To Ed:
Hell'o (Hoosier style)
Best of Luck,
The Grandchild
Tanya Heikkila

MANAGING COMMON-POOL RESOURCES IN A PUBLIC SERVICE INDUSTRY:

THE CASE OF CONJUNCTIVE WATER MANAGEMENT

by

Tanya Heikkila

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

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TABLE OF CONTENTS

TABLE OF CONTENTS - *CONTINUED*

TABLE OF CONENTS - *CONTINUED*

LIST OF TABLES

LIST OF TABLES - *CONTINUED*

LIST OF EQUATIONS

ABSTRACT

Water providers, public administrators, and policy-makers in the Western United States face consequential decisions regarding the use and management of limited water supplies for growing populations. A tool that water providers have employed to address this issue is conjunctive water management, or the coordinated use of ground and surface water supplies. Using the natural capacity of groundwater basins for storage of surface supplies, this method aims to enhance overall supplies and guard against drought. Implementing conjunctive water management, however, is not simple. Water providers operate under a complex array of institutional settings that affect conjunctive water management. This dissertation explains the development and implementation of conjunctive water management in the western United States in relation to the institutional arrangements that govern water resources.

This dissertation looks to two literatures from a common research framework to evaluate conjunctive water management: the literature on public service industries and common-pool resource management theory. This dissertation identifies where the two literatures are weak and shows how the two theories can complement each other, helping resolve their respective weaknesses. Common-pool resource theory sets up criteria for sustainable resource management that requires matching institutional boundaries to natural resource boundaries. This dissertation explains how the criteria limit the theory's generalizability to large, complex systems. To resolve this weakness, the theory development section of this dissertation uses insights from public service industry theory on inter-jurisdictional coordination. Second, this dissertation considers the weakness of

public service industry theory in explaining coordination across jurisdictions. It borrows from common-pool resource literature to resolve this deficiency. The theory development section then derives hypotheses from the two literatures to explain how institutional arrangements affect conjunctive water management.

The empirical section of this dissertation tests these hypotheses. In addition to testing the inferences from the theory development, the empirical analyses illustrate the different ways in which water providers coordinate the management of groundwater and surface water supplies in the West. Understanding these management outcomes in relation to their institutional settings has important policy implications for natural resource management in general.

I. INTRODUCTION AND BACKGROUND

In the field of water resource management, public administrators and policy makers face the perplexing task of finding ways to increase water resource supplies for growing populations, while conserving water for environmental needs such as in-stream flows and habitat conservation. Determining the most efficient way to organize the provision and management of water supplies is complex. Indeed, determining what "efficient" means is a challenge when the policy environment is characterized by changing goals and values for water resources and their uses. Consumers have diverse and competing needs for limited water supplies and expectations regarding the quality of those supplies are escalating.[1]

The fact that the physical boundaries of water resources often do not coincide with the boundaries of political jurisdictions adds further complexity to water resource management decisions. Water management decisions that affect resources within a given political jurisdiction can also impact water resources outside of the jurisdiction boundaries. The boundary mismatch between political jurisdictions and water resources is compounded by the fact that consumptive supplies come from both ground and surface waters – each with unique geographic boundaries and characteristics. These two seemingly distinct sources of water are part of the same hydrologic cycle and their flows are inter-related. Surface water flows feed alluvial groundwater supplies, while groundwater supplies support surface water flows. This problem of "distinct yet related" water supplies can make decisions about the governance and management of water supplies, as well as the implementation of those decisions and the assessment of their effects, especially difficult.[2]

One body of literature that provides some guidance in explaining how institutional arrangements affect water management is derived from studies on local public economies and public service industries. This body of literature is grounded in theories of public choice economics and federalism. Empirical and theoretical studies on local public economies has shown that limited jurisdictional scales and multiple, overlapping jurisdictions can provide effective and cost-efficient means of delivering public services in metropolitan service areas (Ostrom, Tiebout, & Warren 1961; V. Ostrom 1971; Oakerson & Parks 1988; Oakerson 1999). This conclusion is based on the theoretical assumption that jurisdictions both compete for citizens and coordinate the production and provision of goods and services with each other. Understanding the extent to which jurisdictions actually coordinate to provide water management services, whether such coordination is beneficial to citizens, and what types of conditions affect the likelihood of coordination can provide valuable evidence to assess and guide the public service industry/local public economy literature.

This dissertation also evaluates a theory of common-pool resource (CPR) management. This theory provides insights into how institutional arrangements affect the management of water resources (E. Ostrom 1990; Ostrom, Gardner & Walker 1994;

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[1] Demands for both groundwater and surface water supplies are expected to grow, particularly in the West, where the population is expected to increase by nearly 30 million people over the next 25 years (Case and Alward 1997).

[2] Most western states maintain separate doctrines for governing ground and surface water supplies, yet many of these states have struggled with the inter-related nature of ground and surface water supplies. See

Schlager, Blomquist & Tang 1994: Lam 1998). Both CPR management theory and studies of public service industries have evolved out of the Institutional Analysis and Development (IAD) Framework, developed by colleagues at Indiana University (E. Ostrom 2000). The IAD framework provides common underlying assumptions between the two literatures about how actors make decisions and about the types of variables that are likely to influence resource management outcomes. (E. Ostrom 1999).[3] Given their common research framework, I argue that CPR theory can help explain the emergence and structure of coordination and cooperation in public service industries. At the same time, the literature on public service industries can inform CPR theory, providing a way to generalize the theory to large-scale complex resource settings. Using both bodies of literature, I consider a) how the boundaries of the institutions under which local water providers operate affect water management decisions, and b) how water providers and producers coordinate water management within a complex water industry.

To explain the relationship between institutional settings and the management of water resources, this dissertation considers multiple levels of analysis. The IAD framework, within which both of the theories have evolved, explains that institutions generally operate at three different levels: the constitutional level, collective choice level, and operational level (Kiser and Ostrom 1982; E. Ostrom 1990; E. Ostrom 1999). Any

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Glennon and Maddock (1994) for an analysis of the inconsistencies in Arizona case law in recognizing the relationship between groundwater and surface water.

[3] Frameworks identify general variables that are essential to explaining a social or physical phenomenon, and multiple theories can operate within a research framework (E. Ostrom 1999; Schlager 1999a). The IAD framework, for example, identifies key variables that should be used in evaluating the role of institutions in shaping social interactions and decision-making processes, which include the rules that govern an action arena, the characteristics of the community of interest, and the physical environment within which actors interact (E. Ostrom 1999). Theories, such as CPR theory, establish more specific relationships among the variables identified in the research framework.

one decision-making group or action arena may operate at more than one level of institutional action. For example, in water resource management, a state constitution sets a basic standard for water rights and establishes the collective choice arenas where decisions on water rights, allocation, and management can be made. Local constitutional rules, such as municipal charters, also affect collective decision-making on water resource provision and management. At the collective choice level, numerous jurisdictions and organizations participate in providing the rules and institutional framework regulating water resources and modifying water rights including state courts, state legislatures, as well as federal and local regulations. Operational level rules directly affect the authorized actions that water providers, public and private, undertake.

In addition to providing insights into the effects of different levels or types of institutions on water resource management, this study helps relate micro-level and macro-level theories of collective action. Research on water management from a public service industry approach has focused on macro-level descriptions of the water industry, with only a few empirical studies on the water industry (V. Ostrom 1971; U.S. Advisory Commission on Intergovernmental Relations 1991). On the other hand, common pool resource management studies rely largely on in-depth case studies of self-governed systems, particularly in small or micro-level resource settings (see Blomquist 1987; Schlager 1990; E. Ostrom 1990; Tang 1992; Lam 1998). Thus, one of the benefits of examining these two streams of literature in tandem is that it helps relate explanations of how institutions affect individual incentives for collective management of resources to explanations of industry-level coordinated action. Little work has been done to relate these two theories, despite the fact that these two streams of literature have evolved from a common research framework and that they could bridge micro and macro explanations of water resource management.

STUDY SETTING: CONJUNCTIVE WATER MANAGEMENT IN THE WEST

One of the responses to the dilemma of ensuring adequate water supplies for growing demands has been to coordinate the management of groundwater and surface water ("conjunctive water management"). This study uses data on conjunctive management activities in Arizona, California, and Colorado to evaluate the explanations offered by the public service industry literature and CPR theory of a) the relationship between institutional boundaries and conjunctive management and b) the role of inter-jurisdictional coordination in conjunctive water management.

Many studies on conjunctive management claim that it is a more cost-effective method of maximizing the availability of total water supplies compared to managing surface or groundwater supplies separately (National Research Council 1997; Fisher et al. 1995; U.S. ACIR 1991; Bookman-Edmonston 1979).[4] A key assumption of this dissertation, therefore, is that conjunctive water management is an advantageous and effective water management tool compared to alternative supply management methods. This section of the chapter describes conjunctive water management to demonstrate why this tool is appropriate for testing the assumptions raised by CPR theory and the public service industry literature. It then discusses the development of conjunctive water management across Arizona, California, and Colorado.

The Role of Conjunctive Water Management

Water providers and managers in the face growing conflicts between environmental needs and human demands for water. Adding to this dilemma in the arid West, when surface water flows are least abundant during summer months, water demand for municipal and agricultural uses usually is highest. Conversely, when flows are most abundant, demand is much lower. Due to the disparity between the timing of water availability and peak water demand, municipal water providers in California, for example, invest more than a billion dollars a year to establish water supply systems and reservoirs that provide reliable flows for peak demand (Purkey et al. 1998).

In general, the goal of conjunctive water management is to provide water supply reliability by coordinating the timing of the use of ground and surface water supplies (Thorson 1978; Bookman-Edmonston 1979; Trelease 1982; Western States Water Council 1990). Conjunctive water management can be accomplished in various ways. Conjunctive management projects often use the capacity of underground aquifers to store surface water supplies. When surface water is abundant during times of high precipitation, excess supplies can be stored underground through artificial recharge or seepage. Stored water can then be extracted through pumping in times of drought or high demand. Conjunctive water management is also done indirectly, by importing surface water to areas that are reliant on groundwater, in order to reduce groundwater pumping during peak times and allow basins to refill naturally. These basins can then be drawn down at times when surface supplies are low.

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[4] Conjunctive management differs from the term "conjunctive use". Conjunctive use does involve the

One of the benefits of this approach is to economize on the costs of surface water storage and distribution facilities to meet peak demands. When water providers have the capacity to change from surface water to groundwater supplies during peak demand, they can avoid the costs of adding higher increments of storage and delivery capacity to their surface supply systems. Similarly, when communities that rely on groundwater take advantage of surplus surface flows and allow groundwater basins to replenish naturally, they can avoid the costs of deepening wells to reach lowered water tables. Moreover, the strategic location of wells within a conjunctive management system can minimize the expanse of surface water distribution facilities that must be constructed. The use of groundwater for consumptive use during peak demand also provides a way to help maintain instream flows that are often critical for meeting non-consumptive needs during dry seasons.

In addition to augmenting water supplies and reducing the costs of storage, pumping and distribution, conjunctive water management can help resolve more specific problems related to the overuse of water supplies. For example, through groundwater basin recharge or replenishment of instream flows with groundwater, conjunctive management can protect water quality (U.S. Department of the Interior 2000). It can also be used to replenish depleted groundwater supplies, to prevent land subsidence caused by groundwater overdraft, and to avert salt-water intrusion into groundwater basins (Matthews 1991; U.S. ACIR 1991; Blomquist 1992).

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coordination of surface and groundwater supplies, but it may not necessarily be a managed effort per se (U.S. ACIR 1991).

"produced" or managed by some organization or entity. Production of conjunctive management involves surface water delivery to a site for underground storage and subsequent recovery. Such production may require cooperation and coordination among multiple jurisdictions or organizations to move water from surface sources to groundwater basins and to consumers.

From a practical standpoint, organizations or jurisdictions that bear the costs of conjunctive management presumably require some assurance that they will benefit from their investments. In other words, organizations logically need to be able to identify and quantify project benefits and determine if benefits outweigh the costs of engaging in conjunctive management. The information available on the cost of water being stored or saved, the value of water recovered from the project, the capital costs of constructing a recharge site, operations and maintenance costs, and permitting and monitoring costs are all likely to affect the determination of net benefits. The Western States Water Council (1990) and the U.S. Department of the Interior (2000), however, have both found in surveying groundwater recharge activities in the West that financial feasibility of most projects is often uncertain, requiring continued cost monitoring and re-estimation of benefit/cost ratios. In addition, even when the benefits of doing conjunctive management are clear, jurisdictions may not have the funding capacity to pay for the ongoing costs of projects. Likewise, locating sufficient financing sources for initial capital costs of projects can be difficult, especially when multiple jurisdictions are involved and the source of repayment is not clearly defined.

Studies also suggest that the institutions governing water resources can impede effective conjunctive management (Western States Water Council 1990; U.S. ACIR 1991; Purkey et al. 1998). For example, whether or not state water law recognizes groundwater recharge as a beneficial use of water affects the determination of benefits that water providers perceive from engaging in conjunctive management. Various regulatory rules, such as the federal Clean Water Act or state and local permits for wells, impose project costs, such as legal and permitting, that organizations or jurisdictions must incur on top of project production costs. Despite the recognition of the importance of institutional factors in some studies of conjunctive management and speculation about the types of institutions that may facilitate conjunctive use, few empirical studies have specified how different institutional settings affect conjunctive use.[5]

Conjunctive water management provides an excellent empirical setting for examining explanations of effective resource management boundaries and inter-jurisdictional coordination. First, conjunctive water management involves both ground and surface water systems, which are not likely to lie within a well-defined physical area. In fact, the process of conjunctive management actually can alter resource boundaries when water from a surface stream is diverted to recharge groundwater basins that may be hundreds of miles away from the original stream. Second, the organizational nature of conjunctive management may require the involvement of multiple jurisdictions or organizations to provide conjunctive management services, or more than one jurisdiction

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[5] See, for example, Western States Water Council (1990), U.S. ACIR (1991), MacDonnell et al. (1994) and Purkey, et al. (1998), for descriptive and comparative case studies that discuss institutions relative to conjunctive water management. These studies, however, have not focused specifically on measusring the

may benefit from participating in the provision of a single conjunctive management project.

The Development of Conjunctive Management in the West

A few studies consider how institutional arrangements can facilitate or impede the development of conjunctive water management (Blomquist and Schlager 1998; Western States Water Council 1990; MacDonnell et al 1994). These studies show variation both in the extent to which water providers use conjunctive management and in the conjunctive management techniques they employ. A number of western states, including Arizona, California, Colorado, Idaho, Oregon and Washington have experimented with several groundwater recharge and water banking methods in recent years (U.S. Department of the Interior 2000). Some states actively recharge groundwater basins and recover the stored water, while others rely on exchanges of groundwater for surface water. California has displayed the largest number and variety of conjunctive management programs, including injection well recharge, basin recharge, water banking, in-lieu exchanges, and stream-bed recharge (MacDonnell et al 1994). This section describes the development of conjunctive water management in California, Arizona, and Colorado, emphasizing the physical and institutional factors that have precipitated conjunctive management in these states.

California

California is one of the first states in the western United States to use conjunctive water management to help resolve supply and demand problems with its scarce water

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variance between water governance institutions and conjunctive water management outcomes across and resources. The earliest projects started in the beginning of the twentieth century in the southern portion of the state. Water providers in the Los Angeles area, for example, started experimenting with artificial groundwater recharge in the 1920s (Blomquist 1992). Some of the first conjunctive management projects in California were developed in the following way:

> Flood waters were moved out of stream channels, diked and ponded in permeable areas, and allowed to sink into the underground strata. Temporary dams were constructed in more permeable stream channels to obstruct surface flows and increase recharge to groundwater basins, which could then serve both storage and transmission purposes. (U.S. ACIR 1991, 37).

In the 1950s and 1960s, conjunctive management projects in California included large-scale, multi-use spreading grounds and in-lieu replenishment programs. Such programs often involved the coordination of multiple types of jurisdictions (U.S. ACIR 1991). For example in the 1950s, the Los Angeles County Flood Control District, the California Department of Water Resources, and the West Basin Water Association (overlying the coastal plain in Los Angeles) created a groundwater recharge project to prevent sea water from intruding into the freshwater supplies (U.S. ACIR 1991).

California's lengthy history of conjunctive water management can be attributed partially to the state's physical circumstances and to its water demand patterns. Adequate underground storage is vital to developing conjunctive water management programs. Groundwater is relatively abundant in California, lying below nearly 40 percent of the state's lands, and surpassing the quantity of surface water available in the state nearly sixfold (CDWR 1998a). According to the California Department of Water Resources

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within states.

(1998a), about 850 million acre-feet of water exist in the state's 450 groundwater basins. At least 250 million acre-feet are close enough to the land surface to be pumped feasibly. Overall, groundwater supplies about 40 percent of the state's annual consumptive use of water in normal rainfall and flow years. In drought conditions or in areas where surface water is scarce, that percentage is much higher (CDWR 1998a).

California's reliance on groundwater has resulted in problems of basin overdraft and conjunctive management projects, such as the West Basin project, have been used to address these problems. Overdraft occurs when groundwater users continually pump more water from aquifers than the natural rate of replenishment of those supplies, either from rainfall or stream seepage. California's Department of Water Resources estimates that groundwater overdraft averages about 1.46 million acre-feet per year (CDWR 1998a, 3-68) Sustained overdraft has resulted in land subsidence throughout large areas of the state. Between the 1920s and 1970s, the area of land in the San Joaquin Valley affected by subsidence totaled about 5,200 square-miles (Brickson 1992). The subsidence created an estimated loss of 16 million acre-feet 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. The Orange County Water District started taxing groundwater users in the 1950s to pay for groundwater replenishment in order to deal with overdraft problems (Blomquist 1994).

The availability and geographic distribution of surface water supplies also play an important role in conjunctive management in California. The northern half of the state receives about 75 percent of the state's rainfall and contains the most abundant surface water flows, while about 75 percent of the state's water demand comes from municipal and agricultural users in the southern half of the state (Argent 1994). To address this disparity, the state and federal governments have financed the construction of large north-south water diversion projects since the 1930s. These surface water diversion and storage projects facilitate conjunctive management because they can conserve high but sporadic storm water flows for gradual release to replenish streams and aquifers. The State Water Project, for instance, captures surface water from the snow melt in the northern Sierra Mountains flowing into the Feather River and the Sacramento River, which is then pumped through the California Aqueduct to southern California (CDWR 1998a). In the Los Angeles area, water districts have imported surface water directly from the State Water Project since the 1970s as a source of groundwater replenishment in the Main San Gabriel Basin (Blomquist 1992).

Following the construction of large-scale surface water diversion projects in the mid-twentieth century, water users in California's agricultural valleys also began to use conjunctive water management. In Kern County, for example, various large-scale water banking and recharge projects have stored approximately six million acre-feet of water since the early 1970s (Argent 1994). The Kern Water Bank, a program developed by the state, uses recharge ponds and extraction wells to store up to one million acre-feet of State Water Project water annually (MacDonnell et al 1994). Local water districts water can pump this water during scarce years.

Project water diversion systems have helped southern California cities to engage in groundwater for surface water exchange programs. For instance, the Metropolitan

Water District of Southern California (MWD) receives most of its water supply from the California State Water Project. MWD has developed large-scale programs among its member agencies to provide surface water at a lower price during high flow seasons in its 5,200 square-mile service area (MWDSC 1997). This promotes the reduction of groundwater pumping and some direct recharge among these agencies. Metropolitan's Seasonal Storage Service Program sold about 2.5 million acre-feet of water to member agencies between 1989 and 1997 (MWDSC 1997). Member agencies that receive this water are able to recharge aquifers naturally, which increases available groundwater for use when surface water supplies are scarce.

The physical setting in California is not the only factor that has influenced the development of conjunctive water management. Conjunctive management programs have evolved in California within a complex legal and institutional setting. California has a 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 (see Blomquist 1992). For instance, California's legislatively-authorized water management institutions include: irrigation districts, county water districts, municipal water districts, water storage districts, community service districts, flood control districts, and groundwater management agencies (U.S. Census Bureau 1994).[6] The benefit of this system is that water users are more likely to create institutions that fit their unique situation most appropriately. Yet, the lack of state-level water administration means that water users can face significant costs in organizing and maintaining water management institutions. This can inhibit local water users from resolving shared problems when the costs of organizing outweigh the benefits of devising new institutions (Ostrom 1990).

The laws governing rights to water resources in California also reflect the state's home-rule tradition. California, unlike most western states, recognizes multiple surface water rights doctrines. These include riparian rights of landowners adjacent to streams and appropriative rights allowing individuals to divert water for use on non-adjacent land. California has separate systems for surface water rights and groundwater rights. California does not have a statewide statutory provision that limits rights to the use of underground aquifers, although the state does recognize that property owners have the right to pump groundwater that lies under their land. Different doctrines and rules have been further devised at the local level by courts and local jurisdictions that govern the use of groundwater in certain basins. Thus, conjunctive management programs for storing and saving water in underground aquifers or exchanging groundwater for surface water have evolved in a variety of institutional settings.

Some of the earliest conjunctive management efforts came about when local groundwater users in southern California sought to resolve conflicts resulting from virtually unlimited legal rights to use underground water supplies. The lack of recognition of quantified groundwater rights in some California basins led to conflicts such as diminished water supplies, sea water intrusion into basins, and increased pumping

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[6] California also has over 20 individual special purpose acts that have created local water agencies such as

costs (Blomquist 1992). Individuals in these settings had few incentives to conserve or manage groundwater basins, knowing that other groundwater users can consume their supplies. In response to such dilemmas, water users in some basins devised various judicial decisions, legislative actions, and local ordinances to govern groundwater use. One way groundwater has been managed is through the adjudication of water rights of overlying users, which occurred in a few southern California basins in the 1960s and 1970s (Blomquist 1992). Special "Watermaster" agencies were then formed to administer the adjudicated water rights and management agreements. According to a report by the U.S. Advisory Commission on Intergovernmental Relations (1991),

> Frequently, they employed adjudications in order to take advantage of a process that limited decisionmaking to the users affected, allowed for expert investigations of hydrologic conditions, balanced total extractions with the available groundwater supply, and produced enforceable water rights for individual users (37).

In some of California's basins, groundwater users, municipalities, and local water agencies formed special districts to manage shared groundwater supplies (Blomquist 1992). Water users in these districts pay taxes or fees for basin replenishment programs. 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 sea water intrusion along the coast and to raise water levels in the two basins (U.S. ACIR 1991).

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the Orange County Water District and the Metropolitan Water District of Southern California (U.S. Census

In summary, the development of conjunctive water management in California is tied to its physical and institutional environment. The earliest conjunctive management projects began in southern California, particularly near the coast, where populations have been more heavily reliant on groundwater. In these areas and in the state's Central Valley, opportunities to engage in conjunctive water management have been enhanced by the creation of and access to large surface water diversion systems. These physical factors are intertwined with the state's myriad groundwater institutions and home-rule system of governance. Efforts to devise groundwater use rules to address the problem of over-pumping have preceded the development of conjunctive water management in California.

Arizona

Unlike California, the use of conjunctive management did not begin in Arizona until the late 1980s. Despite this later start, water providers in Arizona have employed a variety of conjunctive management methods including recharge, water banking, and in-lieu projects. Similar to California's projects, the development of Arizona's projects is partially attributed to the physical circumstances facing water users and the availability of large water project diversions. The institutional impetus for the growth of conjunctive water management in Arizona has been much more centralized and state-driven than in California.

Arizona's climate is arid or semi-arid and thus natural surface water supplies are limited, similar to parts of southern California. Most of Arizona's rainfall comes from

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Bureau 1994).

heavy summer storms that produce flash floods. Areas of higher elevation in the state are cooler and wetter than surrounding valleys and lowlands. High temperatures in the Phoenix valley average between 100 and 110 degrees F in the summer and between 60 and 70 degrees F in the winter (ADWR 1999a). Average yearly precipitation in the state varies from four inches in the southwestern deserts to over 30 inches in some mountain ranges. Arizona has relatively low humidity, causing high rates of evaporation. Native surface waters in Arizona include the Salt, the Verde, the Agua Fria, and the Gila rivers in the central part of the state; the Santa Cruz and San Pedro rivers in the southern part of the state; and the Colorado River along the northern and western borders. Arizona's surface water availability can vary widely depending on the season, year, and location of the watershed.

Groundwater is most abundant in central and southern Arizona aquifers, which are made of sands and gravels (ADWR 1999a; Mann 1963).[7] Increasing water usage has overwhelmed even these abundant supplies. The introduction of turbine pumps following World War II enabled groundwater to be extracted from greater depths, thus expanding its use tremendously. Between 1940 and 1953, groundwater pumping for irrigation increased from an estimated 1.5 million acre-feet to 4.8 million acre-feet per year in Arizona (Mann 1963). A population boom and rapid growth followed the agricultural expansion. Following World War II, Arizona's population expanded from 590,000 in 1945 to 3.67 million in 1990, mainly in the Phoenix and Tucson areas (Mann 1963; U.S.

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[7] Northern Arizona aquifers are characterized by fractured rock where wells must be drilled to great depths, and may yield very little water.

Census Bureau 2001). By 1997, the population had grown to 4.5 million. Groundwater now provides about 40 percent of the state's consumptive water use (ADWR 2001).

In addition to aquifer capacity, the population centers in the central and southern portions of the state have greater access to large-scale surface water diversion systems. Large-scale storage reservoirs and delivery systems were constructed in the early 20th century along rivers in central Arizona to provide more stable supplies for growing populations and irrigated lands (Mann 1963). Reservoir storage systems are located on the Salt River, Verde River, Gila River and Agua Fria River (ADWR 2001).

Like California, Arizona now faces a mismatch between the geographic location of a major surface water source in relation to its population centers. To address this mismatch, the Colorado River is diverted over three hundred miles through the Central Arizona Project from the northwestern region of the state to support water demands in the metropolitan and agricultural centers of central and southern Arizona (Central Arizona Project 2001). At the same time, both Arizona and California have extensive groundwater basins with the capacity to supply urban and agricultural demands and to serve as storage systems. Not surprisingly, conjunctive water management projects in Arizona began in the southern and central areas of the state where water users have access to surface water diversion systems and large aquifers for underground storage.

Significant investments were made throughout the twentieth century in Arizona to maintain and ensure more stable supplies of water, but these investments have led to problems of over-use. Most of Arizona's native surface water supplies are over-appropriated, and many perennial streams only receive intermittent flows following major storms (ADWR 2001). In parts of Arizona, groundwater overdraft is a serious problem that has led to land subsidence, lower well yields, water quality degradation and the drying up of streams and rivers (ADWR 1999a, 1999b, 1999c; 2001). Over the past decade, conjunctive water management in Arizona has been a way for water users to address both over-appropriation of streams and groundwater overdraft.

Water users in Arizona did not pursue conjunctive management activities as solutions to these problems independently. Rather, the state government provided the institutional incentives for conjunctive management activities. Unlike California, the State of Arizona does not follow a home-rule tradition of governance. Whereas California ranks 4th among the 50 states in number of local governments, Arizona ranks 38th (U.S. Census Bureau 1994). This greater reliance on state-level institutions is reflected in Arizona's groundwater management policies and in the evolution of conjunctive management.

Arizona's conjunctive management programs emerged following major changes to state groundwater laws in the 1980s and the completion of the Central Arizona Project (CAP) in the early 1990s. Prior to 1980, the year of the passage of the Arizona Groundwater Management Act, Arizona's groundwater was treated as an open access resource throughout the state. The 1980 Groundwater Management Act quantified groundwater rights in the areas of the state with the highest agricultural and urban groundwater demands (Ariz. Rev. Stat. §45-411 to 45-637). In these areas, known as Active Management Areas (AMAs), the amount of groundwater available to municipal, industrial, and agricultural users is limited based on historic use. The limits become increasingly strict over time. Arizona's four AMAs are defined around the major groundwater basins that underlie the most populous areas of the state.[8]

While the Arizona Groundwater Management Act quantified rights to groundwater and limited the use of those supplies, the act alone was insufficient to protect parties that may want to store surface water underground for future use. It did not formally recognize rights to water supplies that are stored in groundwater basins through artificial recharge, offering no guarantee that entities could lawfully recover water if they stored it underground. In part, the institutional impetus for storing surface water underground came when the Arizona legislature passed the Groundwater Storage and Recovery Projects Act in 1986 (Ariz. Rev. Stat. §45-651; §45-801). The 1986 act established rights to recover surface water that is stored in underground aquifers through artificial recharge. It charged the Arizona Department of Water Resources with developing a permitting and monitoring process for conjunctive management projects.[9]

The Groundwater Storage and Recovery Act provided the institutional support to protect those who store water and recapture it in Arizona. It did not, however, fully provide the institutional direction necessary to promote the coordination of conjunctive

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[8] The smallest AMA is the Prescott AMA, which encompasses 485 square miles in central Yavapai County about 50 miles north of Phoenix (ADWR 1999c). The largest AMA is the Phoenix AMA, covering 5,646 square miles (ADWR 1999b). It is located in central Arizona, overlying most of Maricopa County and small portions of Yavapai and Pinal Counties. Within the AMA are 23 incorporated cities and towns, 37 irrigation districts one Air Force Base, and three Indian communities. The Pinal Active AMA is located just southeast of the Phoenix AMA in central Arizona in Pinal and Pima Counties (ADWR 1999a). It has 5 sub-groundwater basins and covers approximately 4,000 square miles. Just southeast of the Pinal AMA is the Tucson AMA, which covers 3,866 square miles and includes portions of Pima, Pinal and Santa Cruz Counties (ADWR 1999d). Within the AMA are five incorporated cities and towns and the lands of two Indian tribal nations.

[9] The Arizona legislature passed additional underground storage legislation between 1986 and 1993 and in 1994 consolidated the programs under the Underground Water Storage, Savings and Replenishment Act (UWS). The Arizona Department of Water Resources administers the UWS program.

management efforts among water providers. The 1980 Arizona Groundwater Management Act directed the Department of Water Resources to develop requirements for long-term assured water supplies in order to lessen municipalities' and developers' dependence on mined groundwater. In 1994, Assured Water Supply Rules were established after repeated attempts to modify the Groundwater Management Act (ADWR 1994). These rules were derived following the legislature's creation of the Central Arizona Groundwater Replenishment District (CAGRD) in 1993. The CAGRD is as a subdivision of the Central Arizona Water Conservation District, the managing entity of the Central Arizona Project (Ariz. Rev. Stat. §48-3701). The CAGRD has the authority to participate in groundwater recharge and to contract with domestic water suppliers to help them meet the assured water supply requirements of the Arizona Groundwater Management Act. Water providers that serve new subdivisions in the Phoenix and Tucson Active Management Areas must prove they have access to sufficient renewable surface water supplies, or must become a member of the CAGRD. Thus, the Assured Water Supply Rules facilitate conjunctive water management by encouraging water providers to acquire excess surface water, which they can store underground for future use, either on their own or through the CAGRD.

The most recent institutional change in the state of Arizona that has encouraged coordinated efforts to store surface water underground was the creation of the Arizona Water Banking Authority. In 1996, the state legislature formed the Arizona Water Banking Authority (AWBA), a political subdivision of the state, to store Arizona's currently unused Colorado River allotment (Ariz. Rev. Stat. §45-2421; ADWR 2000). The AWBA is authorized to use Central Arizona Project water in groundwater recharge projects or to sell Central Arizona Project water to irrigators as an alternative to groundwater pumping. It can also contract with entities from surrounding states to store surplus Colorado River water for future use (AWBA 2000).

These state-imposed institutional changes have allowed water users in the Phoenix and Tucson metropolitan areas and in the surrounding agricultural regions to develop conjunctive management projects, reducing their reliance on groundwater and storing surface water for future use (ADWR 1999a; 1999b; 1999c; AWBA 2000). Various organizations now participate in Arizona's conjunctive management projects, including the Central Arizona Water Conservation District, the Arizona Water Banking Authority, municipalities, irrigation districts, and private companies.

The institutional stimulus for developing conjunctive management in Arizona has been more centralized and state-centered than the California experience. 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, on the other hand, witnessed a rapid development of conjunctive management projects over the past decade, facilitated by state policies that limit groundwater use and provide incentives to store water underground for future use. While the organization and governance of conjunctive management activities in Arizona and California differ remarkably, these two states do share some similarities in their development of diverse types of projects and their reliance on project water supplies for conjunctive management programs.

Colorado

Conjunctive water management in Colorado differs from the programs that emerged in California and Arizona. Most conjunctive management projects in Colorado developed in agricultural areas. Rather than storing water for long-term supplies or seasonal drought, the bulk of the Colorado programs assure sufficient flows for surface water users whose flows are depleted by groundwater pumping.[10] The emergence of this type of conjunctive management is a result of the heavy reliance on surface and groundwater supplies that are hydrologically connected in Colorado.

Colorado's institutional impetus for conjunctive water management also differs from Arizona and California. Conjunctive management has been facilitated by rules devised by state water administrators to address problems created by groundwater pumping in basins that are tributary to streams in the state's major watershed. These rules resulted from pressure on the state by irrigators within individual watersheds to control tributary groundwater pumping, reflecting Colorado's reliance on local institutions for governing water resources (Schlager 1999b). Thus, compared to Arizona, Colorado's water administration is more decentralized. The system of water administration represents Colorado's reliance on a home-rule system governance, although not to the extent of California. For instance, Colorado ranks 18th among the 50 states in number of

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[10] A demonstration recharge project has been developed in the Denver groundwater basin by the Willows Water District that stores water for long-term municipal use (U.S. DOI 2000). This project stores water in a deep confined aquifer using an injection well. The water district can recover stored water during times of

local governments, while California is among the top five states (U.S. Census Bureau 1994). Yet, state-level institutions still play a role in facilitating conjunctive management, which is not the case in California.

Just as in California and Arizona, physical circumstances have determined the need for conjunctive management activities in Colorado and have shaped the institutional mechanisms that encourage conjunctive management. In Colorado, as in California and Arizona, population growth and a semi-arid environment have strained the state's water supplies in recent years, especially in the eastern half of the state and the Denver metropolitan area (Colorado Water Resources Research Institute 1991). The eastern plains, which are comprised largely of the South Platte and Arkansas River valleys, receive only about 12 inches of rainfall per year. The South Platte River valley, which has heavy agricultural water consumption, as well as growing urban demands, has the longest history of conjunctive management in the state (Schlager 1999b). In Colorado's Arkansas River basin, which has strains on surface and alluvial groundwater supplies comparable to the South Platte River basin, conjunctive management has been used to a lesser degree for only the past few years.

Like many western states, Colorado uses about 85 percent of its water for agriculture (Colorado Water Resources Research Institute 1991; Colorado Division of Water Resources 1998a). The development of irrigation in both the South Platte and Arkansas River valleys began in the mid-1800s when settlements such as the Fort Collins Agricultural Society formed to develop irrigation diversions from the two river basins

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surface water drought. Such methods more closely reflect the practices found in California and Arizona

(Grantham 1991). These companies built canals from the rivers, and provided a share of the water to individual farmers for irrigation. The development of these irrigation companies led to the over-appropriation of a majority of surface flows in the Arkansas and South Platte basins by the late nineteenth century, meaning that the quantity of water rights claims had exceeded available supplies.

Irrigators in the South Platte and Arkansas valleys started pumping groundwater to supplement surface flows by the early 1900s, but groundwater use was minor compared to surface consumption (MacDonnell 1988). Three of Colorado's four major groundwater basins are located in these two river valleys, and these major basins potentially store over 177 million acre-feet of water (Radosevich 1976).[11] In the 1940s, changing technology increased well capacity, allowing irrigators to make greater use of groundwater. With a severe drought in the 1950s, irrigators in the South Platte and Arkansas basins began to pump increasing supplies of groundwater and to drill hundreds of new wells. In 1929, approximately 800 wells existed in Colorado and by 1959 the number had grown to over 8,900 (Radosevich et al. 1976). While groundwater development seemed to increase overall water supplies, pumping actually had a detrimental effect on surface flows. Many of the new wells in the Arkansas and South Platte River valleys that were drilled the mid-1900s were located in aquifers that are tributary to streams. Pumping groundwater from these aquifers thereby reduced the available surface flows in these streams.

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than the conjunctive management activities in the agricultural areas of Colorado.

[11] One acre-foot is equivalent to about 325,000 gallons. It is enough water to cover about one acre of land with one foot of water.

The rules that developed to govern the relationship between tributary groundwater and surface water in these two basins are tied to Colorado's surface water rights doctrine. Since the 1880s, water users and the state have recognized the doctrine of prior appropriation as the principal law for assigning property rights to Colorado's surface waters (Radosevich et al. 1976). The appropriation doctrine establishes that individuals have rights to divert or appropriate any water that they put to "beneficial" use; and individuals who put the water to use at the earliest time have the highest priority to use the water.[12] Therefore, early water users have rights that are considered "senior" to recent users, and, in times of shortage, senior rights must be satisfied first.

Prior to 1957, groundwater usage was not managed or administered by the state. While new wells required permits starting in 1957, the state imposed no formal rules establishing that tributary groundwater appropriators were subject to the same priority rules as surface water users (Radosevich 1976). In 1969, the legislature passed the Water Rights and Determination Act, which encouraged the adjudication of tributary groundwater rights bringing well owners under the same prior appropriation system as surface water users. The act charged the Division Engineers to devise rules that maximize the use of the state's water resources. To promote "maximum" use of the state's water resources, the legislature allowed the Division Engineers to restrict groundwater diversions only if the state could demonstrate that a particular well caused direct material injury to senior surface water users. The legislature also offered the Division Engineer an

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[12] The prior appropriation doctrine establishes who has rights to appropriate water resources based on where and when they first put water to beneficial use. It also clearly specifies the restrictions placed on the quantity of water that can be used and specifies that transfers of rights must be consistent with the type of use, timing of use, and location of use of the original water right.

alternative enforcement solution, known as Augmentation Plans, which allow well owners to continue pumping if they guarantee a source of replenishment for depleted stream flows when senior surface water appropriators made claims to their water rights (Radosevich 1976).

In the early 1970s, a number of well owners in the South Platte basin began to manage pumping in coordination with surface flows under the court decreed Augmentation Plans, thus facilitating conjunctive water management (MacDonnell 1988). These plans rely on direct or "in-lieu" recharge for groundwater pumpers to find alternative sources of water to replace water depleted by pumping. In-lieu recharge in Colorado involves acquiring supplemental surface water and placing that water directly into the stream, in exchange for pumping. Direct recharge involves taking supplemental water and placing it in ponds or dry stream beds, allowing the water to filter into the aquifer. The recharged water then replenishes the water depleted from groundwater pumping.

The use of temporary Augmentation Plans, known as "Substitute Supply Plans", is another way in which conjunctive management began in the South Platte basin (MacDonnell 1988). Under the temporary plans of augmentation, groundwater users provide an estimate to the State Engineer of the amount of water to be pumped. They also give an estimate of the amount of water that the well owner will supply to satisfy senior water users, based on the volume of water pumped (see Col. Rev. Stat. §37-180-120). Since the inception of the temporary plans, the Division Engineer has continued to approve many of these plans on a case by case basis each year (Colorado Division of

Water Resources 1998b). Unlike Augmentation Plans, Colorado's water courts do not decree the temporary plans.

Temporary augmentation plans started in 1972 when a group of well owners formed the Groundwater Appropriators of the South Platte (GASP). GASP worked with the Division Engineer to come up with a plan for annual approval that lists all members, wells, estimates of pumping and amount of water they would provide to replace stream depletions (MacDonnell 1988). GASP covers thousands of wells in the South Platte Basin and its members pay annual fees depending on the quantity of water that each member expects to pump each year. GASP uses membership fees to purchase surplus replacement water or to pump additional water from different wells. GASP then replaces pumping depletions at the appropriate time and location. Organizations such as GASP play an important role in facilitating conjunctive water management in Colorado. They handle the administrative requirements of Augmentation Plans or Substitute Supply Plans for their members and the financial transactions and contracts involved in acquiring supplemental sources of surface water.

In the early 1990s, irrigators in the Arkansas River basin in Colorado began to incorporate large-scale in-lieu projects, similar to those in the South Platte basin, as part of the Division Engineer's efforts to reduce the long-term negative impacts of groundwater pumping on surface flows (Colorado State Engineer 1996). These in-lieu replenishment activities in the South Platte and Arkansas basins manage water conjunctively, but the methods used in Colorado's South Platte and Arkansas basins differ from California and Arizona's conjunctive management projects. Colorado water users coordinate the timing of the use of ground and surface water supplies, but do not recharge water underground in deep aquifers for banking or long-term use. In Colorado, water is recharged into aquifers or placed directly in streams to replenish surface flows when surface water users make claims to their water rights.

