Evaluation Report

Part IB: Conjunctive Management of Surface and Ground Water in the Rio Grande Basin

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Prepared by

Walter Rast, Ph.D., Principal Investigator
Susan V. Roberts, Ph.D., P.G.
River Systems Institute, Texas State University-San Marcos

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Summary

The Rio Grande basin of the southwestern U.S. has known, demonstrable, and complex water issues, including water shortages, flooding, non-flows along several riverbed segments, and water quality challenges. This report and a second report to follow, focus on the possibilities inherent in a long-term approach to water management with the flexibility to address water issues. The water management approach is typically known as conjunctive use or conjunctive management. While different approaches to water management have been used in the Rio Grande / Río Bravo del Norte basin, a planned, coordinated conjunctive management program has not yet been formally applied to this basin.

The goal of the Evaluation Report is to provide information collected about conjunctive use and conjunctive management in the basin. The information was gathered through reviews of published literature and documents, information about conjunctive use programs, websites, results of an online survey, and selected interviews with water resources professionals. The results indicate the potential usefulness and applicability of conjunctive management in the river basin. As might be expected with any new water management approach, there are impediments to implementing a successful program.

Although conjunctive management may be generally recommended as a water resource tool, it can be involved to plan, develop, organize, and execute conjunctive management strategies without sufficient funding and coordination between agencies. There is a lack of consensus on its appropriate implementation, and no single document provides key parameters and standards for successful policies and conjunctively managed program. The goal of this research is to address these gaps.

1.0 Introduction

The Rio Grande / Río Bravo del Norte basin (Rio Grande for brevity in this report) is experienced unprecedented stresses on its water system. Whether one considers the effects of drought, occasional extreme floods, or water quality degradation, only a few places along the river might be defined as pristine. Several times in 2001, the river ceased to flow to the Gulf of Mexico for several months at a time, a great concern to humans and a threat to estuarine and marine environments (Sansom 2008). In addition, growing population centers along the river require increasing quantities of usable water, despite increased conservation methods that have helped decrease per capita use in recent years. To address current and future water solutions, practical ideas and in-depth discussions about increasing water management efficiency warrant serious consideration by water agencies and stakeholders of the basin.

One water management approach with the flexibility to address multiple aspects of these water stresses and challenges is conjunctive use/conjunctive management. Simply stated, it is the optimized use of water sources over time when more than one water source is available. In theory, it is straightforward to use one water source while another source is conserved, stored, or allowed to recharge. In reality, the policy can be difficult to implement as a practice, particularly when other water management tools have been in place for years. Over the decades since recognition of conjunctive use for water management, it has been recommended in research and policy documents. Definitive methods for implementation, however, are rarely included in such documents, indicating a lack of knowledge and/or agreement on which scientific, economic, and political factors determine whether or not conjunctive management is a viable water management strategy.

Adding to a common idea that conjunctive use is rather vague, almost every publication provides a definition that aligns with the discussed study's goal and focus. While a flexible approach to understanding conjunctive use is important in getting projects to the planning stage, variations in understanding, technical approaches, and goals can add to general confusion about its applicability. To illustrate how researchers and experts in hydrology/hydrogeology, agricultural, economics, and law define conjunctive use, a list of selected definitions and associated citations is provided (Appendix A). For this report, the definition of conjunctive use is simplified to, *the optimized use of more than one source of water, such that one source allays the temporal or spatial shortcomings of another source through additional or storage options*. Optimization of water supplies may be achieved through a variety of technical applications to realize goals such as water supply distribution, storage, and/or economic targets.

This report, one of two technical reports under development through the EPA Geography and Water Grant at Texas State University-San Marcos, Part IB, focuses on the background and information necessary to understand the context in which conjunctive use/management strategies might be utilized in the Rio Grande basin. The following subsections provide information about the development of conjunctive use research over time, and a brief description of three illustrative programs that illustrate the application of conjunctive use as a water resource management strategy.

1.1 Development of Conjunctive Use

Conjunctive use of more than one water source has most likely been utilized ever since people created the ability to transport water and dig wells. More formally, conjunctive use as a water strategy was discussed in a study discussing the economic advantages inherent in groundwater storage (Banks 1953). Interest and research in the strategy grew. Economic factors, positive and negative, were assessed in hydrology texts (Todd 1959). Linear optimization techniques were applied in an allocation model to agricultural areas (Castle and Lindeborg 1961), while programming techniques were used to explore design and operations for dams and aquifers in agricultural applications (Buras 1963). Groundwater valuations based on stochastic modeling of an "optimal inventory policy for ground water" firmly identified conjunctive use as a viable water strategy (Burt 1964). Studies of conjunctive use continued to focus on economic analysis and agricultural efficiency for several decades (Gisser and Sanchez 1980; Feinerman 1988; Tsur and Graham-Tomasi 1991; Knapp and Olson 1995). Young and Bredehoeft (1972) were the first to address the problem of simulating groundwater withdrawal effects on river flows, and the associated economic responses by water users to changes in water flow volumes and costs. Conjunctive use was analyzed in terms of systems and levels of associated issues (Maknoon and Burges 1978), and optimization of operations and controls for agricultural and urban water uses (Noel et al. 1980). With the advent of improved computing power, conjunctive use research began to incorporate large data sets in numerical models for basin-scale water availability and resource management decisions. Selected examples are provided by Papadopoulos and Associates (2000), Barlow et al. (2003), Cai et al. (2003), Fleckenstein et al. (2004), Rao et al. (2004), and Booker et al. (2005).

As a water management strategy, conjunctive management has been recommended by policy analysts and decision makers. Under Texas Water Development Board rules, for example, a required goal of a groundwater conservation district's management plan (31 Texas Administrative Code, 31 TAC 356.5) is to address conjunctive management of surface and groundwater. However, the code does not include specifics on implementation of conjunctive management. In 2004, a Texas Senate Committee was tasked with reviewing water policy issues for the state. Although Recommendation 3.2 included "Conjunctive Use of Both Surface and Ground Water Sources" (Texas Senate Select Committee 2004), none of the report's attachments explicitly discussed execution of conjunctive management.

Current conjunctive management programs have different goals and therefore varying designs and operations. The California Department of Water Resources supervises a conjunctive management program focusing on local partnerships and needs for those local basins (CDWR 2009). The Central Arizona Project deals with large groundwater overdrafts through a large canal that transports water from Lake Havasu on the Colorado River, thereby serving municipal, industrial, agricultural, and tribal nation users (CAP 2009). Internationally, organizations such as the Consultative Group on International Agricultural Research (CGIAR) of the International Water Management Institute (IWMI) may include conjunctive management in specific projects (IWMI 2009). Each project has its own approach, thereby providing information and insights as to appropriate implementation of conjunctive use.

1.2 Selected Conjunctive Management Programs

Details of individual programs best illustrate the application and results of conjunctive use. Unique programs that are considered successful due to their growth and longevity are discussed below.

