Conjunctive Water Management in the San Joaquin Basin:

A Case for Groundwater Management Reform

by

Joshua David Pollak

A thesis submitted in partial satisfaction of the

requirements for the concurrent degrees of

Master of City Planning

and

Master of Landscape Architecture

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor G. Mathias Kondolf, Chair
Professor Emeritus Robert. H. Twiss
Dr. William A. Eisenstein

Spring 2010

The thesis of Joshua David Pollak, titled Conjunctive Water Management in the San Joaquin Basin: A Case for Groundwater Management Reform, is approved:

____ Date: ____________________

Chair: Professor G. Mathias Kondolf

____ Date: ____________________

Professor Emeritus Robert. H. Twiss

____ Date: ____________________

Dr. William A. Eisenstein

University of California, Berkeley

Abstract

Conjunctive Water Management in the San Joaquin Basin:

A Case for Groundwater Management Reform

by

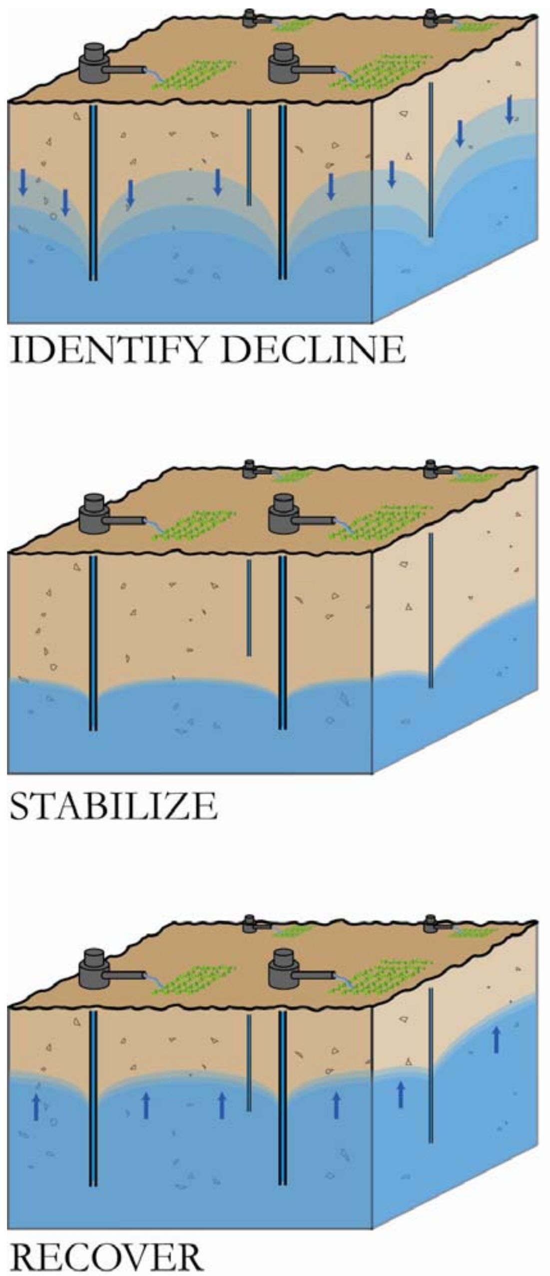
Joshua David Pollak

B.S. (University of California, Berkeley) 2005

Conjunctive management means managing surface water (water from rivers and lakes) and groundwater (water in underground aquifers) together. A common conjunctive management arrangement is diverting surface water, infiltrating the water into an aquifer, then pumping to recover the groundwater from the aquifer when it's needed. The California Department of Water Resources has estimated that there is over 140 MAF of aquifer storage space usable for conjunctive management projects, which is more than 3 times all the surface water storage space in the state combined. However, only a small fraction of the storage potential is being used in conjunctive management projects. Although surface water and groundwater are hydrologically connected, they are managed and legally seen as two separate entities in California. In general, surface water withdrawals are regulated, but there are no statewide controls on groundwater extraction. The lack of statewide groundwater management has also led to problems with groundwater overdraft, particularly in the San Joaquin Basin. My research question is: how do conjunctive management programs work in the San Joaquin Basin and what are the policy and management implications for California water management? The three different projects I examined were the Tehachapi Basin in foothills of the Tehachapi Range, the Kern Water Bank, near Bakersfield, and the proposed Madera Water Bank,

southwest of Madera. The common theme running through each of the projects is the control of groundwater extraction. Both the Tehachapi Basin and the Kern Water Bank have developed unique mechanisms to control groundwater extraction. The development of the Madera Water Bank shows the uncertainty that's created by the lack of groundwater management. Under current California law, where groundwater generally can be extracted without limit and the ownership of water infiltrated into an aquifer is nebulous, there exists little incentive to develop conjunctive management projects. If an agency wants to develop a conjunctive management project, there is no guarantee that they will be able to recover the water they infiltrate or that there will be no interaction between the project operations and adjacent landowners. In order to address the uncertainty inherent in current groundwater management, I developed a locally-run groundwater permitting system that can encourage conjunctive management projects by providing better information for management and a mechanism to control groundwater extraction.

Conjunctive Water Management in the San Joaquin Basin: A Case for Groundwater Management Reform

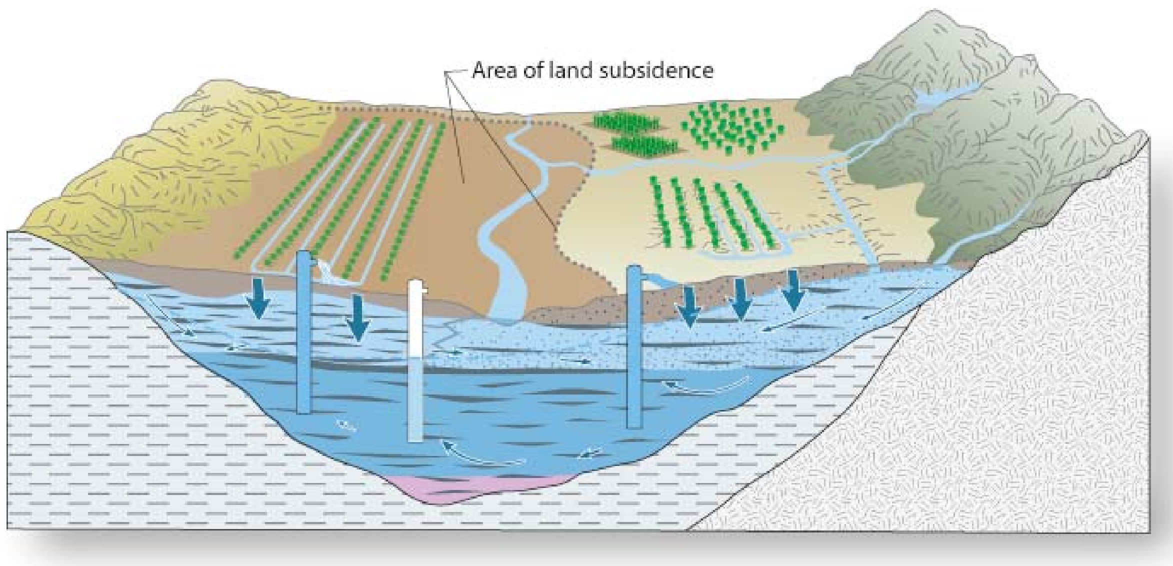


Steps in Creating a Groundwater Management Plan

Josh Pollak

May 2010

**Conjunctive Water Management in the San Joaquin Basin:
A Case for Groundwater Management Reform**



Schematic of San Joaquin Valley Hydrology
USGS, 2009 < http://pubs.usgs.gov/fs/2009/3057/>

Table of Contents

1.0 Introduction: Motivation & Research Question

1.1 Motivation

California's groundwater is a vital yet poorly managed resource. Groundwater provides up to 40% of the state's supplies in dry years, forms at least a portion of the drinking water supply for 16 million Californians, and can provide up to 100% of irrigation water in dry years in certain areas (LAO, 2010). California has vast storage space in underground aquifers, yet does not regulate the extraction of groundwater on a statewide basis. A number of projects have sought to utilize the aquifer space as a method for water storage, including the proposed Madera Water Bank. The development of the Madera Water Bank exposes the problems with California's lax groundwater management and shows why the large potential benefit from conjunctively managing surface and groundwater has yet to be realized.

On the surface, the proposed Madera Water Bank seems logical enough: excess surface water from surrounding irrigation districts would be infiltrated into Madera Ranch's permeable soils, where it would percolate into the aquifer. The project operators could then pump this stored water out of the ground, where it could be used as a source of irrigation water during surface water shortages. The seemingly straightforward project, however, belies the complex history of the Madera Water Bank, which has followed a tortuous path from when it was initially proposed to the present. After 12 years, 2 false starts, and considerable opposition from local landowners, the water bank has yet to be constructed. The complications in developing the water bank raise a number of questions: is the Madera Ranch site suitable for a water bank? What was the source of the controversy? Is it a good idea to develop water banks in California? After examining the hydrogeology, economics, laws and policies and politics related to conjunctive management and two other case studies of conjunctive management projects, the institutional barriers to the efficient management of water resources become clear. In the concluding chapter, I develop a locally-run groundwater permitting system to address the mismanagement of groundwater that can allow California to begin to utilize its potential for conjunctive management.

1.1.1 Why do we need to store water?

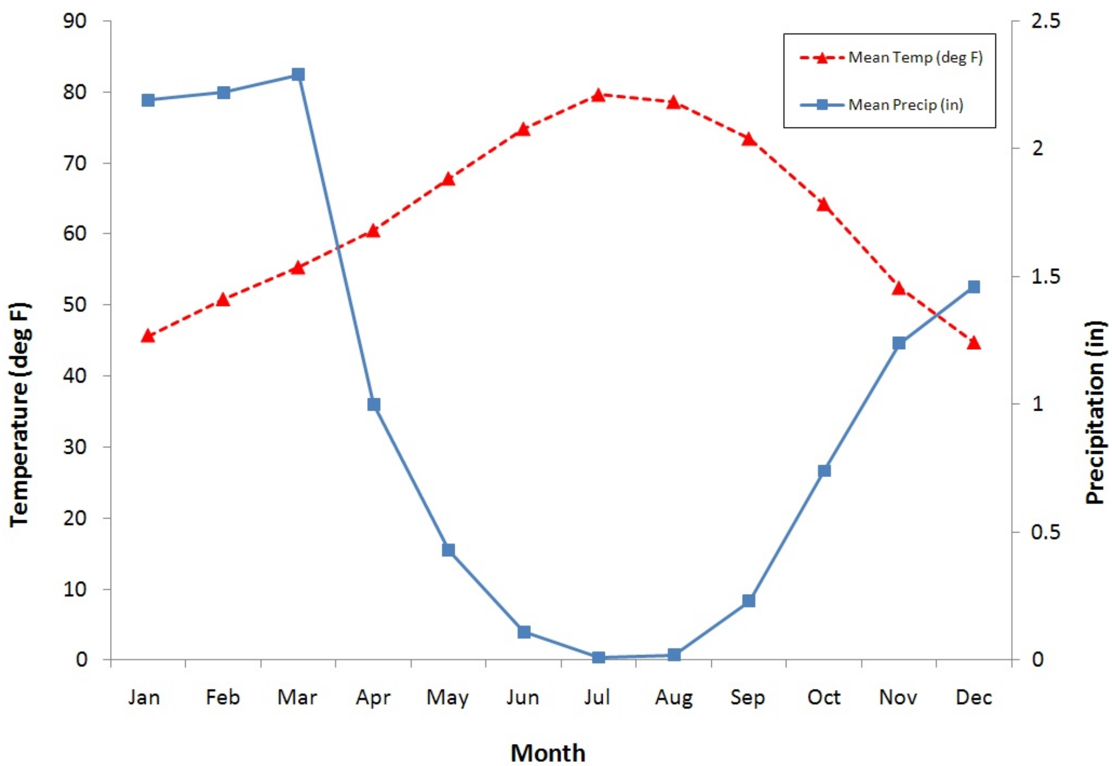


Figure 1.1: Temporal mismatch between supply and demand.
(Data from Madera, CA)

The development of California is inextricably linked to the development of its water resources. California's Mediterranean climate of short, wet winters and long, dry summers (Figure 1.1) has made water management a central concern since the state's inception. About three-fourths of the state's precipitation falls north of Sacramento (Figure 1.2) while three-fourths of the water demand is south of Sacramento (Carle, 2004). The combination of long seasonal droughts and a spatial mismatch in water supply and demand contributed to create one of the world's largest and most complex water infrastructure systems. However, California's massively engineered water infrastructure has not resolved water resource management issues. Myriad water resource challenges exist in California, including the allocation of water between urban, agricultural, and ecological uses, the impacts of climate change, the potential ecological collapse of the Sacramento-San Joaquin Delta, the ecological consequences of heavily modified river systems, and the political, social, and ecological consequences of infrastructure capable of transporting water hundreds of miles.

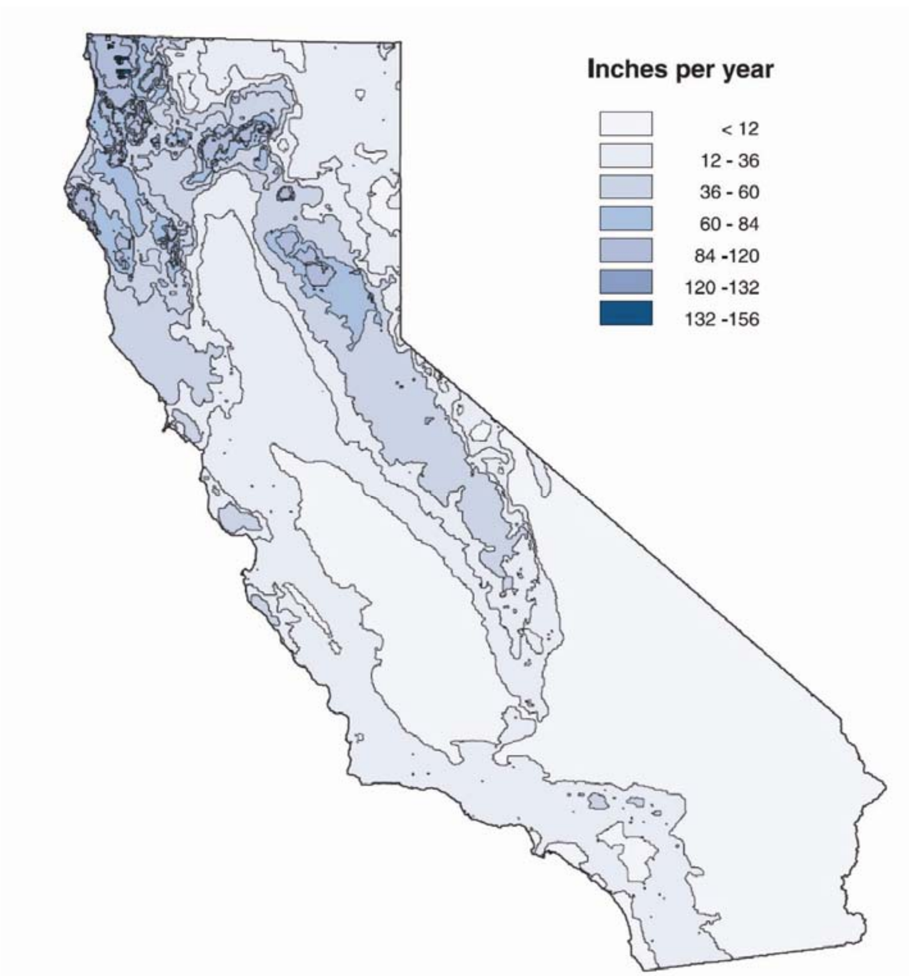


Figure 1.2: Spatial Distribution of Precipitation
(From DWR Bulletin 118, 2003)

1.1.2 Challenges facing irrigated agriculture

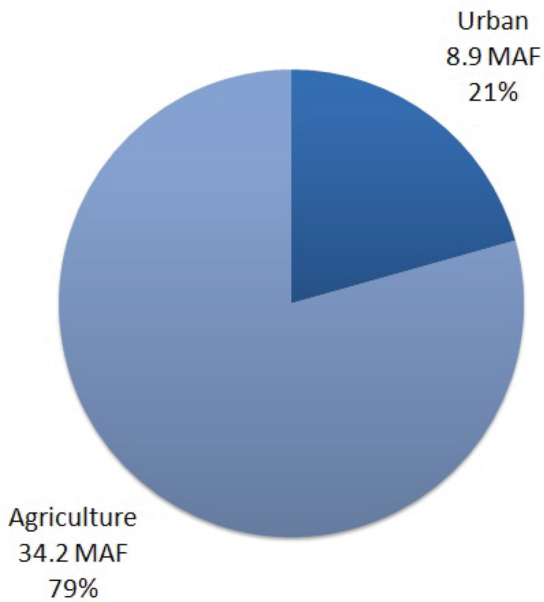


Figure 1.3: Average Year (2000) Water Use
(DWR, 2005)

As the state's single largest user of water—about 80 percent of the total on average (Figure 1.3)—concerns about water management in California must necessarily address the agricultural sector. California's agricultural industry is highly productive and grows about 25 percent of the nation's food on only 1 percent of the nation's farmland (Galloway and Riley, 2006). California produces 11 percent of the total U.S agricultural value (Galloway and Riley, 2006) and has 8 out of the top 10 producing agricultural counties in the country (USDA, 1997). Agriculture in California provides a number of benefits, including a local food supply, a source of income and character for rural communities, habitat and endangered species preservation, and carbon sequestration. Agricultural land also acts as barrier to urban sprawl and the negative environmental impacts that come with urbanization.

Agriculture in California, however, faces a number of challenges going into the future. As a sector, agriculture is more vulnerable to the damages from water shortages than urban users.[1] Because of changing environmental values and legal battles, the environmental impacts of the Central Valley Project and the State Water Project have only relatively recently began to be addressed. Addressing the environmental impacts can reduce the historic allocations of water to agriculture. Rising land prices for housing development can also entice farmers to sell their land. In addition, agriculture historically played a larger role in the state's economy, which can reduce the political clout of agricultural sector in the future. Agriculture generated $22.3 billion dollars in 2007 for the direct value of crop and animal production (BEA, 2009). This is however, only $1.2% of the state's $1.8 trillion gross domestic product. Other sectors that rely on water supply, real estate and construction, for example, produce a higher proportion of the states' GDP, 15% and 4% respectively (BEA, 2009).

The vast majority of farming in California occurs in the Central Valley. The Central Valley contains about one-sixth of the irrigated farmland in the United States (Reilly et al., 2008). The San Joaquin Basin, the southern half of the Central Valley, is one of the most productive and heavily farmed agricultural regions in the world (American Farmland Trust, 1995). The San Joaquin Basin receives an average of about 10 inches of rain per year and is classified as semi-arid to arid. The region is heavily dependent on outside water sources and groundwater pumping in dry years. The San Joaquin Basin embodies many of California's water management problems and is an ideal location to examine water management.

[1] While the highest priority of use is given to domestic use [California Water Code Section 106: "It is hereby declared to be the established policy of this State that the use of water for domestic purposes is the highest use of water and that the next highest use is for irrigation"] in reality, many irrigation districts began using their allocations before urban interests, and therefore have a higher priority under the system of prior appropriation.

1.2 Research Question

The challenges facing the agricultural community in the San Joaquin Basin, the overdraft in the San Joaquin and the associated negative impacts, and the groundwater storage potential provide a strong incentive to implement conjunctive management projects in the San Joaquin Basin. For this thesis, my research question is:

- How do conjunctive management programs work in California's San Joaquin Basin and what are the policy and management implications for California water management?

In order to answer this question, I examine three different conjunctive management projects in the San Joaquin Valley; the Kern Water Bank, which has been operating since 1988, the Madera Water Bank, which has been proposed three times and is currently undergoing environmental review, and the Tehachapi Basin, an agriculture-dominated adjudicated basin in the foothills of the Tehachapi Range.

My aims in answering this question are threefold. First, I aim to show how both the Tehachapi Basin and Kern Water Bank conjunctive management arrangements work, in terms of environmental characteristics, institutional arrangements, and project operations. Second, I examine the barriers that have prevented the Madera Water Bank from being implemented previously and the factors that may make the currently proposed version of the project successful. Third, based on my analysis of these case studies, I develop recommendations to improve California's groundwater management through a locally-run groundwater permitting system. The proposed permitting system uses a targeted approach by focusing on basins that have the most serious overdraft, and encourages local allocation of permits to pump groundwater.