In Colorado, the institutional mechanisms for engaging in conjunctive management and the organization of conjunctive management activities also contrast with the cases of Arizona and California. Conjunctive water management programs have evolved around the goal of satisfying surface water rights in Colorado. The Colorado State Engineer's rules have provided alternative administrative tools to force groundwater users to replace depleted surface flows. These rules are devised on a watershed-by-watershed approach, seeking to address local problems that have evolved among ground and surface water users. Colorado's institutions clearly differ from those that the Arizona legislature has sponsored to encourage water users to store water for long-term use. They also differ from California's local groundwater basin institutions that have sought to replenish over-drafted basins.

To summarize the key differences across the three states, Table 1.1 highlights the timing, location, types of practices, physical setting and institutional setting surrounding the development of conjunctive water management, as discussed in this chapter.

TABLE 1.1: Emergence of Conjunctive Water Management in California, Colorado and Arizona

	California	Colorado	Arizona
Timing of earliest efforts	Early 1900s	1960s	Late 1980s
Location	City of Pasadena 1914; San Fernando Valley 1930s; Los Angeles area 1950s – 1960s.	Primarily in S. Platte and Arkansas Watersheds.	Primarily in Maricopa, Pinal, and Pima Counties.
Type of early CWM Practices	Various. Spreading basins, with reclaimed water and imported surface water, and sea water intrusion barriers.	In-lieu. Well pumpers (with junior rights) purchase surplus supplies to replace depleted surface flows affecting senior surface users.	In-lieu and Direct. Irrigators begin to take Central Arizona Project Water instead of pumping. Cities begin direct recharge.
Physical Setting	Over-pumping begins to deplete groundwater in south coast basins and San Fernando Valley.	Drought in 1950s. Increased ground water pumping reduces availability of surface water.	Emerging problems of groundwater overdraft in metropolitan and agricultural portions of 3 counties.
Institutions Governing Water Management	Decentralized, "home-rule" tradition. Minimal state involvement in groundwater governance.	Tradition of local governance in water management. State involvement in devising rules at water basin level.	Centralized, state-imposed rules and institutions.
Key Institutional Changes	Local groundwater management institutions emerge through courts and local jurisdictions.	1965 – State Engineer given legislative authority to regulate tributary wells. 1969 – Legislature integrates tributary groundwater law with surface water law.	1980 – AZ Groundwater Management Act creates rights to ground water. 1986 – Ground Water Storage and Recovery Projects Act

Summary

Conjunctive management is a tool that can help address water supply dilemmas in water scarce areas by taking advantage of the storage capacity of groundwater basins and the cyclical availability of surface flows to maximize overall supplies. It has both economic and environmental advantages over more traditional water supply management techniques, but the likelihood of its use can be affected by physical, financial, organizational, and institutional variables. To reiterate, one reason for focusing on the effects of institutional variables on conjunctive management is that they are not well understood but are often viewed as barriers to implementing conjunctive management.

Another reason to focus on the institutional variables affecting conjunctive management is that the link between institutions and coordination in the water industry has not been well-specified or empirically tested. A study by the Advisory Commission on Intergovernmental Relations on metropolitan governments noted that one of the key areas for future research on public service industries is investigating "to what extent governance rules frame a process that enables citizens to make optimal choices of provision arrangements" (U.S. ACIR 1987, 51). More than a decade later, in his study on local public economies, Oakerson (1999) claims that this research is still needed because "it is essential to understand how rules affect choices" (126).

A study of conjunctive water management is appropriate for examining the relationship between institutional arrangements and inter-organizational coordination in managing water resources because of the physical, institutional, and organizational complexities involved in conjunctive management. Furthermore, variation exists across the types of institutional arrangements governing organizations that provide and produce this service. Finally, if the coordinated management of groundwater and surface water supplies is indeed an economically and environmentally viable method of water supply management, it is important to understand the role that the structure of political jurisdictions and institutions play in facilitating conjunctive management.

OVERVIEW OF STUDY

While a paucity of prior research exists on the relationship of institutional arrangements to conjunctive water management, there is a growing body of theoretical and empirical work on the relationship of institutions to water resource management, notably common-pool resource management (CPR) theory and the literature on public service industries. Examining different institutional arrangements governing water supplies, within the context of conjunctive management, can provide in-depth and useful information on a particularly popular approach to water management. It also can expand the body of evidence available to test institutional theories. Using a study of conjunctive water management, the purposes of this dissertation are:

1) to offer theory development by examining how common pool resource management theory can inform and complement one another;

2) to describe the development and implementation of conjunctive water management across different institutional settings;

3) to test hypotheses regarding the relationship between institutional boundaries and conjunctive water management and hypotheses regarding the use of inter-jurisdictional cooperation in the management of water resources; and

4) to identify policy implications for conjunctive water management services and natural resource management in general.

Chapter Two examines the public service industry literature and CPR management literature and suggests how the two streams of literature can inform each other. The description of conjunctive water management in this chapter provides insights into the theoretical weaknesses examined in the next chapter. Based on the theory development, Chapter Two presents hypotheses explaining the relationship between institutional arrangements and conjunctive water management. The empirical analyses in this dissertation use data on conjunctive management projects in Arizona, California and Colorado. The project data comes from a 1996-1999 study funded by the National Science Foundation and the Environmental Protection Agency. The study includes survey data on water providers and water management organizations that are involved in conjunctive water management in the three states. The specific data collection procedures including sampling and survey design are discussed in Chapter Three. The data analyses are presented in Chapters Four, Five, and Six.

In conclusion, this dissertation contributes to resource management theories by examining the theoretical assumptions about effective jurisdictional boundaries for resolving resource supply and demand dilemmas. It also helps guide public policy theory more generally by identifying explicitly the conditions under which organizations and public jurisdictions coordinate to provide public services. This dissertation provides both qualitative and quantitative analyses of conjunctive water management in the western United States, which can advance our understanding of the utilization and impacts of this technique.

II. THEORY DEVELOPMENT

The relationship between institutions and conjunctive management is not well understood. Descriptive evidence on the development of conjunctive water management indicates that institutions affect both the feasibility of engaging in conjunctive management and how conjunctive management is practiced. This chapter turns to theories of public service industries and common-pool resource management to explain more completely how institutions are likely to influence conjunctive water management programs. It examines how the two theories can inform one another and resolve theoretical weaknesses. From this analysis, hypotheses are derived explaining the relationship between institutions and conjunctive water management.

OVERVIEW OF THE LITERATURE

Public Service Industry Theory

In general, the literature on public service industries (or local public economies) describes how overlapping political jurisdictions can meet citizen demands for public goods and services adequately and cost-efficiently. With respect to water resources, this literature discusses the connection between institutional arrangements that exist under the United States federal system of government and the ability of political jurisdictions to meet citizens' numerous and competing demands for water resources. This section discusses public service industry theory and its application to the provision of water supplies and water management services in the United States.

Polycentric Production, Provision, and Governance

Institutional scholars have pointed out that the United States' constitutional choice for a federal system of government has led to the development of political jurisdictions that overlap geographically. This can lead to functional overlap or fragmentation of services within regions or sectors (V. Ostrom 1989; Oakerson 1989; E. Ostrom 1997). Such a system of overlapping political and administrative jurisdictions can be called "polycentric" (Ostrom, Tiebout, and Warren 1961).[13] According to the theory, this system of government can create a need for jurisdictions to coordinate the provision of goods and services with other jurisdictions. Scholars of a polycentric model of governance have developed a significant body of theoretical and empirical research on the organization and benefits of public service provision in overlapping political systems, particularly in metropolitan areas (Parks 1985; U.S. ACIR 1987, 1988, and 1991; Oakerson and Parks 1988; Parks and Oakerson 1993; Oakerson 1999).

Studies on public service provision in metropolitan areas have referred to the collection of overlapping jurisdictions that supply and produce various public goods and services in a community as "local public economies" (U.S. ACIR 1987; Oakerson and Parks 1988; Oakerson 1999). In addition, this research has described the collection of overlapping jurisdictions that coordinate to provide and/or produce specific goods or services within a particular sector of the public economy, such as police protection. Overlapping jurisdictions that comprise a particular service sector are referred to as a "public service industry" (V. Ostrom and E. Ostrom 1991; US ACIR 1991).

The provision and management of water resources in the United States is one sector that the literature portrays as a public service industry. Studies of the U.S. water industry describe it as a collection of public, private and quasi-governmental water providers, and government regulators and administrators that cross multiple political jurisdictions (V. Ostrom 1971; U.S. ACIR 1991; Grigg 1996). This research shows that a complex system of overlapping jurisdictions and institutional arrangements administers and governs water resource provision and management.[14] Vincent Ostrom (1971), in a study of the California water industry, described water resource development throughout the United States as following a pattern of overlapping, or "polycentric," water service jurisdictions. He described these water service jurisdictions as "a public service industry without a competitive product market but with a competitive rivalry among the principal agencies for the resource supply" (4).

A public service industry, such as the water industry, has three components. They are: 1) jurisdictions and organizations that provide (fund) a good or service, 2) jurisdictions and organizations that produce or supply a service or good, and 3) jurisdictions and organizations that legislate and administer rules governing production and provision (Oakerson 1999; V. Ostrom and E. Ostrom 1991; U.S. ACIR 1990). While conceptually distinct, the three components of a public service industry can overlap

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[13] According to V. Ostrom, Tiebout, and Warren (1961): "'Polycentric' connotes many centers of decision-making which are formally independent of each other" (831).

[14] Institutional arrangements are defined as the agreed upon rules and constraints that individuals create, change and use in order to guide human activities and thereby reduce uncertainty of interactions with people or the physical world (E. Ostrom 1986; North 1990; E. Ostrom 1990). Institutions can be formal or informal, but, in this analysis, institutional arrangements largely include formal governance mechanisms such as laws or jurisdictions.

jurisdictional boundaries or scales, or the same jurisdiction can be involved in more than one of the components of the public service industry.

The literature on local public economies and public service industries distinguishes between production and provision of public goods and services (Oakerson 1999; U.S. ACIR 1987, 1988; Parks 1985).[15] Provision occurs through the efforts of "collective consumption units," or groups of individuals clustered within geographic boundaries, who impose taxes or other public funding requirements on themselves to supply a good or service. Provision jurisdictions for water resources, for example, can include municipal governments, public authorities, special districts, voluntary associations, or any other collective group (U.S. ACIR 1991). The members of provision units make decisions about the amount and/or quality of a public service or good to acquire or produce as well as how to distribute the funding costs (Oakerson 1999).

Provision units sometimes produce or deliver the public services that they fund. Alternatively, they may contract with other government agencies and/or private firms for the production of all or parts of the service, thus separating provision from production (U.S. ACIR 1987; V. Ostrom and E. Ostrom 1991). In a water industry, "producers" include organizations that build and maintain infrastructure and secure water rights to deliver water to users. In this sense, producers in the water industry can also be labeled water suppliers or distributors. These suppliers can be further distinguished among wholesalers, retailers, and importers (U.S. ACIR 1991).

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[15] In economic terms, public goods, as opposed to private goods, are characterized by varying degrees of 1) difficulty in excluding potential users from receiving benefits from the goods, and 2) non-rivalry among users for the benefits of those goods (Baumol and Oates 1988).

The supply and delivery of water to end users in a water industry often involves complex contractual arrangements among and between providers and producers (Grigg 1996; Burton 1992; U.S. ACIR 1991). Large-scale importers, such as the Bureau of Reclamation, produce and deliver water through contractual arrangements with wholesalers and retailers; other large-scale importers and wholesalers are formed as special districts producing and delivering to member agencies or under contract with other retailers. Some wholesale districts, such as the Metropolitan Water District of Southern California, establish contracts with large-scale importers for water supplies (a provision activity), or they may supply the infrastructure to import their own water (a production activity). Likewise, larger end-user retailers can act as wholesalers to smaller retailers. Members of special wholesale districts or customers of federal or state importers typically include municipal or agricultural water providers, as well as end-user retailers like private water companies or regional utility districts. Retail water organizations such as municipal utilities, special districts, and private companies are provision units through which water users decide from where to acquire their water supplies and on what terms.

The governance level of public service industries includes organizations that are responsible for establishing and administering the rules that manage the production and provision of a service or good (U.S. ACIR 1987). The governance portion of a water industry can involve Congress, state legislatures, municipal councils, courts, federal regulatory agencies such as the Environmental Protection Agency, and state regulatory or administrative agencies such as a department of water resources. Water providers also can develop jurisdiction-specific rules through city councils, water commissioners, or a district board of directors. These bodies have governance authority over provision units and can serve to resolve conflicts with different providers (Burton 1992). Inter-organizational associations are also important components of a public service industry, which may serve to lobby governance organizations on behalf of producers and providers or to resolve conflicts among members.

While the water industry in the United States generally has been described as "polycentric" or comprised of overlapping institutional and organizational arrangements, there are differences in the organization of the water industry across different state and local jurisdictions. As Ostrom (1971) noted, in his study of the California water industry:

> We would expect experience to vary in other regions of the United States with 1) environmental conditions, 2) patterns of demand, and 3) the terms and conditions of political choice reflected in differing constitutional arrangements. However, we also assume that these variations will occur within the limits of those features which are common [to] the American political system (sic). Common patterns reoccur with varying elements (143).

Ostrom's description suggests that over time and across regions, the degree of jurisdictional fragmentation and overlap within this industry is likely to vary. This variation can support comparative analysis.

Assumptions and Theoretical Implications of a Polycentric Water Industry

In addition to providing a description of the structure of water resource supply and management, the literature on public service industries offers theoretical explanations for the advantages of polycentric systems over consolidated jurisdictions. Alternative theories do exist that contradict the assumptions of the public service industry literature, which promote consolidated systems of governance. One of the major arguments against the literature promoting polycentric systems of governance is that fiscal and political accountability may be obscured if citizens are unable to obtain adequate information on the multitude of jurisdictions that provide public goods and services (Lyons and Lowery 1989; Downs 1994). Alternative theories also recognize that making changes to rules or agreements among multiple jurisdictions that provide a common service is not necessarily easy. For instance, bargaining time can become excessive within polycentric systems, particularly if hampered by political differences. These theories are not discussed explicitly in this dissertation since the focus of the theory development and empirical analyses is to examine how common-pool resource theory can help develop the weaknesses of the public service industry literature. In doing so, certain assumptions of the public service industry literature are tested, but not in comparison with alternative theories.

A principle argument of the public service industry literature is that polycentric jurisdictions are more efficient in "maximizing human welfare" than are centralized bureaucracies (U.S. ACIR 1987; 49). According to the literature, welfare maximization involves two criteria. The first criterion is the satisfaction of "individual preferences" for public goods and services. The second criterion is the use of resources to develop "preferred outputs at least cost" (49).

The satisfaction of citizen preferences, which is the first efficiency criterion, depends upon opportunities created by the provision side of a polycentric service industry. The theory posits that polycentric provision jurisdictions provide citizen-consumers with a richer and more accessible information base with which to judge the comparative performance of provision and production organizations (Oakerson 1999). If multiple communities within the same metropolitan region or state have diverse arrangements for providing and producing public services, their residents can "see" the service combinations (including quality and cost) being enjoyed by their neighbors more easily than if comparisons had to be made from one centralized region to another.

Citizens, theoretically, have enhanced opportunities to voice their concerns and preferences for public services within a polycentric system because jurisdictions are smaller, more accessible and multiple economies exist from which they can "choose" services (V. Ostrom and E. Ostrom 1991: Oakerson and Parks 1988). In addition, service providers in polycentric systems have various production options, such as co-production and contracts, and therefore, ample opportunities to meet changing citizen demands (Oakerson and Parks 1988). Service providers can coordinate with other jurisdictions when they lack adequate inputs or facilities to supply emergent needs or fluctuating demands. The theory maintains, however, that different scales of provision are needed for various types of services to respond to the interests and demands of political communities and to achieve cost-efficient service production or delivery (Oakerson 1999; Ostrom, Tiebout and Warren 1991).

The availability of alternative supply arrangements allows officials to "seek changes in multiorganizational arrangements that enable them to do more for less" (Oakerson and Parks 1988, 108). The combination of overlapping provision jurisdictions with multiple production or supply options encourages officials to achieve the second efficiency criteria – cost efficiency (Ostrom, Tiebout, and Warren 1961). In the case of the water industry, the literature maintains that the existence of multiple suppliers, including wholesalers, importers, and retailers "can allow for greater flexibility and efficiency in water pricing" (Ostrom, Tiebout, and Warren 1961; 58).[16] Also, providers are able to adapt to changing economic conditions because they "can then make decisions about use and delivery in response to the incentives signaled by pricing practices" (U.S. ACIR 1991, 58).

In addition to providing flexibility to meet fluctuating demands, the literature suggests that multiple producers and suppliers encourage cost efficiency because they can take advantage of economies of scale. In the water industry, municipal and agricultural providers typically contract with various types of water wholesale districts. Wholesalers can deliver water across multiple jurisdictions at a lower cost than if the municipality paid for the infrastructure and delivery alone. The literature maintains that even if such inter-jurisdictional arrangements add transaction costs, these "relationships based on cooperation can be expected to be cost-effective for the parties concerned and thus not to increase costs overall" (Oakerson 1989, 127).[17] In other words, the benefits of increasing economies of scale through coordinated production of goods and services can outweigh the costs of contracting and negotiating coordinated production arrangements.

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[16] Criticisms of polycentric governance have been made even more explicit with respect to water resources. A common argument against fragmented jurisdictions, particularly functionally specialized jurisdictions, is that they lack both the ability for comprehensive resource planning and the ability to internalize externalities that cross state and local boundaries (Gottlieb and FitzSimmons 1991; Dzurik 1990; Haddock 1997; Kenney 1997). These critics argue that smaller-scale organizations may lack the expertise to cope with complex and highly technical issues, especially regarding water quality protection or ecosystem effects. Many of the critics of fragmented governance have looked to the federal government and large regional authorities as the institutional solution to these problems (Lepawsky 1950; Getches 1985; Gottlieb and FitzSimmons 1991).

Jurisdictional scale is one of the key factors underlying the two efficiency criteria under public service industry or local public economy theory. In a polycentric service industry, the scale or boundary of a provision unit is shaped partly by "the variability of citizen preferences and the way that citizens with similar preferences cluster geographically" (U.S. ACIR 1990, 36). The appropriate geographic scale is one that will allow a jurisdiction providing a public service or good to internalize the benefits and the negative effects of provision. This means that all individuals affected by or benefiting from the good or service will take part in paying for it (Oakerson 1999; Ostrom, Tiebout, and Warren 1961). This scale criterion is referred to as fiscal equivalence. According to Ostrom, Tiebout, and Warren (1961; 1991), other criteria that influence the appropriate geographic extent of a service provision jurisdiction include: physical control over the good or service, fiscal and political accountability, and local political independence or self-determination.[18]

The public service industry literature does not reject the possibility that certain goods and services may require large-scale provision authority. As mentioned, responding to different demands of communities can require various provision, production, or governance scales. For example, where significant infrastructure and investment is needed for importing water, larger-scale jurisdictions may have more capacity to achieve economies of scale. However, the literature maintains that large-scale jurisdictions are not suited for providing all type of services demanded by citizens.

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[17] Transaction costs include the costs of obtaining information about a resource, monitoring and enforcement costs.

[18] The governance and production components of a public service industry or local public economy theoretically address changes in the geographic scales of citizen preferences or of the effects of service provision by adjusting the rules governing provision or altering production scales (U.S. ACIR 1987).

Overall, a public service industry operates efficiently with a combination of different jurisdictional scales and forms (Oakerson 1999). As the U.S. ACIR (1991) notes, overlapping and functionally specialized jurisdictions are beneficial for managing water resources because they offer differing scales and coordination opportunities to satisfy the various aspects of water resources management.

The assumption that underlies the benefits of public service industries is that multiple and overlapping jurisdictions have opportunities to coordinate and will coordinate the production and provision of goods and services. The theory purports that innovation and efficiency in the supply of public services are dependent upon the ability of jurisdictions to coordinate and jointly produce services (V. Ostrom and E. Ostrom 1991, 197). While the use of coordination is essential to efficiency in a public service industry, the structure of such coordination is not explicitly stated. Organization theorists recognize that coordination can be structured in various ways for the purposes of producing goods and services. These include hierarchies (production within a single organization), markets (usually self-governing), and networks of organizations, (see e.g. Williamson 1985; Miller 1992; Milward and Provan 1993).[19] The structure of coordination in a public service industry is implied the literature's discussion of the structure of a public service industry itself. The structure of public service industries is described as neither hierarchical nor purely market-based, although market-like forces

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[19] The concept of transaction costs is a key factor in differentiating the forms of coordination that are most productive in a given situation (Williamson 1981; Miller 1992). Contracting among individuals in a market setting can impose transaction costs because such contracts involve time and resources to write and enforce, particularly given the assumption that individuals are "boundedly" rational, or limited in their information processing skills. Where markets fail to control transaction costs, different forms of coordination, such as hierarchies, may be more efficient in organizing human actions.

can promote efficiency within the structure of multiple and overlapping jurisdictions (V. Ostrom and E. Ostrom 1991, 190). The coordination that occurs within the structure of a public service industry could therefore be deemed neither hierarchical nor purely market-based. Efficiency pressures exist among overlapping jurisdictions that facilitate coordination, yet jurisdictions that choose to coordinate the production of a service often are governed by funding arrangements or common operational rules regulations. In this sense, the coordination identified in the public service industry fits within the structure of network coordination. In general, networks include groups of organizations that coordinate the delivery of goods and services, "shaped by law, funding structures, and ideological presuppositions" (Milward and Provan 1999). When jurisdictions within a public service industry coordinate the production of a good or service, they form production networks by taking advantage of a structure of overlapping independent jurisdictions, while sharing funding arrangements.

The weakness in the public service industry literature is that it does not fully explain what factors influence decisions to engage in coordinated production of goods and services through networks of overlapping jurisdictions. The theory development section of this chapter attempts to clarify the literature's explanation of coordination and considers how the theory of common-pool resource management can inform or complement the explanations offered by the public service industry literature.

Common-Pool Resource Management Theory

The theory of common-pool resource (CPR) management also provides an explanation of how water resource management institutions can satisfy citizen needs while maintaining sufficient resource supplies. CPR literature identifies problems associated with the use of common-pool resources. It then describes the rules, characteristics of the community, and characteristics of the environment that are associated with the resolution of these problems (E. Ostrom 1990). CPR studies and public service industry studies both have developed out of a research framework that emphasizes the importance of institutional arrangements in shaping solutions to collective action problems.[20] CPR theory considers the effective resolution of collective action problems from an individual, rather than an organizational, level of analysis. Therefore, the two literatures offer related, yet distinct, solutions to resource management dilemmas. This section provides an overview of CPR management theory. It also examines some of the weaknesses in applying this literature to water resource management in a public service industry.

CPR Dilemmas

Common-pool resources exhibit varying degrees of two key characteristics: 1) difficulty in excluding users and 2) subtractability of supply when used (V. Ostrom and E. Ostrom 1991).[21] Surface and ground water resources can be characterized as common-pool resources based on these defining characteristics. Water resources, in most settings, are difficult to contain; and when individuals consume surface or ground waters from a particular watershed or basin, they reduce available supplies for others to use.

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[20] Collective action problems include any problems that require individuals to cooperate in order to solve problems, which they all benefit from but would not have the incentive to undertake individually, such as public service provision (Olson 1965).

[21] Common-pool resources differ from pure public goods. In theory, it is difficult both to exclude potential users of public goods and to reduce the availability of public goods. Thus, little incentive exists for private

The characteristics of CPRs can lead to different CPR dilemmas. The first category of CPR problems is that of appropriation (or demand). Demand dilemmas are related to the non-excludability characteristic of CPRs because they typically result when too many users have unlimited access to a shared resource (Ostrom, Gardner and Walker 1994). For instance, overcrowding of a CPR or extensive use can prevent users from maximizing the benefits of the resource for all.[22] The second category of CPR dilemmas is that of provision (or supply). Supply problems are related to the characteristic of CPR subtractability. These problems arise when CPR users do not maintain or conserve supplies adequately, leading to less than optimal productivity levels of the resource.[23]

CPR theory has demonstrated that appropriation and provision dilemmas may prompt institutional solutions that encourage individuals to act in order to benefit the collective group of CPR users. Institutional solutions to appropriation problems often limit 1) the quantity of the resource that any one user can appropriate, 2) the time or location of resource use that is available to appropriators, or 3) the type of technology that can be used to harvest the resource (Ostrom, Gardner and Walker 1994). Solutions to supply dilemmas include provision rules that require users to fund, or provide labor and supplies for resource protection and maintenance. Resolving supply dilemmas involves

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market firms to provide such goods or services because of the tendency for free-riding and the inability for providers to internalize benefits to any particular user (Baumol and Oates 1988).

[22] Demand dilemmas also can be created by the technology that appropriators use to harvest resources. Certain appropriation technologies or methods may interfere with the stream of benefits available to other resource users (Ostrom, Gardner and Walker 1994).

[23] Schlager, Blomquist and Tang (1994) identify two additional characteristics of CPRs that exacerbate both appropriation and provision problems; they are mobility of resource flows and lack of capacity for storage. Unlike the characteristics of non-excludability and subtractability, which are present to varying degrees among all CPRs, mobility and storage capacity may be present or absent to varying degrees across different types of CPRs.

maximizing resource productivity or the net present value of returns (Ostrom, Gardner and Walker 1994, 13).

The Likelihood of Cooperation and Successful CPR Management

Awareness of CPR problems does not guarantee that users will decide to act collectively to implement solutions to supply and demand problems. Various factors influence the likelihood that users will engage in collective action to resolve problems according to CPR theory. These conditions affect the costs and benefits associated with efforts to engage in coordinated action. Social characteristics of the community of resource users, such as the degree of trust and the level of communication among appropriators, are likely to affect the understanding that users have of the impacts of others on the resource (E. Ostrom 1990; Ostrom Gardner and Walker 1994). A shared understanding of rules and resource conditions, complemented by high degrees of trust and communication, is often associated with cooperation; such awareness reduces the costs involved in bringing people together to develop agreed upon rules of resource use (Ostrom, Gardner and Walker 1994).

Beyond open communication and trusting relationships, empirical research from field and laboratory settings has added that factors such as the salience of a resource to appropriators and the value placed on future resource supplies are likely to affect the emergence of coordination. A high-level of dependency on a common-pool resource and a long time horizon regarding the potential benefits of a resource can increase the likelihood that appropriators will cooperate to manage a CPR (E. Ostrom 1990; 1998).

Table 2.1 summarizes the attributes of the community of resource users that affect the likelihood of coordination emerging in a CPR setting.

CPR studies also demonstrate that physical factors affect the likelihood that appropriators will engage in cooperative action to manage CPRs sustainably. The mobility and the capacity for storage of a CPR influence how easily resource boundaries can be defined, and thus impact the costs of defining rules to manage those resources and the costs of monitoring resources (Schlager, Blomquist and Tang 1994). Flow and storage conditions of the CPR can influence how easily groups can identify who uses the resource or who is impacted by rules to maintain supplies and control appropriation. Ostrom (1997) adds that self-governance generally is more likely to arise where CPR users can identify feasible improvements in resources, or where they "are not at a point of deterioration such that it is useless to organize" (15). In theory, these physical factors can be controlled most easily in small resource settings or where information about the resource is accessible. Table 2.1 also summarizes the physical attributes that contribute to the presence of coordinated management according to CPR theory.

TABLE 2.1: Summary of Physical and Appropriator Attributes Increasing the Likelihood of Coordination in Open-Access CPR settings

Physical Attributes	Appropriator Attributes
Potential for improvement in CPR conditions	Shared dependency among appropriators on the resource system
Availability of indicators on the condition of the resource	Shared understanding of how resource operates and how actions affect each other
Predictability of flows	Low discount rate relative to future benefits of the resource
Limited spatial extent of the resource, given information and transportation technology, so that users have accurate information about the conditions and boundaries of the resource	Need for coordination is distributed evenly across political and economic interests
	Resource users trust each other
	Resource users have relative autonomy to devise appropriation rules
	Users have prior organizational experience

* Adapted from E. Ostrom (1990; 1998)

The characteristics of a CPR and of CPR users put forth by the CPR literature are conditions that reduce the transaction costs involved in resolving collective action dilemmas. As Taylor and Singleton (1993) note, transaction costs involve "*search costs, bargaining costs,* and *monitoring and enforcement costs*" (sic, 196), which affect the ability of parties to achieve successful resolutions to collective action problems. The factors listed in Table 2.1 reduce the costs involved in searching for information, bargaining with other parties and monitoring cooperative agreements.

In CPR settings characterized by relatively low transaction costs, CPR studies also find instances where communities are able to establish institutions to successfully resolve CPR management dilemmas (E. Ostrom 1990; Ostrom, Gardner & Walker 1994). These studies have identified a set of institutional factors that are common among communities that are able to sustain coordination and successful CPR management over many years, whereby resource supplies are sustained for human and environmental needs. CPR studies show that effective rules, which may be explicit or implicit in a CPR setting, will vary depending on physical and community conditions and should be flexible over time. While effective institutional arrangements may vary across settings, CPR studies have identified some general principles of long-enduring CPR institutions.

The first general design principle associated with sustainable CPR governance institutions is the establishment of clearly delineated boundaries around the resource. These boundaries identify who has rights to withdraw or use the resource (E. Ostrom 1990; 1997). A second key design component relates to the congruence of institutions. This principle states that where a) appropriation rules reflect local conditions and b) the benefits of appropriation rules are relatively proportionate to the costs of provision rules, CPR management is likely to be more successful. Third, CPR studies commonly find long-enduring CPR management institutions where appropriators have the authority to establish their own rules and a majority of those individuals affected by the rules can participate in determining the rules (E. Ostrom 1990; Ostrom, Gardner and Walker 1994; Lam 1998).

Within self-governing arenas, CPR theory adds that a) a majority of resource users participating in defining those rules, and b) non-interference by higher authorities in rule-making can increase the likelihood of successful CPR management (E. Ostrom 1990, 90). To ensure that rules are followed, the design principles for successful CPR institutions emphasize the importance of monitoring rules, sanctions with graduated severity, and venues for conflict resolution (E. Ostrom 1990, 90). Finally, where CPRs operate within larger institutional settings, CPR studies have shown that institutional arrangements that are "nested" within multiple levels of governance institutions can encourage long-term cooperation in the management of CPRs.

Limitations to CPR Management Theory

CPR theory presents some limitations in its applicability to water resource management in the United States, particularly within a polycentric state water industry or even within a metropolitan area.[24] The primary limitation deals with CPR theory's criterion for defining institutional boundaries. It implies that CPR management institutions whose boundaries are congruent with the scale of the physical boundaries of a common-pool resource are more likely to be successful and sustainable. Ostrom (1990) notes: "Without defining the boundaries of the CPR and closing it to 'outsiders,' local appropriators face the risk that any benefits they produce by their efforts will be reaped by others who have not contributed to those efforts" (91). The problem is that this boundary criterion limits the generalizability of CPR theory outside of relatively small, well-bounded CPRs.

When considering the implications of the boundary criterion to large or complex resource settings a number of theoretical inconsistencies arise. First, in most natural resource settings, it is not likely that the physical boundaries of the resource can be identified clearly. The reality is that any natural resource is likely to be somewhat mobile

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[24] This is not to say that CPR theory cannot be applied to complex water industry management in the United States. In fact, CPR theory has been used to explain the governance and management outcomes of a number of groundwater basins in Southern California, in which complex water industries and economies operate (see Ostrom 1990; Ostrom, Gardner, and Walker 1994).

and inter-related with other natural resources. Therefore, deciding on the location of common-pool resource boundaries can be difficult or even impossible. For example, to determine the boundaries of a river basin, the theory does not clarify the extent to which boundaries include the river's tributaries, connected groundwater flows, and riparian habitat, just to name a few possibilities. Even where resources are stationary or relatively stable, such as in a confined groundwater basin, users of those resources often divert, alter or change the location of the resources. When diverting resources, it is possible that CPR users are physically unrelated to the origin of the CPR flows.

Even under the assumption that it is possible to identify general physical boundaries of CPRs, a second problem with the boundary criterion is that people constantly redefine institutional boundaries based on changing perceptions of their needs and problems. In CPR management settings, the perceived physical and social boundaries of problems may not reflect the physical boundaries of related common-pool resources. The boundaries that CPR users identify around a resource may be based on the human problems associated with the use of the resource rather than on the physical location or flow of a CPR.

A third problem with the boundary criterion is that it ignores the assumption that CPR users usually live within complex and overlapping institutional settings that may not be conducive to devising management institutions that apply to some physical boundaries. CPR theory focuses explicitly on the emergence of self-governing institutional arrangements that combine governance, provision of CPR activities, and CPR production within a single self-governing unit. Yet, the CPR literature acknowledges that self-governing jurisdictions can function in concert with larger institutional arrangements within which they are embedded (E. Ostrom 1990). It describes ways in which larger institutional arrangements can provide information and support to facilitate local governance. For example, Ostrom, Gardner and Walker (1994) note that "fair and inexpensive conflict resolution and back-up enforcement mechanisms" can help sustain local institutions and "ensure that common understandings are shared and enforced" (327). The limited applicability of the boundary criterion again arises when trying to explain how overlapping jurisdictions or groups of users within the same CPR might operate in concert to devise rules and manage the resource effectively over the long term.

Comparing the Theories

The theory development in the following section considers how the two bodies of literature can inform each other, despite their differences. To summarize these differences, CPR studies emphasize the role of institutional arrangements in solving collective action problems of overuse or degradation associated with the demand for a CPR in micro-level settings. A basic proposition presented by this literature is that water management institutions are effective when citizens solve problems and maintain sustainable resource supplies to meet the needs of their community. Public service industry literature, on the other hand, focuses on the functional and structural nature of institutional arrangements to solve problems of public service delivery in macro-level settings. The key assumption is that effectiveness is achieved when jurisdictions can meet the demands of citizens for water management services through low cost production. Table 2.2 highlights the key differences between the two theories as identified in the literature review.

The two bodies of literature come from a common research framework, but they are distinct in evaluating water resource management problems in different settings. They can positively inform each other in explaining how institutions in a public service industry can manage a common-pool resource effectively. Specifically, insights from the public service industry literature on coordination and jurisdictional boundaries can contribute to broadening the applicability of CPR theory to more complex CPR settings. On the other hand, the CPR literature offers guidance to the public service industry literature by explaining the emergence and structure of coordination. The public service industry literature assumes this coordination will occur to achieve cost-efficient service production and to the control service fragmentation that can arise with multiple overlapping boundaries.

TABLE 2.2: Key Differences between Public Service Industry and CPR Theories

Point of Comparison	Public Service Industry	CPR Management Theory
Unit of analysis	Macro / System-Level	Micro / CPR Unit
Decision-Making Level	Organizations / Jurisdictions	Individuals
Key Problem Faced by Decision-Makers	Provision and supply of public goods or services	Appropriation of / demand for Common-Pool Resource
Institutional Effectiveness	Satisfy Citizen Preferences and Cost Efficient Supply	Long-term sustainability of CPR and self-governance
Scope of Institutional Authority	Limited: maintain separate provision, production, conflict resolution authorities	Self-contained: users define all rules, but rules are consistent with larger institutional arrangements
Criteria for Jurisdictional Boundary	Citizen preferences – fiscal equivalence	CPR boundaries and relevant users
Incentives for Coordination or Cooperation	Efficiency incentives encourage coordination among provision and production units	Communication, trust, history of interaction, appropriation rules congruent w/ costs & local conditions, monitors, graduated sanctions, low-cost conflict resolution, rights to organize, etc.
Solution to Supply Problems	Multiple and overlapping jurisdictions – create various production opportunities for goods and services	Rules to fund, maintain, conserve, and invest in supplies
Solution to Demand Problems	Regulate use (non-specific)	Rules to control timing and location of use, and extraction technology – enforced by monitoring and sanctions.

THEORY DEVELOPMENT AND HYPOTHESES

This section examines the key weaknesses of both CPR theory and public service industry theory. It focuses on CPR theory's boundary criterion for institutional effectiveness, and considers how public service industry theory's assumptions of coordination can develop this criterion. Second, this section considers how CPR theory can clarify the reasons why jurisdictions coordinate the provision of goods and services in public service industries. Finally, this section derives hypotheses, using the proposed theory development to explain how institutional arrangements relate to conjunctive water management.

Resolving Weaknesses in CPR Theory

One of the limitations in applying CPR theory to a water industry is that the theory presumes that CPR institutions are more likely to be effective and sustainable when they have boundaries that are congruent with natural resource boundaries. The problem with this boundary criterion is that it conflicts with certain institutional and physical factors of the water industry. First, a true physical boundary can be difficult to identify. Second, the problems that groups attempt to solve through institutional design are not always congruent with natural resource boundaries and they change over time. Another problem with the boundary criterion in complex physical and community settings is that it can imply that one large institutional arrangement would be necessary to encompass a large physical system and its users. This implication contradicts the public service industry literature, which explains that overlapping institutional arrangements are more effective at providing public services than are large centralized bureaucracies.

Institutional Boundary Definition

The public service industry literature provides another way of conceptualizing the purpose and definition of institutional boundaries that can help resolve the contradictions presented by CPR theory. In the case of a public service industry, collective consumption units create institutional boundaries around individuals who share a common problem or need for public goods and services. These groups, who determine a shared set of institutional arrangements to provide public goods and services, can also be defined as political jurisdictions. Thus, according to the public service industry definition, the boundaries of CPR management institutions could be defined by the communities of individuals who follow shared rules to manage the supply or appropriation of a common-pool resource. This definition merely re-focuses the boundary definition offered by CPR theory from the physical resource to the shared problems of a group of individuals. Boundaries are made around collective groups, which define who is responsible for funding or maintaining a good or service produced (as in a public service industry) or a physical resource that is used collectively (CPRs).

Given that self-governed CPR institutions and public economy jurisdictions can both be understood in terms of collective groups of individuals, what does the public economy/industry literature offer in terms of understanding institutional boundary criteria for managing complex CPRs? In contrast to CPR theory, public service industry literature does not emphasize the physical boundaries of a resource or good as a criterion for identifying the appropriate scale of provision jurisdictions. It does encourage jurisdictions to have physical control over the services they provide (Ostrom, Tiebout, and Warren 1991). The public service industry literature claims that efficient provision scales can be determined by considering which individuals share a common interest in, receive benefits from, and are impacted by the provision of a good or service. When considering the appropriate scale of a provision jurisdiction, citizens are supposed to be able to make the best decisions over the tradeoffs between "preference satisfaction" and "the transaction costs associated with organizing and operating additional provision units" (U.S. ACIR 1987, 36).

One way to bring together the two theories to explain boundaries in relation to successful resource management involves reexamining CPR theory's underlying reasoning for defining jurisdictions around physical boundaries. Essentially, CPR theory implies that clearly defined boundaries are important for resource users to know how their actions impact one another and for resource users to internalize those impacts. Public service industry theory also implies that effective institutional boundaries take into account physical externalities when considering the effects that users of goods and services have on each other. Yet, the theory considers these effects in terms of the common problems that users of a shared good or service face. Therefore, rather than establishing institutional boundary criteria based on physical attributes of a resource, public service industry literature focuses on controlling the impacts of human actions and satisfying human needs.

The public service industry literature illustrates that there are different ways that jurisdictions or institutions can be devised to meet these boundary criteria. Functionally specialized jurisdictions can address the preferences of water users for specific services while also accounting for externalities associated with human uses of natural resources. For instance, a groundwater replenishment district could satisfy the needs of a group of groundwater users by taxing all users or beneficiaries of the water stored in the basin to pay for replenishment services. Such a jurisdiction may include individuals who are not physically located in the vicinity of the groundwater basin, or may exclude individuals who overlie areas of a groundwater basin but who do not benefit from its replenishment.

Applying the public service industry definition and criteria for jurisdictional boundaries to CPR theory suggests that the institutional arrangements do not need to be organized around a groundwater basin or surface water flow in order to engage in conjunctive water management. The public service industry boundary criteria implies that effective management of a CPR is achieved by provision jurisdictions whose boundaries are determined by a common CPR problem affecting a collective consumption unit. When a group of citizens or a local jurisdiction decides to provide a conjunctive water management program, the basis for that decision is likely to rest on the recognition of some common water supply or demand problem. Such a problem could arise when a city or group of irrigators does not have sufficient surface water supplies in dry seasons. These problems may or may not coincide with the physical boundaries of a resource, such as a groundwater basin or stream.