1.2.1 California's Conjunctive Water Management Branch

Conjunctive use as a water management tool is found in different regions across California, a state that benefited from academic and field research in this field beginning in the

1950s. The California Department of Water Resources (CDWR) oversees the current conjunctive management program. The program focuses on outreach to groundwater basins that request planning assistance and funding through competitive grants (CDWR 2009). Over the last seven years, the Conjunctive Water Management Branch (CWMB) has partnered with local and regional agencies in groundwater use, storage, and recharge. Other aspects include state and federal agency coordination, grants awarded to local programs, and assistance to local agencies for drought planning and relief, and planning studies. In partnering with 24 local agencies since 2000, the program has allocated $30 million ($30M) from a state water bond and $7M under the Local Groundwater Management Assistance Act. The underlying link between these programs is the CWMB mission: "Through the coordinated optimization of surface and groundwater supplies, California can increase its water supply reliability and water supply system flexibility, and reduce dry year demand deficit, overdraft, and subsidence" (CDWR 2009). The emphasis on groundwater in the program results from surface water being managed under successful, decades-long programs in California, whereas groundwater has not received as much attention or regulation.

Each local program has specific water use needs, geographic and hydrogeologic constraints, and stakeholder concerns. A review of 18 partnerships listed on the website indicated the following (CDWR 2009):

- Major concerns are to reduce or eliminate basin overdraft, provide for increasing water demands, and develop a more detailed understanding of basin characteristics.
- Problems are addressed as a partnership, typically under a memorandum of understanding between the local agency(s) and the CWMP. The issues most often noted in the 18 partnerships are: 1) development of recharge and storage in the basin; 2) basin assessment; 3) identification of conjunctive use projects; and 4) facilitated stakeholder involvement, outreach, and/or education.
- Twelve of the 18 partnerships have been awarded grants; many of the partnerships listed funding and technical support from CWMB, as well as in-kind labor and support at the local level.

2.2 Central Arizona Project

The Central Arizona Project (CAP) was planned, designed, and implemented to store and use as needed, allocated water from the Colorado River. Its mission states: "CAP is the steward of central Arizona's Colorado River water entitlement and a collaborative leader in Arizona's water community" (CAP 2009). Under the Colorado River Compact, seven western U.S. states have rights to Colorado River water on an annual basis. Arizona has rights totaling 2.8 million acre-feet per year. With federal funding close to $4 billion, construction of 336 miles of aqueducts, pipes, and pumping stations began in 1973 and was completed 20 years later. CAP carries water from Lake Havasu to southwest Tucson. Its customers are municipalities, industries, agriculture, and Native American tribes.

The CAP Association began educational programs in 1946 to educate people in the state about the need, benefits, and costs of CAP, as well as lobbying Congress for construction funding. While the focus of the program is to transport allocated Colorado River water to its users, there is a groundwater storage component. The need for CAP is expressed succinctly in the volume of groundwater overdraft in Arizona: 2.5 million acre-feet. To repay the federal funds over a 50-year timeline, the Central Arizona Water Conservation District was created to assess property taxes in the District boundaries. The current tax rate is 6 cents per $100 of assessed property. In addition, the District assesses a 4-cent per $100 of assessed property to purchase water for underground storage in case of drought. The underlying concerns of drought and its effects on surface and ground water are an ongoing part of the education, as are taxes and benefits of the CAP.

2.3 Murray-Darling Basin

Close to a decade of drought in the Murray-Darling catchment of southeastern Australia has brought intense scrutiny and belt-tightening to the rich farming and ranching region. The basin area is 1.06 square kilometers (km^2), less than 15 percent of the continent, yet contains the three longest rivers and based on 1992 estimates, around 71 percent of irrigated lands of the Commonwealth (MDBC 2009). Irrigation uses around 70 percent of surface and ground water, accounting for over 40 percent of the national gross value for agriculture. In addition to its economics importance, the catchment also has environmental issues due to the extent of 35 endangered bird species, 16 endangered mammals with 20 extinct species, and an estimated

30,000 wetlands (MDBC 2009). In light of these vital signs about the region, the ongoing drought, estimated to have caused the lowest water flows over the last 115 years, continues to be of great concern.

The oversight agency, Murray-Darling Basin Commission, collected and analyzed a large quantity of data, information, and reports. Work efforts and milestones include ensuring water supplies even during the lowest river flows on record, ongoing public outreach and education about the drought and its effects, managing for salinity levels, initiating water trades, and working on the health of the river system and its fish habitats (MDBC 2009).

The commission initiated planning and field studies into the application of conjunctive use (REM 2004). Key to planning for conjunctive use projects were two major concerns: 1) declining groundwater levels away from the river systems, and 2) increase of salinity levels in areas of heavy irrigation with waterlogged areas cleared of native, deep-rooted vegetation (REM 2004). Over the years, surface and ground water resources were separately managed, with a focus on surface water. Thus, the interactions between surface and ground water processes were not well understood until recent years. The need for conjunctive planning and management led to studies and planning documents about conjunctive management within the context of highly varied sub-basins and their associated geologic, hydrologic, and geomorphic characteristics, all of which affect water management design, studies, and possible implementation of policies and resource management infrastructure.

Recent changes in basin management also indicate ongoing stresses on the involved communities. In 2008, four Australian states created legislation supporting amendment of the Commonwealth's Water Act 2007 and, in part, enabled creation of the Murray-Darling Basin Authority (MDBA 2009). For the first time in the basin's history, one independent authority will plan and implement integrated management of the basin's water resources. The focus has moved from agency involvement with surface water issues separated from groundwater, societal, or environmental concerns, to planning for sustainable groundwater use through conjunctive management, to integration of water resource management. It is possible that only an unrelenting crisis, and daily to monthly visible reminders of the severity, could have brought about agreement between the differing states and their agencies.

These examples demonstrate the development of conjunctive use from strategy to implementation and provide illustration of its successful application. The similarities between these programs and regions in the Rio Grande basin are striking – each program is found in an area with significant economic reliance on agriculture in productive soils, yet subject to drought; municipal areas continue to experience population growth, affecting not only demands on water supplies but also water quality; and environmental and institutional factors play a large role in development of the program. The following sections discuss the current state of conjunctive use in the Rio Grande basin.

2.0 Conjunctive Use in the Rio Grande Basin

While it is difficult to succinctly encompass the physical setting of a complex and varied river basin such as the Rio Grande, it is helpful to understand its setting with relation to water resource management. The following information about the physical systems pertinent to water management is taken from cited research and websites.

2.1 Overview

2.1.1 Watershed and Hydrology

With a drainage area of approximately 472,000 km^2 and a length of 3,033 km, the Rio Grande is among the 25 longest rivers in the world. It flows from the southern Rocky Mountains of Colorado, south through central New Mexico, and then south and east between Texas and México, to drain into the Gulf of Mexico. The river receives drainage from two countries, three U.S. states, five Mexican states, and more than 20 Native American nations. Major tributaries are the Río Conchos, which supplies the majority of mainstem surface water in the Presidio/Ojinaga area, and the Pecos River, which joins the river to flow into International Lake Amistad. The Río Conchos has a drainage area of 68,375 km^2, including three large tributaries, Río Chuviscar, Río San Pedro, and Río Florido (IBWC 2002).