1.3 Relevant Literature

Conjunctive management has been a topic of California water literature since at least 1957, when the 3rd State Water Plan discussed managing surface water and groundwater together. The three main categories of the literature on conjunctive management are technical modeling studies, policy analyses, and case study approaches.

A number of studies utilized technical modeling to analyze conjunctive management in the Central Valley at various scales using economic optimization models, including Basagaoglu et al. (1999), Botzan et al. (1999), Draper et al. (2003) and Knapp et al. (2003). In general, the studies using an economic optimization framework first develop a model of water storage and conveyance, determine economic values for agricultural and urban water use, develop environmental constraints, and determine allocations that maximize the net benefits to society. For example, in Draper et al. (2003), data about surface and groundwater hydrology, facilities and capacities, environmental flow constraints, urban and agricultural values of water and operating costs were put into an economic optimization model. The model then evaluated, among other outputs, the estimated amount of economic scarcity and the willingness of users to pay for water. The model simulated different scenarios involving a base case, a regional water market, and a statewide water market to see how these would affect scarcity and total cost. The model demonstrated "significant additional potential for conjunctive use operations in California" (Draper et al., 2003).

The second category in the literature of conjunctive management in California is policy analysis. A number of studies have done a legal, institutional, and policy analysis of California water management as it applies to conjunctive management, including Schlager and Blomquist (1999), Foley-Gannon (1999), and Blomquist et al. (2004). Foley-Gannon (1999) exemplifies the legal and institutional analysis approach. The report looks at conjunctive management programs and suggests a number of legislative reforms to encourage the implementation of conjunctive management projects, including expanding local authority to engage in groundwater management and clarifying the powers of local agencies and importing agencies in situations where water is transferred outside of a basin (Foley-Gannon, 1999).

The third category in the literature of conjunctive management in California is a case study analysis. This approach is used to understand how particular conjunctive management projects have operated, or the barriers to implementation for projects that have been blocked. Two studies that have followed this approach are Thomas et al. (2001) and Jenkins (1992). Thomas et al. (2001) examines seven different conjunctive management programs and characterizes level of success of the projects. The study presents how success was measured, the factors in successful programs, and the factors in unsuccessful programs. The main factors common to successful programs are trust between the program operators and the overlying landowners, financial benefit for the program participants, and hydrologic benefit in terms of increased water quality and reliability of water supply (Thomas et al., 2001).

This thesis falls in between the two categories of policy analysis and case study analysis. I aim to bridge the gap between the two by using the conclusions from the case study analysis to inform the policy analysis to keep my policy recommendations grounded.

References

American Farmland Trust. 1995. "Alternatives for Future Urban Growth in California's Central Valley: The Bottom Line for Agriculture and Taxpayers." American Farmland Trust, Washington DC.

Basagaoglu, Hakan, Miguel Marino, Robert Shumway. 1999. "δ-Form Approximating Problem for a Conjunctive Water Resource Management Model." *Advances in Water Resources* 23: 69-81.

Blomquist, William, Edella Schlager, Tanya Heikkila. 2004. *Common Waters, Diverging Streams: Linking Institutions to Water Management in Arizona, California, and Colorado.* Washington, DC: Resources for the Future Press.

Botzan, Tudor, Angelica Necula, Miguel Marino, and Hakan Basagaoglu. 1999. "Benefit-Cost Model for an Artificial Recharge Scenario in the San Joaquin Valley, California." *Water Resources Management* 13:189-203.

Bureau of Economic Analysis (BEA). 2009. "Gross Domestic Product by State: California." United States Department of Commerce. Web. 12 Dec. 2009. <http://www.bea.gov/ regional/gsp>.

Carle, David. 2004. Introduction to Water in California. University of California Press: Berkeley, CA.

Department of Water Resources (DWR). 2005. "Final California Water Plan Update 2005." California Department of Water Resources. Web. May 2009. <http://www.waterplan.water. ca.gov/previous/cwpu2005/index.cfm>.

Draper, A.J., M.W. Jenkins, K.W. Kirby, J.R. Lund, and R.E. Howitt. 2003. "Economic-Engineering Optimization for California Water Management," *Journal of Water Resources Planning and Management*, 129(3).

Foley-Gannon, Ella. 1999. "Institutional Arrangements for Conjunctive Water Management in California and Analysis of Legal Reform Alternatives." University of California Water Resources Center, Technical Completion Reports, Paper 877. Web. 10 Apr 2009. <http://repositories. cdlib.org/wrc/tcr/877>.

Galloway, Devin and Francis Riley. 2006. "San Joaquin Valley, California: Largest Human Alteration of the Earth's Surface." U.S. Geological Service. Web. Apr. 2010. <http://pubs.usgs.gov/circ/circ1182/pdf/06SanJoaquinValley.pdf>.

Jenkins, Mimi. 1992. "Conjunctive Use Without Management: Yolo County, California's Water Supply System." Thesis. University of California at Davis, Web. 10 May 2009 < http://www. dcn.davis.ca.us/dcn /projects/conjunctiveuse/>.

Knapp, Keith, Marca Weinberg, Richard Howitt, and Judith Posnikoff. 2003. "Water Transfers, Agriculture, and Groundwater Management: A Dynamic Economic Analysis." *Journal of Environmental Management* 67: 291-301.

Legislative Analyst's Office (LAO). 2010. "Liquid Assets: Improving Management of the State's Groundwater Resources." Web. 25 Mar. 2010. <http://www.lao.ca.gov/laoapp/ PubDetails.aspx?id=2242>.

Reilly, Thomas, Kevin Dennehy, William M. Alley, and William L. Cunningham. 2008. "Ground-Water Availability in the United States." U.S. Geological Survey Circular 1323. Web. 27 Sept. 2009 <http://pubs.usgs.gov/circ/1323/>.

Schlager, Edella and William Blomquist. 1999. "A Comparative Institutional Analysis of Conjunctive Management Practices Among Three Southwestern States." Environmental Protection Agency, National Center for Environmental Research. Web. 15 April 2009 <http://cfpub2.epa.gov/ncer_abstracts/index.cfm/>.

Thomas, Gregory, David Brown, Nicholas Pinhey, Jennifer Spaletta, and Peter Kiel. 2001. "Designing Successful Groundwater Banking Programs in the Central Valley: Lessons from Experience." Natural Heritage Institute. Web. 07 Feb. 2009 < www.waterexchange.com/ market_research/waterBanks/downloads/Designing_Successful_Groundwater_Programs_2001 .pdf >.

United States Department of Agriculture (USDA). 1997. "1997 Census of Agriculture." United States Department of Agriculture. Web. Sept. 2009.<http://www.agcensus.usda.gov/ Publications/1997/index.asp>.

2.0 Background

Figure 2.1: Major Water Projects in California, including the Federal CVP in the Central Valley in brown (DWR, 2005)

This chapter covers the scope and impacts of large water infrastructure, the continued groundwater overdraft in the San Joaquin Basin, the opportunity for conjunctive management as a storage alternative and the four dimensions of conjunctive management.

2.1 Scope and Impacts of Large Water Infrastructure

A large system of water infrastructure developed in California to address the spatial and temporal mismatches in the supply and demand of water. The Central Valley Project (CVP), managed by the Bureau of Reclamation, and the State Water Project (SWP), managed by the Department of Water Resources (Figure 2.1) are capable of transporting water hundreds of miles from the wet north to the arid south. California's CVP (Figure 2.2) was constructed mostly in the 1940s and 1950s and is the single largest source of irrigation water in the San Joaquin Basin.

Figure 2.2: Shasta Dam, part of the CVP and the largest reservoir in California, under construction in 1942 (hdl.loc.gov)

The CVP is one of the federal government's largest water infrastructure projects both in terms of spatial extent and water delivered. The CVP transformed the arid southern portion of the Central Valley into some of most productive farmland into the world by transferring water from the Sacramento Valley to the San Joaquin Basin. The Central Valley Project spans over 400 miles, reaching from Shasta Dam near Redding in the north to the Tehachapi Mountains south of Bakersfield in the south. The CVP has 20 dams, 11 power plants, and 500 miles of major canals, as well as smaller networks of canals and tunnels for water distribution.

The CVP manages about 9 million acre-feet of water per year. About 3.4 million acre-feet (MAF)[1] of the water is allocated to environmental uses, including maintaining instream flows and providing water for wetlands. The remaining 5.6 million acre-feet are allocated to agriculture, urban, and industrial use, with agriculture receiving about 90% of the total amount allocated. The 5 MAF allocated to agriculture is enough to irrigate about 3 million acres, or about one-third of the agricultural land in California (USBR, 2009). 5.6 MAF is about 20% of the water used in the state (DWR, 2005). To put the amount of water used by agriculture in the CVP in perspective, the average annual amount used by agriculture in the CVP is enough to provide water for the equivalent of 7.25 Cities of Los Angeles, or nearly 28 million urban dwellers that use the same amount of water as an average Angelino (DWP, 2008).

The CVP, along with the State Water Project and other local projects, has had an enormous impact on the ecology and environment of the Central Valley. The construction of the Central

[1] An acre-foot is the volume of water required to cover an area of one acre one foot deep, or 43,560 cubic feet of water. A rule of thumb among water planners is that an acre-foot of water satisfies the needs of a family of four for one year.

Valley Project and the State Water Project was driven by a different set of environmental values and is a product of an era of large public works projects that ended in the 1960s. In 1950, Justice Robert Jackson of the U.S. Supreme Court eloquently captured the sentiment that the Sacramento and San Joaquin Rivers "collect tribute from many mountain currents, carry their hoardings past parched plains and thriftlessly deposit them in the Pacific tides." It was a common notion at the time that fresh water is wasted when it flows into the ocean (Dunning, 1993).

Prior to widespread settlement, agricultural development, and CVP and SWP construction, the Central Valley contained large seasonal wetlands—approximately 4,500,000 acres in times of high flow—that supported fish, bird, and large mammal populations (Dunning, 1993). As a result of project operations of the CVP, the SWP, and ecological alterations, the seasonal wetlands have largely disappeared, and 12 fish species are listed as threatened or endangered in the Delta (DFG, 2006). In 1992, the Central Valley Project Act was passed to address the environmental impacts of the CVP (Dunning, 1993). The CVPIA represents an important shift in federal water policy by dedicating 800,000 acre-feet of water to fish and wildlife and changing the terms of water contracts (Dunning, 1993), however the Bureau has been criticized for failing to implement reforms called for by the CVPIA (EWG, 2009).

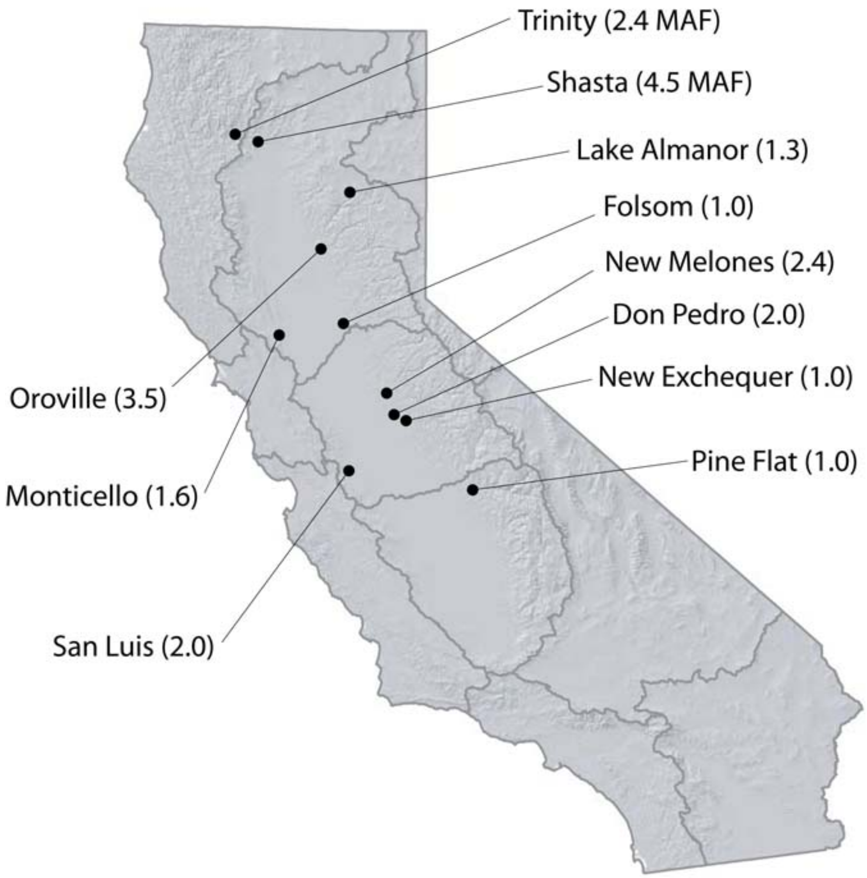


Figure 2.3: Surface Water Storage Over 1 Million Acre-Feet
(Data from http://cee.engr.ucdavis.edu/faculty/lund/dams/DamList.html,
Basemap from DWR, 2005)

2.1.1 Dams are politically beneficial, but economically infeasible

California has close to 1,000 dams built on the most productive and accessible sites to provide water supply, flood control and hydropower (Zito, 2009). The combined capacity storage capacity surface water storage is 43 MAF (DWR, 2005) with over half of the storage in the 11 reservoirs with a capacity of over 1 MAF (Figure 2.3). Constructing additional dams can be costly and only supply minimal amounts of water (Zito, 2009). Recently, political leaders, including Governor Arnold Schwarzenegger, U.S. Congressmen Devin Nunes and Tom McClintock, have pushed for new surface water storage projects (dams) to address perceived water shortages.

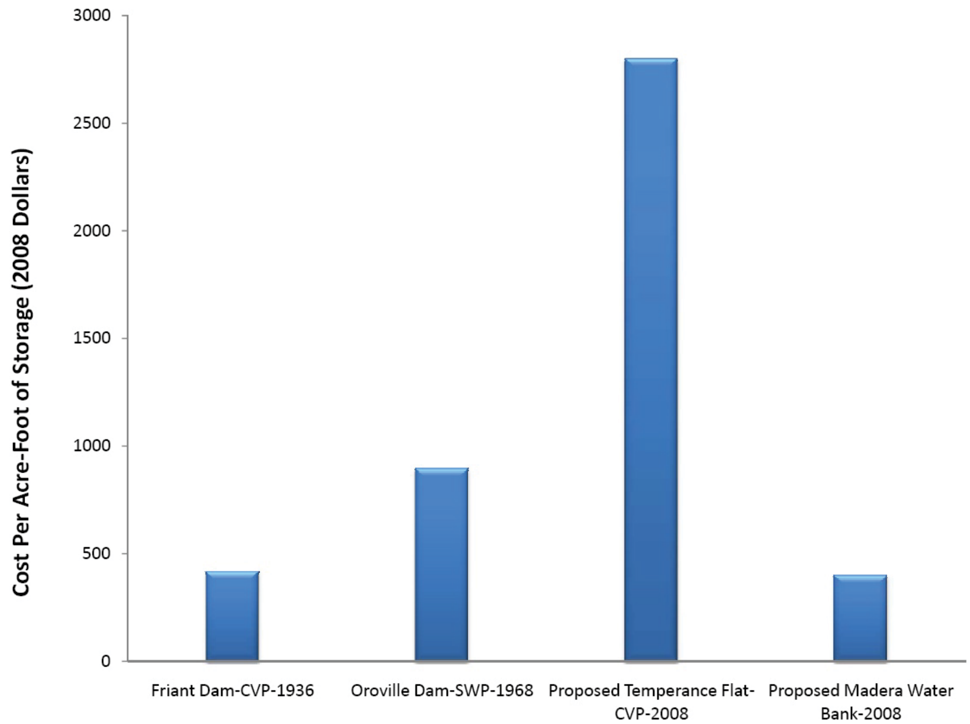


Figure 2.4: Rising Cost of Surface Water Storage and Lower Costs of Conjunctive Management

The cost of building new surface storage, however, has increased substantially over time and has become economically infeasible (Figure 2.4). Friant Dam, on the San Joaquin River, was constructed in 1936 as part of the Central Valley Project at a cost of $217 million[2] and has a capacity of 520,528 acre-feet. The project cost approximately $415 per acre-foot of storage at capacity. Oroville Dam, on the Feather River, was completed in 1968 at a cost of $3.16 billion[3] with a capacity of 3,537,577 acre-feet, costing $894 per acre-foot of storage.

The Temperance Flat Dam site, further up in the watershed on the San Joaquin, is one of a few new dam sites considered by the Bureau of Reclamation. In October 2009, the Bureau of Reclamation released a long-awaited feasibility study for the Temperance Flat Dam that placed the construction cost of the dam at $3.36 billion dollars for the 1,200,000 acre-feet of storage

[2] In 2008 dollars, adjusted using the Consumer Price Index. The construction cost was $14 million in 1936 dollars.
[3] Also in 2008 dollars. Construction cost was $563 million in 1968 dollars.

(USBR 2008). Assuming that the Bureau's cost-benefit study is accurate, the proposed Temperance Flat Dam would cost $2,800 per acre-foot of storage, nearly *7 times the cost* of storage per acre-foot of Friant Dam. In contrast to the rising costs of dams, the estimated storage cost of the Madera Water Bank (discussed in detail later) is $328 per acre-foot (Lund and Howitt, 2001), nearly *9 times less* than the projected $2,800 per acre-foot of storage of the Temperance Flat Dam (Figure 3.8).

2.1.2 Water infrastructure constructed to address groundwater overdraft

Both the Central Valley Project and the State Water Project were constructed, in part, to address local groundwater overdraft. In the late 1920s and early 1930s, most of the farmers in the San Joaquin Basin depended on groundwater as their primary water source (Angel, 1945). In response to widespread overdraft that threatened to put farmers out of business, the lure of hydropower, in the guise of flood control, the federal government constructed the Central Valley Project (Angel, 1945). The water delivered by the Central Valley Project did little to lessen the dependence on groundwater in the Valley and instead brought new lands into production (Hundley, 2001). The state legislature approved the State Water Project to address groundwater overdraft and water supply concerns in the San Joaquin Basin, population growth and urbanization (Hundley, 2001).

2.2 Groundwater Overdraft and Storage Potential

Groundwater plays a major role in California's water supply. Forty percent of the state's average annual water supply is pumped from the ground (Carle, 2004). Despite the importance of groundwater in California, groundwater is not managed on a statewide level. California is the only western state aside from Texas that does not manage groundwater at the state level. Other western states use statewide groundwater permitting, establish active management areas, publish well data, and require metering, measurement and reporting of groundwater use (Figure 2.5). In California, the state formulates guidelines on well construction and abandonment, and has thousands of monitoring wells to document changes in aquifer levels (Ashley & Smith, 1999). The State does not monitor or regulate individual groundwater use and is unable to accurately track pumping rates. Groundwater in California is managed on a local scale, and generally occurs through one of three avenues: 1) no management, or the "cumulative uncoordinated decisions of individual groundwater pumpers," 2) creation of a water district, or 3) adjudication, where rights are quantified through a legal process (Ashley & Smith, 1999).

GW Mgmt Components	CA	AZ	TX	CO	NM
Statewide GW use permitting	-	X	-	X	X
Active Management Areas	-	X	X	X	X
Well data made public	-	X	X	X	X
Metering, measurement, and reporting	-	X	-	X	X

Figure 2.5: Comparison Between Groundwater Management in California, Arizona, Texas, Colorado, and New Mexico (Based on LAO, 2010)

The consequences of uncontrolled groundwater pumping in the San Joaquin Basin are evident from the chronic overdraft, which has caused long-term decline in aquifer levels. The United States Geological Survey (USGS) has actively monitored groundwater levels in the Central Valley. The USGS estimated groundwater depletion in the Central Valley from predevelopment to 1961 (Faunt, 2009). Some areas in the west side of the San Joaquin Basin were particularly affected by overdraft and experienced a decline in the aquifer levels of between 200 and 400 feet from predevelopment to 1961 (Figure 2.6).

