INSTITUTIONAL BOUNDARIES AND COMMON-POOL RESOURCE MANAGEMENT: A COMPARATIVE ANALYSIS OF WATER MANAGEMENT AGENCIES IN CALIFORNIA*

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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. Increased urbanization and higher intensity agriculture have created severe water supply and water quality dilemmas worldwide, particularly in arid regions such as the southwestern United Sates (El-Ashry and Gibbons 1986; Reisner and Bates 1990; Case and Alward 1997).[1] What factors affect our decisions to use limited water resources more efficiently? Obviously, physical and technical factors, such as access to storage and distribution systems, can largely determine the feasibility of different types of water management methods. Institutions, however, also can influence on the implementation of water management programs. Institutions are the laws, policies, and organizational arrangements that communities devise to permit, forbid, or require certain human behavior (E. Ostrom 1990; Crawford and Ostrom 1995; North 1990). In the water resources field, institutional arrangements can include formal laws governing individual behavior, public and private organizational arrangements, as well as informal norms and standards shared among communities. These institutions shape how water users and water providers coordinate their actions to resolve water resource dilemmas (Ingram et al. 1984; Lord 1984; E. Ostrom 1990; Lam 1998).

This article examines one way that institutions governing water resources can affect the management of scarce water supplies. Specifically, it analyzes the relationship between the scale of water management institutions and the use of a promising water management method, known as conjunctive water management. The scale of institutional boundaries, or jurisdictions, has been considered particularly important in shaping water resource management. For instance, recent calls for "watershed level management" have argued that small or fragmented institutions governing water resources lack both the ability for comprehensive resource planning and the ability to address problems that cross state and local boundaries (Gottlieb and FitzSimmons 1991; Dzurik 1990; Kenney 1997). While such studies acknowledge the importance of institutional boundaries for managing water resources, the relative effectiveness of different types of institutional boundaries in facilitating improved watershed use remains open to empirical analysis.

This article begins by describing conjunctive water management, as an example of a water management method that offers improved resource efficiency and sustainability. The first section also discusses why the state of California provides an appropriate study setting for analyzing the relationship between institutions and water management decisions. This article then examines two streams of literature that offer propositions about the effects of institutional boundaries on water management decisions; they are common-pool resource management theory and the literature on public service industries. It considers the implications from these two bodies

[1] For instance, U.S. Census data show that between 1990 and 2000, populations across some western U.S. states increased more than 30 percent and the most rapid growth has been concentrated in areas such as Las Vegas, Phoenix, Denver, and San Diego (U.S. Census 2001). Meanwhile, the number of western farm acreage decreased slightly, but the average value of croplands across the West increased (USDA-National Agricultural Statistics Service 1999).

of literature for understanding how institutional boundaries affect water management decisions.[2] The final section of this article empirically tests the assumptions derived from the literature review using data from water management agencies in California. The data are evaluated using both a logit regression model and a Boolean analysis, also known as Qualitative Comparative Analysis (QCA).

Study Setting: Conjunctive Water Management in California

One of the responses to the dilemma of ensuring adequate water supplies for human and environmental demands has been to coordinate the management of groundwater and surface water, or “conjunctive water management”. 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; Todd and Priestaf, 1997). For more than 50 years, conjunctive water management has been promoted as an effective alternative to expensive and ecologically damaging dams and reservoirs, which have become less palatable politically as water management options (Thomas 1955; Thorson 1978; Trelease 1982; US ACIR 1991).

Conjunctive water management can be accomplished in various ways. Many conjunctive management projects rely on 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. Recharge can occur through constructed basins where surface water is delivered and then percolated through soils, through injection wells, or through streambeds (Bookman-Edmonston 1979). Stored water can then be extracted by pumping groundwater 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.

One of the benefits of this approach is to economize on the costs of surface water storage and distribution facilities to meet peak demands (Bookman-Edmonston 1979; Trelease 1982; Fisher et al 1995).[3] In addition to the dilemma of growing demands for water supplies in the arid western United States, water providers are faced with the fact that surface water flows are least abundant during summer months when water demand for municipal and agricultural uses usually is highest. Conversely, when flows are most abundant, demand is much lower.[4] 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

[2] Both bodies of literature have developed out of a research framework, known as the Institutional Analysis and Development Framework (IAD), which defines key variables and concepts that are essential for evaluating the role of institutional arrangements in shaping solutions to collective action problems (E. Ostrom 2000).
[3] For example, according to the California Department of Water Resources (1994) the estimated cost of storing surface water in reservoirs is about $800 per acre-foot of water; whereas storage through conjunctive management costs about $150 per acre-foot. An acre-foot is equivalent to about 325,000 gallons of water.
[4] 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).