With the exceptions of mountainous headwaters, its route through high elevation grasslands in northern New Mexico, and the productive bays and estuaries near the Gulf, the Rio Grande is primarily a river of the desert. Its character is demonstrated as much through limited flow, seasonally and spatially, as extreme high and low flow conditions. Several reaches, such as the Forgotten River between El Paso and Fort Quitman, segments within Big Bend National

Park, and the river's mouth at the Gulf of Mexico, ceased to flow over the last decade due to drought and other factors (Sansom 2008).

2.1.2 Springs

Hundreds of springs are found in the watershed, including Hot Springs near the Elephant Butte Reservoir, at least 13 major springs near the river in Coahuila (Boghici 2004), San Felipe Springs in Val Verde County, Texas, and the Las Moras/Pinto Springs system in Kinney County, Texas. The springs typically respond quickly to rainfall; historic flows in the Texas springs range from a low of 0 cubic meters per second (m^3/s), to an estimated 4.22 m^3/s in the San Felipe Springs in 1899 (Brune 1975). Spring-fed rivers, such as Las Moras Creek and Devils River, provide significant flows to the Rio Grande downstream of Amistad Reservoir.

2.1.3 Aquifers

A significant component of the basin's water resources is groundwater. These subterranean waters interact with rivers, support habitats, and are of great importance to the watershed's hydrologic system. Acting as storage reservoirs, shallow groundwater provides baseflow to the river in some areas, while the river provides recharge to groundwater in other locations. Without groundwater discharge, springs along the river and adjacent lands would cease to flow. Much of the river flow downstream of the International Amistad Reservoir is from springs and spring-fed streams on both sides of the border. If groundwater supplying these springs should be negatively impacted, significant inflow to the river would be reduced.

Aquifers are found along the length of the Rio Grande (see Table 1 for selected aquifers and parameters). East of the headwaters in the southern Rocky Mountains of Colorado are the San Luis Valley aquifer systems. These systems were formed by tectonic rifting that began around 26 million years ago (mya) and continues to the present day. The aquifers extend into northern New Mexico (Wilkins 1998). Known as "basin-fill aquifers", they are bordered to the east and west by normal faults, with up to 20,000 feet of vertical displacement (Robson and Banta 1995). Discontinuous geologic bounding has allowed development of open and closed basins along the Rio Grande valley. The closed basins have no surface water drainage, therefore tending to contain waters with much higher salinities than for the open basins.

The aquifers can be very productive. Agriculture in the San Luis Valley of southern Colorado depends on a recharge of 101 m^3/s, about 15 times the recharge of the next largest

Table 1. Selected Aquifer Parameters in the Rio Grande/Río Bravo Basin

Aquifer	Thickness (m)	Transmissivity (m^2/day)	Recharge* (Mm^3 / year)	Discharge* (Mm^3 / year)
Santa Fe system[1]	up to 9100	--	2,460	1,235
Mesilla bolson[2]	610	930 – 2,780	22	21
Hueco bolson[3]	2,745	8.7	7	85
Rio Grande alluvium [3]	--	--	41	--
Alto Río Florido[4]	--	--	63	20
Delicias-Meoqui[4]	--	--	418	392
Edwards-Trinity[5]	varies	0.15 – 25,100	86	155
Carrizo-Wilcox[6]			31	530 [7]
Carrizo sands	0 – 30	92 – 9,302		
Wilcox formation	50 – 550	165 – 5,005		
Gulf Coast system[8]:			59 – 97	136 [7]
Chicot aquifer	0 – 610	3,266		
Evangeline aquifer	0 – 671	613		

* Recharge values vary physically across outcrop area and temporarily with changes in precipitation. Discharge values are not separated into stream loss-gain regions, cross-formational flows, natural spring discharge or pumping.

-- Not discussed in researched literature

1 Robson and Banta 1995

2 Hawley et al. 2001. Values not separated for U.S. and México.

3 Sheng et al. 2001. Values for Texas portion of aquifers.

4 Schmandt et al. 1993 for aquifers in México.

5 Boghici 2004. Values primarily for region of aquifer in Texas.

6 Deeds et al. 2003. Associated aquifers (Queen City and Sparta) not included in table.

7 TWDB 2002; reported groundwater use in 1997.

8 Davidson and Mace 2006; Chowdhury and Mace 2006. Burkeville confining system and underlying Jasper aquifer not included in table.

basin in the upper Rio Grande region (Wilkins 1998). Around Albuquerque, however, "induced recharge" may be a significant water source. This type of flow is caused by groundwater levels near rivers being impacted by excessive groundwater pumping. The low groundwater levels can induce a "losing stream," whereby some of the subsurface waters flow into the aquifer. Estimates of induced recharge around Albuquerque indicated that 80% of the pumped groundwater was induced between 1920 and 1960 (Robson and Banta 1995).

2.1.4 Demographics

Large agriculture regions predominate in the San Luis Valley, the region around El Paso and Cuidad Juárez, and the lower Rio Grande Valley. Agriculture is by far the highest water use in the basin. Of the 2010 projections for water use in the El Paso and surrounding counties, 175,540 of the total (193,171 acre feet), or around 91 percent, will be needed for irrigation (TWDB 2007). Industries and municipalities are associated with 14 binational “sister” cities. Municipal population growth is a major factor in calculating future water demands upon the river. Whereas population growth on each side of the border was estimated to be 26 percent during 1980–1990 (TWDB 2002), growth in El Paso and surrounding counties is projected to increase by 79 percent between 2010 and 2060 (TWDB 2007). Corresponding water demands projected for 2060 in the same region indicate a 9 percent increase in agricultural water use, but a 51 percent increase for municipal water demands.

2.1.5 “Law of the River”

The U.S. states of Colorado, New Mexico, and Texas have relatively similar approaches to water law and individual water rights. In Western U.S. water law, prior appropriation recognizes property rights, allocation through permitting, and senior vs. junior water rights. Beneficial use of the permitted water is another common theme. Colorado uses prior appropriation and adjudication for surface water permitting; groundwater is managed through permits and local groundwater districts (Hobbs 1997). Through the State Engineer’s Office, New Mexico manages surface water through prior appropriation, and groundwater is managed within specific districts and well permits. Texas utilizes prior appropriation and water rights for surface water. However, groundwater is either managed through groundwater conservation districts or by rule of capture in non-district areas.

The 1917 Constitution of México establishes federal domain over land, mineral resources, and water bodies, with the exception of a 2001 amendment that recognizes the rights of indigenous communities to natural resources. Thus, water statutes are founded on the Constitution, including water utilization prioritization, federal jurisdiction for all water delivery systems, and restricted zones and a permitting system for use and development of groundwater (Hernandez 2003). In addition, Article 27, Section 5, of the Constitution allows landowners to appropriate underground waters. If the public interest is affected, a “concession” is required under an extensive program, created to permit and manage these concessions. The 1992 National Waters Law created a new government agency, the Comisión Nacional del Agua (CNA), vested with all federal authority regarding national waters. The law also obligates all water users to pay fees for the use of national waters. Certain uses may be permitted, such as public urban use, agricultural use, power generation, and other productive functions. These uses apply to groundwater as well as surface water.