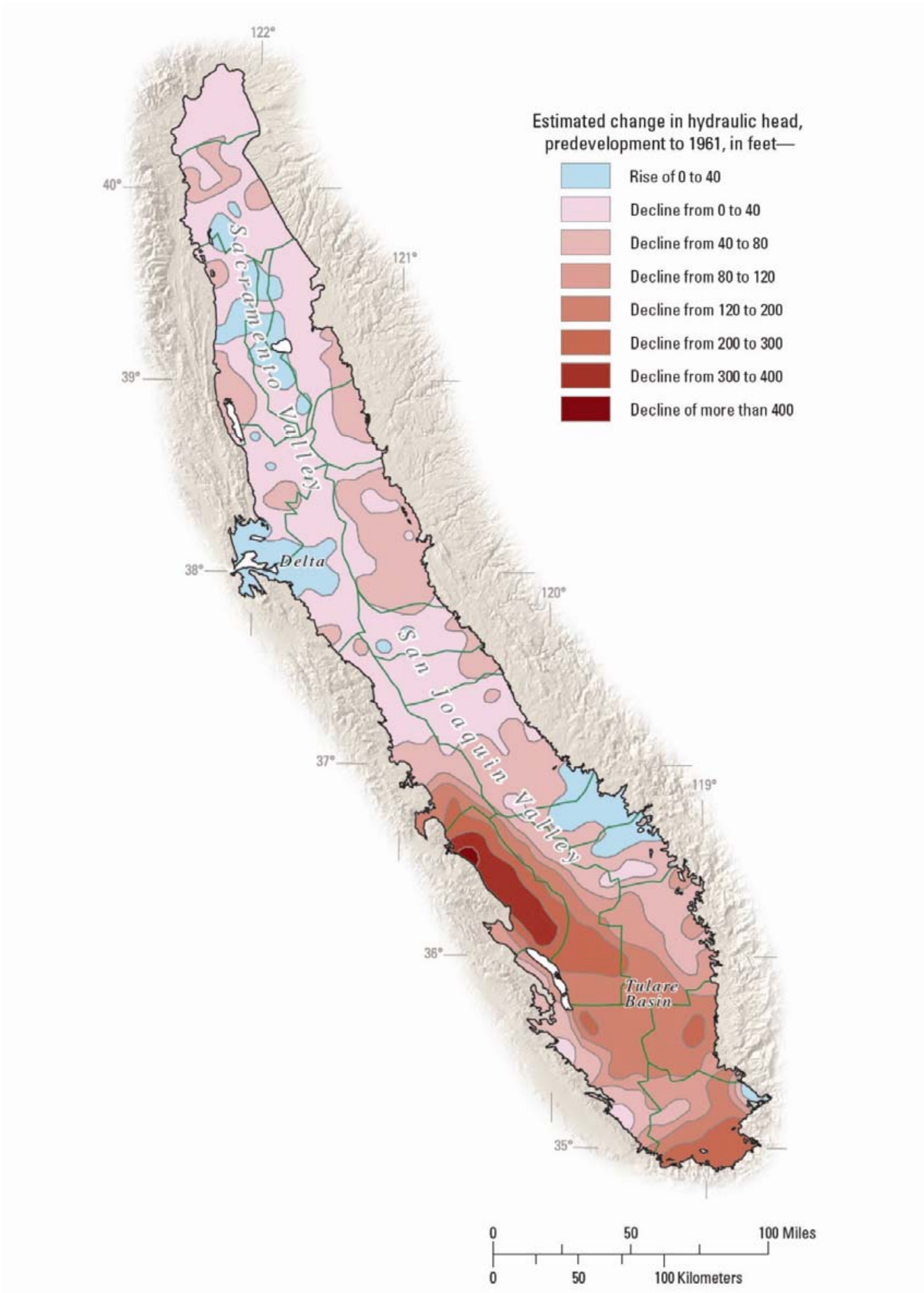


Figure 2.6: Groundwater Depletion in the Central Valley, Predevelopment to 1961 (From Faunt, 2009)

The groundwater table has continued to decline in the San Joaquin Basin from 1961 onwards, with over 1 MAF of water pumped from the aquifer each year (Figure 2.7). From 1961 to 2005, a total of 60 MAF of water was pumped from the San Joaquin Basin (Faunt, 2009), enough water to fill all of the state's reservoirs nearly one and a half times.

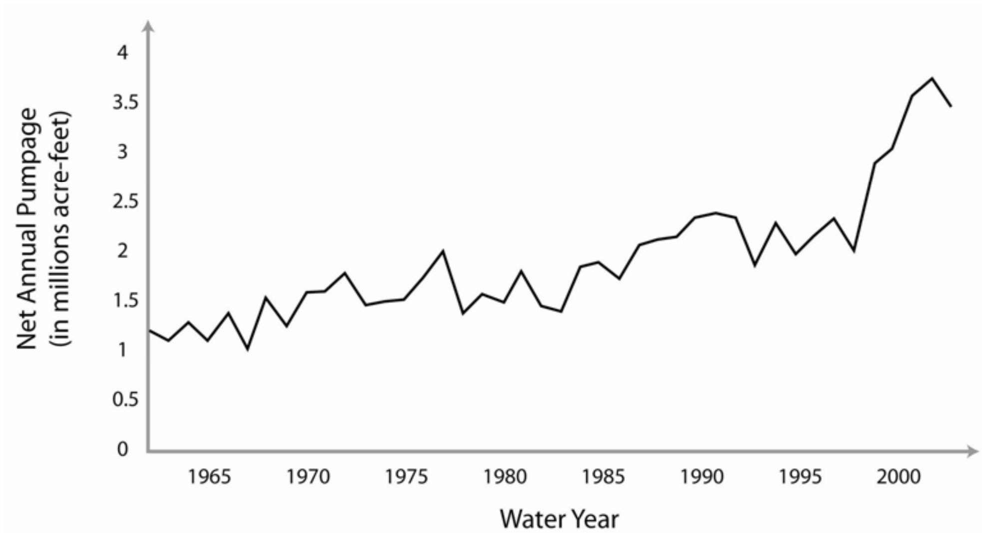


Figure 2.7: Continued Groundwater Depletion the San Joaquin Basin
(Data from Faunt, 2009)

Groundwater overdraft has numerous harmful consequences, including land subsidence, effects on surface water flows, salt water intrusion, and contaminant migration. Overdraft can cause land subsidence, which can have a significant financial impacts if infrastructure is damaged as the ground lowers. Land subsidence has historically been a problem in the San Joaquin Basin. In the 1970s, when the last comprehensive surveys of land subsidence were made, 5,200 square miles—over one-half the entire San Joaquin Valley—had subsided in excess of 1 foot (Galloway and Riley, 2006). The maximum subsidence in 1977 from groundwater overdraft was over 28 feet (Figure 2.8). While the economic effects of land subsidence are not well-known, a conservative estimate of damage from decreased aquifer storage space, partial or complete submergence of canals and associated pipe crossings, regrading irrigated land, and replacing well infrastructure and irrigation pipelines, is about $180,000,000 dollars *per year* (Galloway and Riley, 2006).

Figure 2.8: Subsidence in the San Joaquin Valley (Dr. Joseph Poland, USGS, 1977. Near Benchmark S661 southwest of Mendota, Calfornia)

Groundwater overdraft can also impact surface water flows and the ecosystem that depend on these flows. In coastal areas, salt water intrusion from groundwater overdraft lowers the water quality and can make the output from a well unfit for human or agricultural use. Groundwater overdraft also accelerates the migration of contaminated groundwater to municipal or agricultural wells.

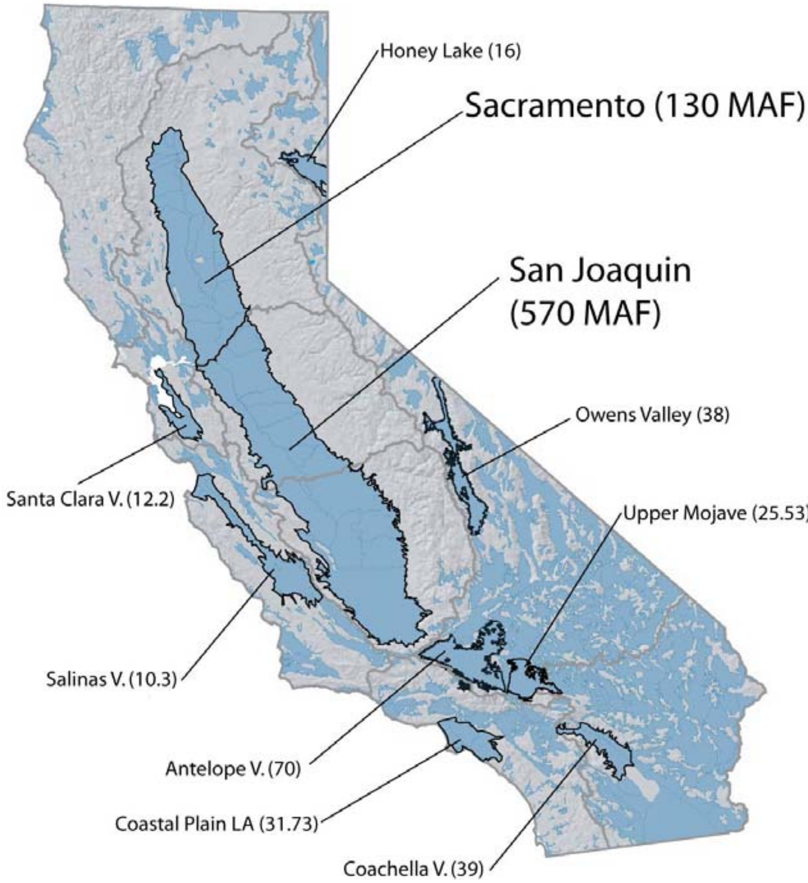


Figure 2.9: Groundwater Basins with Storage Capacity over 10 MAF
(Data from Carle, 2004, basemap from DWR Bulletin 118, 2003)

2.3 Groundwater Storage and Conjunctive management

California has plentiful storage opportunities for groundwater. Statewide, there are 515 groundwater basins. Twelve of the basins have a storage capacity of over 10 MAF (Figure 2.9). The San Joaquin Basin has an estimated 570 MAF of storage. As a comparison, Shasta Dam, the largest in the state, has a capacity of 4.6 MAF. The total storage capacity of all the reservoirs in the state is 43 MAF (DWR, 2005). Although not all of the aquifer storage capacity is economically feasible for use in conjunctive management projects, the sheer magnitude of potential storage is too large to ignore. In 1975, the Department of Water Resources has estimated the usable aquifer storage space for conjunctive management projects at 143 MAF

(DWR, 1975), over 3 times the total surface storage capacity. The cumulative overdraft of 60 MAF from the San Joaquin Basin over the last 40 years can be seen as an opportunity, since the majority of this storage space would still be usable for groundwater storage.

Conjunctive management, or managing surface water and groundwater together, uses aquifer space for water storage (Figure 2.10). Conjunctive management is a valuable tool to deal with both excess flows and droughts. Excess surface water flows can be used to recharge depleted aquifers. During dry periods, groundwater can be pumped when surface water resources are scarce. Different arrangements exist for conjunctive management depending on the source of groundwater recharge, the mode of recharge and recovery, and the destination of the water (Figure 2.11).

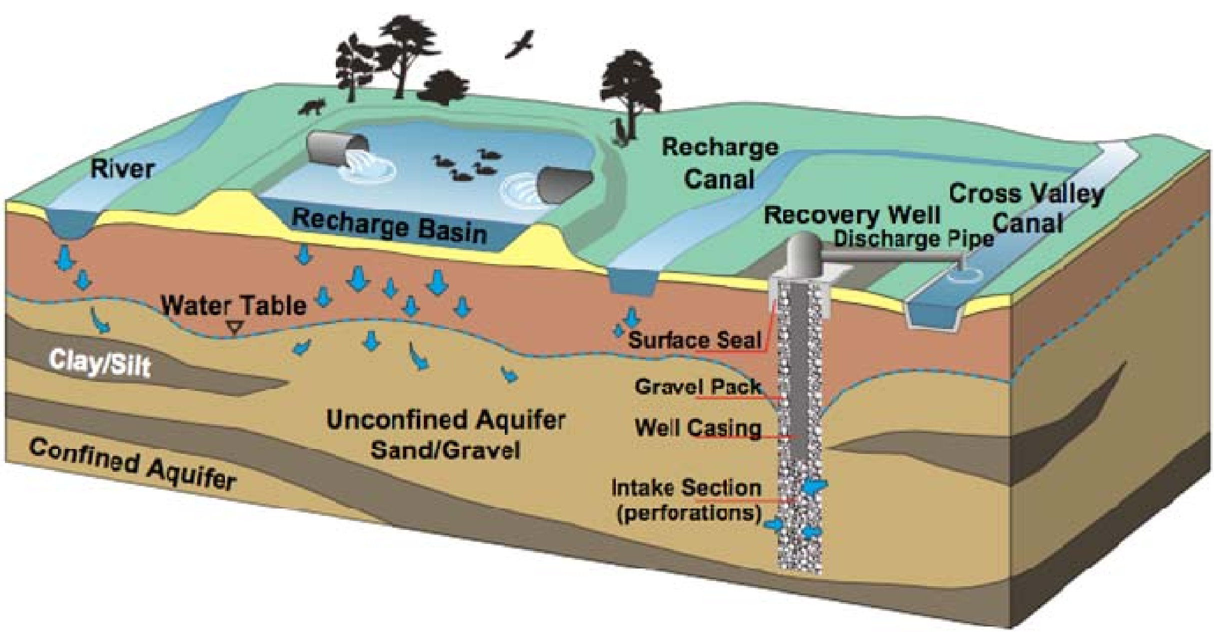


Figure 2.10: Conjunctive Management Diagram
(From Kennedy/Jenks Consultants)

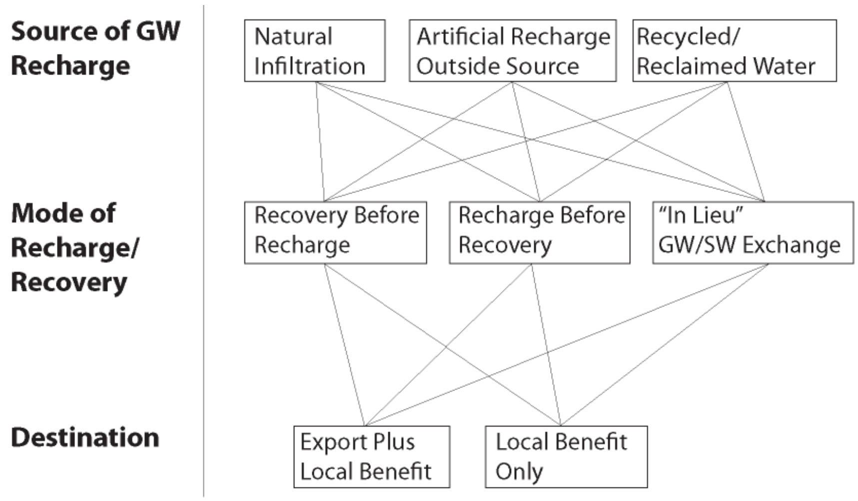


Figure 2.11: Conjunctive Management Arrangements (based on Purkey and Mansfield, 2002)

Conjunctive management has a number of advantages as a water storage strategy. Conjunctive management has fewer environmental impacts than dam construction and can create habitat as part of the infiltration process. Seasonal wetlands can form in infiltration basins to create temporary wetland habitat favorable to migratory birds and small mammals. Conjunctive management also provides local water supply reliability. Water can be stored closer to where it is used. Water is retrieved by pumping from the aquifer, instead of being transported long distances, where environmental flow restrictions can impact delivery.

There is an important distinction between groundwater management and conjunctive management. Groundwater management, as used in this thesis, refers to using incentives or regulation to control groundwater extraction. Conjunctive management refers to intentionally coordinating the use of surface water and groundwater, through the arrangements discussed above. Through the case studies examined in this thesis, I argue that effectively implementing conjunctive management in California first requires groundwater management—i.e. some level of control or a knowledge of groundwater extractions.

Despite the potential benefits from conjunctive management, California has policy barriers that prevent groundwater and surface water from being managed together. There are, however, at least 34 conjunctive management projects operating in the state of California (Blomquist et al., 2004), but these projects only utilize a small fraction of the available aquifer space. The following section on the dimensions of conjunctive management elucidates the source of the policy barriers to conjunctive management.

2.4 The Four Dimensions of Conjunctive Management

Conjunctive management involves four different dimensions: hydrogeology, or the study of how water moves through aquifers, economics, law and policy, and politics. Each of these dimensions plays an important role in understanding how conjunctive management projects operate and barriers that face the development of conjunctive management projects.

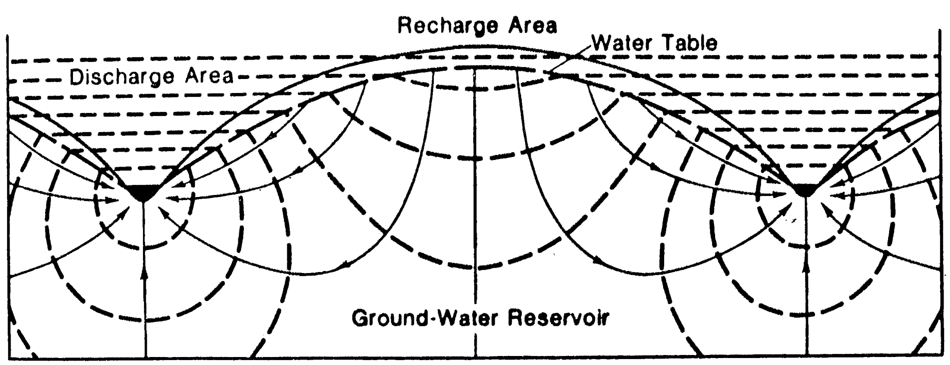


Figure 2.12: Patterns of Groundwater Flow in Uniformly Permeable Material (Water Resources Council, 1973)

2.4.1 Hydrogeology

Hydrogeology is the science of understanding how water flows through aquifers (Figure 2.12). Given detailed information about the characteristics of an aquifer, recharge locations, pumping rates, and the interactions with surface water, hydrogeology can fairly accurately predict how groundwater will move through an aquifer. The depth to groundwater can be determined relatively easily by finding the water level in a monitoring well. Groundwater flow through an aquifer, however, is complex and cannot be directly measured. Integrating observations of the level of the water table, information about the geology and aquifer characteristics, and the influence of water infiltrating from the surface requires modeling. Computer models, including the USGS' MODFLOW, are used to predict the movement of groundwater through an aquifer. A detailed examination of hydrogeology and the models engineers and hydrogeologists use is beyond the scope of this thesis.

2.4.2 Economics

Economics is a useful tool to understand the incentives that an individual groundwater user faces and the societal consequences of uncoordinated individual decisions on groundwater levels. Chapter 3 provides a detailed analysis of the economic considerations affecting conjunctive management, including a comparison of the costs of building surface water storage to the construction costs of conjunctive management projects.

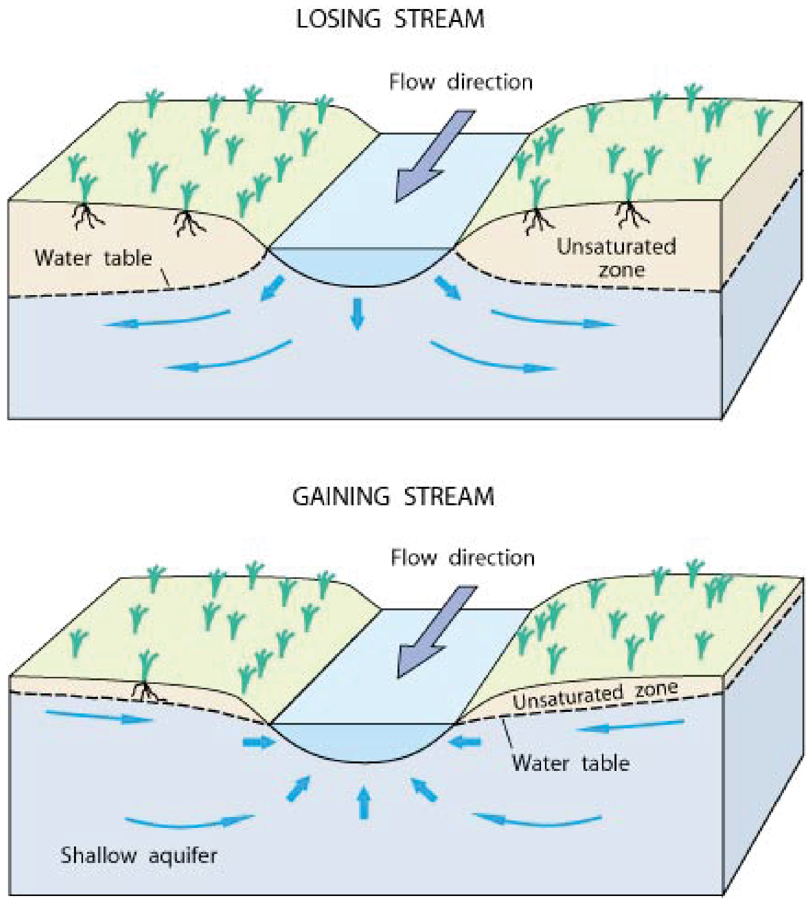


Figure 2.13: Connections Between Surface Water and Groundwater (Winter et al., 1998)

2.4.3 Legal and institutional

California's current water management system adds a significant barrier to conjunctive management. Overall, California's laws and regulations governing the use of surface and groundwater are "one of the most complicated areas of law in the United States" (Schlager, 1999). In California, surface water (lakes and rivers) and groundwater are legally viewed as separate resources, although the two are hydrologically linked (Figure 2.13). Nearly all surface water bodies interact with groundwater and pumping groundwater can affect surface water bodies (Winter et al., 1998).