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. 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 stabilizing available 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).[5] Despite the relative advantages of conjunctive management, the use of this method varies widely across water scarce regions (Western States Water Council 1990).

California offers a useful setting for evaluating the variation in conjunctive water management in relation to institutional boundaries. California's water demands have been growing consistently over the past decades, while a large portion of the state is relatively arid (CDWR 1998a). Due to the high water demands for agriculture and urbanization, the need for conjunctive management certainly exists, yet the use of conjunctive water management varies across the State. For instance, in some metropolitan areas of southern California, conjunctive water management has been practiced for over fifty years (Blomquist 1992). On the other hand, in the Sacramento Valley where agriculture consumes some of the largest quantities of water in the world and surface supplies are over-appropriated, conjunctive management is relatively new (Purkey et al. 1998).

Another reason California is an appropriate setting for evaluating conjunctive management programs is that many areas of the state have the physical capacity to devise conjunctive management programs. 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). Statewide, water users also have access to the delivery of surface water supplies, despite the fact that the northern portion of the state receives the majority of the state's rainfall. Since the State and the Federal government have financed the construction of large north-south water diversion projects throughout California beginning in the 1930s, much of California has access to infrastructure and surface supplies that are often used in conjunctive management programs (U.S. ACIR 1991).

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[5] Conjunctive management, however, is not a panacea. When pumping and extraction occurs from basins that are hydrologically connected to surface flows, drawing down the water table can damage the natural hydrologic connection between ground and surface flows (Glennon and Maddock 1997; Matthews 1991). Also, such pumping may reduce available flows for surface users, or impact endangered species. Excessive recharge of a basin that is hydrologically connected to a stream can move the water table too close to the ground surface and exacerbate flooding problems. In some basins, artificial recharge could potentially cause spreading of contamination plumes or aggravate soil compaction in areas susceptible to land subsidence.

In addition to the demand and physical capacity needed for conjunctive management, California is an appropriate setting for evaluating institutional boundaries because of its diverse institutional arrangements governing groundwater. While surface water institutions are relatively similar throughout California, the State has left the authority to govern groundwater use and storage to local governance institutions.[6] For example, one form of local institutions governing California's groundwater basins are those that have undergone special court adjudications, which quantify and limit rights to all users overlying a geographically defined groundwater basin. Other institutional arrangements include city and county management ordinances that regulate basin activities and special districts authorized by the state legislature (CDWR 1998b).[7] These institutions may be involved in determining groundwater water rights, regulating groundwater pumping, or funding the storage of water underground (CDWR 1998b). While individuals have rights to pump groundwater in all basins, not all basins in California have an overlying groundwater governance institution that imposes limits on pumping or regulates pumpers' activities. Since conjunctive management projects rely on basin level storage and retrieval, the different institutional arrangements can clearly influence the feasibility of engaging in conjunctive management.

Theory: The Role of Institutional Arrangements in Water Resource Management

Institutional Boundaries

Two long-term research programs that examine the role of institutions in resolving social dilemmas can help explain how and why the boundaries of California's groundwater institutions might affect the implementation of conjunctive management programs. One of these research programs, developed most notably by Elinor Ostrom and colleagues, evaluates how institutions influence the use of common-pool resources, such as water, fisheries, and forests (E. Ostrom 1990; 1998; 1999). Common-pool resources (CPRs) exhibit varying degrees of two key characteristics: 1) difficulty in excluding users, and 2) subtractability of supplies, where each resource user reduces the supply available to others (Ostrom, Gardner and Walker 1994). The first characteristic can lead to problems of free-riding or insufficient maintenance of supplies. The second characteristic can create problems of over-appropriation or congestion. While conventional wisdom may presume that the use of CPRs leads to the "tragedy of the commons" or ultimate destruction of the resource, CPR management studies have shown that CPR users often devise institutional arrangements to resolve these dilemmas (E. Ostrom 1990; Schlager 1990; Tang 1992; Ostrom, Gardner and Walker 1994).