In the Treaty of 1944, the International Boundary and Water Commission, a bilateral agency, was created to handle water issues along this border, (IBWC 1944). The IBWC's primary focus is on surface water allocations and associated issues. In response to the North American Free Trade Agreement of 1992, the Border Environmental Cooperation Commission (BECC) was created to review groundwater and surface water problems associated with contamination along the U.S-Canadian border and the U.S.-México border. The North American Development Bank (NADBank) finances projects to address pollution and other related problems along the borders.

In summary, the hydrologic system of the Rio Grande watershed is an intricate system of surface water bodies and aquifers, as well as a complex array of natural habitats and human infrastructure. Droughts and floods affect the inhabitants, as does pollution. The laws that provide the framework for managing water vary greatly, posing barriers to integrated water management within the basin. A challenge in this study is to develop appropriate boundaries and limits for potential conjunctive management in the basin.

Conjunctive use as a water management approach is found in the basin, as are specific programs. There is also a very large quantity of data and information that is available on the Internet. Appendix B lists data sources considered of interest for potential conjunctive use in the Rio Grande Basin.

2.2 Conjunctive Use Programs Along the River

Within the Rio Grande basin, particularly near the river's mainstem, conjunctive-type water management is found in three areas that demonstrate the strengths offered by such projects. The first, the San Luis Valley in southern Colorado, indicates how conjunctive use can move from outgrowth of utilization of surface and groundwater, into part of a state's legal system. The second is an innovative demonstration project near Albuquerque, New Mexico, concerning storage of surface water through artificial recharge and what the project may indicate for legal precedent of similar projects in the future. Lastly, the Far West Texas planning region and the city of El Paso have included conjunctive management as part of long-term strategies for maintaining water availability through low flows and drought.

2.2.1 San Luis Valley, Colorado

As true of most western U.S. states, evolution of water law in Colorado over the last 150 years can be traced to its history, settler expansion, lean water supplies and disputes in times of drought, and understanding how surface water systems are linked to aquifers. The resulting Colorado system of water law is complex, multi-layered by intention, and has evolved over the years to deal with previously unknown water issues. Though the majority of laws deal only peripherally with conjunctive use, several legal milestones set precedent for conjunctive water management in Colorado.

During the early 1900's, state law embraced prior appropriation, beneficial use, and the right to transport or deliver water to lands not immediately adjacent to streams or tributaries (Hobbs 1997). Groundwater in CO was not well regulated, but was increasingly used for irrigation in the valley and other agricultural areas of the state. Unexpected changes in stream levels led to the supposition that increases in pumping wells affected stream flows. In the 1960's, hydrologic studies determined that such was the situation. The 1965 Groundwater Management Act was intended to bring groundwater into surface water rule. Along with designation and management of local groundwater districts, the Act authorized the State Engineer to protect surface water rights by managing well permits, including denial of permits on the basis that pumped groundwater could effect diversion of surface water. This Act, along with existing surface water law, was intended to provide full economic development of water rights and bring into effect the conjunctive administration of surface and groundwater. Furthermore, the 1969 Water Determination Right and Administration Act created a system of water districts and adjudication procedures for water rights to surface and tributary groundwater. Well pumping came under the existing priority system, but junior rights would not be curtailed unless they caused definable injury to senior water rights.

In additional to the growing metropolis of Denver, several agricultural regions of Colorado have experienced myriad water issues and lawsuits over the years. The San Luis Valley, located near the headwaters of the Rio Grande, is a small region with a fairly short growing season due to its elevation, but one remarkable for its famous river and the large volume of groundwater, located in shallow, unconfined water tables and artesian aquifers. The Rio Grande runs through the valley, and the productivity of irrigated lands using surface and ground water has stayed high for decades. Crops include hay, alfalfa hay, spring wheat, spring barley, fall potatoes, spinach, lettuce, and carrots (SLVRC 2009).

While the lawsuits that have brought the South Platte and Arkansas River regions to national attention have not been as prevalent in the San Luis Valley, the groundwater is tributary to the river in the valley and therefore subject to concerns under low flow and low rainfall conditions. Conjunctive use in the valley is seen as necessary for productive and economically viable lands, while being subject to changes in state laws. The interstate compacts concerning Rio Grande flows from Colorado into New Mexico and Texas also play a part in managing the water system. The valley provides an example of a conjunctive use system that is not formally managed as a project to achieve specific goals, but rather, a system that evolved out of local and state water needs, responses of the legal system to resolve conflicts, and ever-changing water rights, water demands, and fluctuating water supplies.

2.2.2 Bear Canyon Recharge Demonstration Project, New Mexico

Water resources in New Mexico are subject to prior appropriation and beneficial use. The appropriation system is one of senior and junior rights, overseen by the Office of the State Engineer, and beneficial use provides a measure by which to use waters of the state under permit (Lieuwen 1997). Administration of surface and ground water rights are conjunctive, with the intended effect of protecting surface waters from depletion due to groundwater withdrawals, and ensuring that water deliveries are made as required by interstate compacts. In effect, the groundwater storage potential of conjunctive management is considered limited due to the rights tied to surface water.

A unique artificial recharge demonstration project is underway in the Albuquerque area (Moore et al. 2007). While artificial recharge projects exist throughout the western states, to date there are no other operating and permitted projects in New Mexico. The Bear Canyon project has been designed to exhibit that artificial recharge can effectively provide recharge to an aquifer hydraulically connected to a stream system. The project utilizes surface water rights to San Juan-Chama flows. The allocated water is used to recharge the regional aquifer through an infiltration system in the stream, thereby demonstrating the aquifer’s storage potential. Project goals include use of surface water to recharge the aquifer, monitor water quantity and quality stored, and to establish a legal right to the stored water (Moore et al. 2007). This project, one with strong conjunctive use factors, may provide a precedent of permitted, stored, and retrievable surface water in an aquifer. In the New Mexico water system, already conjunctively managed in its administration oversight of surface and ground waters, the project may demonstrate the applicability of conjunctive use within a definite geographical location and time frame.

2.2.3 Far West Texas Region and El Paso Water Strategies

To better understand the water needs of different geographic areas around Texas, the 1997 Senate Bill of the 75th Legislature created regional water planning groups (RWPGs) (TWDB 2007). The regions and boundaries were developed based on geographic location of river basins, aquifers, socio-economic factors, municipalities, climatic zones, and other considerations, resulting in 16 RWPGs across the state. During each 5-year planning period, the RWPGs are required to evaluate current and future population growth and associated water supplies and demand. Should the projected supplies not meet future demands and uses, then the groups assess strategies to meet the region's needs. One option is conjunctive use.