Public service industry literature shows that jurisdictions can be organized to satisfy citizens' shared needs for conjunctive water management and still control for potential physical externalities. Institutions can be designed to provide a specific service, such as conjunctive water management, while also encompassing the majority of appropriators whose resource use is likely to impact others. These institutions would not need to be formed to encompass all of the problems related to surface and groundwater resources in that area. The implication is that institutional arrangements governing the provision of conjunctive water management can be organized around a local problem.

Coordination and Cooperation as a Solution

According to public service industry theory, the provision of water management services is likely to be effective when all individuals in a jurisdiction who pay for service provision also benefit from the service. Therefore, conjunctive management may require that new institutional arrangements be devised to bring together all individuals affected by the project, which is often the role of limited-purpose or special purpose governments (U.S. ACIR 1991). Functionally specialized jurisdictions that are designed to address or resolve a common problem among a group of individuals are not always a feasible institutional solution, however. First, problems related to the management of water resources can be complex and may not be easily dissected into well-defined functional areas, such as water quality, groundwater recharge or wastewater treatment. Often these problems overlap or are inter-related. Similarly, functional specialization of institutions may not be feasible when water management problems impact a massive group of individuals, or when a single jurisdiction does not have the financial capacity to address the problem.

An alternative way to solve these shared problems, according to the public service industry literature is to take advantage of inter-jurisdictional coordination to provide public goods and services. The literature explains that provision units can be separated from supply or production units. Provision jurisdictions then can address a shared problem related to the management or use of a resource by producing services through inter-governmental coordination. Therefore, one way to deal with the boundary problems related to the supply of water industry services is to use inter-jurisdictional coordination.

Managing resources through inter-jurisdictional coordination, in fact, has been identified as an effective CPR management scheme in complex water industries. The theoretical assumptions underlying CPR theory's boundary definition, however, do not reflect those observations. For example, Ostrom (1990) points out that in the West and Central groundwater basins near Los Angeles, a special purpose replenishment district was formed to provide supplemental supplies to the over-drafted basins. While that jurisdiction is responsible for the provision of basin replenishment, the basins actually "are managed by a polycentric set of limited-purpose governmental enterprises whose governance includes active participation by private water companies and voluntary producer associations" (E. Ostrom 1990, 136). This set of institutional arrangements have been found to be effective in replenishing depleted aquifer levels in the West and Central Basins and in maintaining relatively low management costs (Blomquist 1992).

In relation to conjunctive management, public service industry theory provides evidence that agencies can coordinate their efforts to provide conjunctive water management services that affect multiple jurisdictional boundaries overlying a basin. Inter-jurisdictional coordination, in effect, allows small-scale jurisdictions to engage in conjunctive water management in a way that eliminates the need for a large centralized authority. Coordination can be accomplished through joint funding or joint production of a conjunctive management program. From this discussion, the following hypotheses are derived.

> H1) Institutions governing water resources do not need to be organized around the physical boundaries of the resource in order for water providers to engage in conjunctive water management.

H2) Inter-jurisdictional coordination will be positively associated with the provision of conjunctive water management services.

The first two hypotheses will be evaluated by examining the institutional scale of the jurisdictions associated with the provision and production of conjunctive management projects as well as relationships among entities that produce conjunctive water management. These analyses can test the usefulness of integrating assumptions from the public service industry literature into CPR management theory.

Resolving Weaknesses in Public Service Industry Theory

Using public service industry literature to inform CPR theory provides a more generalizable concept of institutional boundaries and can address the weaknesses in CPR theory's boundary criterion. Through inter-jurisdictional coordination, the public service industry literature implies that common-pool resources can be managed effectively. However, the theory does not adequately describe the types of coordination that can occur in a public service industry, nor does it explicitly clarify the factors that facilitate coordination across jurisdictions. The local public economy literature does, however, indicate that cost-efficient service production and achieving economies of scale results from coordinating the provision of a public service (Oakerson 1999, 73). It further claims that coordination is not necessary "[w]hen economies of scale happen to be closely matched to the scale of the organization of a provision unit" (Oakerson 1999, 16). This suggests that coordination is purely contingent on service production costs, relative to production outputs. Is this a sufficient explanation of coordination within a public service industry or specifically within conjunctive water management projects?

The Need for Coordination in CPR and Public Economy Settings

The purpose of coordination in common-pool resource settings is to resolve collective action problems facing a group that shares an open access resource, particularly appropriation and provision dilemmas. Such coordination generally occurs when resource users devise institutions that resolve such dilemmas. The factors previously listed in Table 2.1 included the physical attributes of the resource and the attributes of the resource user community that, when present, are likely to increase the chances for coordinated self-governance in open access resource settings.[25] These attributes of the community and attributes of the physical environment are associated with successful CPR management since they lower the transaction costs involved in solving collective action dilemmas (Taylor and Singleton 1993). These factors reduce the bargaining, information acquisition, and monitoring and enforcement costs that affect a group of individuals facing appropriation and provision dilemmas.

If a group of water providers face appropriation dilemmas with the use of a shared water supply, as has occurred in southern California's groundwater basins (E. Ostrom 1990), then the conditions identified by CPR theory for explaining the emergence of coordination offer clear insights for public service industry theory. That is, groundwater appropriators in these basins have coordinated to create jurisdictions or institutions that limit groundwater pumping or fund basin replenishment. According to CPR theory, one of the key conditions of the community of appropriators that facilitates such coordination is a shared dependency on the benefits of the resource. If applied to a public service industry setting, this condition would imply that a group of providers and producers in a public service industry are more likely to coordinate to devise new institutions when they rely on a single shared source of water to meet all their members' needs. CPR theory adds that when a group shares a common resource, they are more likely to coordinate when they perceive the benefits from the resource to be long-term. Thus, if jurisdictions perceive that the resource will only benefit their members in the immediate future, the transaction costs associated with coordination may outweigh the benefits.

CPR theory adds that established patterns of interaction and trusting relationships will encourage jurisdictions to coordinate to manage or provide resources jointly (E. Ostrom 1990; Ostrom, Gardner and Walker 1994).[26] In a public service industry context, these patterns may arise through various means. In some cases, overlapping jurisdictions may have experience jointly coordinating the production of a variety of services, such as police protection or health care, which are not related to a specific resource management problem. Similarly, jurisdictions may have experience working together on the management of a specific common pool resource, such as water supplies. Presumably, such shared experiences can facilitate trust among jurisdictions and reduce the bargaining and negotiating costs involved in coordinating water resource management.

In a public service industry setting, the purpose of coordination may not necessarily be to resolve a collective action dilemma associated with the supply of a

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[25] For details on the community and physical factors that improve the likelihood for cooperation in open-access resource settings see Baland and Platteau 1996; E. Ostrom 1990 and 1992; Tang 1992; Schlager 1990.

[26] Community characteristics such as shared beliefs, trust, frequent communication and stable relationships are commonly cited not only in CPR literature, but also in experimental game theory and in organization

public good or demand for a common-pool resource. For instance, a group of water providers concerned with managing the supplies of a groundwater basin may not need to coordinate to resolve a collective action dilemma where the larger institutional setting has effectively controlled demand dilemmas. The purpose of coordination among water providers in such a setting may be to coordinate the production of a service such as water treatment. This form of coordination, for example, might involve sharing water treatment production facilities among multiple jurisdictions that deliver their own supplies of water to their constituents.

Thus, in looking at coordination within common-pool resource settings, the purpose of coordination may not necessarily be to devise institutions that control collective action dilemmas, which is the concern of CPR theory. CPR theory, in fact, recognizes that the larger institutional setting can influence how local resource users address supply and demand dilemmas associated with CPRs. One way that the larger institutional setting of a public service industry affects the demand dilemmas for goods and services is through the establishment of property rights laws. For example, state water laws often quantify rights to use water resources based on priority dates or land ownership. When rights to store and recover water in a groundwater basin are not assigned by the state, this can increase the likelihood that water management jurisdictions face appropriation dilemmas. Such appropriation or demand dilemmas can inhibit jurisdictions from investing in managing and maintaining water resources since there are no assurances that other water users will not use their water. In fact, one of the principles

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theory, as key factors in explaining the ability of individuals to resolve collective action problems (Axelrod of long-enduring CPR institutions is that individuals who are authorized to make use of a common-pool resource are clearly identified. As Ostrom (1990) states, "for any appropriators to have a minimal interest in coordinating patterns of appropriation and provision, some set of appropriators must be able to exclude others from access and appropriation rights" (91). Where these appropriation dilemmas are addressed by the larger institutional setting, the need for coordination to resolve a collective action dilemma is lessened. For instance, where jurisdictions have well-defined rights to groundwater supplies, water providers may not be concerned with coordinating the replenishment of groundwater supplies across all water users in a basin.

In instances where entities do not face appropriation dilemmas, the conditions put forth by CPR theory that encourage coordination may not be adequate for explaining all forms of existing coordination. CPR theory focuses on conditions that reduce the transaction costs of resolving collective action dilemmas. In a situation where resource users do not face collective action dilemmas, coordination may still be useful for the provision or production of a project. If water rights are quantified in a state, what then are the purposes of engaging in coordination to manage water resources? The implication from the local public economy literature is that coordination occurs for cost-efficient production of goods and services.

The Purpose of Coordination in Conjunctive Water Management

An integration of public service industry theory and CPR management theory can help differentiate the purposes of coordination associated with conjunctive water

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1984; Taylor 1987; Taylor and Singleton 1993; Ostrom, Gardner and Walker 1994).

management. As the CPR literature points out, the larger institutional setting impacts the way in which local resource users can manage resources. Water rights laws, in particular, are important in the case of conjunctive management. First, if water users share a common groundwater basin and rights to the water in that basin are not quantified, then water users are likely to require some form of coordination at the basin level to engage in conjunctive water management. Water users need assurances that other entities will not consume water that is stored underground in conjunctive management projects before they can recover that water themselves. When access to water in a basin is open to all users, coordination may be necessary to facilitate conjunctive water management. The purpose of coordination in an open-access setting would be to control demand-side collective action dilemmas associated with underground water storage, bringing together the interests of all entities that may benefit from or be affected by a conjunctive water management program.

The purpose of coordination in the case of conjunctive management, however, may be different where the governance level of a water industry controls demand dilemmas through water rights institutions. The quantification of water use rights and the application of those rights to various uses, such as storage and recovery, indicates the degree of certainty that water users need to engage in conjunctive management (U.S. ACIR 1991). Demand-side collective action dilemmas are effectively reduced when such institutions are in place, diminishing the need for coordination at the basin-level. This, however, does not preclude coordination from occurring for the purposes of conjunctive water management production. In comparing insights from both CPR theory and the public service industry theory, the implication is that basin-level coordination would be less likely where the larger institutional setting effectively controls demand-side dilemmas. Thus, hypothesis 3 is:

> H3) Basin-level coordination among providers of conjunctive water management is less likely where the larger institutional setting controls groundwater demand dilemmas.

Explaining Project-Level Coordination in a Public Service Industry

The assumptions of the public service industry literature can explain coordination when the larger institutional setting has resolved demand-side collective action dilemmas and the purpose of coordination becomes project production. The public service industry theory suggests that the purpose of coordination is to produce public services cost-efficiently relative to project scale. According to the theory, cost-efficiency is possible because of the polycentric structure of public service industries. This structure includes functionally specialized organizations, differentiation among the scale of producers that match the characteristics of diverse goods and services, and competition among multiple service producers (Oakerson 1999). Through this system, multi-organizational arrangements may achieve lower costs of service production through efficiency.

To show how the public service industry literature might explain coordinated production of conjunctive water management, some clarification of the public service industry theory's reasons for coordination are in order. First, the public service industry literature says that producers are added to service production "to realize economies of scale" (Oakerson 1999, 73). Production size, therefore, may influence the perceived need for coordination, based on the assumption that coordination can improve economies of scale. In other words, the public service industry literature assumes that coordination, when production exceeds the capacity of provision organizations, leads to cost-efficiency or lower costs per unit of service output.

The literature further recognizes that organizations engage in cost-benefit calculations when deciding to coordinate the production of some good or service. Oakerson states that an "optimal number of production units depends on a trade-off between scale economies, on the one hand, and coordination economies on the other" (Oakerson 1999, 17). The recognition that coordination imposes transaction costs, and that these costs must be lower than the benefits of coordination, also is an assumption that CPR theory puts forth to explain coordination in collective action settings. CPR theory is explicit about this point when discussing the emergence of coordination and institution building to resolve collective action dilemmas, based on assumptions that individuals are rational or boundedly rational actors (E. Ostrom 1990).

The local public economy literature recognizes that transaction costs can affect inter-agency coordination and, like CPR theory, emphasizes the role of transaction costs in terms of the organization of provision units of government. It can expand the explanation of coordination by considering how coordination might reduce transaction costs that affect project production (versus the costs of devising new jurisdictions) as a component of cost-efficiency. In essence, public service production involves production-level transaction costs, as well as operation costs, which influence cost-efficiency. These transaction costs include contracting, permitting and legal costs, efforts to acquire inputs for service production, and production monitoring. For instance, in devising a conjunctive management project in Arizona, water providers must obtain permits from the state, acquire information on the technical feasibility of storing water underground, acquire land, materials and water for projects, and monitor water quantity and quality while operating projects. If production-level coordination through inter-organizational networks can reduce these costs relative to the benefits of such projects, then presumably that will also lead to increased cost-efficiency.

Conjunctive management projects may involve significant transaction costs associated with the coordination of resources and infrastructure across jurisdictions in a shared basin. Transaction costs can affect the development and maintenance of a public service or project production, just as they can affect the formation of an association of water users (Taylor and Singleton 1993; Williamson 1985). Williamson (1985) theorizes that the primary incentive for creating various organizational structures, which coordinate the production of goods and services, is to economize on transaction costs.[27] Given the implications of the local public economy theory, one of the benefits of coordination may also be reducing the transaction costs of producing goods and services. Thus, cost-efficiency of projects presumably can be achieved by reducing project production and transaction costs, relative to the benefits provided by storing water in conjunctive management projects.

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[27] Williamson (1985) describes transaction costs generally as the "friction" of contractual exchange. The appropriate organizational form for controlling the transaction costs of contractual exchanges depends on certain characteristics of transactions. Williamson characterizes contractual exchanges by the frequency of transactions, uncertainty, and how highly specific the asset (human, site, or physical) is. As asset specificity increases, organizational governance shifts to internal organization. According to Williamson, vertical integration, mergers, hierarchy, unions, multi-divisional corporations, and corporate boards are "efficient" governance tools for the general contract between owner and employee or seller and buyer, where asset specificity is high or information asymmetries exist.

If the public service industry theory offers an accurate explanation of the reasons for coordination at the project-level, then coordination in the production and provision of conjunctive water management projects presumably leads to greater cost-efficiency among larger projects, whose scale of production exceeds the scale of provision units. Based on this discussion, the following hypotheses are proposed:

> H4) In institutional settings where water rights are quantified or resource boundaries are controlled:
>
> > a) Projects with high production capacities are likely to be produced through inter-organizational coordination.
> >
> > b) Coordinated production or provision of conjunctive management projects is likely to be positively related to project cost-efficiency, or lower costs per unit of project output, controlling for project size.

In proposing these hypotheses, this chapter does not presume that CPR theory cannot help explain coordination used for the purposes of project production. CPR theory describes variables that may explain coordination across jurisdictions, even where they do not face extensive collective action dilemmas. That is, CPR theory explains that organizations that are relatively homogeneous, receive relatively equal costs and benefits, and have a history of working together in other areas are more likely to face lower transaction costs of search and bargaining while developing a shared project. However, the theory development focuses on the explanations offered by the public service industry literature in an attempt to determine the adequacy of the literature's assumptions for explaining coordination.

To evaluate Hypotheses 3 and 4, the data analyses in this dissertation will consider the relationship between conjunctive management production costs and coordination across jurisdictions providing and producing conjunctive management projects. In addition, the data analyses will evaluate whether coordination in the production and provision of conjunctive management projects leads to project cost-efficiency. The benefit of this analysis is that it can test the assumptions underlying the local public economy literature and clarify what factors influence coordination. Moreover, it demonstrates the importance of specifying the type and purpose of coordination in terms of the larger institutional setting within which coordination occurs, in understanding the factors that influence coordination.

SUMMARY

This chapter demonstrated that the public service industry literature informs CPR theory's boundary criteria for effective resource governance through its concept of inter-jurisdictional coordination. Public service industry theory conceptualizes institutional boundaries as being formed around local provision problems that affect a group of individuals, rather than around some arbitrary physical boundaries. Using this definition of boundaries provides a way to alter CPR theory's criteria for effective CPR governance, making it possible to apply CPR theory's notion of self-governance to large-scale CPR settings. This re-conceptualization eliminates the problem that CPR theory presents in assuming that physical boundaries can be clearly defined and will coincide with a community of users. This definition provides a more accurate description of how small-scale institutional arrangements can emerge in complex physical and social arenas and still address large-scale CPR governance problems. When multiple, self-governing jurisdictions arise around shared problems they can coordinate to address large-scale CPR problems. Additionally, groups can coordinate to produce or supply certain CPR management services needed to solve local problems in an effort to take advantage of economies of scale. Essentially, this revision to the CPR boundary criterion provides a way to generalize CPR theory beyond small-scale, simple CPR problems to more multifaceted, physical and social settings.

This chapter also considered how the explanation of coordination among jurisdictions in a public service industry. CPR theory points out the importance of considering how the larger institutional setting is likely to influence decisions to coordinate the management of common-pool resources. In doing so, it showed that the larger institutional setting may, in fact, resolve some of the collective action dilemmas associated with CPR use that create the need for coordination. Thus, CPR theory's conditions that reduce the transaction costs of coordinating across a group of resource users may not be appropriate for explaining other forms of coordination. In this case, the public service industry literature offers implicit explanations of coordination for the purposes of service provision.

Borrowing from these two theories to inform each other helps to develop theories that explain the management of water resources in complex institutional settings. It also offers testable hypotheses for evaluating conjunctive water management activities. The following chapters use data on conjunctive water management activities in Arizona, California, and Colorado to test these hypotheses and evaluate the usefulness of this theoretical contribution to explain water resource management.

III. RESEARCH METHODS

The data used to analyze the hypotheses proposed in the previous chapter was collected for a larger study on conjunctive water management, funded by the National Science Foundation (NSF) and U.S. Environmental Protection Agency (EPA). This chapter explains the research methods of the NSF/EPA study and describes how the study and research methods relate to the goals of this dissertation. It covers the data collection methods, including sampling, coding form design, database design, data entry, and response rates for those components of the data set that are relevant to this dissertation. In addition, this chapter considers the reliability of the data and how it affects the validity of the data analyses.

THE NSF/EPA CONJUNCTIVE MANAGEMENT STUDY

The NSF/EPA-funded study that provides the data for this dissertation examined the use of conjunctive water management in the western United States in relation to the institutional arrangements governing water resources. Professors Edella Schlager and William Blomquist, of the University of Arizona and Indiana University respectively, directed the study. The justification for this research was to "advance both the scientific understanding of institutions and their effects and to offer practical aid to decision makers attempting to promote sustainable watershed use and protection" (Schlager and Blomquist 1995, 5).[28] The research questions and methods for the study were based on the Institutional Analysis and Development (IAD) Framework, from which the two

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[28] The study began in 1996 under Grant Number R824781, through the National Science Foundation and U.S. Environmental Protection Agency's Water and Watersheds Program. Research was completed in 1999. The final report for the study will be complete in September 2000. Neither funding agency is responsible for the findings or conclusions reported in this dissertation.

theoretical streams analyzed in this dissertation also have evolved. The grant-funded study focused more specifically on identifying how state water rights, statutes and regulations and jurisdictional forms influence the development of conjunctive management in Arizona, California, and Colorado.

Justification for Study Setting

Arizona, California and Colorado were chosen as the research setting because the three states share certain physical and demographic features, but differ in their institutional arrangements for managing water resources. The physical and demographic similarities among the three states provide quasi-experimental controls for analyzing the relationship between institutional arrangements and conjunctive management outcomes.

All three states have scarce water resource supplies relative to their growing populations, and the natural sources of supplies in each state often are not located near demand centers. For example, according to 1999 U.S. Census data, statewide populations between 1990 and 2000 increased 30 percent in Arizona, 23 percent in Colorado and 11 percent in California (with 25 percent growth in some southern California counties), compared to a 9.6 percent increase nationwide (U.S. Census Bureau 2001). Part of the problem in supplying water to these growing populations is that the concentration of people in these three states are found in arid regions that lack adequate native water supplies. In Arizona, 77 percent of the population is concentrated in the Phoenix and Tucson metropolitan areas, which receive less than 12 inches of rainfall per year on average (U.S. Census Bureau 2001). While the urban populations of these three states have grown rapidly, agriculture still accounts for about 75 percent of their water use (U.S. Department of Agriculture 2001). Although the number of irrigated acres in western states overall is declining, farm productivity continues to rise.

The other reason for choosing Arizona, California and Colorado as settings for the NSF/EPA study and for this dissertation is that the conjunctive management activities and institutional arrangements governing water resources vary across and within these states. The three states have different sets of water laws and regulations, as well as administrative and organizational structures, managing water resources. Based on the physical and demographic similarities and the institutional differences, California, Colorado and Arizona provide sufficient evidence from which to make cross-state comparisons regarding the relationship between state-level institutions and conjunctive management projects.

Principal Research Objectives of the Larger Study

The NSF/EPA-funded study posed seven specific research questions, emphasizing the comparison of the different institutional settings across the three states. The first three research questions sought to identify evidence to explain the role of each state's unique institutional setting in facilitating the development of conjunctive water management activities relative to the other two states (Schlager and Blomquist 1995). Specifically, these questions considered conjunctive management relative to 1) Arizona's relatively new statewide policies governing groundwater management, 2) Colorado's watershed level system of water governance and management, and 3) California's decentralized system of local special districts involved in conjunctive management (Schalger and Blomquist 1995). The fourth research question aimed to identify evidence that demonstrates how the states' different systems of ground and surface water laws affect conjunctive management.

The remaining research questions of the NSF/EPA study focused less on state-level institutional differences. The fifth principal question of the study was to determine the role of large water projects in influencing conjunctive management activities. The sixth research question was to identify whether organizational learning occurs over time in the development of conjunctive management at the project level. Finally, the seventh primary research question was to identify which factors play a role in water providers' decisions not to engage in conjunctive management in locations where conjunctive management is feasible across and within states.

Comparing the Dissertation to the Larger Study

Both this dissertation and the NSF/EPA utilize the IAD framework and both aim to examine the relationship between institutions and conjunctive management. However, the dissertation's specific objectives and methodology clearly differ from the NSF/EPA study. First, this dissertation emphasizes theory development and undertakes a more deductive approach to establishing specific research questions using the theory development component of this dissertation. Chapter Two identifies specific theoretical weaknesses that are evident in two streams of theory from the IAD framework and details how those theoretical weaknesses can be resolved. Based on the theory development, the hypotheses focus on the role of boundaries and inter-jurisdictional coordination in providing conjunctive management services. The larger study does propose to contribute to the theoretical development of IAD research by examining how institutional arrangements influence human decisions to coordinate ground and surface water management. Unlike this dissertation, the larger study does not propose to contribute specific changes to water management theory and test the implications of those changes with the data.

There are general similarities between the research questions evaluated in this dissertation and those posed for the larger study. The dissertation and the NSF/EPA study both examine how institutional arrangements, such as laws governing the interaction between ground and surface water, can impact conjunctive management projects across the states. The NSF/EPA study proposes to answer this question by looking at the overall development of conjunctive management at the state level; while the dissertation evaluates the hypothesized relationship between water rights and the type of coordination that occurs in the production of conjunctive water management. This dissertation, therefore, can supplement the data analysis for the larger study. The similarities between the two studies also strengthen the data analysis of this dissertation. Since the research for the larger study is grounded in the IAD framework, the key variables tracked in the data collection process are transferable as measures for the key terms identified in the hypotheses of this dissertation.

DATA SOURCES & SAMPLING

The NSF/EPA study's research team collected data between 1997 and 1999. To track the organizational, financial, physical, and institutional factors that impact conjunctive management practices, the study used a set of coding forms. The study identified conjunctive management programs across the three states and sampled projects before collecting the data. From the project identification and sampling process, appropriate contacts were identified to interview for data collection.

Units of Analysis and Data Sources

The unit of analysis for the majority of the research questions of the NSF/EPA-funded study and for this dissertation is the water management organization that supplies or produces conjunctive management projects. Public or private organizations' efforts to use groundwater basins for storage of surface water supplies, with the intention of stabilizing overall water supplies for its members, define conjunctive management projects. Organizations that provide or fund these types of water management services include municipal water departments, irrigation districts, private water companies, and special groundwater management districts. The unit of analysis also involves organizations that participate as providers or producers of components of conjunctive management services. These organizations can include federal or state water projects that supply surface water, state water banking authorities, or "wholesale" water management districts that contract for surface supplies on behalf of member organizations in the district.

The organizations operating conjunctive management projects were the primary sources of data for the key dependent variables for this dissertation (i.e. number of projects, project outcomes/performance, and coordination across organizations) and for most of the key independent variables. Using organizations as the sources of data for project-level analysis has some advantages, including the fact that most of these organizations are public and generally provide valid measures of this study's organizational concepts set, particularly from a "face-validity" standpoint (Manheim and Rich 1995). However, the quality, or reliability, of the data across organizations can vary and thus limit the comparability of the data (Manheim and Rich 1995). Standardized coding forms for data collection can greatly improve the reliability of such data.

For some of the key variables on conjunctive management projects, the organizations that operate them, and the physical conditions of project locations, the NSF/EPA study relied on secondary data sources to supplement primary sources. These sources included reports from the Arizona Department of Water Resources, the Colorado Division Engineers' offices, the California Department of Water Resources and additional reports by local water agencies. Engineering and hydrology studies by water agencies and state departments of water resources also provided data on the physical conditions of groundwater basins and surface water flows in each state. Federal and state sources provided macro-economic and demographic data on the three states and their counties. Archived resources yielded data on state constitutional and statutory provisions related to water, as well as court decisions.

Project Populations and Sampling

The process for collecting data for the NSF/EPA study began with the identification of populations of water organizations conducting conjunctive management in each state during 1997, or for any of the ten years prior to 1997. The principal investigators chose 1997 as a base year to compare certain measures of these projects.

In Arizona, identifying the population of active projects in 1997 was relatively straightforward. The Arizona Department of Water Resources issues permits for all organizations actively recharging groundwater or taking surface water "in-lieu" of groundwater. The State also issues permits to organizations for the recovery of any surface water that has been stored underground for future use. The State, therefore, has standardized records of the complete population of projects and of all the organizations involved in those projects. Since the population of active projects in 1997 is relatively small (<50), the study included the entire population of organizations and jurisdictions permitted to run conjunctive use projects.

Arizona Department of Water Resources records indicate that 42 conjunctive management projects held permits in 1997/1998. Despite being permitted, some of these projects were not actively engaged in conjunctive management activities during 1997:. In the Phoenix area, three projects had become inactive since the mid-1990s and had only been in operation for a couple years. Five of the 30 permitted projects in Phoenix had not begun to operate because they were new or experienced technical problems. Four permitted projects in the Phoenix area were pilot projects and had reported limited activity to the State. In the Tucson area, one of the projects was not yet operating in 1997, while another had just become active in 1997. Therefore, only 33 of the permitted projects in Arizona were actively engaged in conjunctive water management activities in 1997, but six more new projects were still involved in the planning and organization of conjunctive management activities. The three projects in the Phoenix area that were no longer active in 1997 were included in the population because they had engaged in activity in the past ten years and maintained the permits and facilities to reestablish activities in the future. Of the 42 permitted projects, only five had been in operation prior to 1992. Thus, most projects in Arizona are relatively new.

In California and Colorado, the population parameters of conjunctive management projects and data accessibility differ widely from the Arizona projects. California has no centralized source of information on conjunctive management operations because groundwater is managed locally. It was not feasible to identify all of the organizations involved in conjunctive management by contacting California's water providers since thousands of water providers operate in the State. To identify the organizations engaged in conjunctive management, the NSF/EPA study used a 30% cluster sample of California's 450 groundwater basins, which the California Department of Water Resources groups into seven hydrologic regions. Before sampling the basins, two hydrologic regions were eliminated based on the physical conditions and low water demands, making the regions not conducive to conjunctive management. From the remaining sample of 70 basins, a list of all the California's water providers by zip code identified water providers operating in the sample basins. Finally, the study team contacted water providers to determine the type of water management activities and groundwater governance institutions operating in the sample basins. Twenty-three sample basins turned out to be in remote locations with little developed water use and no organized water resource management. From the remaining 47 developed basins in the sample, the study found conjunctive management activities under way in 12 basins and planned programs in four others. The investigators for the NSF/EPA study then collected data on the individual projects in those sample basins where conjunctive management was occurring as of 1997.

As in California, the State of Colorado does not systematically track conjunctive management of surface and ground water. The State of Colorado administers water laws and regulations through seven divisions of water courts and the State Engineer's Office which are organized around the state's major rivers. Each of the State Engineer divisions is further divided into multiple districts. Each Division Engineer's Office maintains hundreds of records of Augmentation Plans and recharge diversions, which involve the conjunctive use of ground and surface water. These records do not specify the type of augmentation taking place, or whether it involves conjunctive water use. Therefore, gathering data on conjunctive management activities required contacting water providers individually. As in California, contacting all of the water providers in Colorado was not feasible, so a sample of Colorado's water districts was taken.

To identify projects in Colorado, the study used a 30% cluster sample of the 59 water districts included in the state's five watershed divisions. The final sample totals 17 districts, including five from the South Platte River Division, four from the Arkansas River, three each from the Colorado and Gunnison River Divisions, and two from the Rio Grande River Division. Records from the Division Engineer's offices provided information on the Augmentation Plan filings in each sample district and identified water providers involved in these plans. Within these sample districts, the NSF/EPA study included 42 conjunctive management projects. Water providers within those districts provided data on individual projects.

INSTRUMENTATION

The NSF/EPA-funded study used detailed coding forms (attached in Appendix A) to inventory and describe systematically the conjunctive management activities in each state and the related institutional, physical, and organizational variables affecting these activities. The study investigators entered the data from the coding forms into a Microsoft Access database to track the relationships among projects, organizations, groundwater and surface water sources, and various project facilities. This section describes the coding forms and database. It also explains response rates, missing data, and reliability and validity issues.

Coding Forms: Design

To design the data coding forms for the NSF/EPA study, the principal investigators identified key institutional and organizational variables based on prior research conducted under the IAD framework, incorporating background information on conjunctive management activities. The study separated data collection questions into several coding forms including a form with project questions, a form with organizational questions, a form for performance measures, and a form covering state water laws. (See Appendix A.) Using previous work from the IAD as a guide for the development of the coding forms helped ensure that valid and reliable measures would be taken to represent the concepts of interest in the study's research questions.

The "Organization Form", "Project Form", and "Performance Measures Form" provide the bulk of the questions for measuring the concepts presented in the principal research questions of the NSF/EPA study and for the analyses in this dissertation. (See

Appendix A.) The "Organization Form" measures concepts such as the institutional form of organizations involved in conjunctive management, the financial and institutional power of those organization, and the resources available to organizations for conducting conjunctive management. The coding form poses close-ended questions on the type of organization participating in a project, the number of organizational members and requirements for membership, the population and square mileage of the jurisdiction, the organization's budget, the organizational availability of water resources, and the employment of water resource experts. The form includes questions on the type and number of conjunctive management projects in which an organization is involved.

The conjunctive management "Project Form" elicits descriptive details about individual projects, as well as quantitative measures of the resources dedicated to projects. This form has close-ended questions to identify the purpose of an individual project. It also tracks the organizations involved in each project and includes an open-ended question for describing the set of rules imposed on project operations. Finally, the "Project Form" identifies the dollar amount of the capital costs of each project and identifies the dollar amount of the costs of the individual facilities used for each project. The sub-section of the project form on project facilities is organized according to different types of facilities that are typically used in various types of conjunctive management activities. These include spreading basins, injection wells, pumps, and distribution systems.

The "Performance Measures Form" tracks the impacts of individual conjunctive management projects and their goals. This form encompasses multiple measures of project benefits and costs and various measures of project goals. It contains questions on the number of project inputs and the dollar amount per unit of input going into projects, including water, facilities, labor, monitoring, and administrative work. It also provides a close-ended list of possible options for the measurement of project goals that are consistent with literature on conjunctive management activities. To measure the performance of organizations in meeting the goals, the form provides quantitative indicators of unit-level changes for each type of performance goal over a one-year period.

Another component of the data for the NSF/EPA study comes from the coding form on state and local water doctrines. The "State Water Law Form" covers the gamut of potential water rights doctrines for each type of water resource. Its purpose is to establish a comparative inventory of each state's prevailing water rights doctrines for groundwater, surface water, and effluent. The form contains codes to identify the extent of individual rights to use water, the priority each state assigns to different types of uses, and restrictions on uses. The coding form further clarifies the sets of rules that each state applies to groundwater recharge programs, particularly the rights that individuals and organizations have to store water underground and impose rules on local water users who benefit from programs. Finally, the law coding form includes closed-ended and open-ended questions to determine the extent to which local governments in each state have the authority to manage water resources and define water rights.

The NSF/EPA study investigators tested the coding forms prior to the data collection phase using independent pilot coding of projects and organizations in each state. Study investigators made several modifications to the forms to ensure that questions did not contain vague wording, inconsistent response options, and overlapping response options. In summary, the coding forms contain multiple types of indicators to analyze the research questions of the NSF/EPA-funded study. Many of these indicators, such as project type, organization type and organization goals are qualitative, using nominal and ordinal-level data sources. Others, such as project-level costs and project performance data are available in interval-level data scales. The variety of data scales and data sources provide a rich set of descriptive and quantitative measures of conjunctive management projects, the organizations operating them, and the institutions governing them.

Data Collection, Responses, and Missing Data

To complete the "Organization Form", "Project Form", and "Performance Measures Form" investigators conducted in-person and telephone interviews with individuals responsible for managing conjunctive management projects from the organizations identified in each state's sample. The Arizona Department of Water Resources' applications for conjunctive management projects helped identify the appropriate contact person in each of the organizations in Arizona. In California and Colorado, each organization participating in conjunctive management was contacted by telephone to explain the purpose of the research and to identify appropriate data sources. The study included contacts with 32 organizations in Arizona, 44 in California, and 13 in Colorado. During the initial telephone contact, researchers requested personal interviews with the parties or individuals in each organization responsible for conjunctive management.

After the initial contacts, the NSF/EPA study involved16 in-person interviews in Arizona, 34 in California, and 15 in Colorado with organizations involved in conjunctive management activities. In addition to personal interviews, the study team formally interviewed 13 additional organizations in Arizona, 10 in California, and 10 in Colorado by telephone. Some organizations, particularly large water providers and municipalities, required meetings or telephone conversations with multiple individuals in the organization in order to complete the various questions on forms. Of the 89 organizations initially contacted, three in Arizona did not respond to requests for information. If contact persons in key organizations were not available or did not respond to requests for interviews following the initial telephone calls, investigators made a minimum of three follow-up calls to try to establish a meeting.

After the interviews, most organizations did not have all the data to complete each question on the coding forms. A number of organizations had either no information or only estimates for the project performance forms. Consistently, organizations did not have specific or quantifiable data to measure the costs and benefits of projects or the costs of project inputs. One reason for the lack of these pieces of data across various agencies and organizations is that states and local jurisdictions have very different rules for monitoring conjunctive management projects, and therefore, organizations track only certain types of information on project impacts. Other organizations simply did not have data on certain organizational level questions, depending on the type of organization or the type of accounting system they use. For example, many irrigation districts did not know the population in their service area, while they did know the number of members that belong to the district. Alternatively, municipalities and private water agencies typically tracked the costs of water-related projects differently. Sometimes municipal water departments did not break down the costs of projects so that the costs on individual project inputs could be measured. Organizations often combine these costs into a single departmental line item or include them in a larger capital budget. In such cases, some organizations were able to estimate these costs, while others were not. In addition, some organizations simply failed to respond to our requests for pieces of information on the coding forms if the information was not readily accessible, even after repeated follow-up calls.

To complete and supplement missing data from the coding forms, the study used reliable secondary data sources and conducted additional in-person and telephone interviews. The condition of the groundwater basins and surface water supplies going into a project, for example, is a sub-form of the "Project Form". Many organizations did not have adequate information on these resources to complete the forms. Therefore, data from other state and local agencies, as well as engineering firms, local administrative agencies and research institutes, supplemented or completed many questions. In Arizona, the Department of Water Resources issues quarterly reports on the conjunctive management activities in the state, which provide general information on projects and participants. In addition, the Department collects data on the amount of water each conjunctive management project stores, how much water is pumped from the project, and the amount of groundwater recharge credits that each participating organization receives.

The Arizona Department of Water Resources also has hydrologic data on the conditions of groundwater basins and groundwater use in the basins where projects operate.

Similar to Arizona, the Colorado State Division Engineer's Office tabulates the amount of water used in permitted recharge sites and for approved Augmentation Plans. After reviewing state water court files for Augmentation Plans, the study investigators interviewed in person and by telephone division directors and staff in five of Colorado's seven division offices of the State Engineer. Also in Colorado, the Northern Colorado Conservancy District is an organization that does not participate directly in conjunctive management projects, but monitors and reports on recharge activities to the Division Engineers for organizations within its district. Therefore, this organization provided useful supplemental data that confirmed Division Engineer data. The Northern Colorado Conservancy District's reports on quantities of recharged water for conjunctive management projects in Division One differed in some cases with the reports from the State Engineer's Office, but the discrepancies appeared to result from different water accounting systems. While the District is an official reporting and monitoring agency for entities engaging in conjunctive management within its boundaries, the study relied on the data provided by the State Engineer where discrepancies existed because it tracks site level data for recharge projects and Augmentation Plans.

In California, a variety of secondary information sources supplemented interviews with water providers. The study involved 22 personal interviews and three telephone interviews with experts in the field of water resource management from different offices of the State Department of Water Resources, consultants to the California state legislature, water attorneys, and research specialists in water management. Reports from the Department of Water Resources, from large agencies such as the Metropolitan Water District of Southern California, and from the Watermasters of adjudicated basins also contributed information on various conjunctive use activities, groundwater basin conditions, and the rules and regulations governing projects at the local level. Table 3.1 summarizes the number of conjunctive management projects identified in the samples, organizations contacted, and interviews conducted in Arizona, California and Colorado.

TABLE 3.1: Summary of Data Collection on Projects in Arizona, California, and Colorado

State	Pop. Parameter or Sampling Frame	# of CWM Projects Identified	# of Organizations Contacted	# of CWM Providers Interviewed	# of Supplemental Interviews
Arizona	Population of Projects Permitted by ADWR within 4 Active Management Areas	42	32	29	4
California	30% Cluster Sample of Groundwater Basins within 10 Hydrologic Regions	35	44	21	25
Colorado	30% Cluster Sample of Water Districts within 5 Watershed Divisions	42	31	25	6

Unlike the project and organization forms, data collection on state laws was not conducted during the interview process. To complete these forms, investigators researched water statutes and constitutional provisions using *Lexis Nexis* and additional legal reference sources. Rules and regulations established by the Arizona Department of Water Resources and the Colorado Division Engineers for the administration of water rights provided additional data sources. In California, where state statutes or court adjudications have created the authority for local regulation of groundwater resources, data on local-level rules also applied to the projects found in the sample. This research process provided a complete set of data on the rules governing conjunctive management.

Database Design and Data Entry

The NSF/EPA study used a Microsoft Access database for data storage and analysis, which was designed and modified by two graduate research assistants in conjunction with the design of coding forms in 1997 and 1998. The general format of the database design includes user-friendly forms that follow the same question format as the paper coding forms. The database forms provide the interface to input data into Access tables, which are linked to key fields to facilitate data retrieval and data analysis. The database tables are based on key data attributes that the principal investigators identified in the coding forms, which have multiple records or entities for each key field. These key fields, or tables, are linked by their shared entities or records, such as by organizations or projects.

The relationships in the Access database are established through main tables. The database contains main tables for each of the main coding forms, including the organization table, conjunctive management project table, performance measures table, and state law table. It also contains a table on groundwater resources and on demographic information in each state. Each of the main tables is related to one another through tables identifying the organizational participants in a given project. The main organization table is linked to a table that identifies fields for all of the conjunctive management activities of each organization, and a table that establishes the water law administration activities of participants in conjunctive management activities. The conjunctive management main table is linked to a number of tables based on subsets of questions, including tables for each of the types of facilities of conjunctive management projects. The performance measures main table is linked to separate tables based on subsets of the form; one containing the data fields for performance measures of projects and another containing the data fields for performance measures for the organizations involved in projects. Finally, the state law main form is connected to individual tables that include a surface water law table, groundwater law table, a table for the fields on the laws of instream flows, a table for data fields on recharge projects, and a table for data fields on effluent water law.