California's surface water law is also complex. California uses a dual rights system, blending riparian and appropriative rights. Riparian rights are rights based on owning property adjacent to a river. California's riparian rights system is based on English common law, where landowners near a river could use water as they wished. Many western states have dropped riparian rights, as they are difficult to adapt to drier climates. California still recognizes certain riparian rights. In place of riparian rights, other western states adopted the doctrine of prior appropriation, where rights are based on historic claims to water use and are not connected to land ownership. The first person to use water for a "beneficial use" is allowed to continue to do so as long as they do not impinge upon the appropriative rights of others. In California, the State Water Resources Control Board exercises the authority for permitting appropriative water uses and has the ability to declare a surface water source as fully appropriated (Blomquist et al., 2004).

Current groundwater law in California recognizes a number of legal terms including "underflow," "subterranean streams," and "percolating groundwater" that

> "bear little, if any, relationship to geological realities...from a hydrogeological perspective, such geographic categories are inapt, and efforts to fit water into the law's categories give the enterprise a somewhat daffy air (Sax, 2003)."

The divergence between the recognized principles of hydrogeology and our current legal and management system in California came about through a series of court cases and political decisions early in California's state history. Professor Joseph Sax, in his law review article "We Don't Do Groundwater: A Morsel of California Legal History," covers the cases and policies instrumental to the development of groundwater law in California. In the 1899 *City of Los Angeles v. Pomeroy*, the California Supreme Court ruled that contested water rights to the Los Angeles River were part of a "subterranean stream," which had little relation to the hydrogeological realities of the Los Angeles River system. Sax draws on commentary of the trial judge who later explained that Los Angeles the ruling in *Pomeroy* was intended to establish Los Angeles' ownership of water of the Los Angeles River, and the court used the legal "subterranean stream" construction since it was concerned that it might be on shaky legal footing if had acknowledged the connection between groundwater and surface water.

In a later decision made by the same judge, *Katz v. Walkinshaw* (1903) clarified the legal uncertainty and ruled that correlative rights—or that each groundwater users has an equal right to groundwater pumping—is the doctrine governing competing groundwater users. When the California legislature began to develop what would become the State Water Code of 1914, legislators looked to the artificial distinction from *Pomeroy* that created different types of groundwater rather than the more accurate understanding reflected in *Katz* and a string of later cases.

It is unclear why legislators used the outdated and inaccurate *Pomeroy* idea of "subterranean streams" to create different categories of groundwater, but Sax notes in their debate that the line they drew separating groundwater from surface water "was a human construct, rather than a line separating two distinct hydrological entities." Frank Short, a lawyer and representative of Central Valley agricultural interests, raised issues about the constitutionality of including "percolating" groundwater as part of the permitting system proposed for surface water, which led to the option being dropped from the bill. Whatever the ultimate cause, the State Water Code of 1914 neglected to regulate groundwater other than groundwater in "subterranean streams," leaving California in its current situation where the vast majority of groundwater extraction is unregulated (Sax, 2003).

2.4.4 Politics

Figure 2.14: Sign from the Central Valley
(http://are.berkeley.edu/~bickett/)

The allocation of water resources has always been a political endeavor in California and groundwater is no exception. In many rural and agricultural communities there is an opposition to what some view as government control of water resources (Figure 2.14). A farmer in the Tulare Basin captures strong feelings that water engenders: "I don't want the government to come in and dictate to us, 'this is all the water you can use on your own land.' We would resist that to our dying day."[4]

A group of agricultural economists from the University of California at Davis identified five reasons why farmers might be opposed to groundwater regulation. First, farmers could oppose groundwater regulation because it can shift control over resource allocation to outside interests and increase the chances that water will be transferred to urban or other interests. Second, many farmers feel that regulation is unnecessary if overdraft is not a serious problem. Third, farmers fear that groundwater regulation can result in a loss of irrigated land and an associated loss in

[4] Mark Watte, Farmer. From http://www.nytimes.com/2009/05/14/science/earth/14aquifer.html

profit. Fourth, the costs of overdrafting a basin can be hidden through other pricing factors—for example, fluctuations in the cost of energy to run a pump—or not discernable on a short-term time-scale. Finally, farmers feel that prior to pumping groundwater to levels that make farming unprofitable, new sources of surface water will be made available to offset overdraft (Gardner et al., 1981). The construction of the Central Valley Project and the State Water Project, in part, to provide surface water for farmers dependent on groundwater, lends support to the last reason in particular.

Figure 2.15: Motivation for Push for Groundwater Reform

The political undertone of groundwater regulation became manifest in the late 1970s and early 1980s, as a push for groundwater reform was ultimately defeated by voters. In response to the drought of 1976-1977, Governor Edmund "Jerry" Brown appointed a Governor's Commission to Review Water Rights Laws. The Commission produced a report (Figure 2.15) suggesting changes to California's system of water rights, including increasing the certainty in water rights, efficiency in water use, addressing instream uses of water, and groundwater management (Governor's Comm., 1978). The suggestions for groundwater management, included allowing groundwater management through the authority to levy pump taxes, collect data, require meters, regulate the underground storage of water, and limit pumping in areas not managed on a safe-yield basis. These changes were eventually incorporated into the Water Resources Conservation and Efficiency Act, proposed as Proposition 13 in 1982. A number of groups, including the

Farm Bureau, the Association of California Water Agencies, the California Chamber of Commerce, and the California Cattlemen's Association, opposed the groundwater management on the grounds that it could limit local control over water use. During the campaign, the proponents of the Act spent $650,000, while the opponents spent $1.8 million dollars. The measure was defeated by voters in the November 1982 by a margin of 65 to 35 percent (Smith, 1984).

References

Aladjem, David. 2008. "Groundwater Management in California: The Sax Report and Beyond." *California Water Law & Policy Reporter*: July 2008.

Angel, Arthur D. 1946. Who Will Pay for the Central Valley Project of California? *The Journal of Land & Public Utility Economics*. 22(3):266-272.

Ashley, Jeffrey and Zachary Smith. 1999. *Groundwater Management in the West*. Lincoln, NE: University of Nebraska Press.

Blomquist, William, Edella Schlager, Tanya Heikkila. 2004. *Common Waters, Diverging Streams: Linking Institutions to Water Management in Arizona, California, and Colorado*. Washington, DC: Resources for the Future Press.

Bureau of Reclamation (USBR). 2009. "The Bureau of Reclamation: A Very Brief History." United States Bureau of Reclamation. Web. Dec. 2009. <http://www.usbr.gov/ history/borhist.html>.

Carle, David . 2004. Introduction to Water in California. University of California Press: Berkeley, CA.

Department of Fish and Game (DFG). 2006. Status of Fish Species in the Sacramento- San Joaquin Delta Watersheds. Web. 12 May 2009. <http://dfg.ca.gov/hcph/species/t_e_spp/ tefish/tefisha.shtml.>

Department of Water and Power (DWP). 2008. "City of Los Angeles Water Supply Action Plan." City of Los Angeles. Web. Dec. 2009. <http://mayor.lacity.org/stellent/groups/ ElectedOfficials/@MYR_CH_ Contributor/documents/Contributor_Web_Content/ LACITY_004714.pdf >.

Department of Water Resources (DWR). 1975. "California's Ground Water – Bulletin No. 118." Web. Apr. 2010. <http://www.water.ca.gov/pubs/groundwater/bulletin_118/california%27 s_ground_water__bulletin_118-75_/b118-1975.pdf>.

Department of Water Resources (DWR). 2005. "Final California Water Plan Update 2005." California Department of Water Resources. Web. May 2009. <http://www.waterplan.water. ca.gov/previous/cwpu2005/index.cfm>.

Dunning, Harrison C. 1993. Confronting the Environmental Legacy of Irrigated Agriculture in the West: The Case of the Central Valley Project. *Journal of Environmental Law* (23): 943-969.

Faunt, Claudia C., ed. 2009. "Professional Paper 1766: Groundwater Availability of the Central Valley Aquifer, California" U.S. Geological Survey. Web. May 2009.<http://pubs.usgs.gov /pp/1766/>.

Galloway, Devin and Francis Riley. 2006. "San Joaquin Valley, California: Largest Human Alteration of the Earth's Surface." U.S. Geological Service. Web. Apr. 2010. <http://pubs.usgs.gov/circ/circ1182/pdf/06SanJoaquinValley.pdf>.

Garder, Howitt, and Nuckton. 1981. "The Case for Regional Ground Water Management." *California Agriculture*. (35) 1-10.

Hundley, Norris. 2001. The Great Thirst: Californians and Water: A History. University of California Press: Berkeley, CA.

Legislative Analyst's Office (LAO). 2010. "Liquid Assets: Improving Management of the State's Groundwater Resources." Web. 25 Mar. 2010. <http://www.lao.ca.gov/laoapp/PubDetails.aspx?id=2242>.

Lund, J.R. and R. Howitt. 2001. "Improving California Water Management: Optimizing Value and Flexibility." Web. Feb. 2010. <http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/Report2/>.

Purkey, David and Elizabeth Mansfield. 2002. "Estimating the Potential for In Lieu Conjunctive Management in the Central Valley of California." Natural Heritage Institute. Web. 01 Feb. 2009 < http://www.n-h-i.org/programs/watermanagement/conjunctive management/publications.html>.

Sax, Joseph. 2003."We Don't Do Groundwater: A Morsel of California Legal History." *Water Law Review* 6(2): 269-317.

Schlager, Edella and William Blomquist. 1999. "A Comparative Institutional Analysis of Conjunctive Management Practices Among Three Southwestern States." Environmental Protection Agency, National Center for Environmental Research. Web. 15 April 2009 <http://cfpub2.epa.gov/ncer_abstracts/index.cfm/>.

Smith, Zachary A. 1984. "Rewriting California Groundwater Law: Past Attempts and Prerequisites to Reform." *California Western Law Review*. 20:223-257.

Thomas, Gregory, David Brown, Nicholas Pinhey, Jennifer Spaletta, and Peter Kiel. 2001. "Designing Successful Groundwater Banking Programs in the Central Valley: Lessons from Experience." Natural Heritage Institute. Web. 07 Feb. 2009 < www.waterexchange.com/market_research/waterBanks/downloads/Designing_Successful_Groundwater_Programs_2001.pdf >.

Winter, T.C., J.W. Harvey, O.L. Franke, and W.M. Alley. 1998. "Ground Water and Surface Water: A Single Resource." U.S. Geological Survey Circular 1139. Web. Sept. 2009 <http://pubs.usgs.gov/circ/circ1139/pdf/circ1139.pdf>.

Zito, Kelly. 2009. "Water Interests Argue New State Dam Proposals." San Francisco Chronicle. Web. 29 Sept. 2009. < http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2009 /09/28/MNRO19SUMN.DTL>.

3.0 Methods

California has numerous water resource challenges that are projected to get more severe with the decrease in the Sierra snowpack as the climate changes and with future growth in demand for water. In California, as in other western states, the largest use of water is irrigated agriculture, which uses approximately 80 percent (DWR, 2005) of the state's developed water supply. Large water infrastructure projects, including the federal Central Valley Project and the State Water Project, have supplied water for agriculture. Conjunctive management of groundwater and surface water provides an alternative to building new dams for increasing local water supply reliability and meeting the demand for water. This chapter outlines methods for examining the four dimensions of conjunctive management, the rationale for selecting case studies, how the case studies are analyzed, and how the lessons from each case study are synthesized to provide recommendations.

3.1 Tools to Examine the Four Dimensions of Conjunctive Management

The previous chapter covered the four dimensions of conjunctive management: hydrogeology, economics, legal and institutional, and political. This section elaborates the methods used to address each dimension.

3.1.1 Hydrogeology

Hydrogeology is the science of understanding the distribution and movement of groundwater through aquifers. Conjunctive management programs require an understanding of hydrogeology. Chapter 1 covers some of the basic concepts in hydrogeology and the information needed in order to make accurate management decisions. Developing a detailed understanding of the hydrogeology of conjunctive management projects in order to provide predictive information is beyond the scope of this thesis. I instead use the results of studies examining the hydrogeology of the San Joaquin Basin in general and for each case study in particular.

3.1.2 Economics

Chapter 3 covers general economic concepts influencing conjunctive management programs. I examine the basic economic decisions facing groundwater users to demonstrate that absent groundwater management, pumping costs and the availability of surface water act as unofficial controls to prevent complete aquifer exploitation. I examine the estimated economic benefits of groundwater management and the benefits of pursuing large-scale conjunctive management based on a number of economic papers.

3.1.3 Legal and institutional

As described in Chapter 1, California is unique among other western states for its stringent statewide control of surface water and its lax control of groundwater. California's groundwater law reflects an outdated understanding of hydrogeology. The legislature has the ability to exercise more control over groundwater pumping, but has largely left groundwater extraction unregulated. Following the case study analyses, the final chapter provides recommendations to improve groundwater management and suggestions to implement a locally-run groundwater permitting system.

3.1.4 Political

The first chapter discusses reasons for the general opposition to groundwater regulation and some of the political barriers to implementing groundwater management. Each case study chapter discusses the political factors unique to each project. The locally-run groundwater permitting system outlined in the final chapter addresses some of the political issues common to each of the case studies to present a more politically palatable solution to managing groundwater.

3.2 Case Study Selection

I used a case study approach to understand how conjunctive management projects work in the San Joaquin Basin and the policy and management implications. The San Joaquin Basin is dependent on water imports and can benefit from increased local water supply reliability. I selected the Tehachapi Basin, the Kern Water Bank, and the proposed Madera Water Bank as case studies (Figure 3.1) because all three are in primarily agricultural basins, have favorable geology for conjunctive management, and are all roughly similar sizes. All three projects are also south of the Sacramento-San Joaquin Delta and near the southern end of the area served by the Central Valley Project.

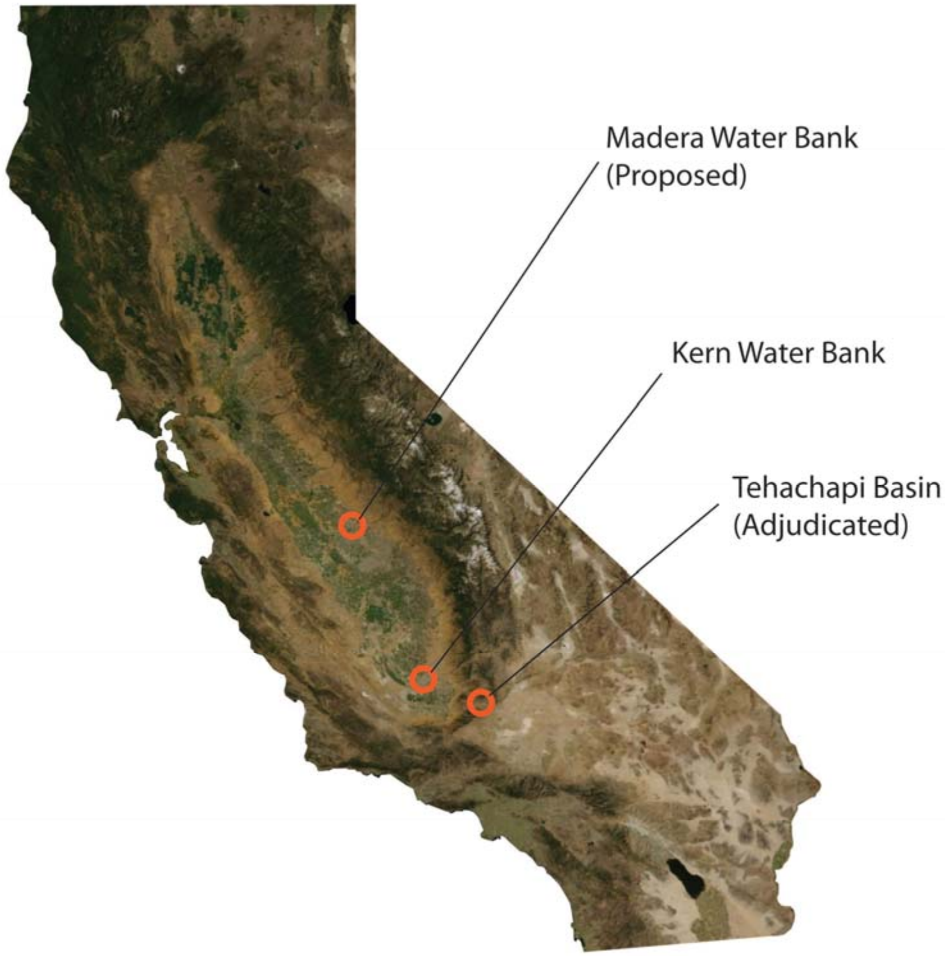


Figure 3.1: Case Study Location Map

3.2.1 Importance of agriculture

Agriculture consumes 80 percent of water used in an average year in California (DWR, 2005). The sheer volume of water used by agriculture means that any statewide water management solutions must involve agriculture. Irrigated agriculture depends on water storage. The timing of water deliveries is crucial, since during dry summer months, crops can die without a steady supply of water. For more permanent and lucrative crops, such as wine grapes and almonds, lacking a source of water for a growing season can mean the loss of a multiple year investment and a significant financial loss. Recent restrictions in water deliveries to provide water for endangered species show the importance of local water supply reliability. Conjunctive management can provide increased local water supply reliability for agriculture. Understanding the existing conjunctive management arrangements in the Tehachapi Basin and the Kern Water Bank can help develop conjunctive projects in the future.

3.2.2 Favorable conditions for conjunctive management

Hydrologic Region	No. of Basins Sampled (Basins CM projects)	No. of CM Projects in Sample	Estimated AF water/yr in CM Projects
San Francisco Area	8 (1)	1	5,500
Central Coast	8 (2)	4	164,050
South Coast	13 (5)	17	613,900
Sacramento Area	10 (1)	1	9,600
San Joaquin Valley/ Tulare	10 (3)	9	468,500
South Lanhontan	13 (2)	1	0*
Colorado Desert	8 (1)	1	3,700
Totals:	70 (15)	34	1,265,250

Figure 3.2: Survey of Conjunctive Management Project
(Data from Blomquist et al., 2004)

The San Joaquin Basin is a favorable location for implementing conjunctive management due to a combination of suitable geology, a high concentration of water infrastructure, an arid climate, and high water demand in the summer that is out of phase with the natural supply. The San Joaquin Basin is essentially a large trough filled with marine sediments overlain by continental sediments (Galloway and Riley, 2006). The aquifer is heterogeneous, but the eastern portion of the valley is mostly coarse and permeable deposits from the alluvial fans of the major streams draining the Sierra Nevadas (Poland and Lofgren, 1984). Despite the suitable conditions and potential benefits of conjunctive management, only a small portion of available aquifer space is used for conjunctive management. Based on an extrapolation from a sample of conjunctive management projects done by Blomquist et al. (2004), about 0.1% of the potential aquifer storage capacity in the San Joaquin Basin is being utilized in conjunctive management programs (Figure 3.2).[1]

3.2.3 Specific project selection

The Tehachapi Basin and Kern Water Bank have conjunctive management arrangements that have been operating since the early 1970s and mid 1980s, respectively, with different approaches to conjunctive management. The Tehachapi Basin underwent an adjudication of groundwater rights. Until the 2008 adjudication of the Santa Maria Basin, the Tehachapi Basin was the only groundwater basin the state with strong agricultural economy where groundwater rights were adjudicated. The Tehachapi Basin also depends on local precipitation for groundwater recharge. The Kern Water Bank operates as an agreement among 14 different partner agencies. The Kern Water Bank uses the imported water from the member agencies that is infiltrated into the project sites and then pumped out later. The proposed Madera Water Bank has favorable geology for conjunctive management and is adjacent to important water infrastructure. The Madera Water Bank has been proposed three different times, most recently in 2008. The history of the Madera Water Bank provides insight into some of the institutional, legal, political, and management issues that can hamper the development of conjunctive management projects.