The Far West Texas Water Planning Group (FWTWPG) is the RWPG responsible for coordination of water resource planning in El Paso County and six counties to the east and south. The 2002-2007 regional plan highlights the population growth centered on El Paso, projected to increase around 79 percent by 2060, and a corresponding future increase in municipal water demand by 51 percent. However, agricultural water demand, by volume the highest use, is projected to decrease 9 percent during the same time frame (TWDB 2007). Overall water demands for the next 50 years may exceed available supplies. In addition to strategies to meet agricultural and other water needs in the entire region, the RWPG has recommended a set of integrated strategies to meet water needs in El Paso - conservation, reuse, conjunctive use of Rio Grande and groundwater, and evaluation of additional groundwater supplies (FWTWPG 2006).

Based on current conjunctive use by the El Paso Water Utilities (EPWU), the long term strategy of conjunctive use relies on pumped groundwater from local aquifers to supplement or replace low flow surface water availability during winters and times of drought. The key to surface water use is El Paso's ownership and lease rights to use Rio Grande waters; if all agreements are met during a year, El Paso has rights to 65,000 acre-feet (FWTWPG 2006). Under the conjunctive use strategy, leases and rights to groundwater would bring in 10,000 to 20,000 acre-feet per year of pumped groundwater into the water resources system. Projected capital costs for this conjunctive use are $103M, including an additional 20-acre treatment plant, and operations and maintenance costs are estimated to be $13M over 30 years and $5.6M over 20 years (FWTWPG 2006). Assessed impacts suggest that the increase in pumped groundwater, up to 20,000 acre-feet per year, would not significantly impact groundwater quality. The conjunctive use strategy is one of six components in the Far West Texas Region future water supply. Water supply realized from conservation, reuse, and purchases and leases to other groundwater sources are considered to be equally critical to long term success.

The FWTWPG recommendations are reflected in the El Paso Water Utilities' "10-Year Strategic Plan" (EPWU 2009). Under the goal for "Government Affairs, Communications, and Marketing Initiatives," Goal II-D, the Board states that it will work with state and federal entities to "promote and implement the utility's state and federal agendas." One measurement of this goal is "continuing to emphasize the need for water resource flexibility through the combination of desalination, importation, surface water purchases, and land acquisition for groundwater rights in order to provide varied approaches in maintaining a sustainable water supply." This goal is further developed in the document's Resource Management Initiative, Goal III-K, acquisition of new water rights "to ensure availability of water resources, especially during times of drought." One of the measurements is integrated water management strategies, under which the conjunctive use of water is included.

El Paso provides an example of how conjunctive use may be evolving in the Rio Grande basin. Rather than implementing one large-scale, long term strategy, the planning groups and stakeholders are working with multiple approaches that provide integration between existing infrastructure and water management, and feasible strategies to meet future needs.

Initial research actions of this project were designed to determine the potential for conjunctive use in the Rio Grande basin. As discussed above, these actions are review of background information on conjunctive use concepts and development, current programs inside and outside of the basin, and data sources specific to the basin. The research also includes an online survey and interviews with water resource professionals. Sections 3.0 and 4.0 discuss the results of the survey and interviews, respectively, and implications for successful conjunctive use in the basin.

3.0 Online Survey

To determine factors that allow creation and implementation of a viable conjunctive use program, an online survey was prepared under the authorization of Texas State University-San Marcos Institutional Review Board. This survey was prepared and addressed in 2007; the results were analyzed in summer 2008.

3.1 Methods

Based on input from Dr. Chad Smith, Department of Sociology, Texas State University-San Marcos, and published documents about conjunctive use, the authors designed questions to collect information about selected conjunctive use topics. These are general management and operations, surface and ground water information, economic benefits and costs, laws and institutions, and viability of conjunctive use programs. The online survey design included quantitative and qualitative aspects. The survey was sent to experts or researchers in water agencies, conjunctive use programs or related experience in water law, economics, hydrology, or hydrogeology. The experts were identified through peer-reviewed publications and website information. No researcher names or email addresses were shared or tracked by the online survey company, SurveyMonkey.

Analysis of the survey was conducted in accordance with the number of responses per question (respondents were allowed the option to respond or not respond to all but two questions), the ratings, and whether the responses were definitive, or varied and subjective.

3.2 Responses

Of 92 survey invitees from 20 U.S. states, 13 responded (14% overall participation), with the number of responses per question varying from 0 to 13. This participation level was considered too low to allow adequate parameterization of the data or inferential projections. However, the responses provided directional feedback for future interviews. The following subsections discuss highlights of the results. A summary table is provided in Appendix C, listing per topic the items of inquiry, summarized results, and ratings.

3.2.1 General Management and Operations

The initial survey section began with location and questions about general conjunctive use operations. The states in which the respondents work on conjunctive use were Arizona, California, Illinois, New Mexico, Texas, and Rhode Island. Responses indicated that the programs typically operate under state-authorized special water districts, irrigation districts, or municipalities. However, special cases included adjudication, court-appointed watermasters, joint-power authorities, and federal agency research programs. Highest rated water uses were municipal and agricultural, while the lowest rated were industry and specific habitat flows. Based on the number of responses, the duration for growth in conjunctive use programs varied, depending upon the stage of growth. Planning might take about 6-10 years; construction and implementation about 1-5 years; operations growth about 11-20 years; and phase-out more than 50 years. Background and years of training for persons working in conjunctive use appeared to vary among scientific, engineering, and business disciplines.

Regarding accessible water rights for various sources of water, rivers and aquifers greater than 100 feet were the top selections, while natural lakes or imported groundwater sources were the lowest rated. The approximate operating budget of a typical conjunctive use program was typically judged "unknown," though some responses indicated such a budget may be between $100,000 and over $1M annually.

3.2.2 Surface and Ground Water Information

Surface and ground water information deemed necessary to develop conjunctive use models included basic flow parameters and volumetric changes over time. Monitoring takes place at those locations already in place for other water management programs, including flow gauges along rivers and wellhead meters. Selected software programs were those in current use in the U.S. (MODFLOW or RiverWare). Typical storage capacity or groundwater pumping might vary from 100 to 10,000 acre-feet per year (AFY). From a hydrologist / hydrogeologist's perspective, possible conjunctive use program triggers that might be used to signal the cessation of use of one source and begin use of another could be surface water decreases below program-defined levels, or water price increases above a program's target.

3.2.3 Economic Benefits and Costs

Of possible major benefits in conjunctive use, survey responses included the potential for increased water availability and drought mitigation. Lower rated benefits were the potential for increased water conservation and flexible water prices. Conversely, possible major costs were deemed to be neutral. Moreover, the costs of conjunctive use may be lower than those of alternative water management programs. Pricing structures that might support efficient water allocations were seasonal or variable rates, whereas block or uniform rates were considered less efficient. Economic incentives were perceived to be effective in conjunctive use, including subsidies to cover the price differential between surface and ground water. However, price markups were not considered effective inducement to conserve water.

3.2.4 Law and Institutions

Questions about laws that support conjunctive use resulted in a high rating for prior appropriation of surface water, and low ratings for beneficial use and equitable apportionment. No groundwater rule of law was considered supportive of conjunctive use; a low rating was given to rules based on "historic use"groundwater. Under transboundary water considerations, a high rating was given for physical differences in water sources across geopolitical boundaries, and the low rating was differences in water laws across geopolitical boundaries. The manner in which government institutions support CU programs were also found primarily at state agencies through grants and water permit support, and at municipalities through direct funding and organizational framework.