The study team tested the functionality of the initial design of the database using sample data before final data entry. Research assistants revised the database following the sample entries to eliminate problems with relationships between tables and problems with using the database forms. The final database is complex and extensive. However, since the data entry forms in the database replicate the data fields on the physical forms, this simplifies the transfer of data from the paper forms to the relational database. After all of the data was entered into the database, investigators compared the final database to the paper coding forms to check for data entry mistakes, duplicate entries, and incorrect linkages.

Reliability and Validity Issues

Many of the procedures followed during the design of this research project and during data collection support the validity of the measurement techniques and the reliability of the data. Some aspects of the research methods and data collection procedures can lead to problems for data reliability and potentially for the validity of the results of analyses using this data. Validity is concerned with whether the choice of study indicators actually measure the concepts that they are supposed to measure. The ability to replicate data and the accuracy of the measurement techniques used in the study determine the study's reliability.

To determine the validity of measurement techniques, it is necessary to consider how the coding forms operationalized the key concepts of the research questions. The use of the IAD framework provides theoretical and empirical support for the types of questions and measures used in the study, offering face validity to the study's questions. Moreover, many of the key concepts identified in the study's initial research questions, such as institutional arrangements, conjunctive management performance, and organizational goals relied on a vast number of distinct measures in the coding forms, offering construct validity to these measures.

The issue of validity also is important when considering the choice of observations and sampling techniques. The study incorporated the entire population of projects in Arizona, and thus a valid set of observations for making inferences about conjunctive management in this state. California and Colorado also involved sufficiently large sampling frames, designed to represent the variance of conjunctive management in different regions of the state. In this study, the choice of disparate sampling frames in each state precludes the likelihood that valid statistical comparisons can be conducted across the three states. This does not suggest that qualitative comparisons or preliminary quantitative comparisons cannot be used with appropriate qualifications on the results. Nor does this imply that quantitative analyses within states cannot be valid, depending on the strength of each state's data set.

The reliability of the instruments and data depend upon how easily the data can be replicated, the accuracy of the data sources, and the accuracy of data entry procedures. Through each stage of the data collection and entry, the NSF/EPA study ensured data reliability. First, coding forms were pre-tested and questions were reviewed for typical problems found in surveys, such as vague wording, double-barreled meaning, and inaccurate scales. Second, in collecting the data, formal interviews with participants ensured that investigators could clarify questions in a standardized format. Third, after conducting interviews, investigators reviewed the coding forms for confusing or incomplete answers and verified responses. Finally, during the data entry phase, one person entered data and confirmed unclear responses with investigators, while another person verified all entries and checked for incorrect entries against the paper coding forms.

Reliability problems do arise with the vast differences in how organizations keep data. For example, water recharge quantities sometimes are calculated differently. Some organizations round to the nearest acre-foot, others estimate recharge volume, and some reduce volumes for evaporation. Likewise, budget data for some organizations are estimates, while others calculate exact dollar figures. Some organizations use different accounting methods. These issues can pose reliability problems, but errors in calculation are likely to cancel each other out. At the same time, every effort was made to ensure that respondents understood the scale and units of measures requested by the coding forms.

For quantitative tests conducted with this data, there are likely to be problems of reliability related to missing and incomplete data. Indeed, the lack of data on some questions and the disparate sampling frames across states limits the full range of analyses that could potentially be conducted with this data set. However, as noted by King, Keohane, and Verba (1994), it is possible to maximize leverage over research problems by using multiple levels and multiple measures of data (208), particularly if aggregate cases (such as state level data in this study) are limited or if observations on some variables are missing. Therefore, quantitative tests across organizations or projects within the three states covered by this study can still provide reliable results. The data set is rich in multiple measures of variables such as organizational strength and project size and history. The reliability and validity of the data with respect to the individual tests used in this dissertation are discussed in the data analysis chapters and revisited in the conclusion chapter.

SUMMARY

This chapter described the data collection procedures and research methods of the NSF/EPA study, which provided the data used to evaluate this dissertation's hypotheses. It outlined the goals of the NSF/EPA-funded study and established that the hypotheses and analytical methods in this dissertation differ from the research objectives of the larger study. The second section of this chapter covered the data collection methods of the NSF/EPA-funded study, including units of analysis and data sources, population and sampling methods. Third, it detailed the development and implementation of the coding form instruments.

This chapter showed that the reliability of the data and the validity of the study's measures are supported by the use of a well-established research framework. The choice of variables and of indicators for institutional variables is based on the IAD framework, which provides face and construct validity. The use of the IAD framework also supports data reliability by establishing a consistent framework for identifying different institutional variables across multiple settings. Pre-tested standardized coding forms and confirmation of data entry further strengthened data reliability. This chapter acknowledged the limitations of the data set for cross-state quantitative comparisons due to differences in sampling frames and missing data, which could lead to validity problems for statistical analysis. Yet, the multiple variables and levels of observations in the data set can facilitate data leverage and support rigorous theory testing.

Understanding the purposes of the NSF/EPA-funded study and its basis in the IAD framework demonstrates the larger implications of this dissertation and supports the appropriate use of the data for the analytical portion of this dissertation. Moreover, identifying the limitations of the study and its strengths explains the choice of the analytical methods of this dissertation. The following three chapters present the data analyses and consider how the analyses either support or reject the research hypotheses.

The analytical chapters use within-state quantitative analyses and cross-state comparisons to test the hypotheses. The analytical chapter on California focuses on the first two hypotheses, which consider the relationship between jurisdictional boundaries and conjunctive management. The second analytical chapter compares the relationship between jurisdictional boundaries and conjunctive management across the three states. It also looks at the differences in the use of coordination in conjunctive management projects across the three states. It provides further insights into the first two hypotheses and evaluates the third hypothesis. Hypotheses 4a and 4b are evaluated in the final analytical chapter, which explains the use of inter-jurisdictional coordination in Arizona.

IV. THE ROLE OF INSTITUTIONAL BOUNDARIES: CONJUNCTIVE WATER MANAGEMENT IN CALIFORNIA

The data analyses in this chapter focus on the first two hypotheses proposed in Chapter Two, which consider the relationship between institutional boundaries and conjunctive water management. The first hypothesis states that jurisdictions do not have to be devised around groundwater basin boundaries in order for water providers to engage in conjunctive management. This hypothesis counters the underlying assumption in CPR theory that institutional boundaries need to be clearly defined around the resource in order to manage common-pool resources successfully. The second hypothesis adds that inter-jurisdictional coordination is likely to be positively related to conjunctive water management, suggesting that a single institutional arrangement is not necessary for successful CPR management. To test these hypotheses, this chapter evaluates a) the relationship between institutional boundaries and the provision of conjunctive water management projects in California and b) the extent to which inter-jurisdictional coordination relates to conjunctive water management in California.

The first section of this chapter introduces data on conjunctive water management activities from the NSF/EPA study's sample of California groundwater basins. It discusses the location and type projects operating in the state, including descriptive statistics on the organizations that supply these projects. The second section of this chapter empirically tests the relationship between the boundaries of groundwater institutions and the likelihood of water providers engaging in conjunctive water management.

CONJUNCTIVE MANAGEMENT ACTIVITIES IN CALIFORNIA

Project Location

Within the sample groundwater basins in California, the NSF/EPA study identified 34 conjunctive management programs. These projects operate in 12 of the 70 sample basins. Through secondary sources, the NSF/EPA study identified conjunctive management programs in three more sample basins, but data was not collected on the specific projects operating in these three basins due to insufficient contact information.[29] Table 4.1 summarizes the conjunctive management projects occurring in the sample of California groundwater basins, organized by hydrologic region. It includes a) the number of basins sampled in each hydrologic region, b) the number of sample basins with conjunctive management projects, c) the number of projects operating in the sample basins, and d) the average number of acre-feet of water per year going into the projects. Across all basins in the sample, the average volume of water going into conjunctive management projects is over 1.2 million acre-feet per year.

Table 4.1 indicates that 50 percent of the conjunctive management projects in the sample basins are located in the Southern California Coast region, which encompasses Los Angeles, Ventura, Orange, and San Diego Counties. The South Coast region uses nearly half of the total volume of water going into conjunctive management in the sample basins. Another 26 percent of the individual projects in the sample are found in the San Joaquin Valley, and 12 percent of the projects are in the Central Coast region. The

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[29] The number of projects reported in this study, and the number of basins with active projects, may underestimate the true extent of conjunctive water management in California. The random sample of groundwater basins included at least 15 groundwater basins that are undeveloped, because they are located

remaining projects are spread throughout the San Francisco area, Sacramento Valley, and the southeastern regions of the state.

Both the South Coast and San Joaquin regions have high water demand with limited native water supplies. For example, the population of the South Coast region in 1995 was over 17 million and urban water demands averaged 4.3 million acre-feet per year (CDWR 1998a). In comparison, the region with the next highest population, the San Francisco area, had approximately 5.8 million people in 1995 and urban water demands of 1.3 million acre-feet per year. At the same time, the San Francisco region receives 7.4 inches more rainfall per year than the South Coast region and has more native surface water resources than the South Coast region. The San Francisco area uses imported water for about 15 percent of the region's total yearly demands,[30] while the South Coast region relies on imported surface water for approximately 60 percent of its yearly water demands.

The San Joaquin Valley and Tulare Lake region, on the other hand, have relatively low urban demands, but agricultural water use is high. Agriculture in this area accounted for nearly 17.8 million acre-feet of water use in 1995 (CDWR 1998a). In comparison, the region with the second highest agricultural water demands in California is the Sacramento Valley. In this region, agriculture consumed about eight million acre-

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in portions of the Sierra Nevada Mountains and the Mojave Desert, which are far from urban or agricultural centers.

[30] The San Francisco hydrologic region has much higher environmental and in-stream flow water demands than the other regions in California. The region's environmental water demands were nearly 5.8 million acre-feet in 1995, totaling 80 percent of the region's overall water needs (CDWR 1998). This water is used to address habitat and water quality problems in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary that have resulted from upstream diversions. The CALFED Bay-Delta program was created in 1995 as a multi-agency effort to deal with these problems.

feet of water 1995. Even with lower demands, the Sacramento Valley receives almost ten inches more rainfall per year than the San Joaquin Valley and over 20 inches more than the Tulare Lake basin. The Sacramento region also has four million acre-feet per year more surface water than the San Joaquin/Tulare Lake area.

TABLE 4.1: Conjunctive Water Management Activities in 70 California Groundwater Basins

Hydrologic Region (& Counties)	# of Basins in Sample	# of Sample Basins With CWM	# of CWM Projects in Sample	Average Acre-Feet of Water Per Yr. in CWM
San Francisco Area	8	1	1	5,500 AFY
Central Coast	8	2	4	164,050 AFY
South Coast (LA, Ventura, Orange, SD)	13	5	17	613,900 AFY
Sacramento Area	10	1	1	9,600 AFY
San Joaquin Valley / Tulare Lake	10	3	9	468,500 AFY
South Lahontan (Mojave, Mono, San Bernardino)	13	2	1	0 AFY (new project)
Colorado Desert (San Bernardino, Riverside, Imperial)	8	1	1	3,700 AFY
Totals	70	15	34	1,265,250 AFY[a]

[a] Data missing on 2 projects.

Project Types

The conjunctive water management methods in California are diverse and address the different types of water supply dilemmas faced by water providers. One of the most common techniques in the sample of California basins, as summarized in Table 4.2, involves in-lieu groundwater savings. Agricultural areas, and some urban areas, use in-lieu methods as a way to use water cost-efficiently (Bookman-Edmonston 1978; Purkey et. al. 1998). One of the largest wholesale water suppliers in California, the Metropolitan Water District of Southern California (MWD), participates as a water supplier in five of the 14 in-lieu projects in the sample basins. MWD provides surplus surface flows to irrigation districts or municipal water providers in exchange for groundwater, which MWD can pump later.

Table 4.2 shows that direct recharge projects, which store surface water in groundwater basins, comprise about 35 percent of the conjunctive management projects in the sample basins. These projects operate most frequently in the sample basins in southern California's metropolitan areas and coastal communities. According to the NSF/EPA study's survey responses from water providers in California, the main purpose of direct recharge projects is to allow local water providers the opportunity to store excess surface water for use during drought conditions or to avert sea-water intrusion into coastal basins. Moreover, this is an advantageous method for some municipalities that use treated effluent as a source of direct recharge water because they can reuse the water in the future and conserve native supplies.

A third conjunctive management technique that comprises about 15 percent of the projects in the sample of California's groundwater basins is "return flow" recharge. Irrigation districts or large-scale surface suppliers are the most common types of organizations using this technique. One of the benefits of return flow recharge is that it requires little or no additional infrastructure to store water directly underground. Return flow projects take advantage of the portion of water diversions or reservoir releases that, after being used for irrigation, returns naturally underground through the soil. Irrigators or water agencies using this method then recover percolated water through pumping groundwater when surface flows are scarce.

Finally, two less common conjunctive management methods, comprising three of the 34 projects, occur in areas with high groundwater levels. Two projects lower groundwater tables slightly to allow excess surface water to be used in irrigation, instead of pumping groundwater. Another involves pumping groundwater in order to supplement in-stream surface flows when native surface flows are low. Rather than storing water underground for future use, these two methods require pumping groundwater so that surface water can be utilized more readily. Each of these techniques average less than 6,000 acre-feet a year in water used within the sample basins.

TABLE 4.2: California Conjunctive Management Projects by Type and Water Use

Project Type	Frequency	% of Total Projects	Av. Acre-Feet of Water Per Yr. in Projects
In-Lieu Groundwater Savings	14	41%	479,250 AFY[a]
Direct Recharge (Spreading Basins or Injection Wells)	12	35%	400,400 AFY
Return Flow Recharge (Excess Irrigation or Dam Releases)	5	15%	377,100 AFY
Draw-Down of Groundwater Table to Allow for Surface Water Irrigation	2	6%	5,500+ AFY[b]
Groundwater Pumping for Surface Water Supplements	1	3%	3,000 AFY
Sample Basin Totals	34	100%	1,265,250 AFY

[a] Missing data on 2 projects
[b] Missing data on 1 project

Project Producers and Providers

The organizations involved in the provision and production of conjunctive water management reflect California's complex and decentralized system of water management. The predominant type of organization involved in providing and producing conjunctive water management in the sample of California water basins is a water district/agency. This form of organization is legislatively authorized as a special purpose government. In addition, Table 4.3 shows that irrigation districts (also special purpose governments), county water agencies, and federal agencies participate in either the provision or production of conjunctive water management projects operating in the sample basins.

TABLE 4.3: Types of Organizations Participating California Projects

Organization Type	Number of Participants	Number of Projects
Special Water Districts/Agencies	13	17
Irrigation Districts	5	10
County Water Agency/Department	6	7
Federal Agency	3	5
Total	27	39[a]

[a]Multiple organizations can participate in a single project and a single organization can participate in multiple projects.

Of the 27 organizations participating in the conjunctive management projects in the sample basins, 16 act as project managers or the principal agencies for project funding. They include nine water districts/agencies, four irrigation districts, two county agencies/departments, and one federal department. Therefore, 11 organizations participate in the production of these projects, most commonly as water suppliers, but do not engage in funding or maintaining the project facilities that store water underground. Instead of supplying water to projects, a few of these eleven organizations participate in conjunctive management by using water that is stored by project operators. Some organizations provide land or conveyance facilities needed for project operations.

Certain organizations involved in conjunctive management projects in the sample also act as local groundwater governance institutions in California. As groundwater institutions, the rules that these organizations devise directly influence the implementation and use of conjunctive management. Depending on the form of groundwater institution, these organizations can define groundwater water rights, regulate groundwater pumping, or provide funding mechanisms for groundwater management (CDWR 1998b). For example, different types of special districts have been legislatively authorized specifically for groundwater management in California. While many special districts, such as irrigation districts or local water districts, participate in conjunctive water management in California, only a portion of these districts have the authority to impose rules governing groundwater use.

Some 34 special groundwater management districts statewide have legislative authority to regulate groundwater use within district boundaries (CDWR 1998a). Thus, only a small number of the organizations involved in conjunctive management in California act as both water agencies and water governance institutions. Among the sample of 70 basins, the Orange County Water District, for example, is authorized by the state legislature to impose pump taxes, but it cannot limit pumping (CDWR 1998b). Other local water agencies that lie within or overlap the District's boundaries participate in conjunctive management projects with the District, including the Municipal Water

District of Orange County and the Orange County Department of Public Facilities and Resources.

A basin Watermaster is another form of groundwater management institution that participates in some conjunctive management programs in California. Unlike groundwater management districts, Watermasters do not determine basin-level pumping rules. Instead, they monitor and administer pumping rules imposed by court adjudications (CDWR 1998b). In some basins, courts appoint existing water agencies as Watermasters. In others, new organizations, such as the Main San Gabriel Basin Watermaster, have been created. Some Watermasters participate in administering pumping assessments and conjunctive management programs. In the sample of California basins in this study, the Main San Gabriel Watermaster participates 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, provides a conjunctive management program with the Mojave Water Agency, a State Water Project contractor. Three more basins with court-adjudicated water rights in the sample have conjunctive management programs, but local agencies provide these projects without the participation of their basin Watermasters. The following section uses two empirical models to consider the relationship between conjunctive water management and the various types of local groundwater management institutions more closely.

EMPIRICAL MODELS

The descriptive data of conjunctive management projects in California indicate that various types of organizations fund or supply inputs into conjunctive management programs in California. These data also suggest that conjunctive management projects may operate under local groundwater management institutions, such as adjudicated basins or groundwater management districts. These two types of groundwater institutions in particular have jurisdictional boundaries that coincide with groundwater basin boundaries. An association between these forms of institutions and conjunctive management could suggest that conjunctive management is more feasible when institutional boundaries are defined around the resource.

This section empirically tests the first two hypotheses regarding the relationship between the boundaries of groundwater management institutions and the use of conjunctive water management in California basins. These hypotheses are as follows:

> H1) Institutions governing water resources do not need to be organized around the physical boundaries of the resource in order for water providers to engage in conjunctive water management.
>
> H2) Inter-jurisdictional coordination will be positively associated with the provision of conjunctive water management services.

A logit regression model provides the first test of Hypotheses 1 and 2. To supplement the logit regression results, a method known as "Qualitative Comparative Analysis" (QCA) is used. This section describes the variables included in the models and indicators of these variables. It then explains the purpose and results of each model.

Variables and Indicators

The dependent variable for the analytical models is the presence of conjunctive water management projects in a groundwater basin, as defined in Chapter Three. For the Logit and QCA models, if the coding forms for the NSF/EPA study identified any conjunctive management projects in a basin, then the basin is coded as a "1" for the dependent variable. If no conjunctive management projects are active in a given sample basin, then the case is coded as a 0 for the dependent variable.

To evaluate how the boundaries of groundwater management institutions relate to conjunctive management activities, the independent variables for the models include the four primary types of groundwater governance institutions whose scope of authority and jurisdictional boundaries differ. Local groundwater governance jurisdictions are appropriate for evaluating the relationship between institutional boundaries and conjunctive management for two reasons: 1) conjunctive management projects require the use of groundwater basins for storage and 2) the use and types of local groundwater institutions in California vary widely. Basins may have multiple groundwater institutions, a single institution, or none of the groundwater governance institutions identified for this analysis. Also, the boundaries of these institutions vary. The first two institutional forms used in the models have boundaries that are congruent roughly with the groundwater basins they overlie. The third form covers the boundaries of multiple jurisdictions that overlie a common basin. The fourth institutional form does not have boundaries that match the physical boundaries of basins. Using data from the California Department of

Water Resources, each basin is coded for the presence or absence of the four institutional variables.

The first type of local groundwater institution is a special groundwater management district. The California legislature has authorized a number of special districts to engage specifically in groundwater management. The state has created 12 groundwater management districts with the authority to regulate groundwater pumping. Additionally, 22 existing water districts also have special statutory authority to engage in various forms of groundwater management, but not all are acting on their authority (CDWR 1998b). Most of these districts have taxing authority for basin replenishment and recharge.

The second type of local groundwater institution is the adjudicated groundwater basin. In 16 of California's groundwater basins, state courts have adjudicated the quantity of rights available to appropriators and have designated basin Watermasters, who ensure that appropriators comply with assigned rights. Adjudicated basins often are subject to high water demands and the need for comprehensive management is critical. The amount of water a well owner can extract from an adjudicated basin is based on the amount of groundwater available in the basin each year (CDWR 1994).

The third form of local groundwater institution in this analysis is a legislatively authorized institutional arrangement called an AB3030 Plan. The state legislature changed the California Water Code in 1992 to provide local agencies with powers to raise money for basin management facilities and to implement groundwater management plans (California Water Code Section 10750). Approximately 150 local agencies have begun the process of implementing AB3030 Plans, but these efforts are relatively recent and compliance with AB3030 Plans is voluntary (CDWR 1998b). The boundaries of this institutional arrangement are limited to the existing scales of local political jurisdictions, which are not devised around basin boundaries. However, all jurisdictions that engage in an AB3030 Plan share a common source of groundwater. Therefore, the institutional boundaries of AB3030 Plans are likely to cover large areas of basin boundaries. Like special districts, AB3030 Plans can coordinate fund raising powers across multiple existing political jurisdictions that would receive benefits from conjunctive management activities.

County ordinances are included as the final form of local groundwater institution. Like AB3030 Plans, they are not devised around groundwater basin boundaries. California law does not preclude cities and counties from implementing groundwater management ordinances, but currently only seven counties have established local management ordinances (CDWR 1998b). Through such ordinances, counties may create funding and regulatory powers that could potentially encourage conjunctive management in a basin. Table 4.4 summarizes the boundaries and regulatory powers of the four local groundwater institutions.

TABLE 4.4: Institutional Forms Governing Groundwater Use in California

Institutional Type	Jurisdictional Boundaries	Local Powers
Special Groundwater Districts	Groundwater Basin	General: may regulate extraction and provide basin management
Adjudicated Basins	Groundwater Basin	Court decrees quantified rights and Watermaster monitors
AB3030 / multi-agency	Cities, counties, irrigation districts in same basin	Revenue raising powers for basin replenishment/ management
County Ordinances	Counties	General: may regulate groundwater use under police powers

Control Variables

In analyzing the relationship between institutional boundaries and conjunctive water management, the models presented in this chapter also incorporate variables that control for certain physical and human conditions in a basin that impact conjunctive water management practices. The first two control variables represent demand for water. As stated earlier, one of the main goals of conjunctive management is to stabilize water supplies and to protect water users from drought conditions. Growing water demand by municipalities, agriculture and industry facilitates the need for various forms of comprehensive water management (Malone 1990). Therefore, conjunctive management presumably would be more likely to occur where urban or agricultural demands are high. While many areas of California have excessive water demands relative to supplies, it still has substantial rural and undeveloped regions with low water demand (CDWR 1994).[31] Demand for water is measured using 1997 U.S. Census data on population density and irrigated acres of land in counties that surround or overlap the sample basins (U.S. Census Bureau 2001). Where more than one county overlaps a basin, the county with the majority of overlying land in the basin serves as the basin-level indicator. If the basin area is roughly equal across county boundaries, then the population and agricultural indicators for the counties are averaged.

The third control variable takes into account the physical capacity of groundwater basins to store surface water. Deciding where conjunctive management is feasible, through underground storage, depends on hydrogeologic conditions of a basin, including the storage and production capacity of groundwater basins and the movement of groundwater within basins (Bookman-Edmonston 1979). Specific sites within basins that are best suited to conjunctive management are found where the soils and clay layers in a basin allow for high rates of infiltration and high well yields (Hauge 1992). These hydrogeologic characteristics, however, can vary substantially across groundwater basins, and can vary within a basin or even a sub-basin. Since this analysis focuses on basin-level factors and not sub-basin conditions, the storage capacity of basins, which can be measured at the basin-level, is used as the third control variable. Basins with low natural storage capacity are less likely to be used for conjunctive use projects (Hauge 1992). The California Department of Water Resources Bulletin 118 provides measures of the storage capacity of individual groundwater basins (CDWR 1994).

Conjunctive water management projects are not likely to be feasible without sufficient access to surface water supplies at some time during the year. Given the scarcity of native surface water supplies in many parts of California, constructed water projects have become an important component in the development of conjunctive management activities (Metropolitan Water District of Southern California 1996; Purkey et. al. 1998). The fourth control variable, therefore, is project water access in a basin. Project water is defined as "non-native" surface flows or surface water that is imported to an area via California's three major projects: the State Water Project, the Central Valley Project, and the Colorado River aqueduct. The indicator for the quantity of project water available in a basin is based on California Department of Water Resources measures of

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[31] Based on 1995 estimates of urban, agricultural, and environmental water uses, overall water shortages in

acre-feet of project water imported to each hydrologic region of the state (CDWR 1998a). A second indicator of adequate surface water flows or supplemental water available for conjunctive use, and the fifth control variable, is average yearly rainfall in each hydrologic region. The measures of average annual rainfall across California come from 1997 California Department of Water Resources data (CDWR 1998a).

Basin-Level Model

Table 4.5 summarizes the expected relationships between each of the independent variables and the presence of conjunctive management in a California groundwater basin. The control variables discussed in the previous section are indicators of physical and demand conditions that facilitate the use of conjunctive management. Thus, all of these variables are expected to have a positive impact on the likelihood of conjunctive management occurring in a sample basin.

The four types of local groundwater institutions provide indicators of institutions whose boundaries differ. The expected relationships between each institutional arrangement and conjunctive management are summarized in Table 4.5. Hypothesis 1 claims that institutional boundaries do not need to match resource boundaries in order for water users to engage in conjunctive management. Therefore, if the county ordinance variable has a positive association with the use of conjunctive management in a basin, or if none of the other institutional variables is significant, this would support Hypothesis 1. If, however, only adjudicated basins and/or special districts, which have boundaries that match groundwater basins, have a positive impact on conjunctive management outcomes,

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the state approach 1.6 million acre-feet in years when water supplies are normal, and 5.2 million acre-feet this would support the alternative hypothesis that jurisdictions need to match basin boundaries. Building on the first hypothesis, Hypothesis 2 claims that inter-jurisdictional coordination can be used to engage in conjunctive management, rather than a single jurisdiction devised around basin boundaries. Thus, if AB3030 Plans have a positive relationship with conjunctive management outcomes, this would support Hypothesis 2.

TABLE 4.5: Summary of Model Variables and Expected Impact

Dependent Variable = Conjunctive Water Management Projects

Independent Variables	Indicator of	Expected Impact
Population Density	Urban Water Demand	+
Irrigated Acres	Agricultural Water Demand	+
Basin Storage Capacity	Physical capacity for CWM	+
Project Water Availability	Surface water access	+
Av. Annual Rainfall	Surface or Storm water access	+
AB3030 Plans	Coordinated Jurisdictions	+ supports H2
County Ordinance	Non-basin level jurisdiction	+ supports H1
Special GW District	Basin-level jurisdiction	+ rejects H1
Adjudicated Basin	Basin-level jurisdiction	+ rejects H1

Logit Regression Analysis

A logit regression model provides the primary test of the effects of the independent and control variables on the likelihood of conjunctive water management occurring in the sample of California groundwater basins. This section presents the descriptive statistics of the basin-level cases used in the logit analysis and then discusses the results of the logit regression analysis.

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in drought years (CDWR 1998a).

Descriptive Statistics of Logit Model Cases

Table 4.6 presents the descriptive statistics of each of the independent variables in the sample groundwater basins. First, the table shows the number of instances of each of the institutional variables (coded as 1=present and 0=absent) in the sample basins. Adjudicated basins are the least frequent institutional form in the sample, while county ordinances are the most common form. Second, the table presents minimum, maximum and mean values of each of the control variables calculated across the sample basins.

TABLE 4.6: Descriptive Statistics of Sample of California Groundwater Basins

Institutional Variables	"1" Cases	% coded 1	"0" Cases	% coded 0
Adjudicated Basin	5	7.1	65	92.9
Special District	8	11.4	62	88.6
AB3030/Coop. Mgmt.	10	14.3	60	85.7
County	20	28.5	50	71.4
Control Variables	Minimum	Maximum	Mean	Std. Dev.
Project Water (taf)	.00	2300.00	369.23	637.15
Population Density	2.00	3496.20	342.85	698.40
Irrigated Acres	.78	1153.81	182.19	294.87
Basin Storage (maf)	.000	570.00	37.12	133.18
Av. Annual Rainfall (in.)	5.50	36.00	18.82	9.84

Notably, the minimum value of the basin storage variable is zero. Seventeen of the 70 basins are coded with zero values for basin storage capacity due to insufficient hydrologic data. These basins are part of the 23 basins identified in the initial data collection phase of the NSF/EPA study as small, undeveloped basins. While coding the storage capacity of these basins as zero is likely to inaccurately represent the true capacity of the basin for storing water, it does accurately represent the underlying condition that the basins are not likely to be used currently for conjunctive water management.[32]

Logit Regression Results

Table 4.7 presents the results from the logit regression analysis. The logit model appears to be a strong estimator of the probability of conjunctive water management. As a whole, the variables used in this model are significant (Chi-Square = 62.56) and the likelihood of correctly predicting the presence of the dependent variable using this model is 97 percent.[33] The coefficients in Table 4.7 labeled Exp(B) (exponentiated betas) are the estimated values of the impact of the independent variables on the probability of conjunctive management occurring in a basin.[34] The standard beta coefficients (B), on the other hand, represent the impact of the variables on the log-likelihood of the dependent variable. Therefore, for interpreting the results, it is more useful to consider the coefficients in Table 4.7 labeled as Exp(B).

The coefficients for the control variables in this model offer some notable results. The coefficients for the variables representing irrigated acres, project water and rainfall are all positive, and significant, as expected. Based on the Exp(B) coefficients, a one-percent change in each of these variables would have a relatively small, but positive, impact on the likelihood of conjunctive management in a basin. The population density

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[32] Despite the fact that the larger NSF/EPA study excluded 23 of these 70 basins from data collection on conjunctive management projects, because they are undeveloped, all 70 basins are included in this analysis. Eliminating the 23 undeveloped basins from the logit analysis would limit the valid inferences that could be made regarding the influence of water demand conditions on conjunctive water management because it would skew the variation in water demand conditions toward the high end.

[33] Note that R-square is not an appropriate indicator of the explanatory power of the model for logit regression models (Gujarati 1995; Kennedy 1993).

[34] Using a logit model, the estimated probabilities of the dependent variable are calculated using the beta coefficients with the logistic function (Kennedy 1993).

variable and the basin storage variable have a relatively small, but negative impact on the dependent variable. While the population density variable is not significant, the impact of the basin storage variable is significant. These results could indicate that within basins with the largest storage capacities, conjunctive water management is not occurring in California. Practical evidence, in fact, has shown that in some of the largest capacity basins of California's Central Valley, conjunctive management has not been used, even though it is a viable supply management tool (Purkey et. al. 1998). From an institutional perspective, these results could represent a different issue: in larger basins, it can be more difficult to coordinate water users to engage in conjunctive water management.

TABLE 4.7: Logit Regression Analysis of Effect of Groundwater Institutions on Conjunctive Water Management

Variable	B	S.E.	Wald X^2	Sig.	Exp(B)
Population Density	-.002	.002	1.92	.166	.998
Irrigated Acres**	.021	.009	5.09	.024	1.02
Basin Storage Capacity (maf)**	-.047	.022	4.64	.031	.954
Project Water Available (taf)**	.011	.005	4.49	.034	1.01
Average Annual Rainfall*	.365	.207	3.12	.077	1.44
AB3030/Multi-agency Plans**	10.78	4.63	5.44	.020	48982.00
County Ordinance**	-16.17	7.27	4.95	.026	.000
Special GW District*	7.18	3.74	3.69	.055	1309.16
Adjudicated Basin	23.97	92.99	.066	.797	25754956319
Constant**	-18.11	8.04	5.07	.024	.000
Constant**	-18.11	8.04	5.07	.024	.000

Model Chi-Square = 62.56	Overall % of Correct Predicted Cases = 97%
* = significant at α= .10	B= effect of variable on log-likelihood of Y
** = significant at α= .05	Exp(B) = effect of variable on likelihood of Y

The logit results further show that conjunctive water management is likely to be implemented under institutional settings that control the boundaries of the groundwater resource in California. For example, the special district variable has an Exp(B) coefficient of 1,309, which suggests that the presence of a special groundwater district in a basin, holding all other variables constant, raises the probability of predicting the presence of conjunctive management by more than 1300 times. This coefficient is high compared to the effects of the control variables with positive coefficients, all of which are less than 2. The impact of the adjudication variable has an even larger magnitude, but it is not significant in this model, which may be attributed to the small number of basins in this sample that are adjudicated. At the same time, the county ordinance variable has a significant negative effect on the dependent variable. The Exp(B) coefficient for the county variable, in fact, approaches zero, which implies that when county ordinances are present in a basin, the likelihood of conjunctive water management is reduced to nearly zero. These results appear to support the CPR theory assumption that institutional boundaries are devised around resource boundaries in successful CPR management settings, rejecting Hypothesis 1.

The coefficient for the AB3030 variable also does not support Hypothesis 1. While AB3030 Plans are not devised directly around groundwater basin boundaries, they create de facto boundaries around basins by incorporating existing institutions that overlie a basin into a common management plan. However, the AB3030 coefficient does support Hypothesis 2. The coefficient for the AB3030 variable can be interpreted to mean that the likelihood of conjunctive management occurring in a basin increases 48,982 times in the presence of an AB3030 plan. As stated earlier, these plans provide legislative approval for local jurisdictions, such as cities and irrigation districts, to manage shared groundwater through these plans by coordinating with other providers in the basins. In other words, AB3030 Plans do not create a single jurisdiction that is co-extensive with a single basin, but they promote inter-jurisdictional coordination that corresponds to the boundaries of a single basin. Therefore, the results support the contention that inter-jurisdictional coordination is likely to be positively related to conjunctive management (H2). These results do not deny that jurisdictions that control basin boundaries are important in encouraging conjunctive management in California. However, they suggest that single jurisdictions are not the only way to ensure that users in the basin can benefit from investments made in conjunctive management programs.[35]

The logit model also demonstrates how changing values of any independent variable can alter the effects of other independent variables. Interpreting the changing effects of the model's beta coefficients on the dependent variable requires some special consideration. Equation 4.1 provides the formula for calculating the impact of an independent variable on the probability of conjunctive management as other independent variables change values.

EQUATION 4.1: Logit Model
Probability of Y = $1/(1+\exp(-(\text{Constant}+B_1X_1+B_2X_2+B_3X_3\ldots)))$

In using Equation 4.1, when no groundwater institution is present in a basin and all other control variables are at mean values, the probability of conjunctive water

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[35] Arguably, AB3030 Plans present some problems in determining their causality of conjunctive management projects, given that these plans only have been in existence since 1992. Conjunctive management has been present in California for nearly 60 years in some areas of the state. Without time series data on the development of conjunctive management relative to groundwater institutions, however, this relationship cannot be clarified. Still, using this data set from 1997-1998, AB3030 Plans are positively associated with the likelihood of conjunctive management occurring, suggesting that the use of AB3030 Plans does support conjunctive management projects.

management is .003, or less than one percent. When county ordinances are the only institution in place and all other control variables are at mean values, the probability of conjunctive management is even lower, at .00006. When all control variables are at maximum values and county ordinances are the only institution present, the probability of conjunctive management is still under one percent (.004).

However, when special districts are present, with no other institutional variables in place, and all of the control variables are held at their mean values, the probability of conjunctive water management increases to 81 percent. If, for example, special districts are present, but the variable for irrigated acres is reduced to its minimum value (.78) (all other controls are at mean values), the probability of conjunctive management decreases to 8 percent.

Calculating the same equation with AB3030 Plans in place, instead of special districts, results in similar, but stronger, effects on the likelihood of conjunctive management. When all control variables are at their mean levels, the likelihood of conjunctive management increases to 99 percent with AB3030 Plans present. Even if the variable for irrigated acres is reduced to its minimum value (.78), while other controls are at their mean values and AB3030 Plans are present, the probability of conjunctive management is still 76 percent.

The variable representing adjudicated basins is not significant in this model, but calculating Equation 4.1 with the coefficient for adjudicated basins shows a very strong likelihood of conjunctive management occurring. The probability approaches 100 percent, even when irrigated acres is at a minimum. When all control variables are at minimum values, the probability drops to only 98 percent with adjudicated basins present. By contrast, if all control variables are at minimum values, and AB3030 Plans are present, the probability of conjunctive management is only about 1 percent.

Thus, the model shows that the institutional variables make a difference in conjunctive management outcomes, yet the control variables can influence these effects. For instance, without some overlying institutional arrangement, the probability of conjunctive water management occurring in a basin is almost zero. At the same time, the results further indicate that as the percent of irrigated acres increases, the effect of the presence of different institutions on the dependent variable becomes stronger.

QCA Model

To supplement the results of the logit analysis, this section introduces results from a method known as Qualitative Comparative Analysis (QCA), developed by Charles Ragin. The QCA method of analysis is based on Boolean comparative logic (Ragin 1987). The QCA method synthesizes features of both case-oriented (qualitative) and variable-oriented (quantitative) research designs. It builds upon the strengths of both research methodologies by allowing a large number of cases to be analyzed, while also assessing complex patterns of multiple causation. It compares different combinations of causal conditions of independent variables in relation to a dependent variable, and then simplifies the causal conditions using a bottom-up data reduction process.

The benefit of Ragin's QCA method for this study is that it addresses two problems present in this data set: limited observations and multiple causality. These problems can reduce the explanatory power of quantitative statistical control models, but

QCA is not constrained by these conditions (Ragin 1987). In most instances, 70 observations are sufficient for quantitative statistical control methods. However, in this study, the number of basins with conjunctive management occurring in the sample of 70 basins is relatively small. Also, the four types of institutional arrangements in the sample basins occur even less frequently. For example, only five instances of adjudicated basins and eight instances of special districts exist in the sample basins. Though the total number of observations is sufficient for statistical control methods, the number of observations representing the variables of interest is small. Despite these limitations, the QCA method can be used to analyze necessary or sufficient causes of the dependent variable (Ragin 1987).

The second problem that warrants the use of the QCA method is that the data set includes nine independent variables, which can produce multiple interaction effects in relation to the dependent variable. QCA offers a quantitative tool that can explain such interactions. The logit model, on the other hand, provides only a rudimentary examination of these potential interaction effects. As Ragin (1987) points out, quantitative statistical control methods are often insufficient for analyzing the complex interactions of multiple independent variables in relation to a dependent variable. One of the benefits of using QCA is that it shows how different types of interactions among many independent variables are related to an outcome of interest. At the same time, QCA overcomes the weakness of case-oriented research when trying to examine these effects because it can be used for more than just a few cases.

Using the QCA approach, all data are coded as binary variables, indicating the presence or absence of each independent variable and the dependent variable. Equation 4.2 summarizes the QCA model. All 70 units of observations are coded with either the presence or absence of each of these variables.

EQUATION 4.2: QCA Model

Conjunctive Management = High Population Density (P) + High Irrigated Acres (I) + High Basin Storage Capacity (B) + High Annual Rainfall (R) + Project Water Access (W) + AB3030 Plan (A) + County Ordinance (C) + Adjudicated Basin (D) + Special District (S)

For this analysis, the combinations of independent variables coded for each case include the same variables used in the logit model. The difference is that all variables in the QCA model are dichotomous. Therefore, the QCA model is concerned with the combinations of the presence or absence of the different independent variables in relation to the presence or absence of conjunctive water management. Like the logit analysis, the dependent variable (conjunctive management in a basin) and the four institutional variables are scored as "1" for the presence and "0" for the absence of these variables in a basin. Unlike the logit analysis, the first four interval-level variables in the QCA model (population density, irrigated acres, storage capacity, and rainfall) are dichotmized using a cut-off point that approximates the mean score of each variable from the sample observations. The last interval-level variable used in the logit model is project water access. For the QCA model, this variable is dichotomized based on whether or not water providers have access to project water in a basin, regardless of amount. These cut-off values are shown in Table 4.8.