[1] There are 12 subbasins in the San Joaquin hydrologic region, and 19 in the Tulare Basin hydrologic region (DWR, 2003) for a total of 31. Very roughly, if 10 of the sampled basin use 468,500 acre-feet of water in conjunctive management projects, then 31 could use about 1,500,000 acre-feet of water. 1,500,000 acre-feet out of the 143,000,000 acre-feet of potential usable storage for conjunctive management projects (DWR, 1975, pg. 3) in the San Joaquin Basin is only 0.1%. Currently, no state agency has an estimation of how many conjunctive management projects there are in California, or how many acre-feet of water are used in conjunctive management projects.

3.3 Case Study Analysis

In order to understand the three different conjunctive management case studies, I obtained information from a number of sources, including non-profit research, peer-reviewed academic papers, government research, planning documents, and newspaper articles. For each case study, I collected information on environmental factors, project history, and management characteristics.

3.3.1 Environmental Characteristics

Each case study includes a review of environmental characteristics. The environmental characteristics include information about soils and geology, hydrology, land use, and water infrastructure. The underlying soils and geology are important since the type and permeability of the soils dictates the rate at which water infiltrates and how easily it can be pumped from an aquifer. The precipitation and runoff patterns dictate local water availability for a conjunctive management project. The land use in the surrounding watershed of the project site influences water quality and runoff rates. Understanding water infrastructure, including the location of water storage, wells, conveyance channels, and infiltration basins, is essential to evaluate a conjunctive management project, since conjunctive management requires storing and transporting water.

In each project, I analyze the surrounding land uses to highlight any potential concerns of adjacent landowners and to determine if any land uses may impact project operations. For example, a vineyard owner with high-value wine grapes adjacent to an infiltration basin may be concerned with how groundwater table fluctuates in a conjunctive management project and if infiltration could potentially drown the root zone and damage the crops. An example of adjacent land uses impacting a conjunctive management project is a holding pond for manure adjacent to an infiltration basin, which could impact the groundwater quality.

I used the Department of Water Resources' Integrated Water Resource Information System (IWRIS) in order to map water infrastructure and hydrology. IWRIS is an online geographic information system showing water district boundaries, water infrastructure, groundwater basins, and political boundaries. These are all important in order to understand where water comes from, where it goes, and who manages it. I used information from the Department of Water Resources' Electronic Water Rights Information Management System (eWRIMS), also an online geographic information system with information on water rights permits to determine water allocation for irrigation districts.

3.3.2 Management Characteristics

The management characteristics of a conjunctive management project include the institutional arrangements, operations, and political factors. I examine the institutional arrangements, including which agencies participate in the conjunctive management project, how decisions are made about how the project operates, and how (or if) adjacent landowners are incorporated into the decision-making process. The project operations include the sources of water, the timing of recharge and recovery, and monitoring to understand where the banked water is, if it is migrating off the project site, or if infiltration or pumping is impacting the adjacent landowners. For each project, I mapped the key elements for the conjunctive management project operations, including the locations of infiltration basins, canals and other water infrastructure, monitoring wells, and recovery wells.

References

Blomquist, William, Edella Schlager, and Tanya Heikkila. 2004. *Common Waters, Diverging Streams: Linking Institutions to Water Management in Arizona, California, and Colorado.* Washington, DC: Resources for the Future Press.

Department of Water Resources (DWR). 1975. "California's Ground Water – Bulletin No. 118." Web. Apr. 2010. <http://www.water.ca.gov/pubs/groundwater/bulletin_118/california%27s_ground_water__bulletin_118-75_/b118-1975.pdf>.

Department of Water Resources. 2003. "California's Groundwater – Bulletin 118, Update 2003." Web. Jan. 2009. <http://www.water.ca.gov/groundwater/bulletin118/bulletin118update2003.cfm>.

Department of Water Resources. 2005."California Water Plan: Update 2005." Web. Feb. 2009 <http://www.waterplan.water.ca.gov/previous/cwpu2005/index.cfm>.

Galloway, Devin and Francis Riley. 2006. "San Joaquin Valley, California: Largest Human Alteration of the Earth's Surface." U.S. Geological Service. Web. Apr. 2010. <http://pubs.usgs.gov/circ/circ1182/pdf/06SanJoaquinValley.pdf>.

Poland, Joseph F. and Ben E. Lofgren. 1984. "Case History No. 9.13. San Joaquin Valley, California, U.S.A." Web. Apr. 2010. <http://wwwrcamnl.wr.usgs.gov/rgws/Unesco/PDF-Chapters/Chapter9-13.pdf>.

4.0 The Economics of Conjunctive Management in California

4.1 Summary

The precipitous and persistent decline in groundwater levels in the San Joaquin Basin underscores the need for improved groundwater management. Economics is a useful tool for understanding the incentives of groundwater users and the implications of large-scale decisions about how water is allocated. As explained in Chapter 1, groundwater overdraft has historically been addressed through constructing large surface water projects. This chapter first explains why low prices for surface water from large water projects create an artificial demand to build new projects and why the cost-benefit analyses used to justify the projects often underestimate the costs and overestimate the benefits. Next, I explain the economic decisions facing groundwater users and why a large number of users overlying an aquifer are not likely to use groundwater efficiently without management. I summarize some of the simulated and estimated economic benefits from groundwater management and conjunctive management. Finally, I discuss issues related to water marketing in general and as it applies to conjunctive management projects.

4.2 Water Pricing & Cost-Benefit Analysis for Surface Water Storage Projects

4.2.1 Low water prices create artificial demand for water infrastructure

A central operating principle of water utility associations is that users and service charges should fully support the utilities' capital and operating costs (GAO 2002). The Central Valley Project (CVP), run by the Bureau of Reclamation, violates this principle by charging artificially low prices for water from the CVP. Low water prices provide a disincentive for farmers to change farm management practices to reduce water use. The low prices charged by the Bureau also lead irrigators to push the Bureau to develop reservoirs and aqueducts that would not otherwise be developed if irrigators had to bear the costs of constructing and operating the projects in their water rates.

The average price paid for irrigation water in the CVP is $17 per acre-foot (Baumann et al. 1998). Including only operation and maintenance costs would raise the price to $30 to $40 per acre-foot (Baumann et al. 1998). If the capital costs of the original construction with interest and the project operation and maintenance costs were all included, as they are with the State Water Project, the water used for irrigation would cost approximately $300 per acre-foot (Baumann et al. 1998).

Contracts are also negotiated for a 25 year period, locking the Bureau into charging lower rates than the market would otherwise dictate (GAO, 1994). Angel (1945) explained that the Bureau of Reclamation Secretary made an egregious error by first constructing the project *then* signing contracts for allocating water, allowing agricultural interests to negotiate for a much lower rate. Raising water rates significantly during contract renewals is politically difficult. Proposed rate increases of 10 to 15% have lead to meetings packed with concerned and angry citizens.

The low rates for irrigation water mean that the vast majority of the initial cost of the CVP remains unpaid. The Bureau's total capital cost to construct the CVP since 1937 (not including inflation) was about $3.4 billion (GAO 1994). As of 1999, approximately 7% of the irrigation share of capital costs has been repaid (USBR 2009b).

The General Accounting Office (1994) and the Congressional Budget Office (1997), two independent and non-partisan government offices, both suggest that increasing irrigation rates could encourage increased efficiency and lower the demand for new projects. Studies by agricultural economists indicate that increasing water rates would increase conservation and irrigation efficiency. Higher water rates provide an incentive for farmers to change farm management practices and reduce water use to mitigate the increased costs. An economic simulation of two hypothetical farms in the Sacramento and San Joaquin Valley indicate that increasing rates to repay capital costs with interest—the scenario with the highest rates—would decrease profits by 6.9 percent and 34 percent, respectively. Under all simulated rate increases, the farms would remain profitable. However, raising irrigation rates is a complex issue, and can affect food prices and agricultural communities (GAO, 1994).

4.2.2 Cost-benefit analyses often underestimate costs and overestimate benefits

Cost-benefit analyses are seen by some economists as a rational, analytic tool and have often been used to make policy decisions (Hahn, 1996). Cost-benefit analyses for dams, however, are criticized on the grounds that they ignore the environmental costs and the costs of dam decommissioning and removal, overestimate the job creation potential, the life of dams, the benefits of recreation, irrigation, flood control and general economic benefits and underestimate the construction cost (Goldsmith and Hildyard, 1984). Despite these criticisms, cost-benefit analysis is still used to justify dam building. The recently released cost-benefit analysis for the proposed Temperance Flat Dam highlights the problems with the use of cost-benefit analysis to rationalize building large surface water storage projects.

The Bureau of Reclamation's cost-benefit analysis for Temperance Flat excludes a number of costs, assumes an unrealistic price for water, and still works out to be barely in favor of the project. The benefit-cost analysis performed by the Bureau determined that a ratio of 1.06, meaning that for every dollar spent on the project, California would receive $1.06 of benefits (USBR, 2008). In order to increase water supply reliability, the Bureau of Reclamation completed a feasibility study in 2008 for an upper San Joaquin River basin dam project, known as the Temperance Flat Dam. If constructed, the Temperance Flat dam would become part of the CVP and managed by the Bureau of Reclamation. The sites considered for the Temperance Flat Dam are between 5 and 10 miles upstream of Friant Dam. The dam is projected to store 1,200,000 acre-feet of water and provide 160,000 acre-feet per year of additional water supply. The Bureau projected that the Temperance Flat project would cost $3.36 billion at an annual cost of $169 million.

The benefit-cost analysis assumes that agricultural water districts will purchase the additional water supply at an average of $780 per acre-foot. Farmers in the area currently pay about $20 per acre-foot, and may occasionally pay up to $300-500 for water transferred in very dry years, so the estimated $780 per acre-foot is over-optimistic (Zetland, 2009). In its benefit-cost analysis, the Bureau also did not quantify many of the ecological and cultural impacts of Temperance Flat Dam, including the effects on the American shad and striped bass fisheries, the loss of rapids used by rafters and kayakers, and the flooding of over 150 archaeological and historical sites in the region (Gleick, 2009). Expensive litigation would also increase the cost of the project. Including future costs for environmental mitigation would also increase project cost. The increased supply provided by the Temperance Flat Dam is minimal. An annual increase of 160,000 acre-feet of supply corresponds to a 3 percent increase in the amount of water supplied by the CVP and a 0.4 percent increase in the state's water supply.

Both the artificially low prices paid by some irrigators and the difficulties with using cost-benefit analyses for dams mean that before supporting any expensive surface water storage projects, Californians need to ask a number of questions. Is the project financially viable? Who will benefit from the project? Who will pay for the project? What are the social and environmental impacts of the project? Are they included in the cost of the project?

4.3 The Economic Decisions of Groundwater Extraction

4.3.1 General economics of groundwater use

Groundwater is a complicated resource to manage. The decision to pump groundwater depends on multiple variables, including the availability of surface water, the depth to the water table, and the cumulative decisions of other groundwater users. Groundwater has a number of unique features that sets it apart from other common property resources. Aquifers recharge naturally. A portion of groundwater applied to crops will infiltrate back into the aquifer. The rate of extraction from an aquifer cannot exceed the average natural recharge—also called the "safe yield"—without causing aquifer overdraft over time. Aside from the relatively few adjudicated basins and cooperative groundwater management arrangements, groundwater in California is a common property resource—a resource without clearly defined property rights that is open to numerous potential users. As a common property resource, groundwater will likely be used inefficiently without regulation (Feinerman & Knapp, 1983).

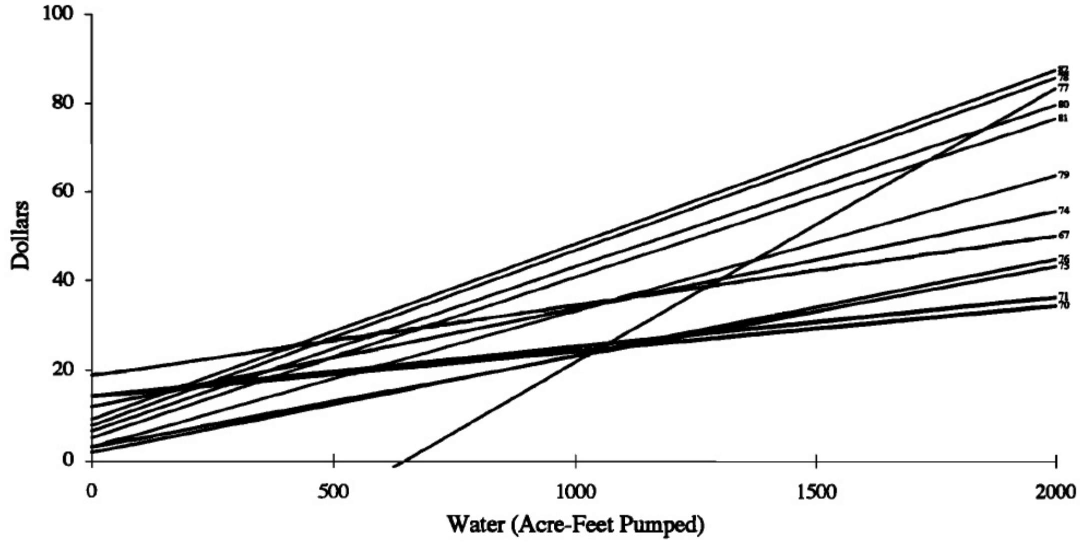


Figure 4.1: Econometric estimation of groundwater pumping costs from Westlands Water District, 1967-1982 (Kanazwa, 1992)

There are two basic economic costs associated with pumping groundwater—the cost of extracting groundwater and the opportunity cost (CGER, 1994). The cost of extracting groundwater is generally a function of pump efficiency, the cost of energy supplying the pump, the depth to the water table, and the permeability of the aquifer. As pump efficiency increases, the cost of extracting groundwater decreases. As the cost of energy and the depth to the water table increase, the cost of extracting groundwater increases. The more permeable and the shallower the aquifer is, the less energy is required to extract groundwater.

Economists have used empirical data and modeling to determine relationships between pumping costs and groundwater extraction (e.g. Figure 4.1). The opportunity cost of extracting groundwater is the cost of extracting the water now rather than saving it in the aquifer for future use (CGER, 1994). The opportunity cost captures that pumping groundwater in excess of the safe yield will lower the groundwater table for future groundwater users and raise pumping costs in the future (CGER, 1994). Aquifer overdraft can be economically efficient in some cases, if the benefits of the use groundwater are much higher than the costs of extraction (Ashley & Smith, 1999).

4.3.2 Common property resource misallocation or "tragedy of the commons"

The economics of groundwater extraction show that when groundwater is treated as a common property resource, it will not be used in an economically efficient manner (CGER, 1994). There is little or no economic incentive for an individual farmer to consider the effect of groundwater pumping on other users or the future level of the water table (Feinerman & Knapp, 1983). If each farmer were pumping from their own aquifer that was geologically isolated from other farmers pumping groundwater, there is an incentive to keep water in the aquifer, since choosing not to pump an acre-foot of water would mean an extra acre-foot of water in storage for the future. However, when many farmers pump from the same aquifer, the individual farmer cannot expect to have more water in storage in the future if she pumps less (Gisser & Sanchez, 1980). Once overdraft occurs, groundwater will continue to be extracted over time until either the groundwater supply is exhausted or the marginal cost of pumping additional water becomes exorbitant (Koundouri, 2004).

Since basic economic reasoning shows that individual pumpers have an incentive to behave competitively in extracting groundwater as a common pool resource, many economists believe that groundwater management (as a form of control) will improve how groundwater is allocated (Koundouri, 2004). Groundwater management can come in a variety of forms, including creating a permitting system with pumping quotas, charging a pump tax, and vesting property rights in groundwater (CGER, 1994). Incorporating all extraction costs as part of a groundwater management program will eventually allow an aquifer to reach an optimal steady-state depth (Koundouri, 2004). Once a steady-state depth has been reached, extraction costs will stabilize[1].

4.4 Economic Benefits of Groundwater Management & Conjunctive Management

Basin	Authors	Modeling Approach	Welfare Gains
Kern	Feinerman & Knapp (1983)	Baseline Model	10%
Kern	Dixon (1989)	Stochastic Dynamic Program	0.3%
Madera	Provencher (1993)	Stochastic Dynamic Program	2-3%
Kern	Provencher & Burt (1994)	Stochastic Dynamic Program	4%
Kern	Knapp & Olson (1995)	Stochastic Optimal Control	2.6%

Data from Koundouri (2004)

Figure 4.2: Estimated Economic Benefits of Groundwater Management in the San Joaquin Basin[2]

4.4.1 Economic Benefits of Groundwater Management

Economic modeling of the potential benefits of groundwater management contains numerous simplifying assumptions and is, by nature, a speculative exercise. Groundwater is a complex resource, with varying demand over space, time, consumer preferences, and the availability of alternative sources of water supply. The impacts of overdraft include increased pumping costs, stream flow reductions, land subsidence, contaminant migration, and saltwater intrusion. The costs and benefits of groundwater extraction are difficult to quantify. Groundwater basins without a management program also lack information on pumping rates and the value of groundwater as an input to production to create accurate economic models. Despite these limitations, economists have attempted to quantify the potential benefits of groundwater

[1] As long as energy costs remain constant

[2] The “welfare gains” used in these studies refer to an overall gain in the sum of the welfare of all the individuals in the basin. Welfare can be measured as a dollar value or as an increase in utility, or the relative satisfaction from consumption of a good. The 10% increase in welfare in Feinerman and Knapp (1983) study, for example, corresponds to $116 per irrigated acre benefit for groundwater management. The welfare gains expressed in these studies do not distinguish between the affect on different users.

management. As Koundouri (2004) emphasizes, economic modeling only provides a general idea of the impact of groundwater management.

The estimation of the impacts of groundwater management depends on the data inputs and the type of model used. An early attempt to quantify the benefits of groundwater management was Gisser and Sanchez (1980), who found a nearly negligible difference between the competitive extraction of groundwater (the common property situation) and a hypothetical system of optimal management. Later work in the San Joaquin Basin (Figure 4.2) shows small but beneficial welfare gains from groundwater management. Figure 3.2 also shows that the modeled results of the benefits of groundwater management for the same basins have changed over time. Koundouri (2004) emphasizes more realistic assumptions that can be included in models that would increase the welfare gain of groundwater management scenarios, including non-linear extractions, groundwater and surface water interactions, accounting for risk-averse groundwater extractors and considering behavioral changes as an aquifer nears depletion.

4.4.2 Economic benefits of conjunctive management

The economics of the conjunctive use of surface water and groundwater has a growing body of literature. In most cases, surface water has lower extraction and conveyance costs than groundwater, but is subject to higher variation in its availability (Zilberman & Lipper, 1999). There also is usually significant capacity for groundwater storage (Zilberman & Lipper, 1999). The optimal management strategy usually involves pumping groundwater in dry years and storing extra surface water in aquifers during wet years, which creates a more stable water supply (Zilberman & Lipper, 1999). A number of economic studies explored the potential benefits of conjunctive management the San Joaquin Basin in California. Botzan et al. (1999) created a model for artificial recharge of groundwater basin adjacent to the San Joaquin River and constructed a benefit-cost index to compare a scenario of "no investment" for conjunctive management to an "artificial recharge scenario" and found significant benefits for artificial recharge over a 30 year climactic simulation (Figure 3.3).