3.2.5 Viability of Conjunctive Use Programs

When queried about water availability in the CU program with which the respondents were most familiar, most respondents indicated that water availability had not significantly changed in the last 10 years; for programs that experienced a decrease in water availability, a low rating went to basin wide droughts or declining ground water levels. Measurable changes in water conservation were generally unknown. Setbacks to viable conjunctive use included differences in legal frameworks for surface and ground water, while a lesser rating for setbacks includes decreasing ground water levels, decentralized water agency oversight, legality under state rules, and a lack of coordinated basin oversight. Finally, the responses as to whether conjunctive use should be included in future federal or state water supply plans were yes (high rating) and no (low rating). The positive responses gave the following reasons: conjunctive use addresses a number of water supply problems; it provides an often-low-cost source of "new" water, and addresses water shortages and availability. The negative response noted the site-specific nature of such programs and therefore the inherent difficulties of involving conjunctive use at state or federal planning levels.

3.3 Evaluation of Results

The responses indicate that general indicators of viable conjunctive use programs may be found in a variety of climatic regions and states. Program water sources are most likely to be rivers and accessible groundwater. Conjunctive use programs may last more than 50 years. A variety of expertise is recognized in conjunctive use programs, and the operating budgets may compare favorably to alternative water management strategies. Although the low number of respondents does not allow projections of the data, analysis of the results suggests directional feedback for interviews, as summarized below:

- Conjunctive use may be most successful in long-term planning and management of large-scale water demands (agriculture and municipalities).
- Oversight authority for conjunctive use programs may be well placed with water or irrigation districts, which have information about local water user issues and site-specific details critical to successful water management.
- Possible benefits may include drought mitigation, but not necessarily water conservation.
- Costs of conjunctive use may be lower than those of alternative programs.
- Transboundary issues may involve physical differences in water sources.
- Setbacks may involve differences in legal frameworks for surface water and groundwater.
- There are substantial arguments for and against inclusion of conjunctive use in future water supply plans.

The online survey provided sufficient feedback to suggest some key factors in successful conjunctive use programs. To better understand conjunctive use programs that are currently in place, and how conjunctive use/management may be perceived by experts in different water resource disciplines, the survey results were used in preparing interview questions. Discussion of the interview results are in Section 4.0.

4.0 Interviews with Water Resource Professionals

During 2008-2009, interviews have been conducted in person or via telephone with selected water resource professionals. The interviews were conducted under authorization by the Texas State University-San Marcos Institutional Review Board. To compile an appropriate list of topics and questions, the survey results were used as a starting point. The list of interviewees was based on persons identified during the survey contact search, recommendations, web searches, and closeness of fit between the person's professional experience and work to conjunctive use. Each interviewee was contacted by email or phone to explain the goals of the research project and request 20-30 minutes of time. From contact through scheduling to the actual interview typically took 1 to 3 weeks. Prior to each interview, the water professional's background, current research or professional projects and publications were reviewed. Emphasis was placed on the water professional's interests and projects in each interview; therefore, no two interviews were alike. If the interview came close to the 30-minute timeframe but was willing to continue, then the interview continued.

The goal of these interviews was to find insights into current views on conjunctive management and knowledge about current implementation strategies. Notes from each interview were reviewed and coded for 1) the interviewee's understanding of conjunctive use, 2) conjunctive use-type projects with which they were involved, and 3) the interviewee's perspective on his/her most critical water management issue for the next 20 years, and suggestion(s) as to the best solution on the horizon.

The interviewees are from the following industries and research fields: water management, surface and groundwater modeling, water law, industry and government affairs, environmental non-government organizations (NGOs), state and federal positions, research in economics, and research in hydrology. The interviewees work in New Mexico and Texas. To date, twelve interviews have been conducted and analyzed, with the following results. No exact wording from the interviews is used without express written permission.

Definitions and understanding of conjunctive use varied; only two interviewees did not have a ready definition. Some interviewees understood the term to indicate the use of more than one source of water. Those actively involved with conjunctive use projects noted that the term also included management and/or optimization of water sources, and possible impacts on those sources.

Conjunctive use-type projects were not alike for any two of the interviewees.

Water resource modelers discussed their experiences with developing conjunctive use-type models, though the goals often were not conjunctive use. In each case, the modeling approach was different and reflected the project's goal, the modeler's background and experience, the local hydrology and aquifer characteristics, and available data.

The legal expert dealing with water law worked with clients whose primary concerns were water availability; the focus was on obtaining water rights through surface or groundwater, and conjunctive use was more of a side result than a goal or water management strategy.

Persons dealing with water management issues in government and NGO positions did not have specific conjunctive use projects, but were familiar with possible impacts of conjunctive use. The overriding concern for these persons was not whether conjunctive use should be implemented but rather, how to minimize the impacts of any water management approach on future water supplies and the environment.

Professionals working in active conjunctive use projects focused on the importance of an aquifer's storage function. Western U.S. surface water, in terms of its legal framework, ease of diversion, and the in-place infrastructure, is more well-defined for surface water allocations than is groundwater. Therefore, these interviewees emphasized the strength in applied conjunctive use is groundwater storage, particularly if stored for times of drought. They also noted difficulties in implementation of groundwater storage and recovery due to a state's rules on groundwater, permits, and interbasin transfers of water.

Critical water management issues for the next 20 years covered a range of issues. Notably, none of the interviewees suggested that there are, or will be, no problems in water management. Discussed issues and suggested solutions are:

- Hydrologic/hydrogeology/economic modeling: The simplest level at which a model can work and answer the questions being asked, should be the starting point. Permitting, institutional requirements, and cost factors play a role in whether a technically feasible model can be implemented.
- Government and NGO water managers: A difficult question is how to limit groundwater pumping to sustainable limits, so as to assure future water supplies and minimize impacts on the aquifers and associated systems. If there are few regulations in place to limit pumping, then future supplies may have to come from conservation and reuse. Local and regional control of groundwater is one key to getting shareholder "buy-in."
- Industry government affairs: There are limits on the amount of available water, and these are understood to be highly emotional issues. All persons need and use water, therefore the solutions need to be found with all parties having a role at the table.

- Economics and agricultural research: During times of crisis such as drought, increasingly agricultural water rights are losing out to municipal water demands. The biggest issue is water availability, particularly in light of climate changes. As an economist, one solution is to use price ranges; if the marginal cost increases to a certain marginal use, then people can pay more or choose to use less. In agriculture, choosing to use less within current water application systems may not be possible without loss of crops.
- Experts with active conjunctive use projects: The most critical problems are developing water management options with legal, established basis for groundwater use, storage, and retrieval. Such a basis is needed for aquifer storage and recovery projects as part of conjunctive use strategies. Solutions can involve education outreach, financial incentives, and permitting.