TABLE 4.8: Summary of Scoring Values for Variables Used in QCA Model		
N=70	Basins Coded "1"	Indicator Value for Score ="1"
Dependent Variable		
Conjunctive Management Projects	15	> or = 1 project in basin
Institutional Variables		
Adjudicated Basin	5	Legislatively authorized, as of 1997
Special GW Management District	8	Authorized by local jurisdictions, as of 1997
AB3030	10	Authorized by courts, as of 1997
County Ordinance	20	Authorized county ordinance, as of 1997
Control Variables		
High Population Density	18	> or = 300 people per square mile
High Irrigated Acres	19	> or = 150,000 acres
High Storage Capacity	32	> or = 100,000 acre-feet
High Annul Rainfall	21	> or = 20 inches per year
Project Water Access	25	> or = 1 project water aqueduct in basin

The QCA method sorts coded data into a "truth table" for analysis. The rows in the truth table represent all possible combinations of the values of the independent variables present in the data set (Ragin 1987). Each row in the truth table contains binary output values for each independent variable and the dependent variable. The truth table also shows the number of cases in the data that match each combination of independent variables, or each row. The data in the truth table can identify necessary and sufficient conditions in relation to the dependent variable. Table 4.9 presents the complete set of configurations found in the data, with the number of cases associated with each combination of independent variables.[36]

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[36] While QCA analysis does not use the relative frequencies of cases in the data reduction process, the relative frequencies are often of interest when examining contradictory cases or comparing actual configurations to theorized configurations.

Table 4.9: Truth Table Configurations and Corresponding Raw Data Cases

Config	Variable Configurations[a] P I B R W A C D S	Conj. Mgmt[b]	Number of Cases
1	1 0 1 1 0 0 0 0 0	N	1
2	0 0 0 1 1 0 0 0 0	N	2
3	0 0 1 1 1 0 0 0 0	N	1
4	0 0 1 1 0 0 1 0 0	N	2
5	1 1 1 1 1 1 0 0 1	Y	1
6	0 0 0 1 0 0 0 0 0	N	3
7	1 0 0 1 0 0 0 0 0	N	2
8	0 1 1 0 0 0 0 0 1	Y	1
9	0 0 1 0 0 1 0 0 0	Y	1
10	0 0 0 0 0 0 0 0 0	N	10
11	1 0 0 0 0 0 1 0 0	N	1
12	0 0 0 0 0 0 1 0 0	N	2
13	1 0 1 0 1 1 1 0 0	Y	1
14	1 0 0 0 1 0 1 0 1	N	1
15	1 1 1 0 1 0 0 1 0	Y	2
16	1 0 0 0 1 0 1 0 0	N	4
17	1 0 1 0 1 0 0 0 1	Y	1
18	0 0 0 0 1 0 0 0 0	N	1
19	1 0 0 0 1 0 0 0 0	N	2
20	1 0 0 0 1 0 1 1 0	Y	1
21	1 1 1 1 1 1 0 0 0	Y	1
22	0 0 1 1 0 0 0 0 0	N	1
23	0 0 0 1 0 0 1 0 0	N	4
24	0 1 1 1 1 1 0 0 0	C	1(Y) and 1(N)
25	0 1 1 0 1 1 0 0 1	Y	1
26	0 1 1 0 1 0 0 0 1	Y	1
27	0 1 1 0 0 0 0 0 0	N	2
28	0 1 0 0 0 0 0 0 0	N	5
29	0 0 1 0 0 0 0 0 1	N	1
30	0 0 1 0 0 1 1 0 0	N	1
31	0 0 1 0 0 0 1 0 0	N	1
32	0 0 1 0 0 0 0 0 0	N	4
33	0 0 1 0 0 0 0 1 1	Y	1
34	0 1 1 0 0 1 0 0 0	Y	1
35	0 1 1 0 0 1 1 0 0	N	1
36	0 0 1 0 1 0 0 0 0	N	1
37	0 1 1 0 1 0 1 0 0	N	1
38	0 0 1 0 1 0 0 1 0	Y	1

[a] Variables: P = Population Density, I= Irrigated Acres B = Basin Storage Capacity, R = Av. Annual Rainfall, W= Project Water Access, A= AB3030 Plans, C= County Ordinance, D= Adjudicated Basin, S= Special Groundwater Management Districts

[b] Conj. Mgmt.: Refers to the dependent variable outcome associated with each configuration. Y = presence, N = absence, C= contradictory case.

Table 4.9 shows that almost twice as many configurations of independent variables are associated with an absence of conjunctive management as the number of configurations related to a presence of conjunctive management in a basin. Only one of the 38 possible configurations is associated with both the presence of conjunctive management and the lack of conjunctive management. Ideally, combinations of conditions associated with the presence of the dependent variable and combinations associated with its absence are distinct in QCA Truth Tables, so that clear patterns in the data emerge Ragin (1987). When contradictory configurations are present, Ragin (1987) suggests that the model may need to be re-specified. In this data set, however, only one of the 38 configurations has contradictory cases. This configuration (011111000) includes one basin with the conjunctive management coded as present and one basin with conjunctive management coded as absent. In both basins the variables representing high irrigation, high storage capacity, high rainfall, and project water access are all coded as present. The only institutional variable coded as present is the AB3030 variable. While both basins may have a capacity and need for conjunctive use, the contradiction could be explained by the fact that the AB3030 process is relatively new. It is possible that groundwater management is still in the planning phases in the non-active basin. Therefore, the model does not appear to require re-specification, despite this one contradictory configuration.

The next step in QCA method is the minimization of the configurations coded as present and absent in the truth table. Since QCA utilizes Boolean algebra, minimized solutions are evaluated based on combinatorial logic. This means that a combination of conditions (a configuration) indicates that the presence or absence of each independent variable in the configuration need to be found together in order for the dependent variable to be present or absent in any given case (Ragin 1987). Data minimization relies on comparing pairs of cases in order to identify causal conditions that could be considered irrelevant. Irrelevant conditions are found where two cases differ in only one independent variable, but still produce the same outcome.[37]

Equations 4.3 and 4.4 show the truth table minimization outcomes for conjunctive management and non-conjunctive management basins respectively. For cases where conjunctive management is present, the minimization technique reduces the number of configurations of independent variables from 13 to 10. A Boolean equation for the presence of conjunctive management is represented by the additive total of each of the minimized configurations of causal combinations. The results from this process are shown in Equation 4.3 below. Variables represented in capital letters signify the necessary presence of a causal condition in a configuration, and variables in lower case letters indicate the necessary absence of a causal condition in a configuration. Where a variable has fallen out of a configuration, this shows that the condition is irrelevant as a causal condition.

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[37] Boolean minimization can be done manually in relatively simple studies, usually with three or fewer variables and a few cases. More complex studies require the aid of computer algorithms. Ragin and colleagues have developed QCA software to handle this task.

EQUATION 4.3: Minimized Configurations of Conjunctive Management Cases
(1) POPDEN AGACRE STORAGE RAIN PWATER AB3030 county adjud +
(2) popden AGACRE STORAGE rain PWATER county adjud SPDIST +
(3) popden AGACRE STORAGE rain ab3030 county adjud SPDIST +
(4) popden STORAGE rain pwater AB3030 county adjud spdist +
(5) POPDEN AGACRE STORAGE rain PWATER ab3030 county ADJUD spdist +
(6) POPDEN agacre STORAGE rain PWATER AB3030 COUNTY adjud spdist +
(7) POPDEN agacre STORAGE rain PWATER ab3030 county adjud SPDIST +
(8) POPDEN agacre storage rain PWATER ab3030 COUNTY ADJUD spdist +
(9) popden agacre STORAGE rain pwater ab3030 county ADJUD SPDIST +
(10) popden agacre STORAGE rain PWATER ab3030 county ADJUD spdist

To interpret the above equation, each line is a combination of conditions or a configuration (also represented by multiplication signs in Boolean algebra). Each of these configurations signifies that those causal conditions must be found together when the dependent variable, conjunctive management, is present. The equation is the sum of various combinations of conditions (configurations). When added together, each individual configuration represents an "either/or" condition that is associated with the presence of the dependent variable. This means that any one of the combinations of conditions listed in the minimized equation could explain the presence of conjunctive management in a basin.

The first configuration, for example, suggests that conjunctive management exists in basins with all of the control variables present: high population density (POPDEN), high irrigation levels (AGACRE), high storage capacities (STORAGE), high rainfall (RAIN), and access to project water (PWATER). The presence of these control variables is combined with the presence of AB3030 Plans (AB3030) where conjunctive management occurs. At the same time, the first configuration shows that these cases are associated with the absence of county ordinances (county) and basin adjudication (adjud).

In comparing each of the individual configurations in the minimized equation for the presence of conjunctive management, some notable patterns emerge. The first pattern is that one or more of the four types of groundwater governance institutions are present in all of the ten configurations in the equation. Also, in each of the configurations, the presence of one or two types of institutions is combined with the absence of two or three alternative institutional variables. This combination of certain institutional variables with the absence of others may be explained by the fact that most basins in California do not have multiple groundwater management institutions. The results also could suggest that multiple management institutions in a basin are not conducive to the development of conjunctive management, but this does not appear to be the case. In fact, configurations 6, 8, and 9 in the equation each have two institutions present in relation to conjunctive management.

The second pattern of interest in the minimized equation for the presence of conjunctive management (Equation 4.3) is that the county ordinance variable is the only institutional variable whose presence does not appear in any configurations without the presence of another institutional variable. The presence of a county ordinance appears in configuration 6 (POPDEN agacre STORAGE rain PWATER AB3030 COUNTY adjud spdist) and configuration 8 (POPDEN agacre storage rain PWATER ab3030 COUNTY ADJUD spdist). These configurations indicate that county ordinances are related to conjunctive management in basins with a) high population density, high storage capacity, access to project water and AB3030 Plans, or b) high population density, low storage capacity, project water access and water rights in the basin have been adjudicated.

Moreover, in six of the ten configurations (2, 3, 4, 5, 7, 9, and 10) the absence of a county ordinance is related to the presence of conjunctive management. Thus, the results show that the county ordinance institution is not associated with conjunctive management projects on its own.

The control variables in Equation 4.3 also follow notable patterns. First, in seven of the ten configurations, either the presence of high population density or the presence of high levels of irrigated acres occurs. Second, the presence of high basin storage capacity appears in nine of the ten configurations. The only configuration with the absence of high basin storage capacity (configuration 8) includes terms for basin adjudication, a county ordinance, and high population density. This shows that high storage capacity is a sufficient, but not necessary variable for facilitating conjunctive management even in areas of high urban demand, where water rights are clearly defined.

Another notable result is that the presence of high levels of rainfall is associated with conjunctive management in only the first configuration of the equation. In all other configurations, low rainfall is associated with conjunctive management. This outcome supports the descriptive data on conjunctive management projects showing that conjunctive management is used most often in the water-scarce areas of southern California and the San Joaquin Valley. Finally, in seven of the ten configurations, access to project water is a key variable related to conjunctive water management. Except in one configuration (8), the presence of project water always occurs in combination with high storage capacity.

Using Boolean minimization processes, the QCA method derives a second equation to represent the causal conditions associated with the lack of conjunctive management in groundwater basins. The minimization process reduces the number of configurations representing cases that lack conjunctive management from 24 to 13, as represented in Equation 4.4.

EQUATION 4.4: Minimized Configurations of Non-Conjunctive Management Cases
(1) popden agacre pwater ab3030 adjud spdist +
(2) popden agacre ab3030 county adjud spdist +
(3) agacre RAIN pwater ab3030 county adjud spdist +
(4) popden rain pwater ab3030 county adjud spdist +
(5) popden STORAGE rain pwater AB3030 COUNTY adjud spdist +
(6) POPDEN agacre storage rain PWATER ab3030 COUNTY adjud +
(7) popden agacre STORAGE rain pwater COUNTY adjud spdist +
(8) POPDEN agacre storage rain ab3030 COUNTY adjud spdist +
(9) POPDEN agacre storage rain PWATER ab3030 adjud spdist +
(10) agacre storage rain pwater ab3030 COUNTY adjud spdist +
(11) agacre storage rain PWATER ab3030 county adjud spdist +
(12) popden agacre STORAGE rain pwater ab3030 county adjud +
(13) popden AGACRE STORAGE rain PWATER ab3030 COUNTY adjud spdist

The equation for basins that lack conjunctive management, not surprisingly, has nearly opposite patterns as those found in the equation for the presence of conjunctive management. In general, the equation shows that groundwater management institutions are not associated with basins where conjunctive water management does not occur. For example, the absence of basin adjudication appears in each of the configurations of Equation 4.4, implying that this is a necessary condition for the absence of conjunctive water management projects. The absence of special districts occurs in eleven of the thirteen configurations in Equation 4.4 and is irrelevant in the other two. Therefore, basin adjudication and special districts are not associated with the absence of conjunctive management in groundwater basins. In addition, the absence of AB3030 Plans appears in eleven of the thirteen configurations, although the presence of AB3030 Plans occurs in one configuration. Since AB3030 Plans are new and some are not well developed, this result is not surprising.

On the other hand, the county ordinance variable, which is absent in most of the configurations of Equation 4.3, is present in six of the thirteen configurations in Equation 4.4. One of these six configurations exhibits the absence of all other control variables and institutional variables, implying that these cases have little demand or physical capacity for conjunctive management. However, in five of these six configurations, at least one of the control variables is present. This suggests that the association between the presence of county ordinances and the absence of conjunctive management is not necessarily due to a lack of water demand or physical capacity.

MODEL COMPARISONS AND CONCLUSIONS

The results from the logit and QCA models overlap on a number of key points. In general, both the logit and QCA analyses point to the importance of overlying groundwater management institutions in California in facilitating conjunctive water management. Moreover, they show that institutional settings devised around the boundaries of the resource, through basin adjudication or special groundwater management districts, can facilitate conjunctive water management. Adjudication is insignificant in the logit model, but has a large effect (probably due to small number of adjudicated basins in sample). The QCA results add that adjudication is an important variable in facilitating conjunctive management, usually in conjunction with demand and physical variables. Just as important, the QCA results explain that a lack of adjudication is a necessary condition for the absence of conjunctive water management in the sample of basins.

In addition, both models indicate that county ordinances are not necessarily effective in facilitating conjunctive water management in California. The logit model shows that county ordinances have a large negative impact on the likelihood of conjunctive management. The QCA model shows that the presence of county ordinances, in fact, is often associated with the absence of conjunctive management. Unlike the logit model, the QCA model indicates that county ordinances can be associated with conjunctive water management when other institutional variables also are present.

Another key point of overlap in the two models is that water providers engage in conjunctive water management under institutional settings where they coordinate with other providers in the basin (AB3030 Plans). As mentioned in the discussion of the logit results, this outcome does not support Hypothesis 1, which claims that institutional boundaries do not need to be devised around groundwater basin boundaries. AB3030 Plans, while not devised as a single institution surrounding a basin, still provide control over basin management by coordinating across existing jurisdictions. Thus, the results bolster Hypothesis 2 that inter-jurisdictional coordination is likely to be positively related to the presence of conjunctive management programs.

With respect to the control variables used in the two models, some key differences in the results emerge. Both models indicate that high water demand (agricultural in the logit model and either urban or agricultural in the QCA model) and access to project water are associated with conjunctive water management. They differed, though, on the impacts of the basin storage variable and the rainfall variable. Despite these differences, the results are still compatible. The differences can be explained in part by the interval-level versus dichotomous measures used in the two models and by considering how these results compare to the descriptive data.

The logit results show that the probability of conjunctive management decreases as basin storage capacity increases. Although, the QCA model indicates that high storage capacity is a key variable associated with conjunctive water management. One explanation for this discrepancy is that the QCA model uses a cut-off point for high basin storage capacity at 100,000 acre-feet, and the actual data includes a few basins with nearly 7 million acre-feet of storage capacity. Therefore, while most of the conjunctive management projects occur in basins with high storage capacity, conjunctive management may not be occurring in a few very large basins. This can lead to a negative correlation between conjunctive management and basin capacity, explaining the negative coefficient for the basin storage variable in the logit model. In fact, the presence of high storage capacity is found in three configurations of Equation 4.4 for the absence of conjunctive management.

Likewise, the logit model shows that higher rainfall levels increase the probability of conjunctive water management, yet the variable for low rainfall is present in most of the QCA configurations associated with conjunctive water management. The discrepancy between the two models on the rainfall variable can also be explained. The cut-off point for dichotomizing the rainfall variable in the QCA model is 20 inches per year. Most of the areas with high rainfall are found in central and northern California, whereas a number of basins with active conjunctive management projects actually occur along the southern coast and in the San Joaquin Valley, which explains the QCA results. The logit results, on the other hand, can be explained by the fact that the rainfall levels in the southeastern regions of California, where less conjunctive management occurs, are extremely low compared to the coast and the valleys where many conjunctive management projects occur. Moreover, a few conjunctive management programs exist in the northern and central areas of the state, as supported by the QCA model. Thus, in looking at the effects of this variable as an interval level measure, it is logical that as rainfall levels increase overall, there is a positive association with the likelihood of conjunctive management projects.

In conclusion, this chapter finds that institutional arrangements play an important role in facilitating the provision of conjunctive management in California. In many cases, institutional arrangements that allow water providers to control the resource are effective; while one form of institutional arrangement, the county ordinance, that is not congruent with resource boundaries is ineffective alone. At the same time, institutions that allow local jurisdictions to coordinate water management programs, even if their boundaries are not physically congruent with the resource, can encourage the use of conjunctive management. Just as important, both models demonstrate that institutions alone do not explain decisions to engage in complex technical practices like conjunctive water management. They operate within a physical world that is vital to understanding effective water management. The QCA method and logit method arguably provide vital, if somewhat distinct, interpretations of how water demand and ground and surface water conditions can influence conjunctive water management.

V. THE ROLE OF BOUNDARIES AND COORDINATION IN CONJUNCTIVE MANAGEMENT: CROSS-STATE COMPARISON

The empirical results from the California data demonstrate that at the basin level, water providers use conjunctive management most often where institutional arrangements are in place to control groundwater pumping and fund basin-level management. This outcome supports the first principle of CPR theory, which suggests that institutional boundaries devised around resource boundaries are associated with the successful resolution of CPR dilemmas. At the same time, the California data analyses offer evidence that inter-jurisdictional coordination is a viable means for facilitating conjunctive management, even in the absence of a jurisdiction that is devised around basin-level boundaries. This evidence demonstrates that the public service industry/local public economy literature can complement CPR theory's predictions about the role of institutional boundaries.

This chapter offers a different view of institutional boundaries and the use of coordination across organizations by examining conjunctive management activities in Arizona and Colorado. It describes conjunctive management projects in Arizona and Colorado, examines the institutional arrangements associated with these projects, and compares the institutional arrangements to those in California. In doing so, this chapter shows that water governance institutions do not need to be devised around resource boundaries to address common-pool resource dilemmas. The data from Arizona and Colorado demonstrate that basin-level institutions are not necessary for facilitating conjunctive management when the larger institutional setting has clearly assigned rights to ground and surface water resources. This chapter then examines the type and degree of coordination that occurs in Arizona and Colorado in relation to conjunctive management projects. It shows that inter-jurisdictional coordination does not occur at the basin-level in Arizona and Colorado, as found in California, yet coordination does occur at the project-level and organizational-level for the purposes of providing conjunctive management.

The first section of this chapter describes the physical and institutional setting of conjunctive water management projects in Arizona and Colorado, comparing these settings to the location of conjunctive management projects in California. It examines the data in relation to the first hypothesis, which states: H1) Institutions governing water resources do not need to be organized around the physical boundaries of the resource in order for water providers to engage in conjunctive water management. Second, this chapter evaluates the jurisdictions that supply conjunctive management projects in Arizona and Colorado. It explains the organizational and institutional purpose of the entities involved in conjunctive management projects. It also describes how coordination is used to produce and fund conjunctive management projects in these two states. The organizational data in Arizona and Colorado then are compared to the data from California. These comparisons provide support for the second and third hypotheses: H2) inter-jurisdictional coordination will be positively related to conjunctive water management, and H3) basin-level coordination among providers of conjunctive water management is less likely where the larger institutional setting controls groundwater demand dilemmas.

INSTITUTIONAL BOUNDARIES AND CONJUNCTIVE MANAGEMENT:

BASIN-LEVEL EXAMINATION

The Location of Conjunctive Management Projects in Arizona

The data from Arizona demonstrate that conjunctive management projects occur only within areas where the state has imposed groundwater governance institutions. The Arizona Department of Water Resources maintained permits for 42 conjunctive water management projects in Arizona in 1997 and 1998. All of these projects operate within one of Arizona's Active Management Areas, designated by the 1980 Arizona Groundwater Management Act (see Ariz. Rev. Stat. §45-411 to 45-637). As discussed in Chapter One, the State of Arizona has quantified groundwater rights in five Active Management Areas, where growing urban and agricultural water demands have placed some of the state's abundant groundwater reserves in overdraft conditions. Also, within these areas, groundwater users are subject to the Department of Water Resource's assured water supply rules, whereby new domestic developments must obtain an adequate supply of water for 100 years. The rules allow entities to contract with groundwater replenishment districts for long-term underground storage of renewable water supplies. Water providers in the Active Management Areas have rights to recover surface or project water that is stored in underground aquifers through artificial recharge, pursuant to the Underground Water Storage, Savings and Replenishment Act (see Ariz. Rev. Stat. §45-651; §45-801).

Across the individual AMAs, urban and agricultural water demands also influence conjunctive management projects. Thirty of the 42 projects are located in the Phoenix

AMA. The Phoenix AMA has the Arizona's highest urban (municipal and industrial) and agricultural water demands, at approximately 886,321 acre-feet and 990,750 acre-feet respectively in 1997 (ADWR 2001). Seven of the remaining 12 projects operate in the Tucson AMA, where agricultural demands were 98,000 acre-feet in 1997 and municipal and industrial demands were about 212,000 acre-feet. Four projects operate in the agricultural areas of the Pinal AMA, which is located between Tucson and Phoenix, and one project is in the Prescott AMA, located in northern Arizona. The Pinal AMA's agricultural water demands were just over 820,000 acre-feet in 1997, while its urban demands were only 26,800 acre-feet. The Prescott AMA had less than 20,000 acre-feet of water demand in 1997.

Whereas most of Arizona's conjunctive management projects operate in the Phoenix AMA, Table 5.1 shows that the four projects in the Pinal AMA contributed 38 percent of the total water stored in conjunctive management projects in the state over the past ten years. After accounting for water that conjunctive management projects pumped for reuse, the projects in the Pinal AMA equal 40 percent of the net water stored through conjunctive management in Arizona. One explanation for the large contribution of these four projects to the state's overall water storage is that the Pinal AMA has the second highest agricultural water demands among the AMAs. Given the Arizona's limited water supplies, this high water demand is likely to impose a greater need for conjunctive management than areas with lower demands. Having high water demand and access to ground and surface water supplies does not mean that irrigators will automatically engage in conjunctive water management, however. Given that three of the four projects in the

Pinal AMA are in-lieu, irrigators also need other organizations to provide supplemental sources of surface water to run these projects. Another reason for the substantial recharge quantities is that Pinal's four projects have been operating since the early 1990s, comparatively longer than most projects in Arizona. The seven projects in the Tucson area had contributed only 5 percent of the state's total recharge and groundwater savings through the end of 1997. The Tucson AMA projects are relatively new, however, with only one project operating prior to 1995 and two starting in 1997.

TABLE 5.1: Total Groundwater Recharge in Arizona by Active Management Area 1989-1997, in Acre-Feet

	Active Management Area				
	Phoenix	Pinal	Tucson	Prescott	Statewide Totals
1989	775.43	175.00			950.43
1990	2,038.35	105.00	2,316.80	2,131.00	6,591.15
1991	1,838.83	190.00	2,500.00	2,128.00	6,656.83
1992	80,960.10	155,377.00	2,408.00	2,559.00	241,304.10
1993	123,640.08	215,206.00	2,618.00	2,272.00	343,736.08
1994	71,431.09	33.00	3,464.60	531.00	75,459.69
1995	132,548.14	43,625.00	13,160.00	875.00	190,208.14
1996	161,680.32	55,947.00	22,129.30	1,329.00	241,085.62
1997	314,256.61	145,438.00	34,812.40	1,510.00	496,017.01
Total AF	889,168.95	616,096.00	83,409.10	13,335.00	1,602,009.05
Recovery	(33,086.00)	(325.00)	(20,809.70)	-----	(54,220.70)
Net Recharge	856,082.95	615,771.00	62,599.40	13,335.00	1,547,788.35

The availability of surface water supplies also is related to the location of conjunctive management projects in Arizona. The scarcity of native surface water in Arizona has meant that project operators have few alternative sources to use for recharge and groundwater savings. Table 5.2 shows that 60 percent of all projects permitted in Arizona use Colorado River water through the Central Arizona Project (CAP) for either direct groundwater storage or in-lieu groundwater savings. The CAP delivery area, in fact, encompasses roughly the same areas as the Phoenix, Tucson, and Pinal Active Management Areas. Furthermore, the Central Arizona Water Conservation District can sell CAP water at reduced rates for groundwater recharge and savings, when CAP supplies exceed the quantity needed for existing contracts.[38] Five of the projects that use CAP water use additional water sources. Of Arizona's 42 projects, about 38 percent use municipal or industrial effluent.[39] Another ten percent of the projects use surface waters other than CAP water, which are mainly from the Salt and Verde Rivers coming from the Salt River Project.

Much of the water going into conjunctive management projects in Arizona is used for in-lieu groundwater savings programs. In-lieu facility permits in Arizona require that project operators exchange an equivalent amount of renewable surface supplies for groundwater that would normally be used by the project operator (ADWR 1997). Table 5.2 shows that in-lieu recharge, or indirect groundwater savings, comprises nearly 70 percent of the permitted storage capacity for conjunctive management projects in

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[38] The Arizona Water Banking Authority (AWBA) purchases incentive recharge CAP water, and uses that water for its intrastate storage. The cost for incentive recharge CAP water set by the CAWCD for 2001, which includes AWBA and municipal and industrial users, is $45 per acre foot (AWBA 2000). The AWBA, however, only pays a portion of this rate when it delivers water to in-lieu facilities because these facilities pay CAWCD about $20 an acre-foot for the use of AWBA's water, which is deducted from AWBA's price (AWBA 1999; 2000). Although, for direct recharge facilities, the AWBA pays the facility operators various rates for the use of their facilities, ranging from about $2 an acre-foot to about $20 an acre-foot (AWBA 1999; 2000).

[39] The ability of municipalities to use municipal effluent as they choose has been raised in Arizona's courts. In the 1989 Arizona Supreme Court case *Arizona Public Service Co. v. Long*, the cities of Phoenix and Tolleson were sued by two downstream appropriators when the cities began to sell their treated effluent to several utilities. In the 1970s and 1980s, the cities had been releasing their treated effluent into the Salt River and it was then used by ranchers downstream with rights to Salt River waters. The court ruled that the cities have the right to sell effluent, but if they choose to release the effluent into the stream bed it becomes surface water that is subject to the prior appropriation doctrine. (See *APS v. Long*, 160 Ariz. 429, 773 P2d 988).

Arizona. Although fewer in-lieu facilities exist than direct recharge facilities, in-lieu projects constitute the bulk of the storage capacity. In-lieu projects generally store more water than direct recharge facilities for two reasons. First, 13 of Arizona's 16 in-lieu projects are located within irrigation districts or individual farms. Farmers use in-lieu facilities to replace groundwater they would have pumped for irrigation. Since irrigation comprises between 65 and 70 percent of Arizona's total water demand, in-lieu projects are likely to require more water than direct recharge projects, which are largely operated by municipalities, to satisfy the needs of project operators.[40] Another reason why in-lieu projects use more water is that they do not require storage facilities, such as injection wells or recharge basins, meaning they involve less infrastructure and maintenance than direct recharge projects. Thus, in-lieu project operators can develop projects more quickly and can contribute a larger portion of project budgets to acquiring water supplies, compared to direct recharge projects.

TABLE 5.2: Arizona Projects by Type and Water Storage Capacity

Permit Type	Frequency	% of Total Projects	Total Permitted Storage (AF)	% of Total Storage (AF)
Direct Recharge Facilities*	25	60%	316,458	29.6%
Spreading Basin	(18)	(43%)		
Injection Well	(7)	(17%)		
In-Lieu Groundwater Savings	17	40%	752,371	70.4%
Statewide Totals	42	100%	1,068,829	100%

*Individual direct recharge facilities may involve both types of techniques

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[40] According to the Arizona Department of Water Resources (2001), water demand across the four Active Management Areas in 1995 totaled over 3 million acre-feet. Among the agricultural, municipal, industrial, and Indian sectors, agriculture was the highest water use, consuming 62% of the total AMA demand.

The Location of Conjunctive Management Projects in Colorado

All of the 42 conjunctive water management projects identified in the sample of water districts in Colorado are concentrated in two major surface watersheds – the South Platte and Arkansas River Basins.[41] The relationship between the physical and institutional settings in these two divisions is tantamount to the development of conjunctive water management, as detailed in Chapter One. Throughout Colorado, rights to groundwater that is tributary to surface water flows have been incorporated under the same prior appropriation doctrine as surface water flows in Colorado. As also discussed in Chapter One, heavy agricultural water demands and over-appropriated surface flows led the State Engineers' offices in the South Platte and Arkansas Basins to devise rules that require groundwater users to replace surface water flows belonging to more senior water users depleted by pumping.

To summarize, the State Engineer's administrative rules in the South Platte and Arkansas Basins established augmentation plans and replacement plans, under which groundwater users guarantee the quantity of water to be replaced, the source of replacement water, and the timing and location of replacement water. A water court judge must decree Augmentation Plans, although in the South Platte basin the Division Engineer can authorize temporary Augmentation Plans (Substitute Supply Plans) on a yearly basis. In the Arkansas Basin, the Division Engineer approves Replacement Plans

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[41] 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. In fact, in Division 3, records from the State Engineer's Office show that between 1994 and 1998 Division 3 contributed about 18 percent of the total statewide recharge diversions, second only to the South Platte Division (Colorado Division of Water Resources 1998a).

each year, like the South Platte Basin's temporary Augmentation Plans, allowing groundwater users to pump water out of priority if they replace the portion of water that their pumping depleted from the stream.

Conjunctive management projects occur most frequently in the South Platte River Basin (or Division One of the State Engineer's Office). These results concur with state water diversion records showing that the South Platte Basin accounted for nearly 84 percent of Colorado's augmentation and recharge diversions between 1994 and 1998 (Colorado Division of Water Resources 1998a). All of these projects operate within one of the four districts sampled in the South Platte Basin, which encompasses Morgan and Weld Counties. There are, however, recharge programs that occur in districts other than those sampled (e.g. farmers and a consortium of groups are actively developing recharge projects near the border with Nebraska). From the population of projects identified in Division One, the cumulative total volume of water going into conjunctive management activities was over 900,000 acre-feet of water as of 1998. The average quantity of water going into conjunctive management projects in this area is nearly 70,000 acre-feet per year.

Table 5.3 shows the projects identified in Colorado by basin, type of project and average quantity of water used. The South Platte Basin has 39 of the 42 projects identified in the sample water districts. In the South Platte Basin, all 39 projects are designated for some form of direct recharge. These direct recharge projects comprise about 58 percent of the water used for conjunctive management in the sample of Colorado water districts, averaging 74,260 acre-feet per year. Most of this recharge, over

65,000 acre-feet per year, occurs through ponds, basins, or stream beds. Three of the 39 projects in the South Platte basin engage in recharge through canal seepage or reservoir spills, using approximately 8,600 acre-feet per year.

TABLE 5.3: Colorado Projects by Type and Average Water Used per Year

	Frequency	Percent of Projects in Sample	Average Acre-Feet of Water per Year	Percent of Total Acre-Feet in Sample
South Platte Basin				
Direct recharge (ponds, basins)	36	86%	65,656	51%
Direct recharge (seepage, spills)	3	7%	8,604	7%
Arkansas Basin				
In-lieu	3	7%	54,000	42%
Total	42	100%	128,260	100%

The three remaining projects identified in the sample of 17 Colorado water districts are in-lieu projects operating in the Arkansas River Basin. These projects are state-authorized Replacement Plans that cover thousands of wells in the Lamar and Pueblo areas of the Arkansas Basin.[42] Since the Division Engineer rules in the Arkansas Basin did not require groundwater users to devise Replacement Plans until 1996, these projects 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. Under the Arkansas Basin's Replacement Plans, the three projects contribute 42 percent of the volume of water going into conjunctive water management in the sample water districts.

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[42] Since the NSF/EPA sample only included a sample of 30 percent of the water districts, these three projects only account for a portion of the Replacement Plans operating in the Arkansas basin. In 1998, the

The South Platte Basin has many more small-scale projects and more diverse forms of conjunctive management activities than the Arkansas Basin. The differences in conjunctive management activities between the two basins are not surprising. Unlike the South Platte basin, the Arkansas basin does not have a history of decreed Augmentation Plans nor is there significant physical capacity in the basin for direct recharge (Schlager 1999b). Moreover, in the South Platte Basin, groundwater users have access to excess flows from the South Platte River in the winter as a source for direct recharge. The Arkansas River, on the other hand, rarely has flows in excess of appropriated rights, so irrigation districts and ditch companies cannot access it as a source of recharge water (Schlager 1999b). This is confirmed by data from the Colorado State Engineer. The volume of water delivered for augmentation and recharge in the Arkansas Basin between 1994 and 1998 was approximately .002 percent of the total water deliveries in the basin, which averaged 3.3 million acre-feet per year (Colorado Division of Water Resources 1998a). Conversely, in the South Platte Basin, augmentation and recharge accounted for about 40 percent of the basin's total water deliveries each year, which averaged 4.14 million-acre feet between 1994 and 1998.

Comparison with California: Boundaries and Conjunctive Management

Compared with California, the relationship between conjunctive water management activities and the boundaries of water management institutions in Arizona and Colorado is distinct. In California, conjunctive water management is found only where local water providers have devised basin-level institutions to govern the use of

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Division Engineer approved fourteen Replacement Plans in accordance with the 1996 Amended Rules and groundwater. Projects in Arizona and Colorado emerge under institutional settings where water rights are clearly defined by the state. Arizona and Colorado also have rules governing the coordinated use of groundwater and surface waters, through storage or augmentation. In Arizona, these institutional arrangements assure that entities can store water underground through direct or in-lieu recharge and later recover that water without the fear of other entities using those supplies. Colorado's institutional arrangements guarantee that groundwater and surface water appropriators can consume their rightful shares of water. This guarantee comes from Colorado's strict enforcement of the prior appropriation doctrine and the rules requiring replacement or augmentation of surface flows by groundwater users. Thus, conjunctive management in Arizona and Colorado does not depend upon groundwater institutions that control appropriators at individual basin levels. Instead, state-level institutions ensure that water users can coordinate the use of ground and surface water supplies through conjunctive management and reap the benefits of long-term storage in Arizona or surface flow replenishment in Colorado.

Since state-imposed institutions create boundaries around all of the basins where conjunctive management appears in Arizona and Colorado, the argument could be made that basin-level institutions indeed exist. The difference is that in California, groundwater users must create basin-level institutions in order to engage in conjunctive management. This is not the case in Arizona and Colorado. Thus, conjunctive management projects in Arizona and Colorado do not depend upon efforts by water users to control basin boundaries where they store or use water.

Regulations (Bagenstos 1998).

The use of quantified water rights in Arizona and Colorado, in effect, address the demand dilemmas that Californians face in using an open-access groundwater basin. These dilemmas, as discussed in Chapter Two, can include over-appropriation and lack of basin maintenance if institutions do not exist to facilitate coordination among all water users. 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. This appears to be the case in California. In Arizona and Colorado, however, basin-level coordination is not necessary for facilitating conjunctive management since 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.

The different types of groundwater institutions in the three states also are associated with distinct methods of engaging in conjunctive water management. Looking at the purpose of conjunctive management activities, Colorado is unique. Groundwater appropriators in Colorado use in-lieu or direct recharge to replace or supplement surface water flows, rather than for long-term storage or water banking. Groundwater pumpers in Colorado engage in conjunctive management by replacing surface water they deplete from rivers. The location and timing of replacement depend upon the particular demands of senior surface water appropriators.

Compared to Colorado, Arizona's conjunctive management activities are more similar to those in California. Water users in Arizona and California engage in conjunctive management through a variety of techniques for the purpose of long-term storage or water banking. Additionally, they frequently rely on large-scale water diversion projects to provide the surface flows for underground storage. Given these forms of conjunctive management, the average volume of water going into underground storage projects each year in Arizona and California is noticeably higher than in Colorado. In Colorado, projects focus on replenishing native surface water flows depleted by groundwater pumping, which equates to a small portion of the actual water used by pumpers.

Like California, physical circumstances, water demand, and institutional arrangements in Arizona and Colorado are related to the location and the form of conjunctive management in each state. The comparative differences across these states are summarized in Table 5.4. These comparisons provide useful insights into the boundary hypothesis tested in the previous chapter. The groundwater institutions in Arizona and Colorado, though not organized at the level of individual groundwater basins, are indeed associated with the use of conjunctive management projects. The lack of association between basin-level institutions and conjunctive management in Arizona and Colorado supports Hypothesis 1, that institutions governing water resources do not need to be organized around the boundaries of the resource in order for water providers to engage in conjunctive water management.

TABLE 5.4: Comparison of Conjunctive Management Location in California, Colorado and Arizona

	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
Are surface and groundwater institutions related?	No	No	Yes
Is conjunctive management associated with basin-level institutions?	Yes	No	No
Does conjunctive management appear in the absence of groundwater governance institutions?	No	No	No
Water Supply and Demand Setting			
Does conjunctive management occur where urban water demand is high?	Yes	Yes	No*
Does conjunctive management occur where agricultural demands are high?	Yes	Yes	Yes
Does conjunctive management occur where native surface supplies are abundant?	Sometimes	No	Yes
Does conjunctive management occur where imported surface supplies are abundant?	Yes	Yes	Sometimes
Does conjunctive management occur where groundwater basins have high storage capacities?	Yes	Yes	Sometimes

*Conjunctive management does not occur in large urban areas in this sample of Colorado water districts. Historically, municipalities have satisfied residents' water demands through large surface water storage and distribution projects. Although, a small number of conjunctive management projects have been started in the Denver area.

In summary, the reason why conjunctive management appears in Arizona and Colorado in the absence of basin-level institutions is that state-level institutions exist – in these cases as quantified water rights -- to control demand dilemmas across basins. As discussed, demand dilemmas are associated with open-access CPRs that lack institutional mechanisms for excluding potential users, whereby individual users have no incentives to conserve resources knowing that anyone can deplete the resource. Thus, quantified water rights in the Arizona and Colorado cases create resource exclusion, without basin-level institutions. This section also explains why conjunctive management in California is associated with basin-level water governance institutions and with multi-jurisdictional arrangements that manage groundwater basins. These arrangements allow appropriators to control the basin in California and engage in conjunctive water management. The relationship between institutional boundaries and conjunctive management are evaluated further in the following section, by looking at the jurisdictions and organizations that engage in conjunctive management. It will also consider how the institutional settings discussed in this section influence the type of coordination used in conjunctive management programs.

BOUNDARIES AND INTER-JURISDICTIONAL COORDINATION: PROJECT-LEVEL ANALYSIS

This section describes the organizations that provide and produce conjunctive management to determine the role of boundaries at the sub-state level in Arizona and Colorado and to examine the use of inter-jurisdictional coordination. If state-imposed groundwater institutions in Arizona and Colorado have controlled demand dilemmas within groundwater basin boundaries, then inter-jurisdictional coordination at the basin-level, as found in California, would not be necessary for providing conjunctive management, as suggested by Hypothesis 3. In controlling groundwater demand dilemmas, the states' water rights regimes assure that water providers can store water underground and legally recover that water without the risk of losing water to other appropriators. Second, given their larger institutional settings, do the data in Arizona and Colorado still support Hypothesis 2, claiming that inter-jurisdictional coordination is positively associated with the provision of conjunctive water management? If so, how? This section evaluates the organizations that fund and participate in conjunctive management in Arizona and Colorado and presents data on the extent to which these organizations coordinate to provide conjunctive management projects. It then compares these results to the data from California.

Providers and Producers of Conjunctive Management in Arizona

Table 5.5 shows that 36 organizations or political jurisdictions participate in Arizona's 42 conjunctive management projects. Some organizations manage and fund projects, while many also participate in project production by supplying water. Among the state's 42 projects, 13 different municipalities manage 19 projects. Municipalities also participate in six of the state's 42 projects in some production capacity, but do not manage these six projects. Twelve irrigation districts, which are special purpose governments authorized by the state legislature, manage 10 of Arizona's 42 projects. Irrigation districts are involved as water suppliers in four more projects. Nine private corporations participate in Arizona's conjunctive management projects. They manage nine different projects and participate in supplying inputs to four additional projects. The Central Arizona Water Conservation District (CAWCD), which is a special purpose government, funds four projects. CAWCD and the state water bank together supply water to 14 additional projects.