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[6] Surface water, on the other hand, is governed largely by the prior appropriation doctrine in California. The prior appropriation doctrine establishes rights to surface water based on the timing of beneficial use. Those who put water for beneficial purposes, such as irrigation or municipal consumption, earliest have superior rights to use that quantity of water when flows are insufficient to supply all water rights claimants.

[7] California has a variety of legislatively-authorized districts that have authority over groundwater, such as irrigation districts, county water districts, water storage districts, community service districts, flood control districts, and groundwater management agencies (U.S. Census Bureau 1994). California also has over 20 individual special purpose acts that have created local water agencies such as the Orange County Water District and the Metropolitan Water District of Southern California (U.S. Census Bureau 1994).

CPR studies also show that effective institutional arrangements for managing CPR dilemmas, which may be explicit or implicit in a CPR setting, will vary depending on physical and community conditions (Lam 1998). While effective institutional arrangements may vary across settings, CPR theory identifies 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 and resource users (E. Ostrom 1990; 1998). CPR studies have identified a number of other key design principles of successful institutional arrangements for managing CPRs.[8] This article focuses, however, on the applicability of the first principle.

CPR theory's boundary principle implies that 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: 91) 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." Thus, the literature has shown a clear relationship between the successful resolution of CPR dilemmas and the organization of institutional arrangements that are clearly defined around CPR boundaries. According to the principle, one can then assume that in order to effectively manage water supplies using a method such as conjunctive management, then the institutions governing the basins where water is stored and recovered would be more effective when organized around the boundaries of the basin. Based on this assumption, the following hypothesis is proposed:

> H1) Water management institutions that are organized around the physical boundaries of groundwater basins are likely to be positively associated with the use of conjunctive water management.

<u>Reconsidering the Boundary Criterion</u>

The institutional boundary principle coming out of CPR theory does present some limitations in its applicability to large-scale or complex water management situations. First, in most natural resource settings, it is not likely that the physical boundaries of the resource can be identified clearly. Any natural resource is likely to be somewhat mobile and inter-related with other natural resources. Therefore, deciding on the location of common-pool resource boundaries can be difficult or even impossible. Even under the assumption that it is possible to

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[8] 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 (E. Ostrom 1990, 1998). 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 (Ostrom 1990; 1998).

identify general physical boundaries of CPRs, 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.

Another potential limitation is 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. The CPR literature does acknowledge that self-governing jurisdictions can function in concert with larger institutional arrangements within which they are embedded. For instance, it describes ways in which larger institutional arrangements can provide information and support to help sustain local governance of a CPR (Ostrom, Gardner, and Walker 1994). The limited applicability of the boundary criterion arises, however, 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.

Some of the apparent weaknesses in applying the CPR boundary principle to such a complex water management situation as California might be resolved by integrating insights from studies of local public economies and public service industries, which provides a macro-level perspective of the role of institutional boundaries. CPR studies and local public economy studies both have developed out of a research framework, known as the Institutional Analysis and Development Framework, which emphasizes the importance of institutional arrangements in shaping solutions to collective action problems (E. Ostrom 2000).[9] Local public economy studies consider the effective resolution of collective action problems from a macro or organizational level, while CPR studies rely more on a micro level of analysis. Therefore, the two literatures offer related, yet distinct, solutions to resource management dilemmas.

In general, the literature on local public economies describes the potential advantages of overlapping political jurisdictions for meeting citizen demands for public goods and services adequately and cost-efficiently. The literature points out that the United States' constitutional choice for a federal system of government has created political jurisdictions that overlap geographically, which can lead to functional overlap or fragmentation of services within regions or sectors (V. Ostrom 1991; Oakerson 1989). This system of government can create a need for jurisdictions to coordinate the provision of goods and services with other jurisdictions, and for jurisdictions to compete with one another (U.S. ACIR 1987, 1991; Oakerson and Parks 1988; Parks and Oakerson 1993; Oakerson 1999). The term "local public economy" refers to the collection of overlapping jurisdictions that supply and produce various public goods and services in a community such as a metropolitan area (U.S. ACIR 1987; Oakerson and Parks 1988; Oakerson 1999). This research also describes the collection of overlapping jurisdictions that coordinate to provide and/or produce specific goods or services within a particular sector of the

[9] 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).

public economy as a "public service industry" (V. Ostrom and E. Ostrom 1991; US ACIR 1991).[10]

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). These studies show that a complex system of overlapping jurisdictions and institutional arrangements administers and governs water resource provision and management. 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.