The interview results highlight the disparity with which conjunctive management is perceived and implemented. The basic concepts are fairly well agreed upon, but conjunctive use in New Mexico and Texas does not seem to be utilized to its full potential as a water management strategy. Not surprisingly, the two persons actively working on conjunctive use projects had the greatest understanding of the strengths and weaknesses of planning and implementing conjunctive use as a water management resource tool. The flexibility of the approach is one of its strengths – conjunctive use can be applied in different geographic regions, different surface water systems and aquifers, and differing legal frameworks, albeit within limits. These persons expressed technical knowledge about two separate designs incorporating conjunctive use, issues overcome during implementation, and enthusiasm for the strengths that conjunctive use can bring to water management in the future.

5.0 Conclusions and Follow-on Studies

Conjunctive use is a water management approach that is proven through research involving surface water and groundwater modeling and economics to have application in various parts of the world, particularly areas subject to drought or other water stressed conditions. Adding groundwater as a buffer to the better-known management strategies for surface water has appeal in its simplicity. However, as in every management approach, there are strengths, weaknesses, and limitations.

The Rio Grande basin is in need of water solutions, present and future. To address the complex issues, approaches such as conjunctive management that support water supply efficiency offer practical options. Conjunctive management programs have demonstrated the efficacy of the strategy in various western U.S. states. Conjunctive management may vary from groundwater basin partnerships to state-led central coordination, but the strengths of conjunctive management – flexibility, sustainable duration, long-term groundwater storage and retrieval – are consistent.

The Rio Grande basin with its complex water system of the main river, critical inflows from tributaries, springs, and aquifers, is in a unique position to take advantage of conjunctive management. The concerns of population growth, different legal frameworks, and varied groundwater systems are the same conditions that can utilize conjunctive management. The Far West Regional Water Planning Group is an excellent example of conjunctive management being put in place alongside other approaches with demonstrable results in water management in drought-prone regions. Rather than implementing one large-scale plan, water managers and stakeholders are working with multiple approaches that provide integration between existing water sources and infrastructure. Conjunctive management thus can supplement existing water management in a streamlined, cost-efficient manner.

Surveys and interviews conducted for this research found that conjunctive use is most likely to be most successful in large-scale water demands as such agriculture and urban water uses. Benefits may include drought mitigation, but not necessarily water conservation, therefore programs that combine relatively low-cost conjunctive strategies with other water savings programs will have a higher likelihood of success. Limitations may involve differences in geopolitical boundaries, differences in aquifer conditions across a water-use region, and the different legal frameworks for surface water and groundwater.

This report provides background, data sources, and information on where conjunctive use is applicable in the Rio Grande basin. The second of two reports, the Guidance Document, will further evaluate the applicability and limits of those factors that support viable conjunctive use.

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[IBWC] International Boundary and Water Commission. 2002. Deliveries of waters allotted to the United States under Article 4 of the United States-México water treaty of 1944. Technical annex: Update of the hydrologic, climatologic, storage and runoff data for the United States in the Mexican portion of the Rio Grande Basin: October 1992-September 2001. Prepared by United States Section IBWC with technical assistance from RJ Brandes Company, Austin, Texas. April 2002.

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Appendix A

Selected Definitions of Conjunctive Use/Management
(Alphabetical by Author)

Definitions from **Hydrologic-Hydrogeologic** Publications

"Successful conjunctive use is defined here as a water resource system where (1) surface water and groundwater users have reasonable access to the water, and (2) no wells are summarily shut down."

National Ground Water Association, AGWSE Division 2007. "Conjunctive use of groundwater water and surface water – success or failure?" by John Bredehoeft, in Ground Water News and Views, v. 4, n. 2, November 2007.

"Conjunctive water use refers to simultaneous use of surface water and groundwater to meet crop demand… Conjunctive management, by contrast, refers to efforts planned at the scheme and basin levels to optimize productivity, equity, and environmental sustainability by simultaneously managing surface and groundwater resources."

World Bank, 2006. Conjunctive use of groundwater and surface water. Agriculture and Rural Development, The Water for Food Team, issue 6, February 2006, 4 p.

"Conjunctive use and management of water simply refers to the situation where water in two or more phases of the hydrologic cycle, in this case groundwater and surface water in streams, are used or managed together as an integrated resource."

Templar, O.W., 2001. Municipal conjunctive water use on the Texas High Plains. The Social Science Journal, v. 38, p. 597-604.

"In basins approaching full development of water resources, optimal beneficial use can be obtained by conjunctive use, which involves the coordinated and planned operation of both surface water and groundwater resources to meet water requirements in a manner whereby water is conserved."

Todd, David K. and Mays, Larry W., 2005. Groundwater Hydrology, 3rd edition. John Wiley and Sons.

Definitions from **Economic** Publications

"Since surface waters can be highly variable from one year to the next, aquifers also function as a natural inventory system for smoothing annual fluctuations in surface flows."

Knapp, K., and Olson L.J., 1995. The economics of conjunctive groundwater management with stochastic surface supplies. Journal of Environmental Economics and Management, v. 28, p. 340-356.

"... [C]onjunctive use refers to the practice of coordinating the use of surface water and groundwater resources during periods of water scarcity and surplus."

Schuck, E., and Green, G.P., 2003. Conserving one water source at the expense of another: the role of surface water price in adoption of wells in a conjunctive use system. Water Resources Development, v. 19, n. 1, p. 55-66.

Definitions from **Combination-Goal** Publications

"Conjunctive water use, or a water supply derived from the complementary use of surface water and groundwater resources, ..."

Hathaway, D.L., Flanigan K.G., Lewis K.J., 2002. Legal and physical constraints on the conjunctive use water supply of the Middle Rio Grande region, in, Groundwater/ Surface Water Interactions, American Water Resources Association 2002 Summer Specialty Conference, July 2002, p. 225 – 230.

"... the potentially large benefits to be gained from efficient joint use of surface water and groundwater in those large alluvial basins where the physical interdependence of the two water resources complicates allocation."

O'Mara, G.T., 1984. The efficient use of surface water and groundwater in irrigation: an overview of the issues. In Efficiency in Irrigation, ed. G.T. O'Mara. The World Bank, Washington, D.C.