TABLE 5.5: Organizations Participating in Arizona Projects

Organization Type	# of Orgs	# of Projects Managed by Org Type	# of Projects Supplied by Org Type*
Municipal Water Agency/Dept.	13	19	6
Special Districts (Irrigation /Water)	12	10	4
Private Corp./Utilities	9	9	4
State Water Bank and CAWCD	2	4	14
Total	36	42	28

*The projects supplied by Arizona organizations are included in the 42 projects managed by the organizations. This category represents the number projects in which each group of organizations participates, but does not manage or fund.

The organizations responsible for producing conjunctive management in Arizona differ across organizational form and purpose. The size of the organizations in terms of geographic extent, individual members, and organizational resources differ widely. The jurisdictional area of these organizations range from two square miles to over 23,000 square miles. The number of members or customers ranges from five to 22,676. The number of full-time employees ranges from one to 575 among these organizations.

A variety of types of organizations are active in producing conjunctive management projects in Arizona, although a few large organizations are responsible for managing or funding the bulk of conjunctive management activities, when considering project storage capacity. Table 5.6 indicates that five out of 42 recharge and recovery projects in Arizona hold 68% of the storage capacity for all projects in the state. For example, the Salt River Project (SRP) holds the permit for the largest in-lieu project in the state. The permit allows the organization to purchase up to 200,000 acre-feet per year of CAP water from eight municipalities and from the Central Arizona Water Conservation District to reduce the utility's groundwater reliance. The City of Tucson Water Department is responsible for providing, or jointly providing, three of the seven projects within the Tucson AMA and maintains permits to participate as water suppliers in two more projects.

At the same time, Table 5.6 shows that the average number of production participants per project increases with project size based on storage capacity. 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 from nine organizations, although, SRP is the principal organization responsible for project management.

TABLE 5.6: Concentration of Conjunctive Management Provision in Arizona

Storage Permit Quantity (AF)*	# of Projects	Average # of Project Providers	% of Total State Storage Capacity
<10,000 AF	24	1.2	7%
10,000 to 99,999 AF	13	2.9	25%
100,000 to 200,000 AF	5	6.2	68%
All Projects	42	2.3	100%

*Total Storage Capacity of AZ Permits = 1,075,879 AF Min = 120 AF Max = 200,000 AF
Mean Storage Capacity = 25,616 AF (St. Dev. = 48,878)

Participation in Arizona's conjunctive management projects by multiple water providers constitutes what the public service industry literature deems coordination. In this case, coordination occurs within individual projects, rather than across all water providers in a basin. The public service industry (or local public economy) literature says that jurisdictions can co-provide services, through joint-funding arrangements, or can coordinate the production of a service by contracting out or joint-production (Oakerson 1999). Project-level coordination in Arizona occurs in a couple different ways: for funding project construction, or capital costs, and for sharing project production inputs.

Coordination to fund the construction and maintenance happens in four of Arizona's projects, or 10 percent of the cases.[43] Two of these projects are direct recharge facilities in the Tucson AMA and two are direct recharge facilities in the Phoenix AMA. Three organizations fund one of the Tucson AMA facilities and two organizations fund the other facility. One of the projects in Phoenix relies on funding from a city and a private organization that supplies the effluent water for the project. The other jointly funded project in the Phoenix AMA, the Granite Reef Underground Storage Project (GRUSP), which is managed by the Salt River Project (SRP), received funding for the capital costs of the project from each of the nine organizations originally permitted to store water at the site, including SRP. The organizations that provide funding for these four projects all are permitted as primary providers of other conjunctive management facilities throughout the Tucson and Phoenix AMAs.

Organizations coordinate most often to produce projects through water storage and acquisition. Table 5.7 shows that 20 out of 42 projects in Arizona have 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, is 2.4 per project. Of the 20 projects with multiple water suppliers, the average number of organizations involved per project is 4.4. Some 15 percent of the projects are permitted with more than four water suppliers per facility.

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[43] To identify joint-provision arrangements using the NSF/EPA data set, I defined inter-jurisdictional coordination as the presence of more than one organization responsible for funding and project maintenance.

TABLE 5.7: 1997 Water Storage Participants in Arizona Projects[a]		
Number of Participants Per Project[b]	Frequency	Percent of Total
1	22	52%
2 to 4	14	33%
5 to 7	4	10%
8 to 10	2	5%
	42	100%

[a]Based on ADWR permits holders per project
[b]Mean Number of Participants per Project = 2.4 (St. Dev = 2.23)

While it may appear that the water storage arrangements among producers of Arizona's conjunctive management projects constitute mere market exchanges for project inputs, they actually are forms of coordination according to the public service industry literature. Any one of these organizations could choose to produce a conjunctive management project on their own through in-house provision and production. In-lieu recharge providers, for example, could go out and purchase a supplemental source of surface water and then obtain groundwater savings credits on their own for not using their groundwater. This does not occur. Indeed, most in-lieu providers pay for supplemental supplies of surface water to engage in conjunctive management, but the surface water suppliers play a key role in producing these conjunctive management projects. They receive credits for selling the water that could be used otherwise, which is then saved for future use. Thus, in-lieu projects do not occur without water suppliers acting in coordination with a water user that wishes to use the water in-lieu of pumping groundwater. Likewise, the sellers of water to these projects could use that water to produce conjunctive management projects on their own. They could, for example, develop recharge basins and then store their own water in their own recharge basins, leaving out any other participants in the project. Instead, they take advantage of an opportunity to coordinate production of conjunctive management projects.

The opportunity exists for organizations involved in Arizona's recharge projects to coordinate in other parts of the production process by sharing facilities such as wells, pipelines and turnouts, and monitoring equipment. Such coordination, however, is rare. Two projects involved multiple organizations during the construction phase of the recharge facility. One project includes multiple organizations participating in facility maintenance and five projects have multiple organizations participating through recovery well permits.[44] With the exception of the CAWCD and SRP, whose pipelines deliver water directly to water providers, no organizations supply distribution facilities to projects unless they are already participating in project funding.

Over 50 percent of the projects involve only one organization. Municipalities are responsible for 68 percent 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 AMAs. All of the projects operated by municipalities and five of the seven projects operated by private water companies are direct recharge facilities. The average volume of water going into these projects is about 4,800 acre-feet per year. The remaining two projects

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[44] Recovery well permits are not designated to any particular facility. 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 AMA. To measure co-production through recovery well permits the coding forms were evaluated to identify facilities with more than one participating organization that also holds recovery well permits in the AMA.

operated by private water companies or utilities are in-lieu. Both of the in-lieu projects are small, averaging 200 to 300 acre-feet of storage per year.

The dominant actors that produce Arizona's conjunctive management projects, considering project participation and water storage, are the state-sponsored special districts – the Arizona Water Banking Authority (AWBA) and the Central Arizona Water Conservation District (CAWCD). Table 5.8 lists the long-term storage credits for groundwater savings and recharge in Arizona through 1997, by the type of organization that stores water at a facility. According to this data, the AWBA and the CAWCD together hold about 70% of the long-term storage credits available in Arizona. While these organizations incur costs of delivery and state permits to bring water to direct recharge and in-lieu recharge facilities, in most cases they do not manage or provide direct funding for the construction of direct recharge projects. The AWBA, in fact, does not manage or directly fund any facilities in the state. CAWCD holds permits for four of the state's 42 projects as of 1997, two of which are constructed recharge facilities for which it provided funding and maintenance.

TABLE 5.8: Arizona's 1997 Long Term Storage Credits by Provider Type

Entity Type	Long Term Storage Credits (AF)	% of Total Credits
State Special Districts (AWBA & CAWCD)	1,065,763	70%
Municipal	405,033	27%
Irrigation/Water/Utility Districts	29,150	2%
Private Corporation	12,442	1%
Total	1,512,388	100%

Providers and Producers of Conjunctive Management in Colorado

The types of entities involved in conjunctive management in Colorado, as well as the forms of coordination occurring among these organizations, differ from those in Arizona. In general, most of the organizations that provide conjunctive management in Colorado are private, whereas most of the projects in Arizona involve municipal water departments or special districts. Among the projects identified in the sample of Colorado water districts, 11 private or non-profit organizations participate in 24 conjunctive management projects. Four irrigation districts participate in 16 different projects. The private and non-profit organizations and irrigation districts fund conjunctive water management through fees paid by its members, who are required to comply with Augmentation or Replacement Plans. They use these funds to acquire supplemental water supplies and to develop recharge sites. Eight private farmers or individual families participate in 12 projects as land owners of recharge sites or as providers of individual Augmentation Plans. Three municipalities participate in producing five conjunctive management projects by supplying water to the private or non-profit well-owner associations that manage projects. One state-agency is involved in the provision and production of a recharge site in the South Platte Basin. Among the 27 organizations involved in the Colorado projects, 11 participate in multiple projects.

Like Arizona, about half, or 20 of the 42 Colorado projects involve multiple organizations. The highest number of participants in the Colorado sample is four organizations per project. Among the 42 projects in the sample, the average number of organizations per project is 1.6, which is slightly lower than the number of participants in

Arizona's projects. As shown in Table 5.9, all of the projects using under 10,000 acre-feet per year include an average of 1.5 organizations, but the four projects over 10,000 acre-feet average 2.25 organizational participants.

TABLE 5.9: Organizational Coordination in Colorado Projects

Average Volume of Water Used*	# of projects	Average # of Organizations
<1,000 AFY	18	1.56
1,000 to 9,999 AFY	20	1.50
10,000 to 25,000 AF	4	2.25
All Projects	42	1.60

*Total Water Use Per Year = 131,144 acre-feet per year   Min = 77 AF   Max = 24,000 AF
Mean Water Use Per Year = 3,122.5 acre-feet per year   (St. Dev. = 4,878.8)

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 share 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 contract with one or two private firms or individuals either to use land for recharge or to lease water as a stream replenishment source. Table 5.10 presents all of the conjunctive management operations in the sample districts of the South Platte Basin, organized by managing, or provision, organizations. It shows which projects involve multiple entities and the types of partners involved in each project and the quantity of water stored by each project.

TABLE 5.10: 1998 Conjunctive Management Projects in Sample Districts of the South Platte Basin

Managing Organization	Project /Type	Other Participants	Av AF Stored/Yr	Total AF Stored
Bijou Irrigation District				
	Bijou Ditch/Canal		4,189	58,650
	Bijou Recharge Pond 1		846	12,696
	Bijou Recharge Pond 2		307	4,600
	Bijou Creek		4,108	45,192
	Kiowa Creek Recharge	Central CO Water Conservancy District	3,456	51,833
	Milliron Draw Recharge Area	Central CO Water Conservancy District	581	8,722
	Goedert Recharge Area	1 landowner	1,350	2,699
	Lost Creek West Pond	Equus Farms	942	11,302
	Lost Creek East Pond	Equus Farms	843	10,117
Fort Morgan Irrigation District				
	Dagenhart/Lundock Recharge Area		77	851
	Fort Morgan Canal		4,049	76,937
	Badger Creek		3,613	65,037
	Charles Henry Pond	1 landowner	761	9,888
	Bolinger Recharge Area	City of Brush; Ducks Unlimited; CO Division of Wildlife	2,267	43,078
	Public Service Pond	Fort Morgan Irrigation District; Public Service of Colorado	387	5,809
	DT Ranch Recharge	DT Ranch	82	247
	South Side Lateral Recharge	2 landowners	529	1,057
	Reed Recharge Ponds	Fort Morgan Ditch Company	1,207	1,207
Lower Platte & Beaver Canal Company				
	Lower Platte & Beaver Ditch		2,534	17,740
	Daily Recharge Area		737	5,899
	Emerson Lake/Seaman	1 landowner	543	8,148
	Wind Recharge Pond		259	4,915
Upper Platte & Beaver Canal Company				
	Upper Platte & Beaver North Ditch		706	9,880
	Beaver Creek/South Ditch		572	6,867
	Kemble Recharge Area		1,156	15,028
	Clark Recharge Area		1,898	11,385
	Dagenhart Recharge Area		376	1,879
Pioneer Water and Irrigation Company				
	Pioneer Ditch		2,382	33,345
	Woodward West Lake		808	11,305
	Woodward East Lake		1,487	20,818
	Peterson Recharge Area		362	2,899
Riverside Irrigation Company				
	Riverside Reservoir Recharge		2,538	25,380
	Vancil Recharge		7,287	
	Goodrich Farms Recharge Area	Goodrich Farms	2,769	41,542
	Antelope Draw Recharge	Farmers State Bank	2,704	27,042
	Headley Recharge	Farmers State Bank of Brush	2,700	16,198
	National Farms Ponds	National Hog Farms	2,814	25,322
	Equus/Riverside Ponds	Equus Farms, Inc	2,211	58,634
	Sublette Recharge Ponds	Sublette Water Co.	10,010	150,152

In the Arkansas Basin, two of the three organizations operating in-lieu programs contract with other entities that provide surface water supplies for their projects. The Arkansas Groundwater Users Association (AGUA) contracts 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 (CWPDA) leases about 10,000 acre-feet per year of water from a local municipality and from a water conservancy district for its in-lieu project. The third organization operating an in-lieu project in the Arkansas Basin sample districts is the Lower Arkansas Water Management Association (LAWMA), which owns all of its replacement water equaling about 14,000 acre-feet per year.

While inter-organizational coordination is not widespread across the Colorado projects in this sample, another level of coordination plays a role in Colorado's conjunctive management activities. This coordination occurs across individual groundwater users who are members of 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 pumpers to replace the stream flow augmentation obligations of their members.

In the sample districts within the South Platte Basin, the six principal organizations listed in Table 5.10 combined have nearly 800 individual members. These organizations act as umbrella companies to fund the acquisition or leasing of surface water supplies and for developing and maintaining recharge sites for individual members. The use of such umbrella organizations has been common throughout the South Platte basin since the 1970s. Two organizations that were not included in the NSF/EPA sample, the Central Colorado Water Conservation District (CCWCD), and the Groundwater

Appropriators of the South Platte (GASP), cover thousands of wells under temporary plans of augmentation in the South Platte Basin (MacDonnell 1988).

The three organizations engaged in conjunctive management in the Arkansas River Basin also coordinate conjunctive management activities for individual well owners. The three water user associations combined organize Replacement Plans for nearly 3,000 wells and over 900 individual members. The Arkansas Groundwater Users Association (AGUA) has 290 members with nearly 500 wells. The Colorado Water Protection and Development Association (CWPDA) has 490 individual members and approximately 900 member organizations, covering 1,819 wells. The Lower Arkansas Water Management Association (LAWMA) covers 640 wells for its 221 individual members. These three organizations 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 those were four other water user associations (Bagentos 1998). These four organizations each cover about 30 wells, on average.[45]

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[45] The argument could be made that Colorado's well-owner association, 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 association 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.

Comparison with California

In comparing the provision and production arrangements in Arizona and Colorado to California, this section focuses on three key points. First, the provision and production arrangements in Arizona and Colorado bolster the data analyses from the first section, which imply that the state, in defining property rights, has resolved the need for basin-level jurisdictions, supporting Hypothesis 3. Second, the evidence from Arizona and Colorado supports Hypothesis 2, which explains that inter-jurisdictional coordination is likely to be positively associated with conjunctive management activities. Third, the cross-state data demonstrate that coordination among providers and producers of conjunctive water management can emerge at different levels.

Table 5.11 summarizes the types of organizations that participate in conjunctive management and their level of involvement, which highlights the different types of organizational-level boundaries associated with the provision of projects across the three states. In California, special districts are the most common organizations involved in providing and producing conjunctive management activities. These special districts, as noted in the previous chapter, 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.

TABLE 5.11: Organizations Participating in Conjunctive Water Management Projects

California (sample basins)	# of Orgs	# of Projects
Special Water Districts/Agencies	13	17
Irrigation Districts	5	10
County Water Agencies/Department	6	7
Federal Agencies	3	5
Arizona	# of Orgs	# of Projects
Municipal Water Agency/Department	13	25
Special Districts (Irrigation /Water)	12	14
Private Corp./Utilities	9	6
State Water Bank and CAWCD	2	18
Colorado (sample districts)	# of Orgs	# of Projects
Private or Non-Profit Water Companies	11	24
Private Family/Farm	8	12
Irrigation or Water Cons. Districts	4	16
Municipal or State Agency	3	3

The data on the organizations involved in conjunctive management in Arizona and Colorado further support the hypothesis that institutional boundaries do not need to be devised around resource boundaries in order to manage the resource successfully. None of the organizations involved in conjunctive management in Arizona and Colorado are devised around groundwater basin boundaries. In Arizona, the most common form of organization involved in conjunctive management is a municipality. The AWBA and CAWCD, 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. California also has various organizations involved in conjunctive management that are not devised around basin boundaries, but these organizations also operate under basin-level groundwater governance institutions. Clearly, Arizona and Colorado have groundwater governance institutions as well, in that they have quantified rights to groundwater. However, unlike California, these institutions are not devised around individual basins.

The coordination that occurs across projects in Arizona and Colorado lends support to Hypothesis 2, showing that inter-jurisdictional coordination can facilitate conjunctive management. However, the type of coordination in Arizona and Colorado is distinct from the coordination present in California. The previous chapter shows that conjunctive water management in California requires some form of coordination at the basin level. This is demonstrated by the fact that conjunctive management is found in those basins where water providers have established basin-wide governance structures or institutions, and where jurisdictions work together on groundwater management plans.

In Arizona and Colorado, where the state defines rights to groundwater, coordination does not occur across basin-level boundaries. These findings support Hypothesis 3. The main form of coordination in Arizona, in general, is surface water supply arrangements at the project-level. This coordination occurs across various types of organizations in Arizona. Municipalities supply water to six projects operated by other jurisdictions; while the state water bank and CAWCD supply water to 14 different projects that are managed or funded by other entities. Coordination does appear in California at the project-level, but coordination in the sample basins averages under two organizations per project, similar to Colorado, shown in Table 5.12.

TABLE 5.12: Participants in California Projects Within Sample Basins[a]		
# of Participants Per Project[b]	Frequency	Percent of Total
1	19	56%
2 to 4	13	38%
5 to 7	1	3%
8 to 10	1	3%
	34	100%

[a] Includes funding organizations and water suppliers
[b] Mean Number of Participants per Project = 1.97 (St. Dev = 1.5)

Across all three states, project-level coordination occurs most often for the purpose of surface water supply contracts and leases. In a few cases, coordination appears across organizations at the project level for sharing recharge facilities or project funding. In Arizona, the level of coordination at the project level is higher than the other two states, based on participants per project. At the same time, Colorado is distinct because coordination occurs within organizations, by bringing together hundreds of individual well owners to satisfy stream replacement obligations. The difference in Arizona and Colorado from California is that organizations do not coordinate their efforts in order to gain control of a basin in an effort to facilitate conjunctive management.

Table 5.13 summarizes the differences across the three states in the types of organizations operating conjunctive management projects and the level of coordination associated with the provision of conjunctive water management.

TABLE 5.13: Comparison of Organizations Providing Conjunctive Management and Coordination

	California	Arizona	Colorado
Organizations Providing Conjunctive Management			
Are organizations that provide conjunctive management organized at basin-level boundaries?	Frequently	No	No
Do sub-state governments, including municipalities, 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

CONCLUSIONS

The data analyses in this chapter have shown that water users in Arizona and Colorado engage in conjunctive management under institutional and organizational arrangements that are distinct from those in California. First, where California's conjunctive management programs are closely linked to basin-level institutions, conjunctive management in Arizona and Colorado is not associated with basin-level water governance. This provides support for Hypothesis 1, claiming that institutional boundaries do not need to be defined around a groundwater basin to facilitate conjunctive management. The distinguishing point in the Arizona and Colorado cases is that, unlike California, conjunctive management occurs under institutional settings where groundwater rights are quantified by the state and water users can be assured that they will reap the benefits of storing or using water though conjunctive management programs. This also lends support to Hypothesis 3, which states that basin-level coordination among providers of conjunctive water management is less likely where the larger institutional setting controls groundwater demand dilemmas.

Second, the descriptive data in this chapter indicate that provision arrangements in Arizona and in Colorado involve inter-jurisdictional coordination in about 50 percent of each state's projects. In Colorado, coordination also occurs within organizations to facilitate conjunctive management production across multiple individuals. This supports the assumptions taken from public service industry theory suggesting that jurisdictions can coordinate their efforts to provide conjunctive water management services that affect multiple jurisdictional boundaries, as predicted by the second hypothesis. As stated in Chapter Two, such arrangements allow small-scale jurisdictions to engage in conjunctive water management in a way that eliminates the need for a large centralized authority for CPR management.

The question remains as to why coordination occurs in these three states for some conjunctive management projects, while no coordination appears in others. One of the implications of the cross-state comparison is that quantified groundwater rights can explain why basin-level coordination does not appear in Arizona and Colorado. The factors that influence coordination at the project-level are explored in the following chapter.

VI. INTER-JURISDICTIONAL COORDINATION IN CONJUNCTIVE MANAGEMENT PROJECTS

This chapter examines the factors that influence the use of coordination in the provision and production of conjunctive management projects. It also examines how coordination affects the outcomes of conjunctive management projects. The previous chapter distinguished among basin-level, organization-level, and project-level coordination associated with conjunctive management in Arizona, Colorado, and California. The previous chapter also discussed the purpose of different forms of coordination, but it did not explain why jurisdictions would choose to coordinate conjunctive management projects or how such coordination impacts projects. This chapter specifically considers a) the factors that influence inter-jurisdictional coordination at the project-level and b) the role that coordination plays in project cost-efficiency.

The first section of the chapter demonstrates that the factors influencing project-level coordination are distinct from the conditions that lead to basin-level and organizational-level coordination. It reviews the types and purposes of coordination identified in the previous chapter and discusses how CPR theory and local public economy theory help explain these forms of coordination. The cross-state analyses demonstrated that basin level coordination in the provision and production of conjunctive management is less likely where state laws assign groundwater rights, as predicted by Hypothesis 3. Given the different forms of coordination identified across the three states, this chapter explains why project-level coordination in Arizona is appropriate for testing

Hypotheses 4a and 4b. Hypothesis 4a explains that projects with high production capacities are likely to be produced through inter-organizational coordination. Hypothesis 4b adds that coordination is positively related to project cost-efficiency, or lower costs per unit of project output, controlling for project size. The second section of this chapter evaluates data in Arizona to consider how well these hypotheses explain coordination occurring across jurisdictions that produce conjunctive management projects.

THE REASONS FOR INTER-JURISDICTIONAL COORDINATION

Types of Coordination Associated with Conjunctive Management: Summary

Chapter Five demonstrated that different types of coordination play a role in facilitating conjunctive management across Arizona, California, and Colorado. One form of coordination that is associated strongly with the provision of conjunctive management in California is the organization of basin-level groundwater management institutions, such as special districts and AB3030 plans. 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.

Another form of coordination is associated with conjunctive management projects in Colorado. This coordination occurs at the level of private or non-profit organizations, mainly through well-owner associations that fund and produce much of the conjunctive management projects in Colorado. These well-owner associations coordinate the efforts of individual groundwater users. Using association membership fees, well-owner associations acquire supplemental water supplies for members and replace stream depletions caused by members' pumping. Unlike California's groundwater management institutions, Colorado's well-owner associations are not devised around basin-level boundaries. The purposes of the well-owner associations in Colorado are not to control basin boundaries and coordinate basin-wide management. Instead, they coordinate the production of individual conjunctive management projects for their members.

Chapter Five also described project-level coordination across organizations that provide and produce conjunctive management. Coordination at the project-level appears in just under half of the projects in each of the three states. Across the three states, project-level coordination occurs for different purposes. For example, some projects involve coordinated funding arrangements for project construction and maintenance, or for developing distribution facilities. Chapter Five suggested that the primary purpose of coordination in conjunctive management projects is project production, rather than funding or monitoring, since surface water supplies are the key component of these production arrangements.

WHY COORDINATION?

Chapter Two examined how public service industry theory and CPR theory compare in their explanations of coordination. This section reviews the theory and the assumptions underlying hypotheses 4a and 4b. In doing so, it considers how the theoretical explanation of project-level coordination differs from and is similar to explanations of basin-level and organizational-level coordination.

The theory chapter questioned whether local public economy theory adequately explains coordination in the production of a public good or service. The local public economy literature implies that cost-efficient service production prompts jurisdictions to coordinate public service production. The theory suggests that multi-organizational systems of service production can achieve cost-efficiency because of the fragmented, or polycentric, structural features of a public service industry. These features include a) functional specialization of organizations, b) production that is differentiated to match characteristics of diverse goods and services, and c) competition among producers. The problem with the literature is that it does not clearly differentiate between the reasons why jurisdictions choose to coordinate and the outcomes of coordination.

The theory chapter also considered how CPR theory informs local public economy theory and helps explain inter-jurisdictional coordination. It suggested that CPR theory's basic condition for cooperation – that the benefits of cooperating outweigh the costs – helps explain cooperation. CPR theory shows that the transaction costs of coordinating among a group must not be higher than the benefits of coordination, (ie. controlling a collective action dilemma) in order for coordination to arise. This point is supported implicitly by the local public economy literature. Recognizing that cost-benefit calculations and transaction costs are points of overlap in the two theories helps explain all three forms of coordination discussed in the last chapter. For example, CPR theory suggests that a basic condition for the emergence of basin-level coordination, as found in California, is that the benefits of organizing basin-level institutions outweigh the transaction costs associated with the formation of these institutions (Ostrom 1990; Taylor and Singleton 1993).

When focusing on public service production, versus the resolution of some collective action dilemma facing a group of resource users, the theory chapter demonstrated that transaction costs also are important in explaining the benefits of coordination. The transaction costs that influence coordination involve information costs, bargaining costs, and monitoring and enforcement costs. Transaction costs are not only associated with the process of coordinating a group of individuals or a group of organizations. Transaction costs also affect the process of producing goods and services. Thus, one of the benefits of coordination may be reducing production-side transaction costs, while one of the drawbacks of coordination may be creating organizational transaction costs. In Colorado, for instance, well-owner associations can lower the production-side transaction costs associated with acquiring water, recharging water, and monitoring conjunctive management activities for individual well owners. At the same time, these well owners face certain transaction costs in forming the associations. One would predict that well-owner associations in Colorado are likely to form when the transaction costs of creating the organizations do not exceed the benefits they can achieve by reducing the transaction costs of conjunctive management production.

The theory chapter demonstrated that the way in which transaction costs influence cost-benefit calculations depends on the purpose of coordination. CPR literature, for instance, emphasizes the various physical, community, and institutional conditions that reduce coordination transaction costs, and therefore increase the likelihood of resolving collective action dilemmas. Again, collective action dilemmas arise where individual rational action among a group leads to inefficient outcomes, while individuals in such a group can achieve better outcomes through coordination. According to CPR theory, conditions such as group homogeneity and small group size can reduce the transaction costs associated with coordinating across individuals facing collective action dilemmas. In resolving a collective action dilemma, the transaction costs of coordinating can be extensive because individuals are faced with the possibility any individual within a group can free-ride off the efforts of others in a group to manage the supply or limit the demand of a shared good or resource. If, however, the larger institutional setting addresses collective action dilemmas, such as those affecting groundwater users in California, then the purpose of coordination changes and the key factors influencing coordination also are likely to change.

In settings where rights to the resource are quantified, coordination is likely to be used for reducing the costs associated with producing a project. This is not to say that the transaction costs of bringing jurisdictions together to coordinate have no impact on project-level coordination, but they are more negligible than the transaction costs that affect groups facing collective action dilemmas. Where rights to resources are quantified, entities do not have to deal with the same information, contracting, and enforcement costs of resolving collective action dilemmas. Individuals cannot easily free-ride off a public service that they do not fund when rights to the good or resource are clearly quantified. In other words, the collective action dilemma is addressed under these conditions because individuals do not have to be concerned that other entities can benefit from efforts to manage the supply. In this case, the local public economy literature's assumptions about the benefits of coordination may offer an appropriate explanation of coordination. The literature explains that coordination can reduce production costs, including production-side transaction costs, or create economies of scale for public service production. Of course, the CPR literature can still be beneficial to explaining the reasons why some organizations would coordinate in similar production situations. This chapter, however, tests the adequacy of the local public economy literature for explaining coordination that occurs for producing conjunctive management projects.[46]

The data analyses in the second portion of this chapter consider whether the local public economy literature can adequately explain the reason for coordinated production of conjunctive water management projects in settings where the larger institutional setting controls collective action dilemmas associated with water use. As discussed in the

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[46] While it is important to test the theory explaining basin-level and organizational-level coordination, quantitative tests on these forms of coordination using this data set are not feasible. The observations of these forms of coordination do not present sufficient variation for statistical analysis. The data from California does not present variation in basin-level coordination related to the use of conjunctive management. Conjunctive management only occurs in basins where water providers and users have organized institutional arrangements to govern groundwater. Similarly, in Colorado, a lack of variation exists across the providers of conjunctive management. All projects in the data set are managed or produced primarily by well-owner associations or irrigation districts. There is variance, however, in the level of coordination associated with the provision of individual projects in the data set.

theory chapter, the literature shows that the organizational structure of a water industry creates opportunities for jurisdictions to achieve efficiency in the production of water resources and water management services. This structure includes functional specialization of organizations, differentiated organizational scales of organizations and competitive pressures among multiple service producers (Oakerson 1999). Organizations in a water industry can take advantage of these structural features to achieve cost-efficiency by coordinating service production. Thus, the implication is that cost-efficiency is a benefit of coordination when organizations seek to achieve economies of scale in service production. The need for coordination, however, depends on whether jurisdictions can achieve economies of scale in-house. Hypotheses 4a and 4b, therefore, attempt to clarify how the public service industry literature explains the reasons for and the benefits of coordinating conjunctive management projects.

Hypothesis 4a explains that projects with high production capacities will be positively related to coordinated production of conjunctive water management projects. Thus, smaller projects, or those that can be produced more easily by individual organizations, are less likely to require project-level coordination. Certainly, large-scale jurisdictions may be capable of producing large-scale projects on their own, given their capacity to acquire extensive project inputs. However, the public service industry literature, suggests that in a water industry of multiple and overlapping jurisdictions, multiple opportunities exist for jurisdictions to coordinate production and acquire alternative sources of production. Hypothesis 4b adds that coordination is positively related to project cost-efficiency, or lower costs per unit of project output, controlling for project size.

PROJECT-LEVEL COORDINATION IN ARIZONA: DATA ANALYSES

The population of projects in Arizona provides the empirical setting for analyzing project-level coordination. Project-level coordination also occurs in the California and Colorado samples, but combining projects from all three states is not appropriate for quantitatively analyzing project-level conditions. First, the Arizona data include a population of projects, while the California and Colorado data include projects identified in sample regions. Second, the sampling frames in California and Colorado are different from each other. The population of projects in Arizona, therefore, is most appropriate for evaluating the hypotheses on project-level coordination.

This section examines the data on Arizona's conjunctive management projects to evaluate Hypotheses 4a and 4b. First, it evaluates how project-level coordination is related to project production capacity. Second, it examines whether project-level coordination is related to project cost-efficiency or economies of scale. Cost-efficiency is concerned with reducing the cost of project production per unit of benefit. Economies of scale can be achieved by improving cost-efficiency relative to project size. Finally, this section examines some of the cost-efficiency differences between single participant projects and multiple participant projects to supplement the quantitative analyses.

Project-Level Coordination and Project Production: OLS Model

This section presents an Ordinary Least Squares (OLS) multiple regression model to evaluate the relationship between project production capacity and project coordination.

Hypothesis 4a explains that projects with high production capacities will be positively related to coordinated production of conjunctive water management projects. This hypothesis should not suggest that project size is a given. Organizations clearly have choices over how large or small the capacity of a project should be. Factors such as economies of scale are likely to influence scale decisions. What the public service industry literature indicates is that the likelihood of water providers coordinating the production of projects increases when projects can be efficiently produced at larger scales. Therefore, in analyzing the relationship between production capacity and coordination, it is assumed that project providers can choose project production capacity based on economies of scale concerns.

Project Participation as an Indicator of Coordination

The dependent variable for the regression analysis is project coordination. The indicator for coordination is the number of organizations participating in a conjunctive management project, as identified in Chapter Five. The previous chapter explained that coordination at the project level occurs most often for project production purposes, often through arrangements for supplying water to projects. It also described other ways in which project coordination occurs, such as joint funding or cooperation through various project inputs. For instance, the largest direct recharge project in the state is the Granite Reef Underground Storage Project (GRUSP). Nine organizations were permitted as "participants" in GRUSP as of 1997-1998. While one organization is permitted to "manage" the project, the participation of other entities is not merely for the purpose of selling water to the facility manager. The other participants in the project store water at the facility and receive underground storage credits for their portion of water storage in GRUSP. They also helped fund the construction of this facility.

The arrangements across multiple organizations involved in conjunctive water management projects are not merely "market exchanges". Even in the case of in-lieu projects, Arizona's water providers co-produce projects that could be accomplished in-house. Chapter Five argued that these multi-organizational arrangements are forms of coordination, according to the public service industry literature. Therefore, the number of project participants is an appropriate indicator for project "coordination" in the quantitative analyses.

Independent Variables

If the Arizona cases support Hypothesis 4a, the data would show more project-level coordination occurring in large capacity projects. While this seems like an intuitive relationship, arguments by consolidation theories, which contradict the local public economy literature, would not support this assumption. A consolidation argument would assume that single jurisdictions are more capable of achieving economies of scale and, therefore, large-scale projects are more attractive to production by a single public entity. The local public economy literature does not hold this assumption. For this model, the assumption is that projects with the capacity to store large volumes of water are more likely to involve multiple participants. The first independent variable, therefore, is the production capacity of a project. Project production capacity, for this model, is measured by permitted water storage capacity, in acre-feet.

As a control, the model includes a dummy variable to represent project type (in-lieu = 1 and direct recharge = 0). It is necessary to control for the effects of in-lieu projects in Arizona because in-lieu projects, by their nature, are likely to involve coordination. An in-lieu facility permit in Arizona requires that the entity operating the facility must replace groundwater that the entity normally uses with surface water supplies. In-lieu projects in Arizona, therefore, usually involve exchange arrangements between surface water providers and groundwater users.[47] In exchange for giving surface water to groundwater users, surface water suppliers receive long-term storage credits for groundwater that can be recovered in the future. This is also an incentive for water providers that are not using their surface water supplies to coordinate with groundwater users to devise in-lieu recharge projects. The model, therefore, is expected to show that in-lieu facilities have a positive impact on the number of project participants.

The use of in-lieu projects as a control variable should not imply, however, that in a water industry, jurisdictions do not have choices for acquiring non-native water supplies or project inputs that are not found within the boundaries of the providing jurisdiction. Many water providers have contracts for their own sources of imported surface water supplies. Such contracts would not be deemed a form of coordination if those imported supplies were used in a conjunctive water management project. Thus, the use of imported water supplies in conjunctive water management projects does not necessarily equate to the use of coordination in conjunctive water management, since such supplies may or may not be owned by the providing jurisdiction. To clarify this

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[47] Two private water companies in Arizona have permits to engage in in-lieu recharge using their own

assumption, another control variable is used in the model that represents projects that use CAP water. The variable representing CAP water may be positively associated with project coordination because many in-lieu and some direct recharge project providers coordinate with the Arizona Water Banking Authority or the CAWCD, which use CAP water in projects. However, it should not necessarily have a significant impact on the use of coordination in a project, since many project providers choose to use their own sources of CAP water in projects.

As a final control variable, the model includes the number of years of project operation. The variable representing the years of project operation is expected to have a negative, yet moderate, effect on the number of project participants. One reason for the expected negative relationship is that newer direct recharge projects would be less likely to undertake expensive capital costs of large project facilities without some coordinated production or funding arrangements. In fact, in Arizona, a number of projects started by developing partnerships with the state as demonstration projects or with capital funding from the CAWCD, which participates in projects to use excess CAP water supplies. Another reason for the expected negative relationship is that as more projects develop over time, water providers are likely to recognize the feasibility of engaging in conjunctive water management and have more opportunities for participating in projects. Therefore, newer projects may be more likely to attract multiple participants than older projects. However, the effect is expected to be moderate since some of the older projects may also be able to attract more participants over time. The variables for the OLS model,

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effluent. Thus they receive credits for forgoing their use of groundwater that they have rights to pump and their expected relationships to project coordination and the descriptive statistics for these variables are shown in Table 6.1.

TABLE 6.1: Descriptive Statistics of Regression Model Variables

Dependent Variable	Min Value	Max Value	Mean Value	Std. Dev.	N=42
Participants	1	10	2.5	2.33	
Independent Variables	Min Value	Max Value	Mean Value	Std. Dev.	Expected Sign
Storage Capacity	120 AF	200,000 AF	26,216 AF	4,878 AF	Positive
Years of Operation	0.5	10	4.19	2.67	Negative
Dummy Variables	"1" Cases	"0 Cases"			Expected Sign
Project Type (1= in-lieu)	16	26			Positive
CAP Water Use (1= yes)	27	15			Positive

Table 6.2 presents the OLS regression results. Overall, the model is significant, with an F-value of 22.97 (99% confidence level). Combined, the variables in this model explain about 68% of the variance in the level of project coordination (Adjusted R-Square = .68). The independent variable coefficients support the expected relationships and Hypothesis 4a.

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replacing that water use with effluent.

TABLE 6.2: OLS Regression Model Relating Project Production Factors to Project Coordination

	B Coefficients	Standard Error	T- stat	P-value
Intercept	1.428	0.495	2.89	0.007
Permitted Storage Capacity	.00003	.000004	6.63	0.000
Facility Type (1=in-lieu)	1.230	0.466	2.64	0.012
CAP Water (1 = yes)	0.583	0.476	1.22	0.229
Years of Operation	-0.125	0.079	-1.59	0.121
N=42 *F* = 22.97 (sig. = 0.00)	R-square = .72 Adj. R-square = .68			

The variable representing permitted storage capacity of a project, has a positive effect on the number of project participants and is significant at the 99% confidence level, but the effect of the variable is small. The coefficient (.00003) shows that a ten thousand acre-foot increase in permitted storage capacity is associated with a third of a unit increase in the number of project participants, holding all other variables constant.[48] This result is attributed to the fact that values of the storage capacity variable range from a few hundred acre-feet to over 200,000 acre-feet, while the participation variable ranges from one to nine. Therefore, it is not surprising that the effects of the storage capacity variable on participation are rather negligible with small increases in storage capacity. An increase in storage capacity of 100,000 acre-feet, however, is associated with an increase of three project participants. As expected, the results indicate that project production capacity has a positive impact on project coordination. The implication is that

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[48] This model was tested to determine if a logarithmic function, using the natural log of permitted storage capacity values, is a more appropriate functional form for the model. The coefficient for the logged storage capacity was significant (t-value = 4.72), but the model overall was weaker (*F*= 12.33) and explained less of the variance in project participation (Adj. R-square = .52). Also, in looking at the metric effects of the variables using logged values of storage capacity, none of the values of storage capacity found in the observed data were significant using a loglinear form.

production capacity is positively associated with project coordination as suggested by Hypothesis 4a.

The coefficient for the dummy variable representing in-lieu recharge facilities also is positive and significant, as expected, with a coefficient of 1.23 (t-value = 2.64). The coefficient shows that in-lieu facilities increase the mean number of project participants over direct recharge projects, when all other variables are equal to zero, by more than 1 participant. This result demonstrates that when project production requires water sources other than those that are traditionally used by the organization managing the project, as is usually the case with in-lieu recharge projects, then project coordination is higher.

The variable representing the use of CAP water in a project also has a positive relationship to coordination, but, as expected, it is not significant. Many of the in-lieu projects and a number of direct recharge projects use CAP water. Given that this variable is not significant, this result suggests that the type of project coordination found in in-lieu projects is not due to the fact that in-lieu projects tend to use imported water supplies. Instead, in-lieu projects in Arizona, by their nature are more likely to be associated with coordination.

