direction or incentives to adopt these institutions, the implementation of effective water management tools may be lacking in places where they are sorely needed.

In studying the different outcomes of the institutions that promote conjunctive management in the three states, it is clear that policymakers should carefully consider the ways in which different water rights regimes shape the incentives of individual water users to manage supplies. While conjunctive water management programs are arguably beneficial in that they can promote more efficient and sustainable use of ground and surface water supplies, the institutions devised to promote these programs can have negative effects. Colorado's strict adherence to a doctrine of prior appropriation, for instance, has encouraged conjunctive water management practices that tend not to focus on the long-term management of water supplies, as they are designed to temporarily satisfy the needs of surface water rights holders. Clearly, the different institutional traditions in a region play an important role in shaping feasible policy options and how those policies will be adopted.

In summary, this paper helps differentiate the purposes of coordination used for the management of water resources and the ways in which water rights shape the need for diverse forms of institutional coordination. The three-state comparison also provides practical insights for water providers interested in developing conjunctive water management programs and helps clarify how different policy settings

governing water rights shape the incentives and alternatives that water providers have to engage in alternative water management techniques. Ideally, future comparative analyses of diverse institutional settings governing water resources can continue to shed light on the ways in which specific water laws or policies influence our ability to manage scarce supplies more effectively and efficiently.

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