Appendix B

Databases Pertinent to Conjunctive Use in the Rio Grande / Río Bravo Basin
(Alphabetical by Agency or Institution)

Institution(s)	Description	URL Address
Commission for Environmental Cooperation (CEC)	Databases on environmental law and transboundary agreements	http://www.cec.org/pubs_info_resources/databases/index.cfm?varlan=english
International Boundary and Waters Commission (IBWC) and Comisión Internacional de Límites y Aguas (CILA)	Database of surface water flows for the US allocation of Rio Grande surface waters; hydraulic station data for each of the major tributaries of the Río Bravo	http://www.ibwc.state.gov/Water_Data/rio_grande_WF.html - Stream and http://www.sre.gob.mx/cila/
IBWC	Information about transboundary aquifers in the El Paso/Cd. Juárez region	http://www.ibwc.state.gov/Water_Data/binational_waters.htm
New Mexico Office of the State Engineer	Internet waters database – information concerning water rights, permits, and use. The url address provides a starting point for entry; site registration is required.	http://www.seo.state.nm.us/waters_db_index.html
New Mexico Water Resources Research Institute (WRRI)	Starting page for database links to the NMWWRI library, groundwater publications, interstate compacts, maps, and GIS data	http://wrri.nmsu.edu/wrdis/wrdis.html
Texas Natural Resources Information System (TNRIS) Borderlands Information Center (BIC)	Digital data within 100 km of either side of the TX-Mexico border for soils, hydrography, hypsography, transportation, population, land use	http://www.tnris.org/BIC.aspx
US Bureau of Reclamation	Data and information on Elephant Butte and Caballo dams along the Rio Grande	http://www.usbr.gov/dataweb/dams/nm00129.htm http://www.usbr.gov/dataweb/dams/nm00131.htm
US Environmental Protection Agency (EPA) & Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT)	Border 2012 program – data and reports for the Rio Grande/ Río Bravo basin to improve quality of water, air, land, environmental health, response, and environmental performance	http://www.cec.org/pubs_info_resources/databases/index.cfm?varlan=english
USDA Sustainable Agricultural Water Conservation Research Project	database of funded projects, ongoing and completed research studies, and institutions, maintained and updated by River Systems Institute and Sul Ross University	http://rsi-db.its.txstate.edu/prjdb/rgDefault.aspx and http://www.sulross.edu/pages/4624.asp
The University of Texas Center for Research in Water Resources, Rio Grande – Río Bravo Studies	ARCHydro binational datasets for water flows, water quality, and monitoring point; list of weblinks for varied information and data concerning digital data, hydrology, land use, soils, climate, global data, Texas data, and maps	ftp://ftp.crwr.utexas.edu/pub/outgoing/PATINOC/RioGrandeInfo ftp://ftp.crwr.utexas.edu/pub/outgoing/PATINOC/INF_SOURCE-WebPage.htm

* This table does not contain all current databases concerning the Rio Grande/ Río Bravo basin. Selected databases are considered relevant to conjunctive use and to projects and data concerning basin hydrology, hydrogeology, water laws, legal agreements, environment, and economics. The preceding subjects are considered key to potential conjunctive management projects and programs. Other links of interest may be found in many of the websites.

Appendix C

Summary of Online Survey Responses

Table C. Summary of Online Survey Responses

Survey Topics	Response Summary	High Rating	Low Rating
General Management and Operations of Conjunctive Use (CU) Programs			
States of respondents' CU programs or research	AZ, CA, IL, NM, RI, TX		
Authority for CU program		Water districts, special districts	Federal agencies
Water uses in respondents' CU programs		Municipal, agriculture	Industry, habitat flows
Stages of CU program longevity			
- Planning		6 - 10 years	> 20 years
- Construction and implementation		1 - 5 years	> 20 years
- Growth of operations		11 - 20 years	1-5 years; > 50 years
- Phase-out		> 50 years	< 1 year
Experience and training for persons in CU	Civil or agricultural engineering, soil science, hydrology, hydrogeology, business management, water law, economics/finance; unknown	Background or training information unknown	
Accessible water rights for water sources	River diversion, reservoir, offsite channel, shallow (<100 feet) aquifer, deep (>100 feet) aquifer, imported surface water, treated wastewater	Rivers and shallow aquifers	Natural lake; imported GW
Approximate annual operating budget		More than $1,000,000 AND "information not available"	< $100,000
Respondents' expertise/training	Government water agency/ district (4), CU program mgt (1), research in SW/GW (3), research in water law (1), research in natural resource economics (4)		
Surface and Ground Water Information			
Aquifer characteristics	Confined and unconfined		

Monitoring of water resources in CU programs	Surface water (flow gauge) and groundwater (wellhead meter)		

Table C. continued

Survey Topics	Response Summary	High Rating	Low Rating
Surface and Ground Water Information (continued)			
Monitoring of water resources in CU programs	Surface water (flow gauge) and groundwater (wellhead meter)		
Significant hydraulic characteristics in CU program's water balance model	Flow, rainfall, evapotranspiration (ET), reach length, channel (width, slope, loss/gain), hydraulic conductance, roughness coefficient	Flow, rainfall, ET, conductance	Water quality
Significant groundwater characteristics in CU program's water balance model	Aquifer geometry and matrix, hydraulic conductivity, storage, leakage, well discharge over time, water quality	Aquifer geometry, hydraulic conductivity, well discharge over time	Spring conductance
Software choices for a new CU model		MODFLOW with stream module, RiverWare	HEC-HMS, artificial neural networks, DHI MIKE Basin
Typical range of storage capacity for CU program's water sources	River or imported SW: 100-10,000 acre-feet per year		
Typical range of pumping for CU program's groundwater sources	Wellfields: 100 - 10,000 acre-feet per year		
"Trigger" to define move from program use of 1 water source to another	Surface water volume decreases below program-defined target level; water prices increase above program target		
Economic Benefits and Costs			
Major benefits of CU programs		Increased water availability; potential for drought mitigation	Potential for increased water conservation; flexibility in water prices; potential for drought mitigation

Major costs of CU programs	Respondents perceived costs to be neutral overall.	Costs are lower than those of alternative water mgt programs	

Table C. continued

Survey Topics	Response Summary	High Rating	Low Rating
Economic Benefits and Costs (continued)			
Pricing structures that support efficient water allocation in CU programs		Seasonal or variable rates	Block rates
Are economic incentives effective in CU programs? If so, which incentive(s) are most effective?	Yes	Subsidies to cover the price differential between surface water and groundwater costs	
Do price markups encourage water conservation by users in CU programs?	No		
Laws and Institutions			
Surface water law that supports CU programs		Prior appropriation	Beneficial use, equitable apportionment
Groundwater law that supports CU programs		None	Historic use
Considerations in transboundary water programs		Physical differences in water sources	Differences in water laws across geopolitical boundaries
How do government institutions support CU programs?	**State:** grants, water permit support. **Municipal:** direct funding, organizational framework		
Viability of Conjunctive Use Programs			
Has water availability in your CU program decreased in last 10 years? If yes, why?		No	Yes: basinwide drought conditions; declining GW

Has the CU program with which you are familiar experienced change in water conservation? If yes, approximately how much change?		Unknown	Yes: increase in conservation by 6-10%

Table 5.1 continued

Survey Topics	Response Summary	High Rating	Low Rating
Viability of Conjunctive Use Programs (continued)			
Applicable setbacks to viable CU		Differences in legal framework for SW & GW	GW level decreases; decentralized water agency oversight; legality of CU under state rules; lack of coordinated basin oversight
Should CU be included in future federal or state water supply plans? Why or why not?		**Yes:** "CU does address a number of water supply problems that are usually addressed by more expensive and environmentally damaging projects." "CU provides a valuable, often low-cost source of 'new' water." "CU addresses water shortages." "CU addresses water availability."	**No:** "CU is so site-specific that there is little to be gained by trying to include it at state and federal levels."