The final control variable in this model is the number of years of project operation. The variable's coefficient is negative (-0.125) as expected, while the effect of this variable on the number of project participants is relatively moderate (significant at a 95% confidence level). The results demonstrate that for each one-year increase in project operations, there is a reduction of one-eighth of a project participant. In other words, every eight years of project operations leads to nearly a one-unit decrease in participants. Given that most of the conjunctive management projects in Arizona were operating less than four years from the last year observed in this data set (median years of operation = 4), this effect is relatively small. The results do suggest, however, that newer projects are associated with more project participants. Looking at the actual data, this is not surprising. Many of the in-lieu projects and larger facilities were not permitted until the mid-1990s, when Arizona authorized CAP water to be sold at "incentive recharge" rates and when the Arizona Water Banking Authority was formed, creating more low cost pools of CAP water for in-lieu and direct recharge projects. This may also suggest that project participation can be explained in part by changes in state policies that made participation in recharge projects less costly.

Coordination and Cost-Efficiency

The OLS regression model provides support for Hypothesis 4a, indicating that projects with high production capacities are positively associated with project-level coordination. Hypothesis 4b examines the other side of the relationship between coordination and project production put forth by the public service industry literature. It examines the argument that coordination facilitates cost-efficiency, or economies of scale. Hypothesis 4b claims that coordination is positively related to project cost-efficiency, or lower costs per unit of project output, controlling for project size.

To evaluate Hypothesis 4b, this section compares cost-efficiency measures of projects that involve coordination (multiple producers or providers) to cost-efficiency measures of projects that do not involve coordination, controlling for project storage capacity and project type. The public service industry literature does not claim that projects cannot be cost-efficient when produced and provided by a single entity. Rather, the literature maintains that projects whose scales surpass the production capacities of a local jurisdiction are more cost-efficient when coordination is used. Project cost-efficiency is measured using various indicators of project costs divided by an indicator of project benefits.

Project Cost-Efficiency Data

Data from the conjunctive management projects in Arizona highlight the different types of production and transaction costs involved in conjunctive management projects, as well as project outputs, that can influence cost-efficiency. The production costs include construction or capital costs for facilities, maintenance costs and operations costs (inputs and labor). Transaction costs of conjunctive management projects (versus costs of collective action) include information costs on project development, contract costs for water or other inputs, legal and coordination costs, and monitoring requirements.

As shown in Table 6.3, organizations reported water costs for 26 projects, out of 28 projects that stored water in 1997. Only four projects, however, reported operations or maintenance costs for 1997 (See Performance Measures Coding Form in Appendix A of Chapter 3).[49] For transaction costs in 1997, eleven projects tracked reporting and

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[49] The small number of organizations reporting project production and transaction costs can be attributed to a couple of different factors. First, based on interviews with the organizations participating in the study, few organizations formally track costs that are not itemized for budget purposes. Second, most of the conjunctive management projects are not broken down in departmental budgets apart from other water operations. Thus, many project inputs cannot be accurately assigned to a particular project. Even measuring the cost of water going into a project is difficult. Many project producers use their own water supplies, so treatment and delivery costs for conjunctive management may not be separate from a larger water budget.

monitoring activities, six projects estimated time spent on project coordination activities, and five projects estimated money and time spent on legal and permitting activities. The small number of responses cannot accurately represent the transaction and operation costs faced by the population of Arizona projects, but they can provide some indicator of the types and ranges of costs facing projects.

TABLE 6.3: Production and Transaction Costs Identified by Arizona Providers

	Average Weekly Labor Hours Per Project in 1997	Average Monies Spent Per Project in 1997	# of Projects Reporting
Production Costs			
Water Costs*	NA	$900,933	26
Operations	87	$68,000	4
Maintenance	29	$26,200	4
Transaction Costs			
Monitoring	28	$2,670	11
Coordination	40	None Reported	6
Legal/ Permit	68	$2,000	5

*For some projects, water costs must be aggregated across multiple project participants that either sell water to in-lieu projects or deliver water to direct recharge facilities.

Table 6.3 compares the reported costs for each production and transaction cost category in 1997, based on estimated labor hours per week and money spent. Water costs, constituted the highest average cost category for projects in Arizona, with a mean project cost of over $900,000 for the year. The range of water costs, however, is quite large. A number of projects using treated municipal effluent calculated water costs in 1997 to be $0, while a few of the large in-lieu projects involved water purchases from various sources, resulting in costs as high as $7.5 million. The average cost of water going into conjunctive management projects was $19.8 per acre-foot in 1997.[50]

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[50] Those organizations reporting water costs of $0 do not have truly cost-free water. Projects using effluent do incur costs of producing the water and treating it. One organization accounted for the costs of treating

The average amount of money spent on operations and maintenance (or production) in 1997 was higher than any of the transaction costs categories. The average cost of project operations was about $68,000 in 1997, with estimates averaging $26,200 per project for maintenance. The average amount of money spent on monitoring and reporting transactions was estimated to be $2,670 per project in 1997, while average permitting/legal costs were $2,000 per project. Thus, spending for monitoring/reporting and permitting, on average, is lower than spending for operations or maintenance. On the other hand, transaction costs of projects are more substantial when looking at the labor hours going into projects. Legal and permitting time averages about 68 hours per week per project. Project coordination time averaged 40 hours per week. Project producers spent an average of 28 hours per week on monitoring and reporting. The average labor time spent in 1997 on operations was 87 hours per week per project, with maintenance adding about 29 hours per week.[51]

Data on capital costs, another component of project production costs, were reported for 32 of Arizona's 42 projects.[52] Table 6.4 summarizes the average capital costs of in-lieu and direct recharge projects in Arizona, relative to the size of facility permits in acre-feet. The capital costs of projects tend to decrease as facility storage permits

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effluent in its facility "production" costs, since all of the effluent treated at the facility goes into conjunctive management. Other organizations, however, did not break down the costs of running effluent treatment facilities for the purposes of conjunctive management because they incur those costs without the conjunctive management project. Thus, the water cost data is skewed toward the low end.

[51] The average labor hours spent on project operations and transactions appear to be somewhat high. Given that only a small number of organizations reported labor hours, these figures may be subject to some selection biases. That is, the organizations that operate the most labor intensive projects may be more likely to report these hours than organizations that require minimal time to operate projects.

[52] Like operations and transaction costs for 1997, some managing organizations did not separate capital costs for conjunctive management projects from other water management operations. Thus, organizations reported capital costs to be unknown for six projects, while data was not provided for five projects.

increase, for both in-lieu and direct recharge projects. Although, the Pearson correlation between permit size and capital costs is -0.19, suggesting that this is not a strong relationship. This inverse relationship may be explained by the fact that a number of projects are still in the pilot phases and are permitted to store only a portion of the water they plan to store in the future, yet they still incur substantial capital costs.

Table 6.4 also shows that the mean capital costs of direct recharge projects are significantly higher than in-lieu projects (F= 7.12, p=.01). This difference is not surprising, given that direct recharge facilities, which involve recharge ponds, injection wells, or water treatment facilities, are likely to require more facility construction than in-lieu projects. In fact, only three of the 16 in-lieu projects have capital costs greater than zero. The capital costs of these three projects were designated for the construction of surface water distribution pipelines or turnouts. The remaining 13 in-lieu projects reported having zero capital costs because their distribution facilities were constructed prior to starting the in-lieu recharge projects.[53]

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[53] In-lieu projects in Arizona rely largely on the infrastructure and distribution facilities created for the Central Arizona Project. These facilities were constructed prior to the development of the in-lieu projects. For eight in-lieu projects, managing organizations estimated the dollar value of the existing surface water distribution facilities, prior to starting the project, which provides some indication of the capital costs needed to develop these projects. Based on these estimates, the value of existing distribution facilities (CAP pipelines, canals, and turnouts) that are used for these in-lieu projects averages over $29.6 million dollars per project.

TABLE 6.4: Capital Costs of Projects in Arizona

Storage permit Quantity (AF)	Average Costs of In-Lieu Projects N=17	Average Costs of Direct Recharge Projects N=15	Average Cost of All Projects* N=32
<10,000 AF	$160,000	$6,202,680	$4,188,450
10,000 to 99,999 AF	$15,530	$4,113,500	$1,505,700
100,000 to 200,000 AF	$0	$1,455,270	$291,054
Category Averages	$56,794	$5,329,070	$2,607,896

*Managing organizations did not report capital cost data on 10 of the 42 individual projects.

Cost-efficiency, or economies of scale, factors also include the outputs that conjunctive management projects produce relative to the costs. The outputs of projects are identified using the "Performance Measures" coding form for the NSF/EPA study (see Appendix A), which lists possible goals of conjunctive management projects and the measurable outcomes of those goals. Based on coding form responses, Table 6.5 categorizes the types of goals associated with participating in a conjunctive management program in Arizona and lists the number of projects for which each type of goal is identified. (Projects may have multiple goals.) The most frequent goal, identified for 31 projects, is to supplement existing water supplies. The second most frequent goal, listed for 12 projects, is to raise the water table of the groundwater basin underlying the project. Avoiding loss of water rights or water use was identified as a goal for 7 projects. This goal was identified mainly for projects operated by CAP contractors who recharge unused portions of their CAP water since CAP contractors pay for their water, regardless of how much they use.[54] Some municipalities using treated effluent for recharge recognize this as a project goal because cities can reuse wastewater that would otherwise not be used. Six projects in Arizona also are designed to improve water quality, while another four projects aim to lower water costs for project operators (usually in-lieu projects). The last three goals, which include providing drought relief, reducing pumping lifts, and creating riparian areas, each are associated with three projects.

TABLE 6.5: Primary Outputs of Projects in Arizona

Type of Goal	Frequency of Projects With Goal	Measures of Project Outputs
Supplement water supply	31	Acre-feet of water stored*
Raise water table	12	Change in water table
Avoid loss of water rights	7	Acre-feet of water stored*
Improve water quality	6	% Change in Water Quality
Lower water costs	4	% Change in Water Price
Drought relief	3	Acre-feet of water stored*
Reduce pumping lift	3	Change in pump lift
Create riparian areas	3	Acres Used for Riparian Area

*Measures are consistent across all projects in Arizona, based on state requirements for project storage credits.

While organizations operating projects in Arizona have multiple goals for conjunctive management projects, few projects identify the actual outputs of projects for all of these goals on a yearly basis. Determining a project's impacts on water quality over a year is difficult because other factors influence water quality in a groundwater basin (U.S. Department of the Interior 2000). Similarly, it is difficult to establish a direct link between conjunctive management projects and changing water tables over a short period of time because water table levels fluctuate with rainfall, changes in surface water

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[54] Using the unused portions of Arizona's allotment of CAP water also helps ensure that water users in Arizona do not lose rights to their portion of Colorado River water supplies. This is one reason for the

flows, groundwater movement from other sub-basins, and changes in pumping (ADWR 1998a). Thus for some measures of goals, projects require more long-term analyses than a single year observation.

One measure of production outputs that is consistent across all projects is the quantity of water stored or saved by the conjunctive management project per year. All participants in conjunctive management projects in Arizona monitor recharge and storage levels in order to ensure that they have rights to recover stored water in the future. Monitoring and reporting is required by the state of Arizona in order to receive storage credits for direct groundwater recharge or for delivery of in-lieu surface water, which can then be recovered in the future or transferred to other entities.[55] The quantity of water stored by a project provides an indicator of three of the main project goals: 1) supplementing the water supply, 2) avoiding loss of water rights, and 3) relieving drought. Given that all projects in Arizona measure the quantity of water stored and that this measure is an indicator of multiple goals, the acre-feet of water stored will be used across projects as a common measure of project outputs for the cost-efficiency analysis.

For the following portions of this analysis, the indicator of project benefits is the average yearly quantity of water stored (in acre-feet). The average yearly quantity is used instead of the total quantity of water stored to control for time, as older projects are likely to have stored more water than younger projects. The first indicator of project

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formation of the Arizona Water Banking Authority (AWBA 2000).

[55] The ability to earn long-term credits through recharge was authorized by the Arizona Underground Water Storage and Recovery Act (A.R.S. §45-801), originally enacted in 1986. The Indirect Groundwater Storage and Recovery Act (A.R.S. §45-851) was enacted in 1990 to allow credits to accrue for substituting surface water for groundwater pumping. 1992 amendments to the acts allowed for the state to develop the Annual

costs is capital costs. The second indicator of costs is transaction costs and the third is production costs. Different measures of cost-efficiency are calculated by dividing each category of project costs by the average yearly acre-feet of water stored.

Cost-Efficiency Based on Capital Costs

Table 6.6 compares the cost-efficiency of projects involving coordination across producers or providers to the cost-efficiency of projects without coordination (provided and produced by a single entity). Given that cost-efficiency would be expected among larger projects using coordination, the analysis controls for project size. Also, based on the descriptive data, in-lieu projects generally have very low capital costs, so the analysis also controls for project type. Cost-efficiency for these categories is measured as the mean cost per acre-foot of water stored on a yearly basis. The data come from 32 of Arizona's 42 projects. The minimum capital cost per acre-foot of water stored at a facility in Arizona is $0, which is the cost reported by a number of in-lieu facilities. The mean capital cost value per acre-foot of water stored each year is $1,962 (standard deviation = $8,012), while the maximum capital cost per acre-foot totals $43,651.

Storage and Recovery program (A.R.S. §45-881) to encourage water providers to use CAP water without incurring the costs of surface treatment.

TABLE 6.6: Difference in Mean Cost Per Acre-Foot of Water Stored Between Projects With Coordination and Projects Without Coordination

	0-10,000 AF Capacity	10,000- 99,999 AF Capacity	100,000-200,000 AF Capacity	Category Means
Projects Without Coordination N=13	$4,139	$1,920	NA	$3,793
Direct Recharge	($5,901)	($1,920)	NA	($4,906)
In-lieu Projects	($1,063)	NA	NA	($1,063)
Projects With Coordination N=19	$14,554	$727	$5	$2,682
Direct Recharge Projects	($43,651)	($2,420)	($24)	($10,187)
In-lieu Projects	($4)	($2)	($0)	($2)
Category Means (All)	$5,946	$926	$5	$3,135

*Missing values for 10 of 42 projects. The minimum value = $0; maximum value = $43,651; median = $18.06; and standard deviation = $8012.

Among all of the projects using coordination, the mean cost is $2,682 per acre-foot (standard deviation = $10,032), while the maximum cost is $43,651 and the minimum is $0 per acre-foot. Among all projects that do not involve coordination, the mean cost is $3,793 per acre-foot (standard deviation = $3,752), while the maximum cost is $14,000 and the minimum is $0 per acre-foot of annual water storage. Projects that involve coordination have slightly lower costs per acre-foot on average, but the difference between these two groups is not statistically significant ($F = .14, p = .71$). This result, however, does not contradict the expectations of the public service industry literature, given that cost-efficiency gains would be expected among larger projects that use coordination relative to larger projects that do not use coordination. In looking at medium size projects (10,000 acre-feet to 99,999 acre-feet), the costs per acre-foot of projects using coordination are nearly $1,200 lower on average than projects not using coordination. The problem is that only two medium size projects do not involve coordination, while 10 projects involve coordination, so the data are not suitable for statistically comparing the differences in category means.

In considering project type, in-lieu projects clearly are more cost-efficient than direct recharge projects (*F* = 11.97, *p*= .002). This outcome is expected, given that most in-lieu projects do not involve capital costs. In comparing in-lieu projects that involve coordination to in-lieu projects without coordination, those using coordination on average cost about $1000 per acre-foot of storage less than those using coordination. However, only two in-lieu projects do not involve coordination. These two projects are run by entities that use their own surface water supplies or re-use effluent in-lieu of pumping their groundwater. When comparing the effects of project size across in-lieu recharge projects, it is also not surprising that larger projects that involve coordination tend to have lower costs per acre-foot of storage than smaller projects, although the differences are small.

Project-level coordination does not appear to be associated with greater capital cost-efficiency when looking only at direct recharge projects. Table 6.6 shows that the average cost-per acre-foot of direct recharge projects with coordination is over $6,000 more than the cost of direct recharge projects without coordination. One factor that explains the difference between the direct recharge categories is that among the projects using coordination is a young project with very high capital costs. This projects includes an expensive water treatment plant for industrial effluent, but only stores a few hundred acre-feet of water each year. It costs $43,651 per average annual acre-foot of storage, while the cost of all other projects using coordination range between $0 and $6,505 per acre-foot of storage. Removing this case results in an average cost per acre-foot of yearly water storage of $1,821 for direct recharge projects using coordination. Excluding this project, direct recharge projects using coordination cost $2,474 less per acre-foot of water stored than projects that do not use coordination on average.

Direct recharge projects using coordination are most cost-efficient among larger projects, compared to small and medium-sized projects. Comparing cost-efficiency data of projects using coordination to those that do not use coordination shows that small and medium sized projects have higher average costs per acre-foot of storage when using coordination. However, with this data it is not possible to make statistically accurate comparisons within categories of medium and larger projects between the average cost-efficiency values of projects using coordination to those not using coordination. This is because only two direct recharge projects do not use coordination in the medium-size project category and all of the large projects use coordination. In comparison, nine of the direct recharge projects categorized as small projects (under 1,000 acre-feet of storage) do not involve coordination.

While direct recharge projects do not necessarily show greater cost-efficiency with coordination even within categories of larger projects, costs per acre-foot do decline with project size and with in-lieu projects. Of course, as the OLS regression model shows, in-lieu projects and larger projects, in fact, are more likely to involve project coordination. In terms of the results from the regression model, the descriptive data indicate that cost-efficiency may be positively related to project coordination. To ascertain the actual relationship between coordination and cost-efficiency, more observations are warranted. With this data set, some additional observations of cost-efficiency can be evaluated using different cost measures.

Cost-Efficiency Based on Operation and Transaction Costs

Operation costs and transaction costs also can be used to evaluate project cost-efficiency. With the exception of water costs, only a small number of Arizona's projects monitored and reported operation and transaction costs. All but three of these projects are direct recharge facilities. Therefore, these data offer limited insights into project cost-efficiency. Table 6.7 lists all of the projects that reported project-level transaction costs or transaction hours, which include project monitoring/reporting and legal/permitting activities. It compares the number of participants in each project to the dollar value of transaction costs per acre-foot of average annual water storage, and to the number of labor hours spent per acre-foot of average annual water storage.

Table 6.7 indicates that among the projects reporting transaction and operation costs, the amount of money and labor time spent on monitoring/reporting, legal and permitting activities, relative to the average quantity of water stored, tends to be lower among projects with larger numbers of participants. These results should not, however, imply that projects with more participants are more cost-efficient. First, two of the single entity projects also have relatively low transaction costs or transaction hours per acre-foot of water storage. Second, it is important to examine larger projects to determine if these projects can minimize costs using coordination. Comparing project coordination among the medium and large categories of projects presents problems in that the projects reporting transaction costs do not involve single entity providers. Moreover, due to limited observations, the data do not show whether transaction costs decrease as the number of multiple participants increases among medium and large projects.

TABLE 6.7: Project Transaction Costs per Acre-Foot of Water Stored

Project, by Permit Size	# of Participants	Transaction Costs Per AF of Av. Annual Storage	Transaction Labor Hours Per AF of Av. Annual Storage
<10,000 AF			
8,963 AFY	1	$2.33	0.21
3,314 AFY	1	*	0.35
5,000 AFY	1	*	2.25
3,100 AFY	2	*	6.60
10,000-99,999 AF			
18,000 AFY	3	$0.25	0.01
11,000 AFY	4	$1.42	1.47
15,000 AFY	4	*	1.05
11,231 AFY	7	$0.06	0.12
100,000– 200,000 AF			
100,000 AFY	6	$0.01	0.03
200,000 AFY	9	$0.06	0.03
200,000 AFY	10	*	0.14

*Data Not Reported

Table 6.8 shows the relationship between project-level coordination and production cost-efficiency, as measured by operations and maintenance costs, controlling for project size. The production costs per acre-foot of water storage tend to decrease among the six projects that tracked operations and maintenance costs. The patterns among these limited number of observations support the public service industry assumptions that larger projects, through coordinated agreements, are able to economize on input costs. However, these results do not show that among projects of similar sizes, coordination leads to greater cost-efficiency. One of the small projects with a single operator has average operating labor hours of 0.19 per acre-foot of annual storage, while a project of similar capacity with two participants has average operation hours of 26.41 per acre-foot of annual storage. The implication of these results is that among smaller projects, coordination may, in fact, not lead to greater cost-efficiency.

TABLE 6.9: Project Production Costs per Acre-Foot of Water Stored

Project, by Permit Size	# of Participants	Operating Costs Per AF of Av. Annual Storage	Operation Labor Hours Per AF of Av. Annual Storage
3,314 AFY	1	$85.08	0.19
5,000 AFY	1	*	11.23
8,963 AFY	1	$16.67	*
3,100 AFY	2	*	26.41
11,000 AFY	4	$18.40	*
20,000 AFY	5	$5.95	0.37

*Data Not Reported

Cost-Efficiency Based on Water Prices

The final production cost variable is the cost of water going into a conjunctive management project. If the data on water costs support Hypothesis 4b, then the cost per acre-foot of water going into a conjunctive management project is likely to be lower among projects with multiple participants, controlling for project size. Again, the local public economy theory implies that projects involving coordination across jurisdictions can lower the costs of production. In Arizona's conjunctive water management projects, the water costs for projects in 1997 were substantially higher than operations or maintenance costs. While these total costs increase with higher quantities of water being stored at a project, the cost per acre-foot of water going into a project is not necessarily tied to the amount of water going into a project. According to the theory, if projects use coordination, they are more likely to have less expensive sources of surface water to store if multiple sources of water are available. Water prices in Arizona vary widely across sectors of users and vary depending on the type of water used. In theory, conjunctive water management projects should be able to take advantage of these sector differences and utilize cheaper sources of water in projects by coordinating the production of conjunctive management projects across jurisdictions.

Using data from projects reporting water costs in 1997, Table 6.10 compares the average price per acre-foot of water to different levels of project participation. Projects with only one project operator have the lowest cost per acre-foot of water ($4.3 per acre-foot). However, projects with five or more participants have lower water costs than projects with two to four participants.

TABLE 6.10: Average Price Per Acre-Foot of Water in Arizona Projects

No. of Project Participants	Av. Price per Acre-Foot	Av. Storage Capacity of Projects (AF)	No. of Projects
1	$4.3	5,190	10
2 to 4	$26.8	41,210	10
5 or more	$19.5	90,005	6

Pearson Correlation between Price and Participants = .24

The primary reason why projects with single providers or producers have very low water costs is that among the ten single-producer projects reporting costs in 1997, nine were using effluent owned or produced by the same entities that manage the projects. Therefore, none of these nine organizations need to purchase water going into their conjunctive management projects.[56] At the same time, the projects with single

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[56] Arguably, effluent recharge projects would be much less cost-efficient, based on water costs, if water costs were assigned. If these organizations were to sell effluent to another organization to produce conjunctive management, undoubtedly they would charge a price equivalent to the costs of producing and treating it. Such exchanges, in theory, could create greater cost-efficiency than producing conjunctive management projects with effluent in-house. The public service industry theory implies that in these cases,

producers average only 5,190 acre-feet of water storage capacity, compared to 41,210 acre-feet for projects with two to four participants. Projects with five or more participants average over 90,000 acre-feet of storage capacity. This suggests that projects produced by single entities also have little need for other entities to participate in these projects. Both of the categories of multiple participants represented in Table 6.10 have relatively high average storage capacities, yet projects with the highest number of participants still have lower average water costs.

CONCLUSION

This chapter reviewed the purposes of the three forms of coordination that are associated with conjunctive water management, which were identified in the previous chapter, focusing on explaining project-level coordination. The first section of the chapter explained that Hypotheses 4a and 4b, which test assumptions offered by public service industry theory, are concerned with project-level coordination. Hypothesis 4a states that inter-jurisdictional coordination in conjunctive management projects is likely to be positively related to production capacity, controlling for project type. Thus, instead of jurisdictions developing large-scale projects on their own to take advantage of production economies of scale, water providers are more likely to coordinate the production of conjunctive management. Hypothesis 4b claims that inter-jurisdictional coordination, in turn, is likely to lead to project cost-efficiency, or create economies of scale, among larger projects.

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the use of multiple organizations to produce conjunctive management can lead to more efficient service production. In the case of effluent recharge projects, such exchanges might allow citizens to gain even greater benefits from the use of effluent if it is sold for a price. Costs that might be internal within a single

The OLS regression model demonstrated that project coordination is positively related to the production capacity of a project, supporting Hypothesis 4a. While this result seems relatively intuitive, it counters consolidation arguments that would predict that larger-scale projects would be more aptly suited to single entity producers. The OLS model also demonstrated that in-lieu projects are positively associated with project coordination. Given that in-lieu projects are likely to involve the use of surface water supplies that are non-native to the organizations operating in-lieu projects, this outcome was expected. These results suggest that the public service industry literature offers appropriate explanations of the reasons for coordination under conditions where water providers do not face appropriation dilemmas.

The quantitative data examining cost-efficiency differences between conjunctive water management projects using coordination and projects not using coordination clearly present some limitations for testing Hypothesis 4b. Despite the limitations for making statistical comparisons, the data do indicate that a relationship may exist between cost-efficiency and coordination, controlling for project size, under certain conditions. In looking at capital costs, for instance, project coordination seems to improve cost-efficiency among medium-size projects. However, the effects of in-lieu facilities may confound this relationship. In-lieu projects have very low capital costs and many of the medium size projects using coordination are in-lieu. As noted in the descriptive data, projects with high capital costs are direct recharge projects. Those with the highest capital costs tend to be ones that have built special facilities for effluent treatment. Thus, costs

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organization become visible in a transaction between organizations. These incentives toward efficiency are per acre-foot of water stored are going to be higher among these projects regardless of the use of coordination.

Not surprisingly, the difference in capital cost-efficiency between projects with coordination and those without coordination tend to be less noticeable than the differences between in-lieu and direct recharge projects. As expected, among projects using coordination, the capital cost data show that project storage capacity does make a difference in reducing the costs per acre-foot of storage.

The data on transaction costs and production costs provide only weak indications that some projects using participants are more cost-efficient than projects not using coordination. Projects appear to be more cost-efficient in the transaction cost analysis when they involve multiple participants. Projects with multiple participants also are associated with larger project production capacities. Further testing of the relationship between lower transaction costs and cost-efficiency would be useful, given that project-level transaction costs presumably would be higher with higher storage capacities. Finally, with the transaction costs and production costs analyses, unlike the capital cost analysis, the effects of in-lieu projects were not evaluated since most of the projects tracking transaction and production costs are direct recharge projects.

The cost per acre-foot of water storage was the final cost factor considered in this chapter. Like capital costs, project size and project types appear to influence the relationship between costs per acre-foot of water stored and project participants. With water costs, projects with five or more participants have lower average water costs than

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non-existent within an organization that does not account for the costs of water going into a project.

projects with two to four participants. The projects with the highest number of participants also have the highest average water storage permits, and include most of the in-lieu facilities. Projects with only one participant still have the lowest water costs, which can be attributed to the fact that many of these projects are direct recharge facilities using treated effluent. However, organizations reporting water cost data did not directly account for a price of treating and producing the effluent water. Thus, the water cost data among smaller projects is somewhat skewed. Overall, the average cost per acre-foot of water going into conjunctive management shows that larger projects can take advantage of economies of scale in water pricing when using multiple participants.

In examining the Arizona data analyses as a whole, including the regression model results and descriptive data, it is clear that production concerns are associated with project-level coordination. In particular, project production capacity and project type influence the use of coordination in conjunctive water management projects. The results only weakly show that such production coordination is associated with achieving lower costs per unit of project output. Given that project size and project type are associated with coordination, and that project size and project type impact cost-efficiency, the cost-efficiency analyses still offer useful insights. The analyses, overall, demonstrate that the local public economy literature can explain coordination in situations where resource users do not face collective action dilemmas.

VII. DISCUSSION AND CONCLUSIONS

Conjunctive water management is a tool that can maximize the availability of water supplies by coordinating the use and storage of ground and surface waters. Conjunctive management has been used in a number of western states to address water scarcity dilemmas, although the type, location, and extent of conjunctive management programs differ widely. This dissertation examined conjunctive water management in Arizona, California, and Colorado using two bodies of literature derived from a common research framework. They are common-pool resource (CPR) management theory and the literature on public service industries. It argued that a synthesis of the two bodies of literature explains more accurately the effective management of water resources within complex physical and institutional settings than either body of literature on its own.

Specifically, this dissertation examined two key points where weaknesses in each body of literature were identified: 1) the role of institutional boundaries put forth by CPR management theory and 2) the reasons for inter-jurisdictional coordination put forth by public service industry theory. In considering the role of institutional boundaries, this dissertation demonstrated that basin-level institutions (or boundary matching institutions) are not necessary for facilitating conjunctive water management when the larger institutional setting controls demand dilemmas, or when jurisdictions coordinate across overlapping boundaries to provide water management services. Second, this dissertation showed that the forms of coordination associated with conjunctive water management differ depending on the larger institutional setting. Also, the factors influencing coordination differ depending on the purpose of coordination.

This chapter discusses the implications of the theory development and data analyses presented in this dissertation. The first section reviews the anticipated and unanticipated findings of the empirical chapters. It also considers alternative explanations for the findings. Second, this chapter discusses the strengths and limitations of the findings. The third section of this chapter examines the impacts of the dissertation on water management research, public policy theory, and water resource policy.

FINDINGS

The data analyses on conjunctive water management projects in Arizona, California, and Colorado evaluated the hypotheses derived from synthesizing two key points from CPR theory and public service industry theory. In general, the findings from the analyses support the hypotheses and theory development proposed in Chapter Two. To review, these hypotheses are:

> H1) Institutions governing water resources do not need to be organized around the physical boundaries of the resource in order for water providers to engage in conjunctive water management.
>
> H2) Inter-jurisdictional coordination will be positively associated with the provision of conjunctive water management services.
>
> H3) Basin-level coordination among providers of conjunctive water management is less likely where the larger institutional setting controls groundwater demand dilemmas.
>
> H4) In institutional settings where water rights are quantified:
> > a) Projects with high production capacities are likely to be produced through inter-organizational coordination.
> > b) Coordinated production or provision of conjunctive management projects is positively related to project cost-efficiency, or lower costs per unit of project output, controlling for project size.

In addition to supporting the hypotheses, the data analyses resulted in some unanticipated findings, which are discussed in the following section. These findings also contribute to a better understanding of the effects of institutional arrangements on conjunctive water management.

Evidence Supporting Hypotheses

The data analyses in Chapter Four evaluated the first two hypotheses. They demonstrate the usefulness of integrating insights from both CPR theory and public service industry theory to explain the role of jurisdictional boundaries in facilitating effective resource management. The data indicate that institutional settings devised around the boundaries of the resource, which allow water providers to control the resource through basin adjudication or special groundwater management districts, can facilitate conjunctive water management. This finding upholds the implications put forth by CPR theory. However, the results also show that institutions that allow local jurisdictions to coordinate water management programs across overlapping jurisdictions in a basin (evidenced by AB3030 Plans) can encourage the use of conjunctive management. In addition, at the project level, the descriptive data indicate that jurisdictions within a basin frequently coordinate the production of conjunctive management programs. These forms of coordination are concordant with public service industry / local public economy theory.

Given these results, the data analyses in California do not support Hypothesis 1, in that institutional boundaries that control the resource are more likely to be associated with conjunctive water management in California. Although, in many cases conjunctive management in California is associated with single jurisdictions devised around basin-boundaries. Water management institutions also have achieved basin-level control by coordination across existing jurisdictions using AB3030 Plans. Therefore, these results support Hypothesis 2, showing that inter-jurisdictional coordination, as indicated by AB3030 Plans and coordinated production arrangements, is positively associated with conjunctive water management programs. These results indicate that a synthesis of the local public economy theory and CPR management theory can explain the relationship between institutions and conjunctive management more accurately than either theory alone.

The cross-state comparison of conjunctive water management in Chapter Five demonstrates that inter-jurisdictional coordination does not occur at the basin-level in Arizona and Colorado, as found in California. Yet, coordination does occur at the project-level and organizational-level for the purposes of providing conjunctive management. In evaluating the data on conjunctive water management projects across Arizona and Colorado, Chapter Five found that boundaries do not need to be devised at the basin-level in order for water providers to engage in conjunctive management, supporting Hypothesis 1. The data on coordination in Arizona and Colorado also backed Hypothesis 2, finding that coordination is positively associated with the provision of conjunctive water management. Although, the types of coordination associated with conjunctive water management in Arizona and Colorado differ from the basin-level coordination found in California.

Upon identifying different levels of coordination associated with conjunctive water management, Chapter Five considered the differences in the institutional settings governing water resources across the three states. The analyses show that Arizona and Colorado differ from California in that these states quantify rights to groundwater. The larger institutional settings in Arizona and Colorado help control the collective action dilemmas facing groundwater users in California that precipitate the need for the basin-level institutions. These findings conform to the expectations put forth by Hypothesis 3, which claim that basin-level coordination is less likely to arise where the larger institutional setting controls CPR demand dilemmas. Given CPR theory's insights on the importance of controlling resource boundaries, these results suggest that CPR theory can help explain coordination in a public service industry more fully.

Chapter Six used data on conjunctive water management projects in Arizona to evaluate Hypotheses 4a and 4b, which explain project-level coordination. The regression analysis demonstrates that project-level coordination is positively related to the production capacity of a project, as predicted by Hypothesis 4a. This hypothesis is derived from the public service industry assumption that fragmented jurisdictions through coordination are better suited to producing large-scale projects than single, large-scale jurisdictions.

The results from the regression analysis further indicate that in-lieu projects are positively associated with project coordination in Arizona. The in-lieu variable was included in the model as a control because in-lieu projects are likely to involve the coordinated arrangements to acquire surface water supplies from entities other than the organization managing the in-lieu project. This finding, while not specified by the hypothesis, fits with the assumptions of the public service industry literature. The literature emphasizes that public service production is likely to involve coordination to increase project efficiency when inputs must be obtained from outside the boundaries of provision jurisdictions. Another explanation for the use of coordination in in-lieu projects is that it is less expensive for irrigators to coordinate with an outside entity who provides the water in exchange for groundwater credits than it is for irrigators to purchase the water and keep the credits. This explanation also supports the public service industry literature because cost-efficiency is gained through coordination. Moreover, surface water providers that have excess surface supplies can achieve cost-efficiency gains if they choose to coordinate the storage of their water with irrigators engaging in in-lieu recharge. In fact, the cost-efficiency analyses show that is that it is less costly on average to store water through in-lieu projects than it is to develop direct recharge projects.

Chapter Six also presented data examining cost-efficiency differences between conjunctive water management projects using coordination and projects not using coordination to evaluate Hypotheses 4b. The findings provide only limited support for the public service industry literature's assumptions about coordination due to the small number of conjunctive management projects reporting cost data. The data analyses still offer useful insights on the role of coordination, supported by the descriptive data and regression results. For instance, medium-size projects using coordination are associated with higher capital cost-efficiency than medium-size projects that do not involve coordination. The findings also demonstrate that capital cost-efficiency tends to improve at higher levels of project-storage capacity. Among projects categorized as medium or high storage capacities, only two projects did not involve coordination.

The data on transaction costs, production costs, and water costs supplement the cost-efficiency analyses using capital costs. The data on transaction costs and production costs are limited to a few cases, and quantitative comparisons among projects of similar sizes are not feasible. Despite the limitations on transaction and production cost data, the 24 projects reporting water costs show that among medium and large projects, average water costs decrease with higher numbers of project participants.

Overall, the findings on the cost-efficiency data in Chapter Six show patterns of improved cost-efficiency among projects with more participants. Projects with low storage capacities tend to have no improvements in cost-efficiency when projects involve coordination. Notably, projects with the most participants usually have high storage capacities. Given the low costs of in-lieu projects and the association between project storage capacity and number of participants, it is impossible to determine whether participation alone leads to greater cost-efficiency. The findings suggest that projects with higher storage capacities, which are also likely to involve coordination, can achieve greater economies of scale than projects that do not involve coordination. However, quantitative support for Hypothesis 4b is weak.

Unanticipated Findings

In addition to the findings that were predicted by the hypotheses, the data analyses resulted in unanticipated findings that explain the use of conjunctive water management. The analyses of California's conjunctive water management projects help evaluate the relationship between physical and institutional factors that affect conjunctive water management. Despite the fact that most of the conjunctive management projects in California occur in basins with high water storage capacity, conjunctive management does not appear to occur in a few very large basins. As a control variable, basin storage capacity was expected to have a positive impact on the use of conjunctive management. In the QCA model, high storage capacity is positively associated with conjunctive management. On the other hand, the results of the logit model suggest that the ability of water providers to organize conjunctive management projects (or the institutional arrangements that are associated with conjunctive management in California) may be limited when basin storage capacity is very large. This confirms predictions about the likelihood of cooperation in collective action dilemmas put forth by CPR theory, which suggests that smaller-scale CPRs are more likely to facilitate coordinated management. This component of the theory was not tested formally in the analyses, however.

Another unanticipated finding from Chapter Four is that both the logit and QCA models show that county groundwater ordinances are not associated with the use of conjunctive water management in California. Given that county boundaries are not congruent with the scale of groundwater basins, this result did not contradict CPR theory. Although, in proposing that CPR theory could be synthesized with public service industry/local public economy theory, it is theoretically plausible that county ordinances could be associated with conjunctive water management if other jurisdictions overlapping county boundaries worked with counties to provide or produce conjunctive management. This was not the case in the California sample.

One of the unanticipated findings from the cross-state analyses is the difference in the types of conjunctive water management programs used in each state. California exhibited the most diversity in types of conjunctive water management projects. This is not surprising given the decentralized, basin-level system of water governance in California. Arizona, which uses some of the same forms of conjunctive management techniques as California, relies on in-lieu recharge to store the largest volumes of water. Yet, the majority of individual projects are direct recharge facilities.

Conjunctive management in Colorado differs from the other two states in that coordination is commonly found within organizations. These organizations engage in conjunctive management for hundreds of individual well owners to satisfy stream replacement obligations. In Colorado, conjunctive water management is not intended to store water for long-term use or drought conditions, as occurs in Arizona and California. Instead, groundwater users acquire excess water supplies seasonally, which is replaced in streams or recharged through ponds to replenish stream flows. This method of stream replacements ensures that groundwater users can continue to pump tributary groundwater, which depletes surface supplies. Surface water users in Colorado still receive their share of water at the appropriate time and place through the in-stream or recharged replenishments.

Despite the vast differences in types of conjunctive management programs and the types of coordination, the extent of coordination used to produce projects is similar across the three states. Project-level coordination occurs in about 50 percent of each of each state's projects, most often for the purpose of surface water supply contracts and leases. Water providers in the three states coordinate the provision, or funding, of project facilities only in a few instances. In Arizona, the level of coordination at the project level is higher than the other two states, based on participants per project. This finding is unanticipated given that Arizona has the most centralized system of water administration and governance of conjunctive management programs among the three states. One explanation of this finding is that the types of institutions devised by the state of Arizona have facilitated coordination among water providers engaged in conjunctive management. In particular, the Arizona Water Banking Authority and the Central Arizona Water Conservation District, both state-sponsored special districts, have the authority to coordinate with local water providers to store excess CAP water in underground storage facilities or to deliver CAP water to these providers for in-lieu recharge.

Chapter Six also produced unanticipated findings. First, the difficulties in ascertaining the impacts of coordination on project cost-efficiency not only result from limited observations, but also from the confounding influences of project production capacities and project type. This outcome demonstrates the potential difficulty in testing the assumptions of the public service industry literature, even if the data included a large number of cases.

Among the specific analyses of cost-efficiency in Chapter Six, the findings on average water costs per project are somewhat unanticipated. Projects with only one participant have the lowest average water costs. In looking more closely at the actual cases, this outcome can be attributed to the fact that many of the smaller projects are direct recharge facilities using treated effluent. Most organizations using effluent in conjunctive management reported that effluent has a cost of $0 since these organizations directly own the effluent. This does not mean that these organizations do not incur costs for treating and producing the effluent. Thus, the costs for single-producer projects may be skewed toward the low end. The data do show that projects with five or more participants involve lower costs per acre-foot than projects with two to four participants. This outcome is explained by the fact that the projects with the most participants are often in-lieu projects, which also have lower water storage costs.

Alternative Explanations of Findings

The data analyses in the empirical chapters were chosen to test the hypotheses derived from the theory development section. The empirical chapters did not test alternative hypotheses formally, although plausible alternative explanations can be gleaned from the theory and background discussions. For instance, the data indicate that institutional boundaries do not have to be devised around basin-level boundaries in order for water providers to engage in conjunctive water management where water rights are clearly assigned. An alternative explanation for the type of boundary arrangements found across the three states is that the system of water administration, not the assignment of water rights, influences the scale and boundaries of water management projects. Second, alternative explanations of coordination can be drawn from CPR literature and collective action literature more broadly which would imply that community and social factors have more to do with decisions to coordinate than production concerns. This section looks specifically at the results from each of the empirical chapters to examine alternative explanations, focusing on how they relate to the hypotheses.