The literature on local public economies and public service industries distinguishes between production, provision, and governance of public goods and services (Oakerson 1999; U.S. ACIR 1987, 1988; Parks 1985). 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). These organizations also may be involved in the governance of public services, such as legislating and administering rules of provision and production; or governance activities may be separated from provision and production.

Given this description of overlapping jurisdictions that provide and produce goods and services, 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 jurisdictions that provide or produce a service such as conjunctive management. 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

[10] A public service industry, or local public economy, 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).

provision units" (U.S. ACIR 1987, 36). Moreover, the provision of services is more likely to be efficient when all individuals in a jurisdiction who pay for service provision also benefit from the service (Ostrom, Tiebout, and Warren 1961; 1991).

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. Local public economy/industry literature 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 local public economy/industry literature therefore implies that effective management of a CPR could be 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 resource management service, 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.

Effective institutions for providing services such as conjunctive management therefore may require bringing together all individuals affected by a project. This is often the role of limited-purpose or special purpose governments (U.S. ACIR 1991). Such jurisdictions, therefore, could be effective in providing conjunctive management programs. 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 for devising resource management programs. Functional specialization of institutions may not be feasible when water management problems are not easily dissected, when they 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 shared problems, according to the local public economy/industry literature is to take advantage of inter-jurisdictional coordination to provide public goods and services (Oakerson 1999). Given that provision and production and governance can be separated, jurisdictions have opportunities to address a shared problem related to the management or use of a resource by coordinating service production. In relation to conjunctive management, water industry jurisdictions may be able to facilitate conjunctive water management by coordinating their efforts to acquire water, store water underground, and recover that water. Inter-jurisdictional coordination, in effect, can allow small-scale jurisdictions to engage in conjunctive water management in a way that eliminates the need for a large centralized authority to encompass a large watershed. From this discussion, the following hypothesis is derived:

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

Empirical Models

This section empirically tests the hypotheses regarding the relationship between the boundaries of groundwater management institutions and the use of conjunctive water management in California basins. A logit regression model provides the first test. To supplement the logit regression results, a method known as "Qualitative Comparative Analysis" (QCA), developed by Charles Ragin (1987) 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. The data for these models comes from a sample of 70 of California's 450 groundwater basins. The data sources, sampling and coding procedures that were used in these analyses are discussed in Appendix A.

Variables and Indicators

The dependent variable for the analytical models is the presence of conjunctive water management projects in a groundwater basin. 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 management institutions whose scope of authority and jurisdictional boundaries differ. Among the population of California basins, some may have multiple groundwater institutions, a single institution, or none of the groundwater management institutions. 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. 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. These institutional arrangements are not devised around groundwater basin boundaries. Table 1 summarizes the boundaries and regulatory powers of the four local groundwater institutions.

TABLE 1: Institutional Forms Governing Groundwater Use in California

Institutional Type	Boundary Scale	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

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. 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).[11] 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). [12]

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 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).

Table 2 summarizes the expected relationships between each of the independent variables and the presence of conjunctive management in a California groundwater basin. The control variables 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. Hypothesis 1 claims that

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[11] Based on 1995 estimates of urban, agricultural, and environmental water uses, overall water shortages in the state approach 1.6 million acre-feet in years when water supplies are normal, and 5.2 million acre-feet in drought years (CDWR 1998a).

[12] 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.

institutional boundaries that match resource boundaries are likely to be positively associated with conjunctive management. Therefore, if only adjudicated basins and/or special districts, which have boundaries that match groundwater basins, have a positive impact on conjunctive management outcomes, this would support Hypothesis 1. Hypothesis 2 claims that inter-jurisdictional coordination can facilitate 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 2: 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	+ supports H1
Adjudicated Basin	Basin-level jurisdiction	+ supports H1

Logit 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. Table 3 presents the results from the logit regression analysis. (See Appendix B for the descriptive statistics of the basin-level cases used in the logit 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.

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.[13] The population density variable and the basin storage variable have a relatively small, but negative impact on the dependent variable. While the

[13] The coefficients in Table 4.3 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. 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 Exp(*B*) coefficients.

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 3: 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

Model Chi-Square = 62.56
* = significant at α= .10
** = significant at α= .05

Overall % of Correct Predicted Cases = 97%
B= effect of variable on log-likelihood of Y
Exp(*B*) = effect of variable on likelihood of Y

The logit results 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 approaches zero. This 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 hypothesis that institutional boundaries that are devised around resource boundaries can facilitate improved resource use.