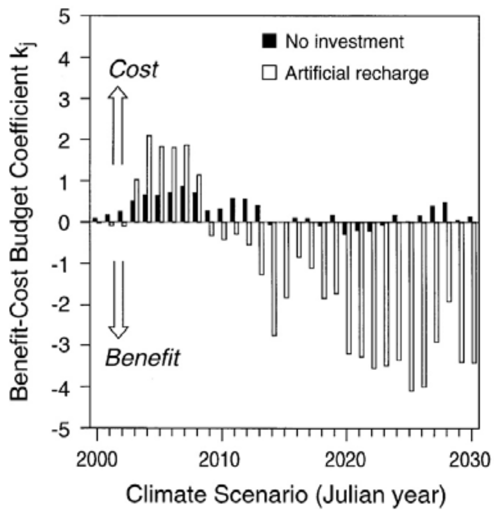


Figure 4.3: Simulated benefits and costs of artificial recharge of the aquifer adjacent to the San Joaquin River (from Botzan, 1999)[3]

From 1999 to 2008, a group of engineers and economists affiliated with the University of California at Davis published a series of papers using an integrated economic-engineering analysis of California's water supply. The California Value Integrated Network (CALVIN) is the only model that represents California's statewide water system in terms of historic hydrologic data, supply, storage, conveyance, and water demand (Figure 4.4). The model covers 92% of California's population and irrigated acreage. The model changed over time as more hydrologic and demand information became available. Howitt et al. (1999) estimated the storage and yield costs for conjunctive management projects in the San Joaquin Basin. The storage costs ranged

[3] The Benefit-Cost Budget Coefficient kj is based on the yearly average cost of groundwater supply but is not directly related to a dollar amount in the study.

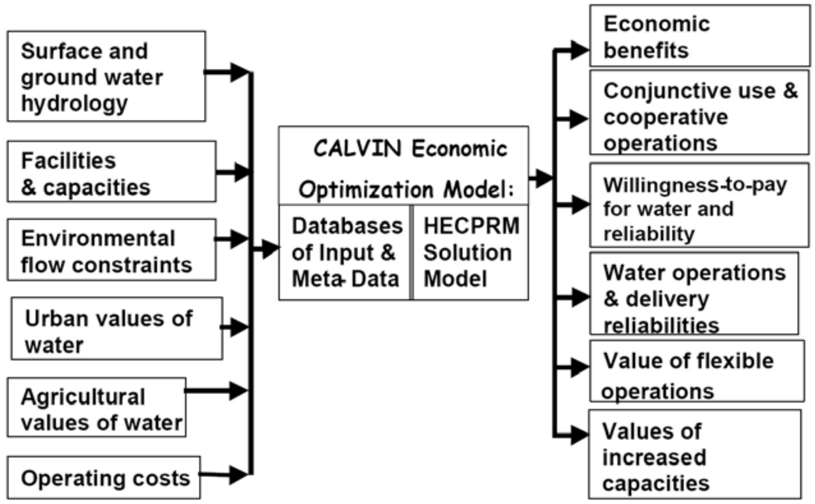


Figure 4.4: Calvin Model Data Flow (from http://cee. engr.ucdavis.edu/faculty/lund/CALVIN/)

from $100 to $328 per acre-ft of storage and the annual yield costs ranged from $50 to $280 per acre-ft of yield (Howitt et al., 1999). Lund and Howitt (2001) found a net benefit of as high as $15 per acre-ft in some areas for reducing groundwater overdraft through conjunctive management and regional water marketing in the San Joaquin River Basin. Since pumping costs range from $15 to $30 per acre-ft, conjunctive management could alleviate groundwater overdraft in the San Joaquin River Basin (Lund and Howitt, 2001). Lund and Howitt (2001) also find that in the Tulare Basin, greater conjunctive management could allow a total of 254,000 acre-ft per year of new supply through system reoperation. In Draper et al. (2003), the authors note that the lack of good data on water use and reuse in the Central Valley has a significant impact on the accuracy of investigating conjunctive use opportunities. Jenkins et al. (2004) predicts that under statewide economic optimization, groundwater use will expand from historic use of 57.5 MAF over the longest drought period to 72.9 MAF in an extended drought. Expanded conjunctive use can result in economic benefits statewide and for each region and can decrease competition with environmental uses in drought years (Jenkins et al., 2004).

4.5 Water Marketing and Conjunctive Management

Water marketing, or the voluntary transfer of water allocations for financial benefit (Sax et al., 2006), is one of the most debated issues in water resource management. On one side, water marketing is seen as means to privatize water resources for profit. Barlow and Clark (2002) believe that "the move to commodify depleting global water supplies is wrong—ethically, environmentally, and socially." On the other side, Frederick (2001) states "greater reliance on economic principles in managing and allocating water is critical for more efficient and sustainable use."

Economists argue that voluntary water transfers can promote a more efficient use of scare water resources (Frederick, 2001). Markets allow resources to move from lower to higher-value uses as societies change (Frederick, 2001). The most common type of transfer is from agricultural use to irrigation use (Glennon, 2005). Since current water allocation is based on historic use and rights, a high portion of water in western states is used to grow alfalfa and cotton, crops with a relatively low value (Glennon, 2005). Water is generally valued much more highly for urban and suburban use. If state law allows water users to sell conserved water, then markets create an incentive to invest in conservation. Since most of the water used in the West is used in agriculture, small amounts of agricultural conservation can provide a "new" source of water that can increase the amount of water available for urban use. Water markets can provide a method for governments and environmental organizations to purchase water to provide for instream flows (Sax et al., 2006).

Although water marketing can increase the efficient use of water, there are obstacles to implementing water markets and potential problems with their operation. Water markets require well-defined and transferrable property rights and require that the full costs and benefits be borne by the buyers and sellers (Frederick, 2001). These conditions are difficult to achieve. California's dual system of appropriative and riparian rights combined with illegal diversions means that water rights are rarely clearly defined. Irrigation districts can prohibit the transfer of water rights outside of service areas. It is often prohibitively expensive to transfer water by building new conveyance systems, and owners of existing systems can charge high fees for use of their conveyance systems. Water marketing in California also raises an important issue: Is it fair for agricultural users who have been receiving CVP water at below-market rates (as detailed earlier in this chapter) to then sell water to urban users for a profit?

Transferring water rights can impact communities and create equity concerns (Glennon, 2005). Communities that depend on agriculture can be affected by water transfers. If a farmer sells water to an urban water provider, her decision impacts farm workers, agricultural suppliers, the local economy and the local government. Owens Valley in the eastern Sierras, is one of the most famous examples of the impacts of water transfers, in which the City of Los Angeles purchased nearly all the water rights in the Valley to supply the Los Angeles Aqueduct, effectively ending irrigated agriculture in the Owens Valley. However, not all water transfers need to involve reallocating an entire community's water supply. The California Drought Emergency Water Banks in 1991 and 1992 illustrated how the state could act as a broker to temporarily transfer water from willing sellers to buyers (Israel and Lund, 1995).

Water marketing through groundwater banking has the same potential benefits and concerns as water marketing, but with an added layer of complexity through the uncertainty about the property rights to the surface water once it infiltrates into an aquifer. Since water stored in an aquifer does not respect property lines, this raises the question of whether a landowner who infiltrates water that moves into a neighboring parcel is somehow intruding upon the property rights of the adjacent owner (Sax et al., 2006).

There is virtually no case law on the issue of who is allowed to appropriate storage space within an aquifer (Taguchi, 2003). The earliest case related to this issue was *City of Los Angeles v. City of Glendale* (1943), in which the City of Los Angeles was storing imported water in the aquifer underlying Glendale, which Glendale began to extract. The Court ruled that the Los Angeles did not lose title to the water that it infiltrated and was allowed to use the aquifer as a "natural reservoir." Current case law in California establishes that public entities have a right to store water in an underground basin and recapture this water; and that property owners cannot use groundwater in a matter that would impact a public groundwater storage system (Taguchi, 2003). There is no system to determine priorities among users competing for the same aquifer space (Taguchi, 2003). There is also no legal mechanism, aside from groundwater adjudication, to address whether an overlying owner can exclude adjacent owners from using a basin as storage space (Taguchi, 2003).

The importance of establishing groundwater rights extends beyond facilitating water marketing. Blomquist (1992) notes that "conjunctive management programs are likely to emerge only when those who share access to and the rights in the groundwater resource can reach agreement on how to use it for storage and recovery." California's lack of groundwater management "can hamper conjunctive management programs… because in many basins, overlying landowners and appropriators have insufficient assurance that the water they place in storage will be available later for pumping and delivery (Blomquist, 1992).

References

Angel, Arthur D. 1946. Who Will Pay for the Central Valley Project of California? *The Journal of Land & Public Utility Economics*. 22(3):266-272.

Ashley, J.S. and Z.A. Smith. 1999. Groundwater Management in the West. University of Nebraska Press: Lincoln, Nebraska.

Barlow, Maude and Tony Clark. 2002. Blue Gold: The Fight to Stop the Corporate Theft of the World's Water. New Press: New York, New York.

Baumann, Duane D., John Boland, and W. Michael Hanemann. 1998. Urban Water Demand Management and Planning. Mc Graw-Hill: New York, New York.

Botzan, Tudor, Angelica Necula, Miguel Marino, and Hakan Basagaoglu. 1999 "Benefit-Cost Model for an Artificial Recharge Scenario in the San Joaquin Valley, California." *Water Resources Management.* 13: 189-203.

Bureau of Economic Analysis (BEA). "Gross Domestic Product by State: California." United States Department of Commerce.Web. 17 Dec. 2009. <http://www.bea.gov/ regional/gsp>.

Bureau of Reclamation (USBR), 2008. "Upper San Joaquin River Basin Storage Investigation." United States Bureau of Reclamation. Web. 20 Dec. 2009. <http://www.usbr.gov/mp/sccao/storage/index.html>.

Bureau of Reclamation (USBR). 2009a. "The Bureau of Reclamation: A Very Brief History." United States Bureau of Reclamation. Web. Dec. 2009. <http://www.usbr.gov/history/borhist.html>.

Bureau of Reclamation (USBR). 2009b. "Ratesetting Process: Frequently Asked Questions." United States Bureau of Reclamation. Web. Dec. 2009. <http://www.usbr.gov/mp/cvpwaterrates/rate_process/faq.html>.

Committee on Ground Water Recharge, National Research Council (CGER). 1994. "Groundwater Recharge Using Waters of Impaired Quality. National Academies Press." Web. Feb. 2010. <http://www.nap.edu/catalog.php?record_id=4780>.

Department of Water Resources (DWR). 2005. "California Water Plan: Update 2005." Web. Apr. 2009. < http://www.waterplan.water.ca.gov/previous/cwpu2005/ index.cfm>.

Draper, A.J., M.W. Jenkins, K.W. Kirby, J.R. Lund, and R.E. Howitt. 2003. Economic-Engineering Optimization for California Water Management. *Journal of Water Resources Planning and Management*. 129(3): 155-164.

Environmental Working Group (EWG). 2009. "California Water Subsidies." Web. Jan. 2010. <http://archive.ewg.org/reports/Watersubsidies/execsumm.php>.

Faunt, Claudia C., ed. “Professional Paper 1766: Groundwater Availability of the Central Valley Aquifer, California” U.S. Geological Survey. Web. May 2009. <http://pubs.usgs.gov/pp/1766/>.

Feinerman, E and K.C. Knapp. 1983. “Benefits from Groundwater Management: Magnitude, Sensitivity, and Distribution.” *American Journal of Agricultural Economics*. 65(4): 703-710.

Frederick, Kenneth D. 2001. “Water Marketing: Obstacles and Opportunities.” *Forum for Applied Research and Public Policy*. 16(1): 54-62.

General Accounting Office (GAO). 1994. “Water Subsidies: The Impact of Higher Irrigation Rates on Central Valley Project Farmers.” United States General Accounting Office. Web. Dec. 2009. < http://www.gao.gov/cgi-bin/getrpt?GAO/RCED-94-8>.

General Accounting Office (GAO). 2002. “GAO-02-764 Water Utility Financing and Planning.” U.S. General Accounting Office. Web. Dec. 2009. < http://www.gao.gov/new.items/d02764.pdf>.

Gisser, M and D.A. Sanchez. 1980. “Competition Versus Optimal Control in Groundwater Pumping.” *Water Resources Research*. 16(4):638-642.

Gleick, Peter. 2009. “Rigged Feasibility Study Shows Desperation for New Surface Reservoirs: Temperance Flat Falls Flat.” San Francisco Chronicle. Web. Nov. 2009. < http://www.sfgate.com/cgi-bin/blogs/gleick/detail?blogid=104&entry_id=46970>.

Goldsmith, Edward and Nicholas Hildyard. 1984. “Chapter 20: Cost-Benefit Studies: The Record of Falsification.” In <u>The Social and Environmental Effects of Large Dams</u>. Wadebridge Ecological Centre: Cornwall, UK.

Hahn, Robert William (ed.). 1996. <u>Risks, Costs and Lives Saved: Getting Better Results from Regulation</u>. American Enterprise Institute for Public Policy Research: Washington, D.C.

Howitt, R.E., J.R. Lund, K.W. Kirby, M.W. Jenkins, A.J. Draper, P.M. Grimes, M.D. Davis, K.B. Ward, B.D. Newlin, B.J. Van Lienden. 1999. “Integrated Economic-Engineering Analysis of California’s Future Water Supply.” Web. May 2009. <http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/>.

Israel, Morris and Jay R. Lund. 1995. “Recent California Water Transfers: Implications for Water Management.” *Natural Resources Journal*. 35: 1-32.

Jenkins, M.W., J.R. Lund, R.E. Howitt, A.J. Draper, S.M. Msangi, S.K. Tanaka, R.S. Ritzema and G.F. Marques. 2004. “Optimization of California’s Water Supply System: Results and Insights.” *Journal of Water Resources Planning and Management*. 130(4): 271-280.

Kanazawa, M.T. 1992. "Econometric Estimation of Groundwater Pumping Costs: A Simultaneous Equations Approach." *Water Resources Research*. 28(6):1507-1516.

Koundouri, P. 2004. "Current Issues in the Economics of Groundwater Resource Management." *Journal of Economic Surveys*. 18(5):703-740.

Legislative Analyst's Office (LAO). 2009. "Financing Water Infrastructure." Web. Dec. 2009. <http://www.lao.ca.gov/handouts/resources/2009/Financing_Water_Infrastructure_82609.pdf>.

Lund, J.R. and R. Howitt. 2001. "Improving California Water Management: Optimizing Value and Flexibility." Web. Feb. 2010. <http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/Report2/>.

Sax, Joseph L., Thompson, Barton H., Leshy, John D., and Robert H. Abrams. 2006. Legal Control of Water Resources: Cases and Materials. Thompson/West: St. Paul, MN.

Taguchi, Tara L. 2003. "Whose Space Is It, Anyway? Protecting the Public Interest in Allocating Storage Space in California's Groundwater Basins." *Southwestern University Law Review*. 32: 117-150.

Zetland, David. 2009. "Aguanomics: Temperance Flat Economics." Web. Jan. 2010. < http://aguanomics.com/2009/10/temperance-flat-economics_18.html>.

Zilberman, D. and L. Lipper. 1999. "The Economics of Water Use." In: J. Bergh (ed.), Handbook of Environmental and Resource Economics. Edward Elgar: Cheltenham, UK.

5.0 The Tehachapi Basin & Groundwater Adjudication

Figure 5.1: Tehachapi Basin Location

This chapter examines conjunctive management through groundwater adjudication in the Tehachapi Basin (Figure 5.1). In this chapter, I discuss the process of groundwater adjudication in general and examine the natural factors, the history, and the adjudication of the Tehachapi Basin. I also discuss lessons that can be applied to other conjunctive management projects.

5.1 The Groundwater Adjudication Process

Since the State of California currently lacks the legal means to control groundwater extraction, a number of basins have undergone groundwater adjudication, whereby the amount of groundwater that landowners can extract from an aquifer is quantified through a court-directed process (DWR, 2004). Groundwater adjudication is distinct from adjudicating a river system, since it examines an entire groundwater basin, rather than groundwater that is more directly connected to a river. Through the groundwater adjudication process, landowners arrive at an equitable distribution of groundwater available each year (DWR, 2004). Each landowner participating in the adjudication process is guaranteed a proportionate share of the available groundwater (DWR, 2004). As part of the adjudication process, a person or agency—known as the Watermaster—is put in charge of determining pumping limits and monitoring the basin to ensure that the terms of the court decision are followed (DWR, 2004).

In California, any groundwater user can initiate groundwater adjudication (Sax et al., 2006). In *Katz v. Walkinshaw* (1903), the California Supreme Court overturned the English common law idea of a landowners' absolute ownership of groundwater below her property and established the correlative rights doctrine. The correlative rights doctrine means each landowner has an equal or "correlative" right to pump groundwater that is used in a reasonable and beneficial manner. The *Katz* decision and subsequent court cases established adjudication as a way to quantify each landowners' correlative right to groundwater. In the *Katz* opinion, Justice Shaw stated that

> "the objection that this rule of correlative rights will throw upon the court a duty of impossible performance, that of apportioning an insufficient supply among a large number of users is largely conjectural… the difficulty in its application is not a sufficient reason for rejecting it."

Even if it is a daunting task, if called upon to quantify groundwater rights, the courts must determine pumping rights. However, despite the option to adjudicate basins, very few basins have been adjudicated since even summoning all groundwater users to appear in court is difficult (Sax et al., 2006). Costly fees to hire professional hydrogeologists and experienced attorneys act as another deterrent to undertaking adjudication.

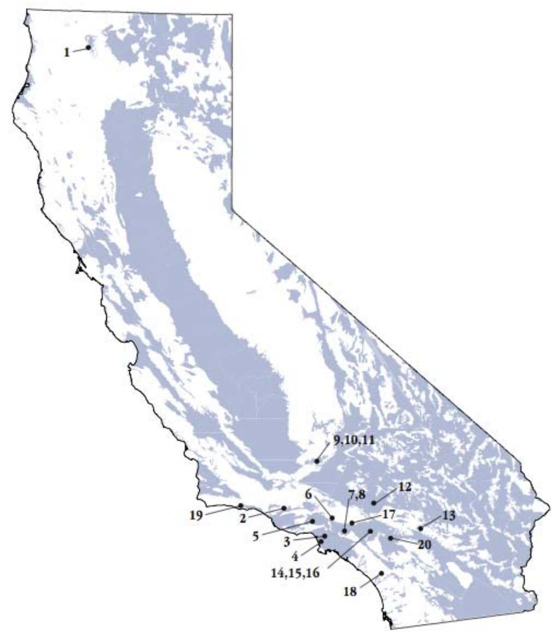


Figure 5.2: Adjudicated Groundwater Basins in California
(Figure from DWR, 2004, numbers correspond to basins in table below)

As of April 2004, there were 20 adjudicated groundwater basins out of a total of 515 in the state (see Figure 5.2 and Figure 5.3), with all but one of the basins in the southern half of the California (DWR, 2004). In early 2008, the Santa Maria groundwater basin was adjudicated, bringing the total of adjudicated groundwater basins in California to 21 (Nossaman LLP, 2008). Excluding the Scott River Valley Basin in the wetter north, the Tehachapi Basin and the Santa Maria Basin are the only ones in the more arid south where a large portion of the basin is devoted to agriculture. As mentioned previously, basins where agricultural water use predominates are of particular concern since the greatest volume of overdraft has occurred and continues to occur in the San Joaquin Basin, where groundwater is primarily used for agriculture.

Basin Name	**Year of Court Decision**
1.Scott River Stream System	1980
2. Santa Paula Basin	1996
3. Central Basin	1965
4. West Coast Basin	1961
5. Upper Los Angeles R. Area	1979
6. Raymond Basin	1944
7. Main San Gabriel Basin	1973
8. Puente Basin	1985
9. Cummings Basin	1972
10. Tehachapi Basin	1973
11. Brite Basin	1970
12. Mojave Basin	1996
13. Warren Valley Basin	1977
14. Chino Basin	1978
15. Cucamonga Basin	1958
16. San Bernardino Basin	1969
17. Six Basins	1998
18. Santa Margarita R. Watershed	1966
19. Goleta	1989
20. Beaumont Basin	1904
21. Santa Maria	2008

Figure 5.3: List of Adjudicated Groundwater Basins in California (Source: DWR, 2004)

5.2 Tehachapi Basin Natural Factors, History, Operation, and Analysis

The Tehachapi Basin is approximately 40 miles southeast of Bakersfield and about 75 miles north of Los Angeles. There are 3 main groundwater basins in the area serviced by the Tehachapi-Cummings County Water District: Brite Basin, Cummings Basin, and Tehachapi Basin, which includes both Tehachapi Basin West and Tehachapi Basin East (Figure 5.3). The Tehachapi Basin is particularly interesting since it was the only example of an agriculturally dominated economy in the southern half of the state which chose to adjudicate groundwater rights (Loux, 1987) until the Santa Maria Basin was adjudicated in 2008.

5.2.1 Natural Factors

The Tehachapi Basin is 32,000 acres and is situated in the Tehachapi Range, on the southern edge of the San Joaquin Basin. Local surface and subsurface inflow from creeks in the watershed are the source of the natural groundwater replenishment (Loux, 1987). The basin is composed primarily of alluvial deposits that are 450 feet thick at the deepest part in the valley (Franson, 1975). The region is semi-arid and receives an average of 10 to 14 inches of precipitation a year (DWR, 2004a).