The California findings support a synthesis of CPR theory and public service industry theory. They show that institutions need to control the resource to engage in conjunctive management, yet institutional control over the resource does not require the development of a single jurisdiction that overlies resource boundaries. An alternative explanation for the findings in California is that other institutional factors, besides control over physical boundaries, affect the use of conjunctive management. The logit and QCA models tested the relationship between jurisdictions, which have different institutional boundaries, and the use of conjunctive water management. The different rules imposed by these jurisdictions such as pumping limitations, replenishment requirements and taxing authority also can impact the use of conjunctive water management. In fact, CPR studies show that different local-level rules governing the supply and demand of California's groundwater basins have led to very diverse groundwater management outcomes. (Blomquist 1994; Ostrom 1990.) Thus, the specific water use rules or replenishment obligations that California's groundwater institutions impose may temper the importance of the physical extent of these institutions in promoting conjunctive management. Given that only a few types of groundwater management institutions exist and many of the specific powers of these forms of institutions overlap, it is difficult to assess how these powers influence conjunctive management using this data set.

Another finding in California that could be explained with alternative hypotheses is the relationship between AB3030 Plans and the use of conjunctive water management.

AB3030 Plans are relatively new compared to other institutional forms of groundwater management. The recent development of these plans leaves open the possibility that the conjunctive management efforts precede AB3030 Plans in some basins. Basin-management efforts could therefore lead to the creation of AB3030 Plans, rather than AB3030 Plans leading to the creation of conjunctive management. The evidence from the other groundwater institutions in California and evidence from the history of conjunctive management in California still suggest that the development of institutions are key to facilitating conjunctive management. Yet, the possibility remains that AB3030 Plans developed in basins where water users previously attempted to engage in basin management and discovered that some institutional mechanism was necessary to continuing such efforts. Testing this possibility would require an examination of the development of conjunctive management projects over time in relation to the development of AB3030 Plans. Regardless of the timing of the creation of AB3030 Plans relative to the development of conjunctive management, the analyses show that these plans are tied to the use of conjunctive management.

Another alternative explanation to consider is that sub-state institutions can play a role in the types of coordination associated with conjunctive water management in Arizona, California, and Colorado. The cross-state findings indicate that state water rights doctrines affect the type of coordination associated with conjunctive management in each state. At the sub-state level, the use of conjunctive management, even in Arizona and Colorado, varies across areas of the state that may have some unique physical or administrative characteristics. The form or powers of the public agencies that administer property rights laws could, therefore, affect how conjunctive management emerges. While sub-state factors were evaluated in California in relation to the use of conjunctive water management, they were not explicitly considered in Arizona and Colorado. In Colorado, for instance, the division engineer's rules and processes could play an important role in facilitating the coordination of conjunctive water management across well-owner associations. The descriptive analyses did show that in Colorado the storage capacities of the South Platte and Arkansas Basins and the different timing of the division engineers' rules led to differences in the use of conjunctive management. In Arizona, the effects of sub-state institutional factors are more difficult to identify with this data set because the system of water administration is centralized and conjunctive management practices are relatively similar across the different AMAs.

Finally, other factors besides production capacity and economies of scale may play a role in project-level coordination. For instance, in testing Hypothesis 4a, the regression model includes years of project operation as a control variable. The negative and significant relationship between years of operation and project participation could be partially due to changes in Arizona laws. In the mid-1990s the state made recharge projects less costly through the creation of cheaper pools of water and the formation of the Arizona State Water Banking Authority. The factors that facilitate project coordination, under this scenario, are state-sponsored institutions, although, this explanation ultimately rests on production cost concerns.

In evaluating the explanation of coordination presented by the public service industry literature, the theory chapter recognized that CPR helps explain coordination in a public service industry. CPR management theory describes conditions that are likely to lower the transaction costs associated with organizing a group of project producers. These factors may include a history of interaction, shared reliance on the resource, and frequent communication, to name a few. Chapter Two recognized that alternative hypotheses explaining project-level production can be derived from CPR management theory. However, to discern whether the explanations offered by the public service industry theory are useful and whether they can supplement CPR theory, the data analyses focused on testing the assumptions of the public service industry literature.

These analyses did not test all of the potential variables that affect coordination or the types of boundary arrangements that are associated with conjunctive water management. Parsimony and accuracy are often mutually conflicting goals of theory (Przeworski and Teune 1970; King, Keohane, and Verba 1994). In developing theories, it is useful to try to explain as much as possible with few variables to achieve parsimony. Yet, accuracy requires theories to specify relationships among multiple variables and conditions. These analyses did attempt to specify more accurately the role of institutional boundaries in the management of common-pool resources, using the example of conjunctive water management. They also attempted to clarify the conditions under which public service industry theory's assumptions can explain coordination. Thus, the theory development and analyses sought to improve the accuracy of resource management theories. Given the goal of parsimony, only the most plausible explanations based on the theory were tested. The impact of the alternative explanations and the limitations and strengths of this study are discussed in the following section.

STRENGTHS AND LIMITATIONS OF THE FINDINGS

The findings of this dissertation can be validated by the strengths of the research design. At the same time, the research design and analytical methods have certain limitations that affect the findings. The methods chapter discussed issues of reliability and validity associated with the NSF/EPA data set used in this study. This section reviews some of the points raised in the methods chapter as they affect the overall strengths and weaknesses of the findings, in terms of theory development and research methods. In addition, this section considers some of the specific strengths and limitations of each of the empirical chapters.

From a theory development perspective, the strengths of the dissertation's findings are that they support the synthesis of key points from two related theories to improve the accuracy of both theories. In addition, this study expands the accuracy of both theories by using them to explain conjunctive water management. Conjunctive water management is a public service and resource management technique that has not been examined extensively through the lenses of either bodies of literature.

The methods chapter demonstrated that the strengths of this research design are based on three factors: a consistent research framework, multiple levels of analysis, and multiple methods of analysis. First, the Institutional Analysis and Development (IAD) framework has guided the dissertation's theory development and research methods. This framework has a consistent and well-recognized record of empirical support for the theories that are evaluated in this study. The explicit recognition of the IAD framework provides a clear link between the results of the dissertation and the empirical findings of the larger NSF/EPA study, which was developed within the IAD framework.

The IAD framework helps identify and define key variables and levels of analysis that are common to most institutional settings. The design of the NSF/EPA study and the data analyses in this dissertation incorporated these variables and levels of analysis. As noted in the methods chapter, the use of the IAD framework provides face and construct validity for the variables used in the analyses. It also supports data reliability, particularly through the standardized coding forms used for data acquisition. While the empirical section of this dissertation focused on testing the theoretical propositions using a particular water management technique, the IAD framework can facilitate transferring the methods and research questions used in this study to other empirical settings.

A second strength of this study is the use of multiple levels of analysis. In evaluating the relationship between institutions and conjunctive water management, comparisons were made at the state level, sub-state level, and project-level. The multiple levels of analysis leverage the data set by providing more observations and more measures for theory testing compared to using one of these levels alone (King, Keohane, and Verba 1994). Chapter Four evaluated the role of institutions at the sub-state, or basin-level in California, which provided four different forms of groundwater governance variables across 70 cases. In looking at state-level institutions, the data set only allowed for an analysis of the various forms of water governance institutions across three cases. Despite the limited number of state-level cases to compare the role of institutions, the cross-state comparison was able to examine multiple measures of conjunctive management projects to compare the different effects of institutions. These included conjunctive management project locations, institutional boundaries, project types, organizations involved in projects, and the institutional form of those organizations. Finally, in analyzing the role of coordination in conjunctive management projects, cross-state comparisons helped explain the effects of different water governance institutions on the type of coordination that is used in each state. To evaluate the implications drawn from the public service industry literature about the purposes and reasons for coordination, Chapter Six offered analyses at the project-level within Arizona. It examined the effects of production factors on coordination across 42 conjunctive management cases.

The third strength of the findings is that the data analyses incorporated multiple methods of analysis and multiple measures to test hypotheses. In studies with limited numbers of observations or cases, using multiple measures also helps leverage the data (King, Keohane, and Verba 1994). Chapter Four used a quantitative logit model and a large-n, qualitative comparative model based on boolean algebra to test the first two hypotheses. The first two hypotheses also were evaluated using qualitative cross-state comparisons and descriptive data in Chapter Five. Thus, different methods and units provided further data leverage for testing the first set of hypotheses. The final two hypotheses were evaluated using the same cases, but with multiple measures and methods. Chapter Six used a quantitative regression model of the 42 cases in Arizona, which related project size and type, as indicators of production capacity, to project coordination. Then, Chapter Five evaluated multiple indicators of economies of scale, looking at project outputs relative to different types of project costs. These descriptive comparisons across Arizona's projects offer more insights into the last two hypotheses than the individual regression model provides alone.

One of the weaknesses of the findings is tied to the data limitations that facilitated the need for multiple levels of analysis and multiple measures. The data set was not conducive to evaluating project-level variables across all three states because of differences in sampling frames and types of data. These data limitations can lead to problems in making valid statistical inferences. In particular, the data limitations make it difficult to evaluate the hypotheses on coordination across projects from all three states. The data from Arizona presents the most complete set of variables from which to test Hypotheses 4a and 4b. However, the Arizona data set also has missing variables across different observations. This hinders the validity of the findings relating project costs to coordination.

Another potential weakness of the study is that alternative explanations of the findings discussed in the previous section were not tested. These explanations might tell a different story of the development of conjunctive water management in the western United States. While this chapter recognizes these possible explanations, the purpose of this study was not to test all possible explanations for the types of conjunctive water management outcomes found across the western United States. The purpose was to test proposed theory development, using a study of conjunctive water management. The findings do not purport to offer all-encompassing explanations of how and why conjunctive water management is used. Instead, the study helps explain part of the reasons for the use and development of conjunctive water management, emphasizing the role of institutional boundaries and coordination across water providers.

This point leads to another potential weakness of the study, which is the generalizability of the proposed theory development to other resource management situations. The theory should explain a wide range of resource management phenomena or public services than conjunctive water management in order to achieve the goal of generality (Przeworski and Teune 1970). However, as shown in Chapter Two, the generalizability of CPR theory and the generalizability of public service industry theory have been demonstrated in various empirical settings. While the points of synthesis between the two theories proposed in this dissertation have not been examined across a number of settings, the points of synthesis are sufficiently general to warrant further testing in alternative empirical settings.

IMPACT OF THE DISSERTATION

This dissertation can contribute to the development of more accurate theories of resource management and of public service provision, while also expanding the generality of existing theories. This section discusses this dissertation's key contributions to resource management theory and to practical knowledge of water resource management techniques. Second, it examines the more general contributions that this dissertation can offer to theories of public policy. Finally, it considers some of the policy implications that can be drawn from this study.

Contributions to Water Resource Management Research

One of the key contributions that this dissertation makes to water resource management research is that it expands the existing knowledge of conjunctive water management in the western United States. As shown in Chapter One, conjunctive water management is a promising technique for addressing a number of water supply management dilemmas. The technique is considered to be less expensive and less environmentally damaging than surface water reservoirs and dams. It also can help maximize the availability of limited water supplies in regions with growing populations and diverse water demands. While some aspects of conjunctive management have been studied extensively, such as groundwater banking and groundwater recharge feasibility, studies on the relationship between conjunctive water management and institutional arrangements have received less attention. This dissertation has contributed to this body of knowledge by examining a) the relationship between institutional boundaries and conjunctive water management and b) the use of coordination in conjunctive water management. It also has quantified the extent to which conjunctive water management is used in Arizona, California, and Colorado and the types of conjunctive management projects commonly used in these states. Finally, this dissertation has described the location of conjunctive water management projects, the types of organizations involved in conjunctive management, and the costs and benefits that accrue to organizations involved in conjunctive management projects.

This dissertation contributes more broadly to an understanding of the water industry in the United States and the relationships among water providers, producers and water governance jurisdictions. Vincent Ostrom's 1971 study of the California water industry presented a more comprehensive description of one state's water industry, but this dissertation has built upon Ostrom's insights in describing some of the salient features of the water industries in three western states, relative to a particular water management practice. In addition, this dissertation has helped expand some of the insights offered by the U.S. ACIR study (1991) that described coordination in the U.S. water industry. The U.S. ACIR study explained how water governance institutions can impede coordinated water management. Conversely, this dissertation has explained how state-level institutions can facilitate different types of coordination in the management of water resources.

Theoretically, this dissertation helps advance the understanding of how institutional boundaries relate to natural resource management. The theory development chapter argued that the public service industry literature informs CPR theory's boundary criteria for effective resource governance through its definition of boundaries and its concept of inter-jurisdictional cooperation. Public service industry theory conceptualizes institutional boundaries as being formed around local problems that affect a group of individuals, rather than around a physical resource or good. This re-conceptualization helps broaden the application of CPR theory's criteria for effective resource management to more complex resource management settings. It helps explain how small-scale institutional arrangements can resolve large-scale and complex CPR dilemmas without resorting to devising single, large-scale jurisdictions. Essentially, the theory development argues that when self-governing jurisdictions arise around shared problems they can coordinate and cooperate to address larger CPR problems that cross the existing institutional boundaries. The data analyses in Chapters Four and Five support these theoretical assumptions. The proposed revision to the CPR boundary criteria, therefore, helps generalize CPR theory beyond small-scale CPR problems to more complex and diverse physical and institutional settings.

Contributions to Public Policy Theory

The theory development and data analyses in this dissertation provide insights into public policy theory, beyond water resource management theories. Specifically, this dissertation has used public service industry theory, supported by CPR theory, to clarify how and why coordination occurs in the production of public services. First, the theory section considered some of the weaknesses that the local public economy literature presents to explain coordination. It recognized that CPR theory describes more precise and testable conditions that facilitate coordination. The theory chapter also recognized that CPR theory's explanation of coordination is dependent upon certain conditions. The empirical portion of this dissertation identified different forms of coordination including basin-level, organizational-level and project-level coordination. The analyses further supported the contention that in settings where entities face collective action dilemmas associated with the use of a resource or provision of a service, this facilitates the need for coordination across all users of a resource. In such instances, CPR theory helps explain the emergence of coordination and institution building. Conversely, in settings where institutions have resolved these collective action dilemmas, the public service industry literature offers more appropriate explanations of coordination. These factors are production costs and economies of scale concerns.

The contributions to public service industry theory can impact policy studies in two ways. First, they demonstrate the conditions under which micro-level theories of collective action can be used to develop macro-level, or organizational-level, theories of collective action. For instance, CPR theory's explanations of coordination across individual resource users can be used to explain coordination across jurisdictions in the California water industry. Second, policy studies that are concerned with examining the benefits of coordinated public service provision can borrow from this study's clarification of the differences between the factors that facilitate coordination and the effects of coordination, when coordination occurs for production purposes.

Policy Implications

The policy implications of this dissertation are based on the study's contributions to resource management and policy theory. At the operational-level of water resource management, this study underscores the importance of understanding the effects of the larger institutional setting before implementing resource supply management programs such as conjunctive water management. Also, in providing and producing conjunctive management projects, this dissertation has demonstrated that coordination across jurisdictions may reduce production and transaction costs per unit of output, particularly among larger projects.

The operational-level policy implications feed into policy decisions at the collective-choice level. At the collective-choice level, where resource management rules and institutional arrangements are defined, this dissertation shows that water management jurisdictions do not necessarily need to be devised around some clearly-defined resource in order to manage resource supplies. Similarly, they do not need to be single large-scale jurisdictions. The data analyses further demonstrate that it is necessary to consider the effects of the larger institutional setting, particularly property rights, when determining appropriate jurisdictional scales or boundaries. Conjunctive water management projects in California, where rights to groundwater resources are not assigned by the state, are associated with jurisdictions that are clearly-defined around groundwater basin boundaries. This was not the case in Arizona and Colorado, however, where appropriation dilemmas are addressed by quantified water rights.

SUMMARY

This chapter has discussed the expected and unexpected findings of this dissertation, showing how data on conjunctive water management projects in Arizona, California, and Colorado support the theory development proposed in this dissertation. These findings contribute to integrating two well-established bodies of policy and resource management literature, based in a common research framework. They show that CPR theory can be more generalizable by recognizing that the larger institutional setting may not require that institutional boundaries overlap with resource boundaries in order for resource management to be successful. The analyses also help clarify the factors that facilitate inter-agency coordination in the provision of public services, demonstrating that the public service industry literature may offer sufficient explanations of coordination in settings where jurisdictions do not face collective action dilemmas.

This chapter also has shown how the theory can explain the development and implementation of conjunctive water management projects in the western United States – a supply management technique that is emerging as an important alternative to traditional water supply management methods. The type of conjunctive water management projects, the location of projects, and the type of coordination used in conjunctive water management vary across the different institutional settings evaluated in this dissertation. Water rights laws, in particular, are a key factor in explaining this variation. Where groundwater water rights are not clearly assigned, conjunctive management emerges within basins where water users coordinate to devise institutions that control basin boundaries. Where water rights are quantified, basin-level coordination does not emerge. Across all the states, the analyses identified common points at the project level where water users tend to coordinate the production of conjunctive management projects. Thus, the findings in this dissertation present a comprehensive picture of conjunctive water management in three states while offering theory development. The findings lend themselves to future analyses using different settings to further examine the adequacy of the theory in explaining the relationship between institutions and resource management.

APPENDIX A: CODING FORMS FOR NSF/EPA STUDY

ORGANIZATION FORM

General Questions

1. Name of organization ____

2. Date of creation ________________________

3. Form of organization:
   - _____ Special District
   - _____ Executive agency
   - _____ Independent agency
   - _____ Not-for-Profit (501(c))
   - _____ Private Corporation or Entity/Individual
   - _____ General Purpose Jurisdiction, or division thereof

4. Does the organization have member organizations?
   - _____ yes
   - _____ no

5. If yes, the number of member organizations: ______

6. Requirements for membership:
   - _____ reside within the jurisdictional boundaries of the organization
   - _____ payment of dues/fees
   - _____ contract with organization for water services
   - _____ other

7. Does the organization have individual members or customers?
   - _____ yes
   - _____ no

8. If yes, the number of individual members or customers: ______

9. Requirements for membership:
   - _____ reside within the jurisdictional boundaries of the organization
   - _____ payment of dues/fees
   - _____ contract with organization for water services
   - _____ other

10. Number of ftes: __________

11. Number of ftes dedicated to conjunctive water management activities: ___________

12. Indicate the types of experts the organization employs, or has on retainer:
    - _____ attorneys (number of ftes: _____)
    - _____ hydrologists (number of ftes:_____)
    - _____ engineers (number of ftes:_____)
    - _____ biologists (number of ftes:_____)
    - _____ chemists (number of ftes:_____)

13. Current annual budget: $____________________

14. Past annual budgets: 1997 $____________________
1996 $____________________
1995 $____________________
1994 $____________________
1993 $____________________
1992 $____________________

15. List the percentage of funding from each source for the organization:
_____ User fees
_____ Taxes
_____ Grants
_____ Bond Issues
_____ Other:______________________________

16. Water rights portfolio of organization: (amount and type of water owned by the organization)
groundwater _______ AF
surface water ______AF
effluent _____AF
project water (contracted for) _____AF

17. Activities of the organization:
_____ administer state water laws
_____ build/operate water projects
_____ deliver water to end users
_____ broker or wholesaler
_____ representing citizens or members in conjunctive use planning or operation

18. List the types of support services the organization provides for conjunctive use activities:
_____ Conflict mediation
_____ Hydrologic surveys
_____ Publications (newsletter, paper series, etc.)
_____ Hosting conferences
_____ Encouraging/funding coordination activities among water users/managers
_____ Training seminars
_____ assistance in completing paperwork
_____ Other: __________________________

19. What is the size of the organization's jurisdiction? _____ miles^2

20. What is the population within this organization's jurisdiction?
current _______
projected: ________5 years
________10 years
________20 years

21. Rank the following uses of water, from greatest to least, based on volume, in this organization's jurisdiction or service area:
_____ in-stream
_____ recreation
_____ hydropower

_____ industrial
_____ municipal
_____ agricultural
_____ not applicable

22. List the three major threats to the quality of water in this organization's jurisdiction or service area, from greatest to least: (use the following list as a guide)
    _____ urban runoff -- storm water/chemicals
    _____ urban runoff -- sewage
    _____ urban effluent
    _____ industrial effluent
    _____ industrial runoff
    _____ agricultural runoff
    _____ decreased inflows
    _____ airborne chemicals
    _____ saltwater intrusion
    _____ other

23. Within the organization's jurisdiction or service area, are there current water quality problems that cause specific damage to plant or animal life?
    _____ yes
    _____ no
    _____ not applicable

24. Within the organization's jurisdiction or service area, do changes in current consumptive uses cause specific environmental damage to plant or animal life?
    _____ yes
    _____ no
    _____ not applicable

25. List the water associations or councils of which the organization is a member
    ____.

26. List any special commissions, advisory boards or panels devoted to water policy matters of which the organization is a member____________________________________.

27. List up to ten organizations with whom this organization regularly discusses conjunctive water management issues.

Conjunctive Use Activities

28. Number of conjunctive use projects in which organization is a direct participant ______.

29. Which of the following conjunctive management activities does the organization engage in?
    ____capturing and storing native surplus surface water underground
    ____purchasing native surface water and storing it underground
    ____importing surplus surface water and storing it underground
    ____in-lieu recharge (use of surface water to store or maintain groundwater supplies)
    ____drawing upon surface water storage to supplement groundwater pumping

____drawing upon stored groundwater to *supplement* surface water flows when the latter are deficient
____drawing upon stored groundwater to *replace* surface water supplies when the latter are deficient
____brokering among parties
____other

30. List the types and number of permits that this organization holds:
_____ Wells #_____
_____ Recharge projects #_____
_____ Water storage #_____
_____ Water appropriation #_____
_____ Water transfers #_____
_____ Water transportation #_____
_____ Water treatment #_____
_____ Instream flows #_____
_____ Other: ____ #_____

31. The storage capacities of the smallest and of the largest constructed projects in which the organization is a direct participant
smallest: _______AF
largest: ______ AF
_____ not applicable

32. If the organization is involved in in-lieu recharge what is the largest and smallest amount of water exchanged within the last 5 years?
smallest: _______AF
largest: ______ AF

CONJUNCTIVE MANAGEMENT PROJECT QUESTIONS

General Questions

1. Project name ____

2. Give a brief description of the project

3. List the organizations involved.

4. Describe the requirements (imposed by laws or regulations) organizations must meet in order to subscribe to the project:

5. What is the average annual amount of water stored by this project? __________afy

6. At this date, what is the total amount of water stored by this project? __________af

7. What is the average annual amount of water withdrawn from this project? ________ afy

8. At this date, what is the total amount of water withdrawn from this project? __________ af

9. What are the total capital costs of this project? $________________

10. What were the sources of funding for the capital costs of this project?

Amount:	2a.	$_______	User fees
	2b.	$_______	Energy sales
	2c.	$_______	Water sales
	2d.	$_______	Property taxes
	2e.	$_______	Energy taxes
	2f.	$_______	Other taxes
	2g.	$_______	Government grants
	2h.	$_______	Bonds
	2i.	$_______	Other: 2j.______________________
TOTAL	2k.	$_______	

11. What are the annual operations, maintenance and repair costs?

__________1997
__________1996
__________1995
__________1994
__________1993
__________1990
__________1985
__________1980

12. How many labor hours per week are devoted to this project ________

13. Which conjunctive use activities are part of this project?
    direct recharge _______
    in-lieu recharge _______
    flows for recreation _______
    flows for environment _______
    capturing surplus flows as available_________
    purchasing supplemental water for import/use in the area_________
    reclaiming water for reuse________
    treating contaminated water_______
    other (briefly describe)

14. Which activities are monitored as part of this project?
    Recharge volume __________
    Surface water flows __________
    Water quality _________
    Water withdrawn __________
    Water table level __________
    Wildlife _________
    Habitat__________

Project Facilities

Pumps for Withdrawal

15. Give a brief description of the facilities.

16. What are the total capital costs of the pumps for withdrawl? __________

17. What is the annual volume of water pumped by this facility._________
    1997 ________
    1996 ________
    1995 ________
    1994 ________
    1993 ________
    1990 ________
    1985 ________
    1980 ________

Injection Wells.

18. Give a brief description of the facilities.

19. What are the total capital costs for the injection wells? __________

20. What is the annual volume of water pumped by this facility.________

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

Spreading Basins.

21. Give a brief description of the facilities.

22. What are the total capital costs for the spreading basins? __________

23. What is the annual volume of water spread by this facility.________

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

Effluent Treatment.

24. Give a brief description of the facilities.

25. What are the total capital costs of the facility (only those facilities built specifically for the project)? __________

26. What is the annual volume of water treated by this facility for the project?

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

Impoundment facilities. (captures flow, runoff, etc.)

27. Give a brief description of the facilities.

28. What are the total capital costs of the impoundment facilities? __________

29. What is the annual volume of water held in this facility.________

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

Distribution Facilities. (turnouts, etc.)

30. Give a brief description of the facilities.

31. What are the total capital costs of the distribution facilities? ___________

32. What is the annual volume of water delivered by this facility.________

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

In Lieu Recharge

33. Give a brief description of the in lieu recharge program.

34. Who supplies the surface water for this project?

35. Who receives the surface water for this project?

36. Who has control over the groundwater that is saved by this in lieu project?

37. What types of water are exchanged?

38. Describe the facilities, if any, that were built for in lieu recharge.

39. What are the total capital costs of these facilities?_________

40. What is the annual volume of water saved by this facility.________

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

Ground Water Resource Questions

41. Describe the ground water basin boundaries.

42. Are there any sub-groundwater basins? ________

43. What is the total storage capacity of this groundwater basin (acre feet) ________

44. List the annual natural recharge (acre feet)

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

45. Describe the source of natural recharge.

46. List the annual artificial recharge (acre feet)

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

47. List the annual natural outflow (acre feet)

1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

48. Describe the destination of natural outflow.

49. What is the annual safe yield? (acre feet) ________

50. Do overdraft conditions exist? ________

51. List water table levels (closest sub-basin to recharge project).
1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

52. List the lowest, the highest, and the mean water table levels recorded for this basin.
lowest ______
highest ______
mean ______

53. Are there any recognized ground water quality problems?
_____ yes
_____ no

54. If yes, describe the threats to ground water quality.

55. How many significant cones of depression exist in this basin? ________

56. Do these cones threaten hydrological connections between surface and groundwater?

57. Are there any subsidence areas in the basin? __________

58. List the height of well lifts

1997	mean ________
	range ________
1996	mean ________
	range ________
1995	mean ________
	range ________
1994	mean ________
	range ________
1993	mean ________
	range ________
1990	mean ________
	range ________
1985	mean ________
	range ________
1980	mean ________
	range ________

Surface Water Resource Questions

59. What is the main surface water source and its tributaries? ________

60. List the annual outflows in this watershed (released into the next watershed).
1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

61. List the volume of annual allocation of surface water.
1997 ________
1996 ________
1995 ________
1994 ________
1993 ________
1990 ________
1985 ________
1980 ________

62. Are there any recognized surface water quality problems? ________

63. If yes, describe any threats to surface water quality.

64. Is the watercourse dewatered annually? ________

65. Is surface water hydrologically connected to groundwater? ________

66. Estimate the annual surface to ground transfer. ___________

67. Estimate the annual ground to surface transfer. ___________

PERFORMANCE MEASURES FORM

General Questions

This form is being completed for an organization or a project. *(Circle one.)*

If organization, name of organization:____________________________

Name of project:____

1. Year of performance considered: __________

2. Sources of O,M&R funding for this project:

Amount:	a.	$_______	User fees
	b.	$_______	Energy sales
	c.	$_______	Water sales
	d.	$_______	Property taxes
	e.	$_______	Energy taxes
	f.	$_______	Other taxes
	g.	$_______	Government grants
	h.	$_______	Bonds
	i.	$_______	Other: 2j.______________________
TOTAL	k.	$_______	

3. Cost per acre-foot of water going into the project and amounts purchased by the organization or project:

Water Types: *Water Uses*	*Cost*	*Amount*
Surface Water:		
Agriculture	a. $_________	b. ____________af
Industry	c. $_________	d. ____________af
Municipal	e. $_________	f. ____________af
Groundwater:		
Agriculture	g. $_________	h. ____________af
Industry	i. $_________	j. ____________af
Municipal	k. $_________	l. ____________af

Effluent:		
Agriculture	m. $________	n. ____________af
Industry	o. $________	p. ____________af
Municipal	q. $________	r. ____________af
Project Water:		
Agriculture	s. $________	t. ____________af
Industry	u. $________	v. ____________af
Municipal	w. $________	x. ____________af

4. Mission Statement for the organization in relation to the project :

____

____

____

5. Goals and Performance Measures: Rank goals in order of priority to the project if possible.

____	a. Raise water table?	b. Change in water table level (feet):__________
____	c. Slow decline in water table?	d. % change in rate of decline:__________
____	e. Increase instream flows?	f. Change in flow volume:__________
____	g. Maintain instream flows?	h. change in rate of decline of flows:____
____	i. Create riparian areas?	j. Increase in riparian areas (acres):______
____	k. Maintain riparian areas?	l. % change in loss rate of these areas:______
____	m.Protect endangered species?	n.Change in species population:________
____	o. Provide drought relief?	p. Emergency water storage: _______af
____	q. Reduce or eliminate subsidence	r.change in rate of subsidence__________
____	s. Reduce pumping lift	t. change in pumping lift _____
____	u. improve water quality	v. change in water quality_____
____	w. supplement water supply	x. AF supplemented_____
____	y. avoid loss of water rights or water use	z. AF captured_____

Organization Questions

(If this form is being completed for an organization, answer the following questions.)

6. If resources contributed to the project by the organization are being earmarked for certain activities, list the resulting distribution of resources (for the year of performance considered) below:

Activity	*FTE's contributed*	*Monies contributed (inc. FTE wages)*
Operation	a.	b.
Maintenance	c.	d.
Reporting	e.	f.
Monitoring	g.	h.
Enforcement	i.	j.
Coordination	k.	l.
Legal	m.	n.
Permitting	o.	p.

7. Physical assets contributed or dedicated to project by the organization overall:
    a. Value of Facilities Constructed: $____________
    b. Value of Facilities In-Place: $____________
    c. List of facilities already in place (i.e. ditches, turnouts, wells, etc.)
    ____
    ____
    ____
    ____
    d. Land Donated: ____________acres

8. What are the benefits to the organization of this project (for the year of performance considered)?
    a. Net acre-feet of groundwater credits accrued? _____
    b. Net acre-feet of stored water accrued? _____
    c. If the organization received necessary permission to develop subdivisions, what is the size of the approved area? _____
    d. Compliance with drinking water quality codes: Y/N
    e. Compliance with environmental regulations: Y/N
    f. If the organization preserved profits from recreational activities dependent on preserving surface flows, what is the estimate of preserved profits? $_________
    g. More efficient allocation of surface and groundwater supplies: Y/N
    h. Stabilized water table (to preserve existing wells): Y/N
    i. Increased water table by ________feet.
    j. Other:____

STATE LAW CODING FORM

1. Which state is described in this form?

Surface Water Rights

2. The predominant legal system for the allocation of surface water rights is:
    ____(1) riparian
    ____(2) prior appropriation
    ____(3) hybrid

3. Were or are riparian surface water rights recognized in this state?
    ____ (1) yes, but no longer recognized
    ____ (2) yes, and are currently recognized
    ____ (3) no

4. Are riparian rights attached to the following waters?
    ____ streams
    ____ lakes
    ____ ponds
    ____ foreign waters
    ____ artificially created waters
    ____ effluent
    ____ flood waters

5. Indicate the specific rights which are considered surface water riparian rights.
    ____ flow of the stream
    ____ reasonable use of the waterbody (provided reasonable uses of other riparians are not injured)
    ____ access to the water body
    ____ wharf out
    ____ prevent erosion of the banks
    ____ purity of the water
    ____ claim title to the beds of non-navigable lakes and streams

6. Are surface water riparian rights conditional upon making reasonable or beneficial use of the water?
    ____ yes
    ____ no

7. Define reasonable use:

8. List beneficial uses of surface water that are recognized in state law.
    ____ domestic
    ____ municipal
    ____ agricultural
    ____ industrial
    ____ stock watering
    ____ power generation
    ____ mining
    ____ recreation
    ____ fish and wildlife
    ____ instream flow protection

9. Define riparian lands:

10. Does state law forbid owners of riparian land to sever/transfer their surface water rights?
Yes _____
No _____
Depends _____

11. Are riparian rights ever subordinate to appropriative rights?
____ (1) yes
____ (2) no
____ (3) not applicable

12. Is prior appropriation of surface water recognized?
____ yes
____ no

13. Are rights of prior appropriation attached to the following types of water?
____ streams
____ lakes
____ ponds
____ foreign waters
____ artificially created waters
____ effluent
____ flood waters
____ salvage waters
____ surplus waters

14. Is surface water use ranked by preference?
____ (1) yes
____ (2) no

15. If yes, list the preference ordering of water use.
____domestic
____municipal
____agricultural
____industrial
____stock watering
____power generation
____mining
____recreation
____fish and wildlife

16. How does state law define priority of use:

17. Are there any procedures other than due diligence that the state recognizes for perfecting water rights?
_____ yes, describe
_____ no

18. What system does this state employ for assigning surface water rights?
    ____permitting
    ____ adjudication
    ____ a mix of permitting and adjudication
    ____ other: ____________________________________

19. Does state law provide for loss of surface water rights through forfeiture or abandonment?
    _____ yes, describe
    _____ no

20. Who bears the burden of proof in forfeiture or abandonment proceedings?
    ____ the water right holder
    ____ the water right challenger
    ____ the state

21. Time period of continuous non-benefical use that results in prima facie forfeiture or abandonment of surface water right.__________

22. List limits placed on senior surface water appropriators rights.
    ____ futile calls on the river
    ____ use of alternative water sources when practicable
    ____ public interest or trust doctrine
    ____ riparians may be shut out
    ____ other

23. For what purposes may surface waters be removed from appropriation?
    ____ in-stream flows
    ____storage
    ____other

24. List the procedures used for transfering surface water rights.
    ____ permitting
    ____ adjudication
    ____ notice or filing

25. List restrictions placed on transfers of surface water rights.
    ____amount of water that may be transfered
    ____changes in use of transfered water
    ____ changes in timing of use of transfered water
    ____ changes in point of diversion
    ____ changes in water quality

26. Who bears the burden of demonstrating the existence (or nonexistence) of "third party" effects of transfers.
    ____the transferor
    ____ the transferee
    ____ those affected by the transfer
    ____ the state

27. Who may object to transfers of surface water rights?
    ____surface water appropriators
    ____any one suffering direct effects, but not a surface water appropriator
    ____state administrators charged with protecting the public interest

28. Are surface water transfers out of basin of origin allowed?
    ____ yes, state-wide
    ____ yes, local option
    ____ no

29. Are or were pueblo water rights recognized in this state?
    ____ (1) yes, but no longer recognized
    ___ (2) yes, and are currently recognized
    ____ (3) no

Groundwater Rights

30. Are groundwater rights allocated by
    ____(1) adjudicatory
    ____ (2) administrative
    ____ (3) statutory
    ____ (6) other

31. Does the legal system (case or statute law) recognize the hydrologic connection between groundwater and surface water?
    ____ (1) yes, describe:
    ____ (2) no

32. Does the state distinguish among different types of groundwater rights?
    ____ (1) yes, memo: (use the following categories to structure memo, hydrologic connection to surface water, intensity of use, type of use, location, timing (prior to or after a specific date)
    ____ (2) no

33. Define reasonable use/beneficial use of groundwater:

34. List groundwater uses that are considered beneficial in state law:
    ____ domestic
    ____ municipal
    ____ agricultural
    ____ industrial
    ____ stock watering
    ____ power generation
    ____ mining
    ____ recreation
    ____ fish and wildlife

35. The system that the state uses to define groundwater rights:
    ____ permitting
    ____ adjudication
    ____ a mix of permitting and adjudication
    ____ other

36. Are groundwater rights quantified?
    ____ yes
    ____ no

37. On what basis are groundwater rights quantified?
____ amount or proportion of land owned above groundwater basin
____ historical use
____ administrative determination of need
____ other

38. Can groundwater rights be transferred to other uses?
____ in whole, all types
____ in part, all types
____ in whole, some types
____ in part, some types

39. Can groundwater be transported out of the basin of origin?
____ yes, memo:
____ no

40. Conditions state law places on out-of-area transports:
____ payment of taxes to jursidiction overlying basin of origin
____ payment of fees based on amount pumped
____ maintenance of property from which water is pumped
____ amount of water permitted to be pumped
____ compensation
____ limit on amount of water
____ maintenance
____ distance of transport

41. Do groundwater wells require a permit?
____ all wells
____ wells above a certain size
____ wells in specific locations

42. Who reviews permit applications?

43. Conditions for granting groundwater well permit:
____ noninterference with other pumpers
____ noninterference with streamflow
____ no excessive mining or depletion of the aquifer
____ no adverse impact on water quality

44. Must groundwater pumpers report amount pumped?
____ yes
____ no

45. Are rights in recharged groundwater recognized?
____ rights to use
____ rights to store
____ rights to transfer

46. Amount of recharged groundwater that may be recovered
____ all
____ some portion

47. May recharged groundwater be recovered in the same year in which it is recharged?
    ____ yes
    ____ no

48. Is there a program that allows the exchange of groundwater rights for surface water rights?
    ____ yes, anywhere
    ____ yes, local option
    ____ no

Effluent

49. Are rights in effluent defined?
    ____ yes
    ____ no

50. Are rights in effluent attached to the full amount of effluent produced?
    ____ yes
    ____ no, only to a portion

51. The system that the state uses to define effluent rights:
    ____ permitting
    ____ adjudication
    ____ a mix of permitting and adjudication
    ____ other

52. Are rights in effluent connected to the physical source (ie. treatment plant) of the effluent?
    ____ yes
    ____ no

53. Is effluent subject to prior appropriation?
    ____ yes
    ____ no

54. Can rights in effluent be transferred?
    ____ yes
    ____ no

55. For what purposes may effluent be used?
    ____ watering turf
    ____ ponds
    ____ maintaining landscape
    ____ irrigating food crops
    ____ irrigating nonfood crops
    ____ maintaining instream flows
    ____ groundwater basin recharge
    ____ other

56. May effluent be transported?
    ____ yes
    ____ no

Instream Flows

57. Are instream flow rights recognized?
____ yes
____ no

58. Are instream flow rights part of the prior appropriation system?
____ yes
____ no

59. What is the basis for instream flow rights?
____ appropriative
____ waters have been removed from appropriation
____ riparian
____ other

60. Who is eligible to hold an instream flow right?
____ state agency
____ non-profit organizations
____ any citizen of the state
____ other

61. Uses that are recognized as beneficial for instream flow purposes:
____ recreation
____ hydropower
____ aesthetics
____ protection of endangered species
____ protection of ecosystems

62. Are there uses that are specifically excluded from instream flow protection?
____ yes
____ no
If yes, list:

63. Can instream flow rights be forfeited?
____ yes
____ no

Recharge Programs

64. Methods of groundwater recharge allowed by the state:
_____off-stream facilities
_____ in-channel impoundments
_____ in lieu exchanges

65. Describe the planning requirements that the state requires applicants to meet:

66. Is acquistion of water for recharge integrated into the state's water rights scheme?
_____ yes
_____ no

67. Is groundwater aquifer recharge limited to certain types of water?
    _____ yes, describe
    _____ no

68. Describe the types of constraints placed on recharge facilities (such as limits on the amount of water recharged or withdrawn, limits on water levels or types of recharged water):
    ____
    ____
    ____
    ____

69. Can the recharging entity
    _____ collect fees/taxes from pumpers
    _____ collect fees/taxes from overlying landowners
    _____ acquire storage rights or credits for its own use or transfer

Delegation of State Authorities Locally

70. Does the state allow sub-state authorities to manage water?
    ____yes
    ____no

71. If yes, which types of water can be managed locally?
    ____ Surface water
    ____ Project/Imported water
    ____ Groundwater
    ____ Effluent

72. What is the purpose for the delegation of such authority?

73. What powers does the state authorize for sub-state management of surface water?

74. What powers does the state authorize for sub-state management of project water?

75. What powers does the state authorize for sub-state management of groundwater?

76. What powers does the state authorize for sub-state management of effluent?

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