The AB3030 coefficient provides support for 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. The coefficient for the AB3030 variable therefore also offers some support to 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.[14]

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 1: Logit Model

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

In using Equation 1, when no groundwater institution is present in a basin and all other control variables are at mean values, the probability of conjunctive water 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. On the other hand, if all

[14] 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.

control variables are at minimum values, and AB3030 Plans are present, the probability of conjunctive management is only about 1 percent.

QCA Model

To supplement the results of the logit analysis, this section introduces results from a method known as Qualitative Comparative Analysis (QCA), which is based on Boolean comparative logic (Ragin 1987). This method compares different combinations of independent variables in relation to a dependent variable, and then simplifies the causal conditions using a bottom-up data reduction process. (See Appendix C for a more detailed description of this method.)

The benefit of a Boolean analysis for this study is that it addresses two problems present in this data set -- limited observations and multiple causality -- which can reduce the explanatory power of quantitative statistical control models (Ragin 1987). In many 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. The second problem that warrants the use of the Boolean method is that the data set includes nine independent variables, which can produce multiple interaction effects in relation to the 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 (Ragin 1987). 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. For this analysis, 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.[15] (See Appendix B for a description of the processes for dichotomizing the interval variables and a more detailed explanation of the QCA method.). 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. The following equation models the feasibility of conjunctive management as the following function:

Equation 2: QCA Model
Conjunctive Management = $f\,(P, I, B, R, W, A, C, D, S)$

[15] The QCA method does present some limitations in that it assumes that relative degrees of the independent variables are not importance. In addition, the process of dichotomizing continuous variables can be problematic if cutt-off points are arbitrary or run contrary to theory.

Where *P* is high population density, *I* is high irrigated acreage, *B* is high basin storage capacity, *R* is high annual rainfall, *W* is project water access, *A* is an AB3030 Plan, *C* is a county ordinance, *D* is an adjudicated basin, and *S* is a Special District. All 70 cases are coded with the presence or absence of these variables. QCA notation uses upper case letters to represent the presence of a variable and lower case letters to represent its absence.

The first step of the QCA method is to sort all possible combinations, or configurations, of independent and dependent variables that exist in the data. In this data, there are 38 possible combinations of variable configurations. Almost twice as many different combinations 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 (Appendix C shows all combinations in the QCA "Truth Table").

The data reduction process in the Boolean method is designed to reduce the possible combinations of variables associated with the dependent variable by identifying necessary and sufficient causes. Equations 3 and 4 show the minimized combinations of variables that are associated with basins using conjunctive management and basins not using conjunctive management respectively. 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.

Equation 3: Minimized Configurations of Conjunctive Management Cases
Conjunctive Management = *PIBRWAcd* + *pIBrWcdS* + *pIBracds* + *pBrwAcds* + *PIBrWacDs* + *PiBrWACas* + *PiBrWacdS* + *PibrWaCDs* + *piBrwacDS* + *piBrWacDs*

To interpret the above equation, each set of variables represented by a multiplier is a combination of conditions of independent variables, or a configuration. Each of these configurations signifies that those causal conditions must be found together when the dependent variable, conjunctive management, is present. The entire equation is the sum of all minimized combinations of independent variables. 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 in Equation 3, for example, suggests that conjunctive management exists in basins with all of the control variables present: high population density (*P*), high irrigation levels (*I*), high basin storage capacities (*B*), high rainfall (*R*), and access to project water (*W*). The presence of these control variables is combined with the presence of AB3030 Plans (*A*) where conjunctive management occurs. At the same time, the first configuration shows that these cases are associated with the absence of county ordinances (*c*) and basin adjudication (*d*).

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, the six, eighth, and ninth configurations all have two institutions present in relation to conjunctive management.

The second pattern of interest in the minimized equation for the presence of conjunctive management 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 the sixth configuration (PiBrWACds) and in the eighth configuration (PibrwaCDs). These configurations indicate that county ordinances are related to conjunctive management in basins with a) high population density, high basin storage capacity, access to project water and AB3030 Plans, or in basins with b) high population density, low storage capacity, project water access and adjudicated water rights. Moreover, in six of the ten configurations, 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 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 (PibrWaCDs) 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 key 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. Finally, in seven of the ten configurations, access to project water is a key variable related to conjunctive water management. Except in one configuration (PibrWaCDs), the presence of project water always occurs in combination with high basin storage capacity.