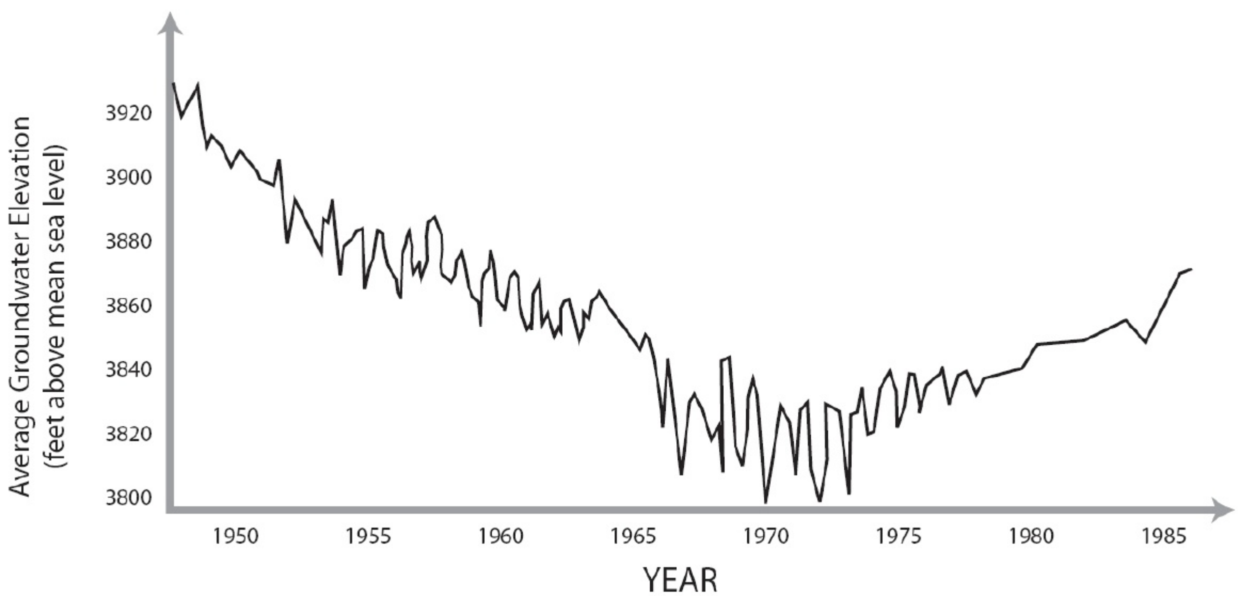


Figure 5.4: Groundwater Declines in Tehachapi, California
(Information from Loux, 1987, pg. 75)

5.2.2 History

Groundwater overdraft began to occur following an increase in irrigated agriculture in the 1930s (Anderson & Snyder, 1997). Increased pumping in the late 1950s and 1960s led to a further decrease in groundwater levels and led to water rationing in the City of Tehachapi for a number of summers (Loux, 1987). From 1951 to 1961 there was an estimated loss of 73,000 acre-feet of groundwater from the basin (DWR, 2004a). Figure 5.4 shows the effect of groundwater withdrawals on the water table in the City of Tehachapi. From 1950 to 1970, the groundwater levels fell nearly 100 feet.

In 1965, the Tehachapi-Cummings County Water District was formed to manage the basins' water supply (Loux, 1987). At the same time, a citizens' advisory committee was also formed to help address the overdrafting problems in the basin. The committee decided to adjudicate the basin and to import surface water from the State Water Project. However, since the basin is at 4,000 feet, water from State Water Project would have to be pumped over 3,400 vertical feet. The large elevation difference made pumping groundwater cheaper than importing surface water. The adjudication process took from 1966 to 1973 and cost about $300,000 for 100 users (Anderson & Snyder, 1997). The groundwater levels began to recover as a result of the adjudication, and rose nearly 80 feet in the 10 years following the adjudication of the basin (Figure 5.4).

Figure 5.5 shows the location of the Tehachapi Basin with respect to the State Water Project. The California Aqueduct is 25 miles southwest of the Basin and considerably lower in elevation, which shows why it would be expensive to extend the State Water Project to the Tehachapi Basin. The intermittent local streams aren't within the boundaries of the Tehachapi-Cummings County Water District, leaving the Tehachapi Basin mostly reliant on local supply.

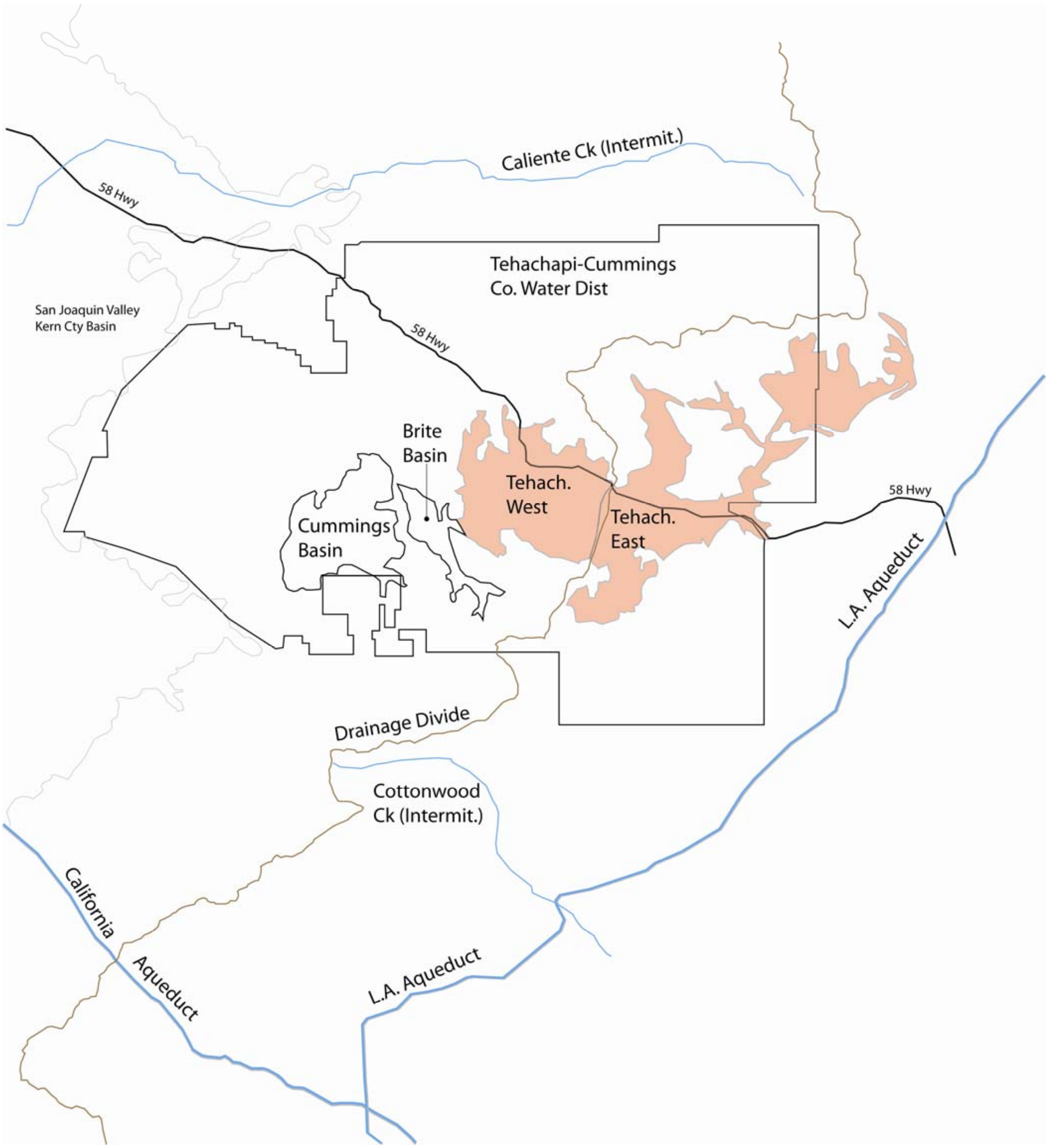


Figure 5.5: Tehachapi Basin Location Map
(Base information from California IWRIS)

5.2.3 Project Operation

As a result of the adjudication process, a "safe yield" of 5,500 acre-feet per year was established, which was two-thirds of the total base water rights amount of 8,250 (Loux, 1987). Each individual groundwater user was permitted to pump two-thirds of his or her established base right. Groundwater pumping permits were made transferrable among groundwater users (Anderson & Snyder, 1997). The court also allowed each pumper to stockpile excess water by pumping less than his or her allocated amounts, but limited the stockpile to 25 percent of the total allocation (Anderson & Snyder, 1997).

An aerial view of the Tehachapi Basin West shows that the basin is currently sparsely developed (Figure 5.6). The gray areas tones designate areas that with a higher concentration of development that are less permeable. The watershed and the groundwater basin boundaries are both delineated on Figure 5.6 as well.

5.3 Application to Other Conjunctive Management Projects

Although adjudication has been used in only 21 of California's 515 identified groundwater basins and only 2 of those basins in the southern half of the state have a high amount of agricultural water use, a number of lessons that can be taken from the adjudication process that can be applied to other basins. Adjudication of a groundwater basin results in a quantified safe-yield that is adjusted depending on groundwater availability. After the court-mandated studies, adjudication prevents further disputes from arising since not only are pumping rates quantified, but individual pumpers are metered, and groundwater levels are closely monitored. The

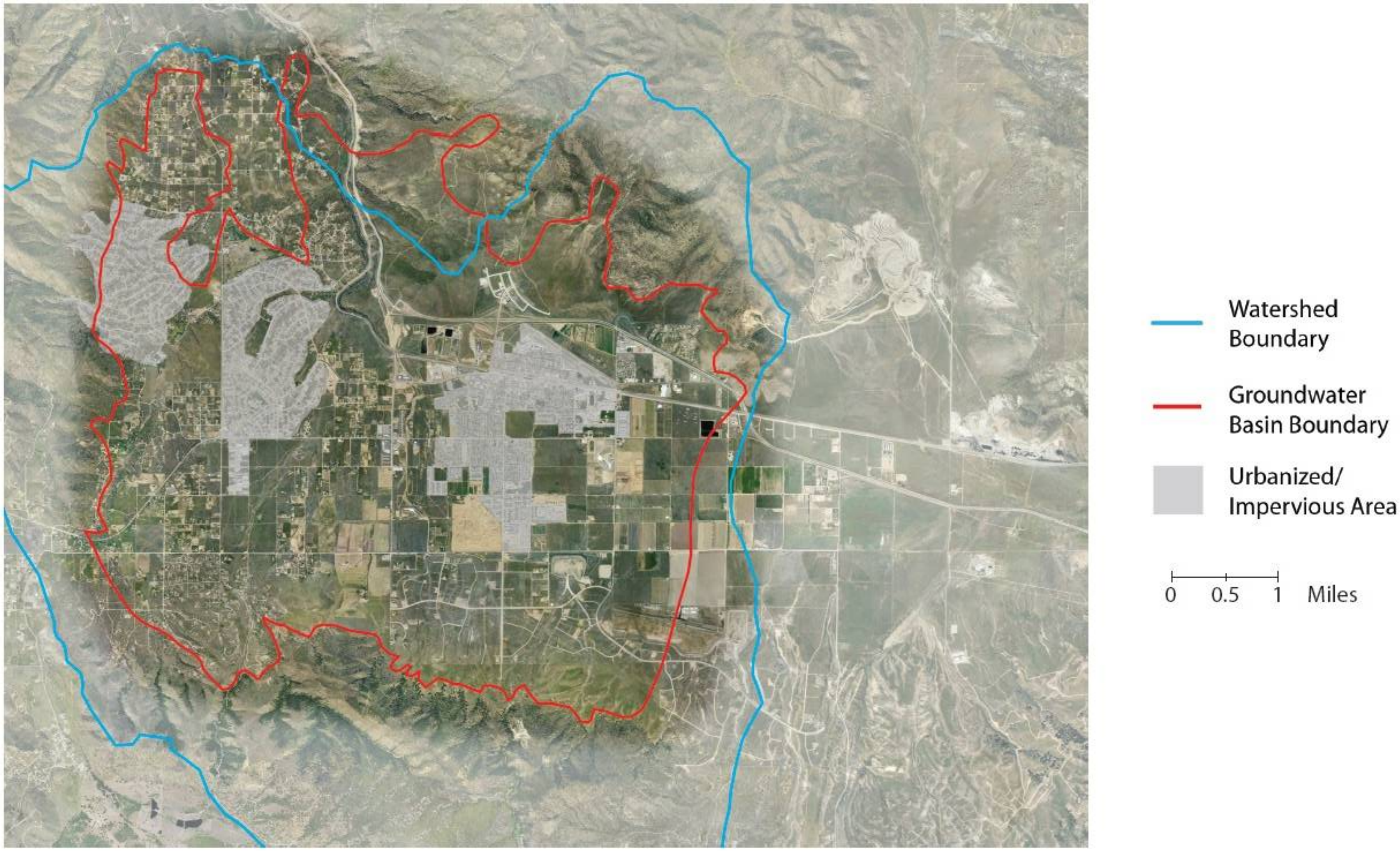


Figure 5.6: Tehachapi Basin West Aerial
(Base information from CaSIL)

groundwater permitting system created during the adjudication also incorporated flexibility, including allowing permit transfers and stockpiling groundwater.

The adjudication of the Tehachapi Basin involved about 100 users and a safe-yield of 5,500 acre-feet. Both the number of users and the safe-yield are small in comparison to the thousands of users in the Madera Irrigation District and the projected 55,000 acre-feet infiltrated into the water bank. Because of the smaller number of users and less amount of water involved in conjunctive management in the Tehachapi Basin, adjudication may not be an applicable model for larger basins, especially ones that do not have clearly defined geographic boundaries like the Tehachapi Basin. Groundwater adjudication provides a form of management by quantifying and clarifying groundwater pumping rights, but the expense, involved process, and difficulty of application to a large basin with many groundwater users all act as deterrents that prevent the groundwater adjudication from being used more widely.

References

Department of Water Resources (DWR). 2004. "Water Facts No. 3: Adjudicated Groundwater Basins in California." Web. Jan. 2009. <http://www.dpla2.water.ca.gov/publications/waterfacts/water_facts_3.pdf>.

Department of Water Resources (DWR). 2004a. "Calfornia's Groundwater Bulletin 118." Web. Dec. 2008. <http://www.water.ca.gov/ groundwater/bulletin118/update2003.cfm>.

Franson, J. 1975. Tehachapi-Cummings County Water District v. Frank Armstrong et al. 49 Cal. App. 3d 992.

Loux, Jeff David. 1987. "A Comparative Analysis of Local Ground Water Management Programs in California." Diss. University of California at Berkeley. Print.

Nossaman, LLP. 2008. "Victory in Santa Maria Groundwater Adjudication." Web. Dec. 2008. <http://www.nossaman.com/showAnnouncement.aspx?Show=4370>.

Sax, Joseph L., Thompson, Barton H., Leshy, John D., and Robert H. Abrams. 2006. Legal Control of Water Resources: Cases and Materials. Thompson/West: St. Paul, MN.

Thomas, Gregory, David Brown, Nicholas Pinhey, Jennifer Spaletta, and Peter Kiel. 2001. "Designing Successful Groundwater Banking Programs in the Central Valley: Lessons from Experience." Natural Heritage Institute. Web. Feb. 2009 < http://www.n-h-i.org/uploads/tx_rtgfiles/7550_Conjusefinal.PDF >.

6.0 The Kern Water Bank & Forming a Water District

Figure 6.1: Kern Water Bank Location

6.1 Introduction

This chapter examines how conjunctive management arrangements work through forming a water district. The Kern Water Bank (Figure 6.1) is run by the Kern Water Bank Authority, an association of public agencies and a private company. In this chapter, I examine the natural factors, the history, and project operations of the Kern Water Bank to determine lessons that can be applied to other conjunctive management projects.

6.2 Kern Water Bank

The Kern Water Bank is located in the southern portion of the San Joaquin Basin, adjacent to the city of Bakersfield (Figure 6.2). The project is approximately 20,000 acres, and is operated by the Kern Water Bank Authority (KWBA, 2009).

6.2.1 Natural factors

The Kern Water Bank is located on the alluvial fan of the Kern River. The estimated storage capacity of the aquifer underlying the property is about 1 MAF. The Kern Water Bank can receive water from the Kern River, the State Water Project (California Aqueduct), and the Friant-Kern Canal. About 7,000 acres of the project are used as recharge basins and about 10,000 acres of the project are set aside for habitat as part of the Kern Water Bank Habitat Conservation Plan (Thomas et al., 2001).

6.2.2 Project history

The idea of banking groundwater at the Kern Water Bank dates back to the late 1970s. A series of technical studies were published in 1979 and 1983 on utilizing conjunctive management of surface water and groundwater. Around the same time, farmers and water districts began to realize that the State Water Project would not be constructed as initially planned, and also began to realize that groundwater overdraft problems needed to be addressed. By the early 1980s, the groundwater overdraft was approximately 300,000 acre-feet per year. The combination of changes in the State Water Project, groundwater overdraft, and a multiple year drought led the Department of Water Resources to purchase the property that would become the Kern Water Bank from Tenneco West in 1988 (Thomas et al., 2001).

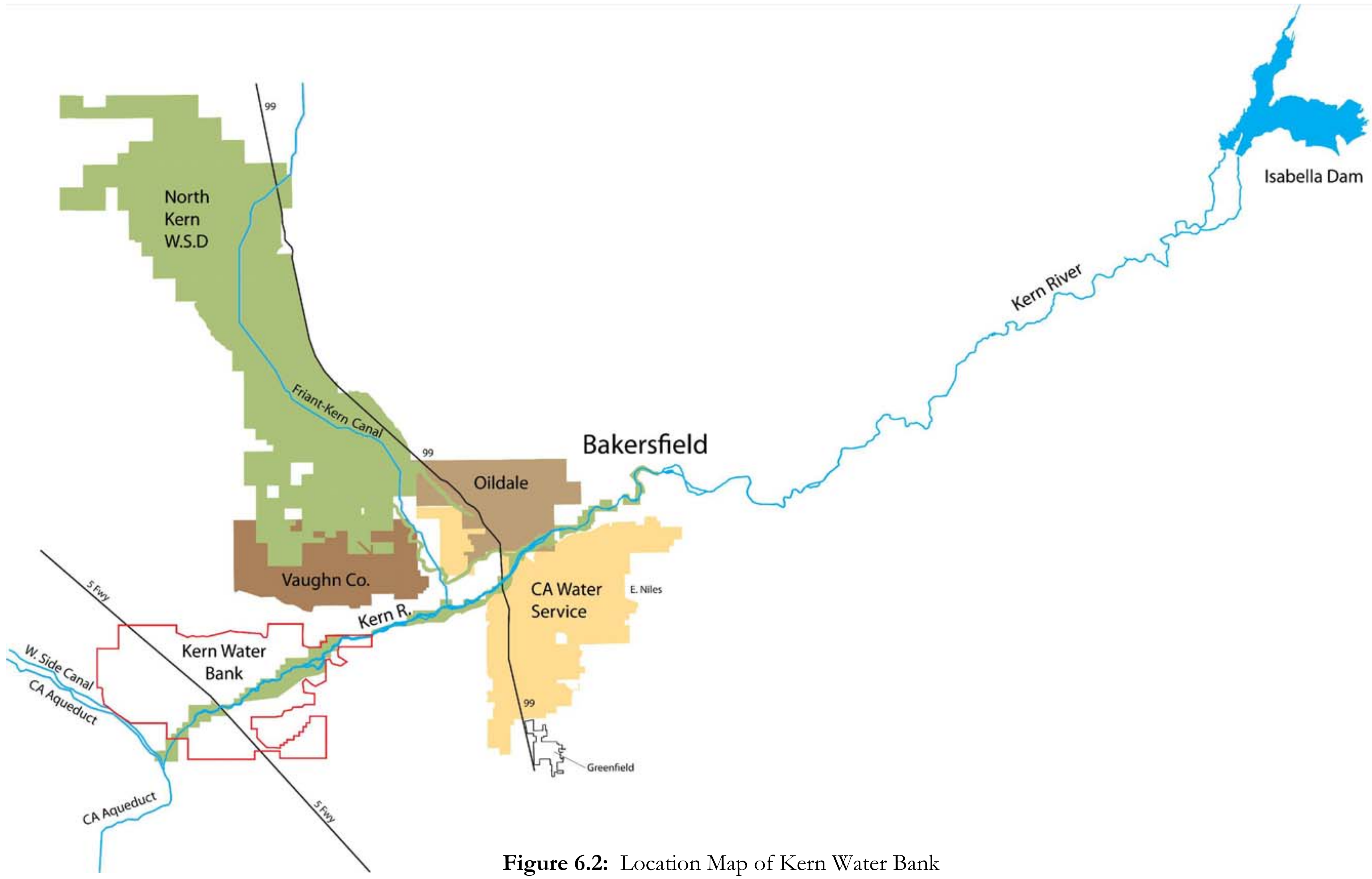


Figure 6.2: Location Map of Kern Water Bank
(Base information from California IWRIS)

The Kern County Future Water Supply Committee was formed in 1990 by local water district managers to evaluate future water supply options including water banking. In 1992, a committee produced a draft set of rules for the joint operation of the Kern Water Bank. The Kern Water Bank began operating in 1994 under the Kern County Water Agency. In 1996, control of the Kern Water Bank was transferred from Kern County Water Agency to the Kern Water Bank Authority (Thomas et al., 2001).