The QCA method derives a second equation to represent the causal conditions associated with the lack of conjunctive management in groundwater basins, as represented in Equation 4.

Equation 4: Minimized Configurations of Non-Conjunctive Management Cases
No Conjunctive Management = *piwads* + *piacds* + *iRwacds* + *prwacds* + *pBrwACds* + *pibrWaCd* + *piBrwCds* + *PibraCds* + *PibrWads* + *ibrwaCds* + *ibrWacds* + *piBrwacd*+ *pIBrWaCds*

Not surprisingly, Equation 4 has nearly opposite patterns as those found in the equation for the presence of conjunctive management. In general, the equation shows that groundwater institutions are not associated with basins where conjunctive water management does not occur.

For example, the absence of basin adjudication (d) appears in each of the configurations of Equation 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 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 3, is present in six of the thirteen configurations in Equation 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 Implications

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 that are devised around the boundaries of the resource, through basin adjudication or special groundwater management districts can facilitate conjunctive water management, as proposed by the CPR literature. Adjudication is insignificant in the logit model, but has a large effect (possibly resulting from the 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). The results also bolster Hypothesis 2 that inter-jurisdictional coordination is likely to be positively related to the presence of conjunctive management programs. AB3030 Plans, while not devised as a single institution surrounding a basin, still provide control over basin management by coordinating across existing jurisdictions.

As mentioned in the discussion of the logit results, this outcome offers some support Hypothesis 1, which claims that institutional boundaries that are devised around groundwater basin boundaries are likely to encourage conjunctive management.

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. For instance, the logit results show that the probability of conjunctive management decreases as basin storage capacity increases, but the QCA appears to show that high storage capacity is positively associated with conjunctive 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 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 summary, the two empirical analyses find that institutional arrangements play an important role in facilitating the provision of conjunctive management in California. 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. These results suggest that institutions may need to control the boundaries of 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. 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.

The analyses ultimately can 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. What these results may call for is a re-conceptualization of the CPR boundary criterion to broaden the application of the theory to more complex resource management settings. Local public economy (or 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. Such a conceptualization helps explain how small-scale, or functionally specialized, institutions arise around shared problems they can coordinate and cooperate to address larger dilemmas that cross the existing institutional boundaries.

Appendix A: Sampling and Data Coding Methods

The data used in these analyses came from a larger study funded by the National Science Foundation (NSF) and Environmental Protection Agency (EPA), grant number R824731, that compared conjunctive management activities across Arizona, California, and Colorado. The process for collecting data for the NSF/EPA study began with the identification of conjunctive management programs 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. Surveys of water providers in each state were used to identify conjunctive management projects. For the variables on the physical conditions of project locations, the NSF/EPA study relied on secondary data sources to supplement primary sources. Federal and state sources provided macro-economic and demographic data on the three states and their counties.

For data in California, the principle investigators conducted a 30 percent cluster sample of the population of California's 450 groundwater basins in order to identify conjunctive management projects. The cluster sampling frame was based on the state's seven major hydrologic regions, identified by the Department of Water Resources. 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 and number of conjunctive water management activities operating in the sample basins. 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.

Appendix B: Logit Model Descriptive Statistics

Table B.1 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 B.1: 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. Despite the fact that the larger NSF/EPA study ultimately excluded the 23 underdeveloped basins from data collection on individual conjunctive management projects, because they are undeveloped, all 70 basins were included in these analyses. 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.

Appendix C: QCA Methodology

The QCA method requires that all variables are coded as dichotomous. Thus, 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 C.1.

TABLE C.1: 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

In order to conduct the process of Boolean minimization, the QCA method first constructs a "truth table" that contains binary output values for each independent variable and the dependent variable (Ragin 1987). The rows in the truth table represent all possible combinations of the values of the independent variables present in the data set (Ragin 1987). The truth table also shows the number of cases in the data that match each combination of independent variables, or each row. Table C.2 presents the complete set of configurations found in the data, with the number of cases associated with each combination of independent variables.

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.

Table C.2: 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.

Using Boolean Algebra, the QCA method minimizes 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. A Boolean equation associated with either the presence or absence of the dependent variable is represented by the additive total of each of the minimized configurations of causal combinations. As shown in Equation 3, which represents cases where conjunctive management is present, the minimization technique reduces the number of configurations of independent variables from 13 to 10. The minimization process reduces the number of configurations representing cases that lack conjunctive management from 24 to 13, shown in Equation 4.

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