6.2.3 Project Operation

The Kern Water Bank can store an estimated total of 1 MAF, with a maximum recharge of 450 TAF per year, and a maximum recovery of 240 TAF per year (Thomas et al., 2001). Figure 6.3 shows the recharge and recovery facilities on the Kern Water Bank. A series of wells surrounding the recharge basins (colored green) recover the groundwater that has been infiltrated in the basins. Most of the recovery wells are clustered near the east end of the project, in the alluvial fan of the Kern River. The recovery wells are also located relatively close to the recharge basins. A series of canals through the property are used to transport water onsite for infiltration and offsite for delivery to the project partners. The western edge of the Kern Water Bank borders the California Aqueduct and the West Side Canal, both conduits for the State Water Project.

The two main participants in the water bank are the Westside Mutual Water Company and the Wheeler Ridge-Maricopa Water Service District, which respectively use 48% and 24% of the total recharge and recovery share. (KCWA, 1997).

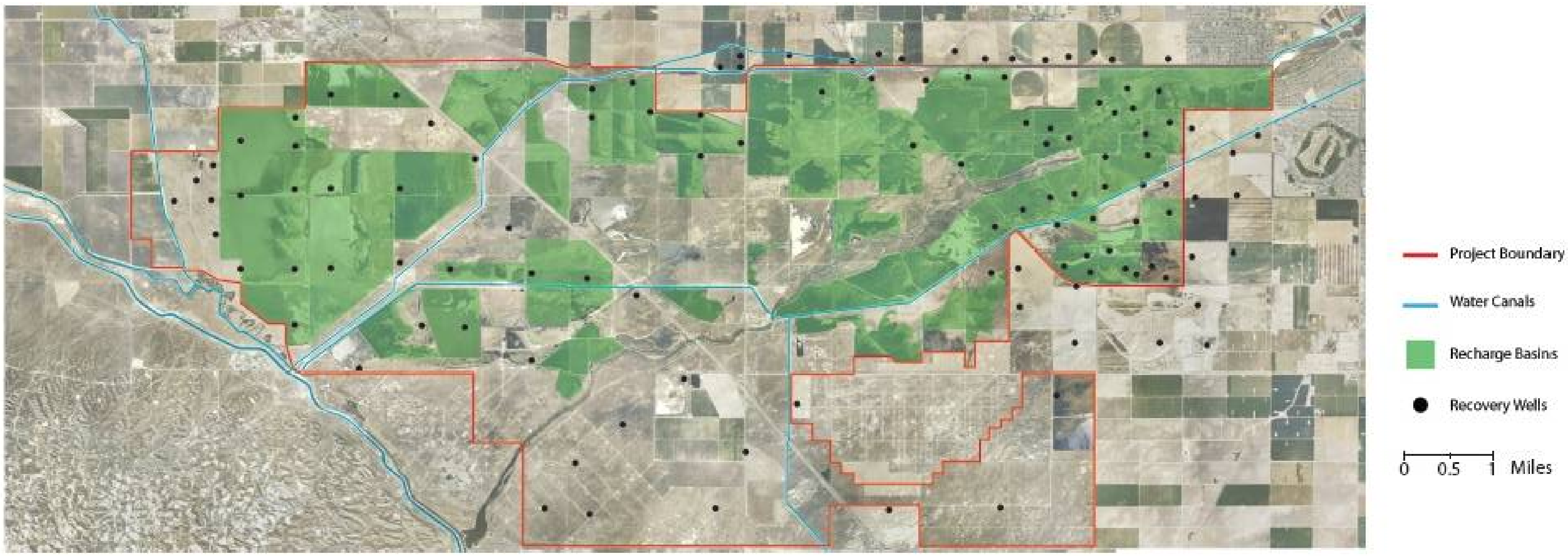


Figure 6.3: Kern Water Bank Recharge and Recovery Facilities
(Data from KCWA, 1997)

Figure 6.4: Average Groundwater Levels at Project Site
(Data from KCWA, 1997)

Figure 6.4 shows how the groundwater levels at the Kern Water Bank have fluctuated over time. The project operations can be seen clearly through the drop in groundwater levels that occurred during the 1987 to 1992 drought. Following the drought, groundwater levels began to recover as project participants began to store water in the bank again.

A key element that governs the operation of the Kern Water Bank is the Memorandum of Understanding (MOU) signed by the 14 project participant agencies in 1995. The MOU established a monitoring committee with representatives from each of the participating agencies and a monitoring well network to evaluated groundwater levels. Spreading losses were set at 6% to account for evaporation and evaptranspiration by plants. The MOU estimated an 6% loss of banked water due to migration, or movement of groundwater beyond where it can be recovered through recovery wells. Further hydrologic studies showed that approximately 4% of the water is lost from migration. As part of the MOU, the Kern Water Banking Authority is only allowed to pump water after it has been recharged (KCWA, 1997).

6.3 Controversy Related to Project

Two main criticisms are raised against the Kern Water Bank. First, the Monterrey Amendments in 1995, in which the Department of Water Resources transferred the ownership of the Kern Water Bank from the Kern County Water Agency, a public agency, to the Kern Water Bank Authority, an association of public agencies and the Westside Mutual Water Company, a private company, gave 48 percent of the stake of the water bank to the Company (Taugher, 2009). Since the Department of Water Resources spent $74 million on the development of the bank, critics argue it is unfair for a private company to have a stake in the control of the project (Taugher, 2009).

A second criticism of the Kern Water Bank is the Westside Mutual Water Company has benefited from selling water it has stored in the Kern Water Bank to outside interests. Taking state subsidized water initially dedicated for agricultural districts and selling it to other interests would amount "gaming the system to gain profits (Taugher, 2009)." For example, in 2001, the Kern County Water Agency bought water from the State Water Project at $161 per acre-foot and sold it back to the state's Environmental Water Account at $250 an acre-foot for a total profit of $29 million (Public Citizen, 2003). The transfer of subsidized water for a profit highlights one of the difficulties with water marketing covered in the Chapter 3. If participants in a water marketing arrangement do not pay the full costs of obtaining water, then there is an opportunity to profit from government-subsidized water.

6.4 Application to Other Projects

The Kern Water Bank was identified by Bruce Babbitt, the former Secretary of the Interior as "the most effective groundwater storage program in the United States, probably the whole world" (KWBA, 2009). The Kern Water Bank appears to be successful due to the combination of favorable hydrogeology, access to a number of sources of water, a clear statement of project operations articulated in the MOU, local control of the project, financial benefits, and support of local agencies and landowners. It may be difficult (or impossible, in the case of underlying geology) to replicate all the characteristics that contribute to the success of the Kern Water Bank, but potential conjunctive management projects can apply elements from project development and operations the Kern Water Bank to other projects in California.

References

Kern County Water Agency (KCWA). 1997. “Groundwater Banking in Kern County: Presented to American Water Resources Association 1997 Annual Meeting.” Presented by Rick Iger, Engineering and Operations Manager. Web. Nov. 2009. <http://www.sfwmd.gov/portal/page/portal/pg_grp _sfwmd_ watersupply/subtabs%20%20asr/tab16318099/gwbankingkerncounty-calf-oct1997.pdf>.

Kern Water Bank Authority (KWBA). 2009. “Kern County Water Bank: General Information.” Web. Nov. 2009. <http://www.kwb.org/main.htm>.

Public Citizen. 2003. “Water Heist: How Corporations are Cashing in on California’s Water.” Web. Jan. 2009. <http://www.citizen.org/documents/Water_Heist_lo-res.pdf>.

Taugher, Mike. 2009. “Gaming the Water System.” Contra Costa Times. Web. 11 Dec. 2009. <http://www.contracostatimes.com/search/ci_12443070>.

Thomas, Gregory, David Brown, Nicholas Pinhey, Jennifer Spaletta, and Peter Kiel. 2001. “Designing Successful Groundwater Banking Programs in the Central Valley: Lessons from Experience.” Natural Heritage Institute. Web. 07 Feb. 2009 < http://www.n-h-i.org/uploads/tx_rtgfiles/7550_Conjusefinal.PDF >.

7.0 The Proposed Madera Water Bank & Barriers to Conjunctive Management

The Madera Ranch property, site of the proposed Madera Water Supply Enhancement Project (Madera Water Bank), is in the northern portion of the San Joaquin Basin and is roughly between the cities of Firebaugh and Madera (Figure 7.1). The Madera Water Bank is currently owned by the Madera Irrigation District. The project site is presently mostly fallowed agriculture land. The site is 10 miles southwest of Madera, a city of 56,000 residents. This chapter provides information about the Madera Water Bank including the environmental factors, project history, and proposed management characteristics, model predictions, and managing uncertainty.

Figure 7.1: Madera Water Bank Location Map

7.1 Project Overview

The proposed Madera Water Bank project is to store Central Valley Project (CVP) water in the aquifer underlying Madera Ranch. The water will come from the Madera Irrigation District's CVP allocation. The project would require changes to a federal water conveyance canal, Canal 24.2, the use of natural swales to infiltrate water, new wells to recover the banked groundwater, and new infrastructure to convey this water back to the Madera Irrigation District when it is recovered.

7.2 Environmental Factors

7.2.1 Precipitation and water demand

The temporal mismatch between temperatures and precipitation at the Madera Ranch site mean demand for water is the highest in the summer months for urban and agricultural uses. The city of Madera received an annual average of 10.96 inches of precipitation over an 81 year period of record (Western Regional Climate Center, 2009). Most of the precipitation falls in Madera in the late winter and early spring, from December to March (Figure 7.2). March has the highest average precipitation of 2.29 inches, and July has the lowest average precipitation of 0.01 inches. The average monthly temperature pattern fluctuates out of phase with the average monthly precipitation pattern, so temperatures and evaporation rates are highest when precipitation is the lowest. The highest temperatures are in June, July, and August. August has the highest average temperature of 79.6 degrees Fahrenheit (Western Regional Climate Center, 2009). The local response to this seasonal drought has been to import surface water stored in large reservoirs or to pump groundwater during the summer months.

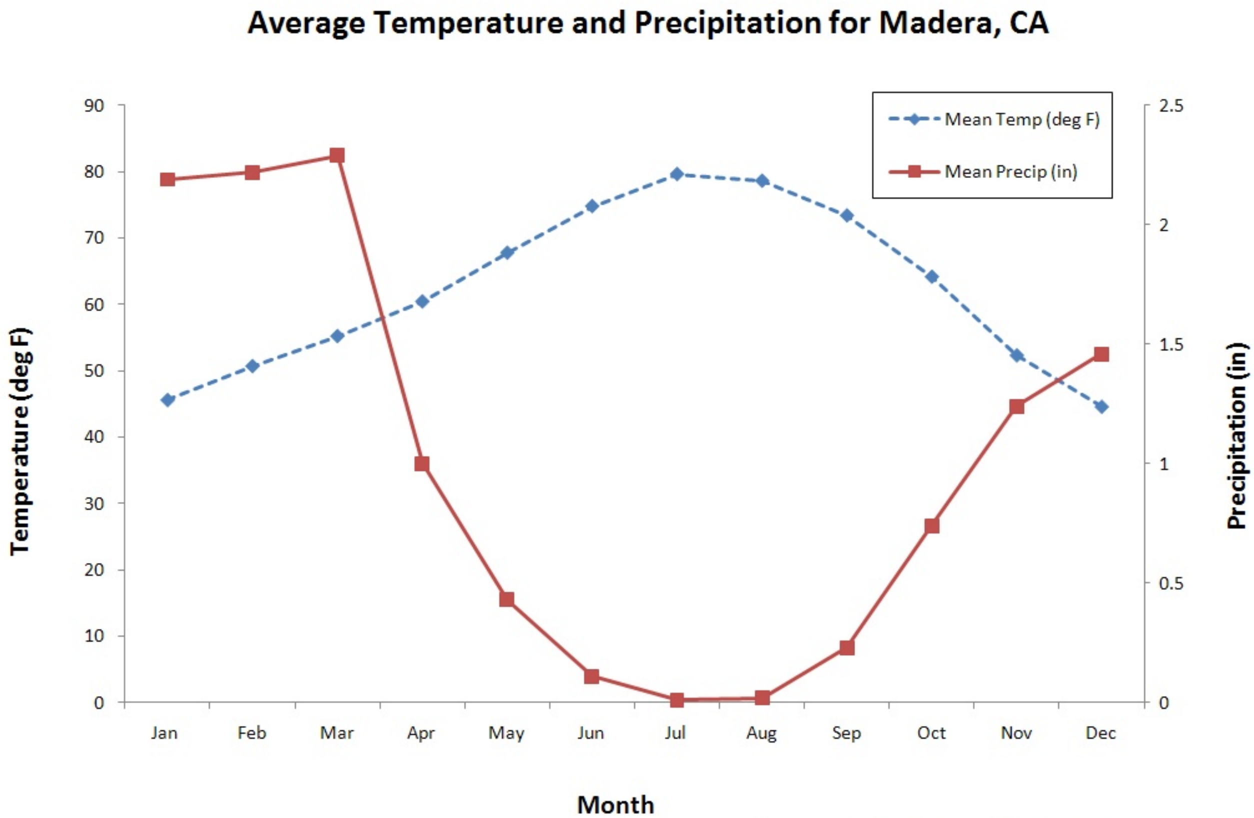


Figure 7.2: Average Temperature and Precipitation for Madera, California
(Data from http://www.idcide.com/weather/ca/madera.htm)

7.2.2 Hydrology, Water Infrastructure, and Water Rights

Due to the seasonal drought, high agricultural productivity, and large yearly variations in water availability, farmers in Madera County have long relied on outside water sources. Figure 7.3 shows the major water infrastructure in the area as well as some of the natural creeks and rivers. Water comes to farmers in Madera County through a variety of sources. The Central Valley Project, a federal project built in the 1930s and 1940s and maintained by the U.S. Bureau of Reclamation, provides a major source of water for farmers in Madera County. Friant Dam, on the San Joaquin River, distributes water to much of the San Joaquin Valley through the Madera Canal and the Friant-Kern Canal. The US Army Corps of Engineers constructed Hidden Dam on the Fresno River in 1947. Madera Irrigation District operates the dam for flood control and also to provide water for irrigation and groundwater recharge.

Over-appropriation of water from the Fresno River and the upper portion of the San Joaquin River have made these streams run dry before reaching the main stem of the San Joaquin River for most of the year. The Fresno River is heavily altered above the main stem of the San Joaquin, and mostly flows through a series of agricultural bypasses. Starting in October 2009, a program to restore flows on the San Joaquin began with the goal of restoring native salmonid populations, following settlement of a lawsuit brought by the Natural Resources Defense Council in the late 1980s (Grossi, 2010). Water released from Friant Dam to maintain flows on the San Joaquin River will decrease the allocation of San Joaquin Valley farmers by 230,000 acre-feet, or an 18 percent decrease (Grossi, 2010).

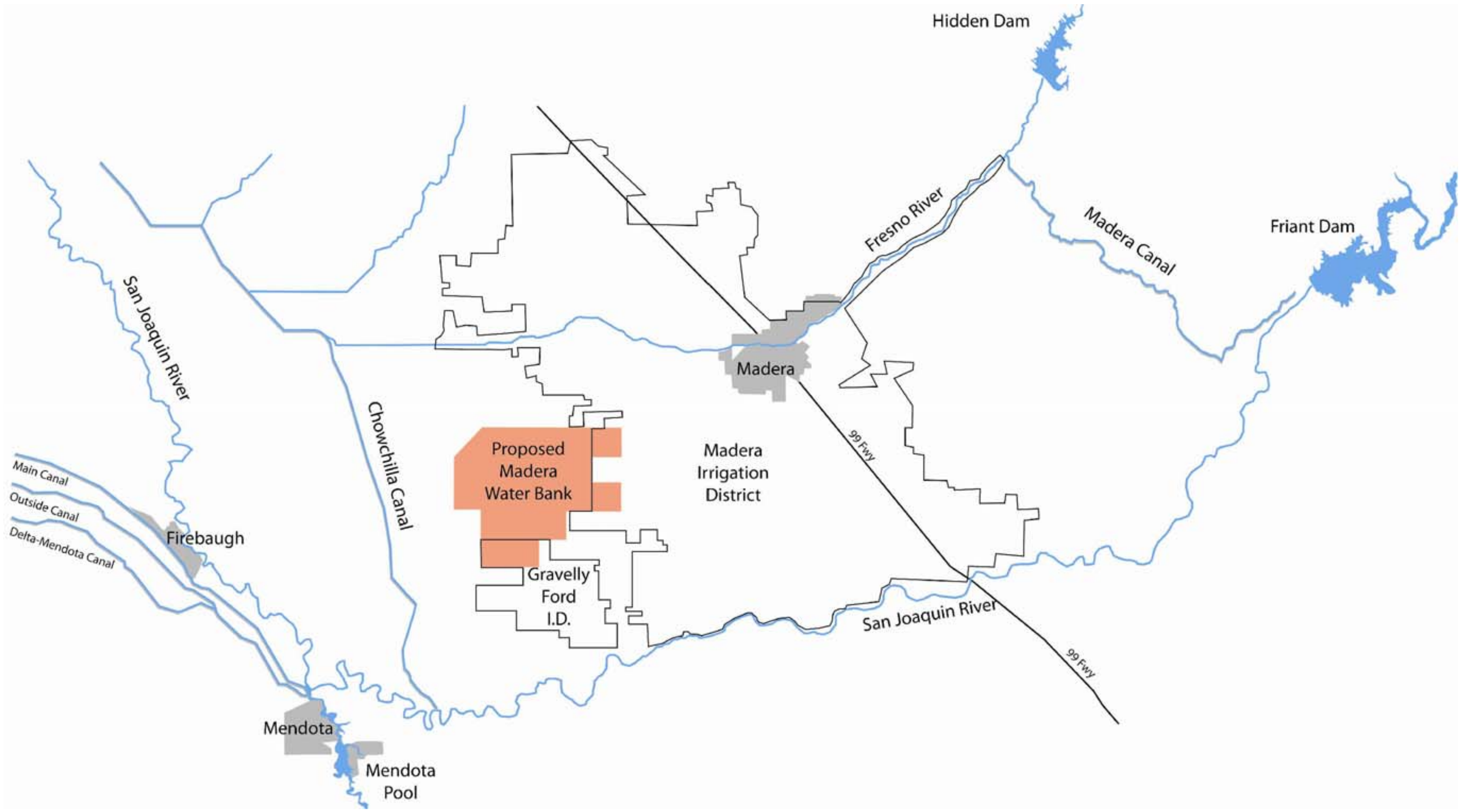


Figure 7.3: Water Infrastructure and Rivers Near Madera Ranch
(Data from IWRIS)

During drought years, many farmers in the Madera Irrigation District depend on groundwater withdrawals to augment the lack of surface water supply. Since groundwater pumping is not managed in the area surround Madera Ranch, a *de facto* policy of groundwater mining has developed. Figure 7.4 shows that the average Madera Basin groundwater levels have declined over 65 feet from 1945 to 2003. The goal of the proposed Madera Water Bank is to help reverse overdraft, reduce dependency on outside sources of water, and improve local water security. The project is meant to benefit landowners within the Madera Irrigation District and Gravelly Ford Irrigation District.

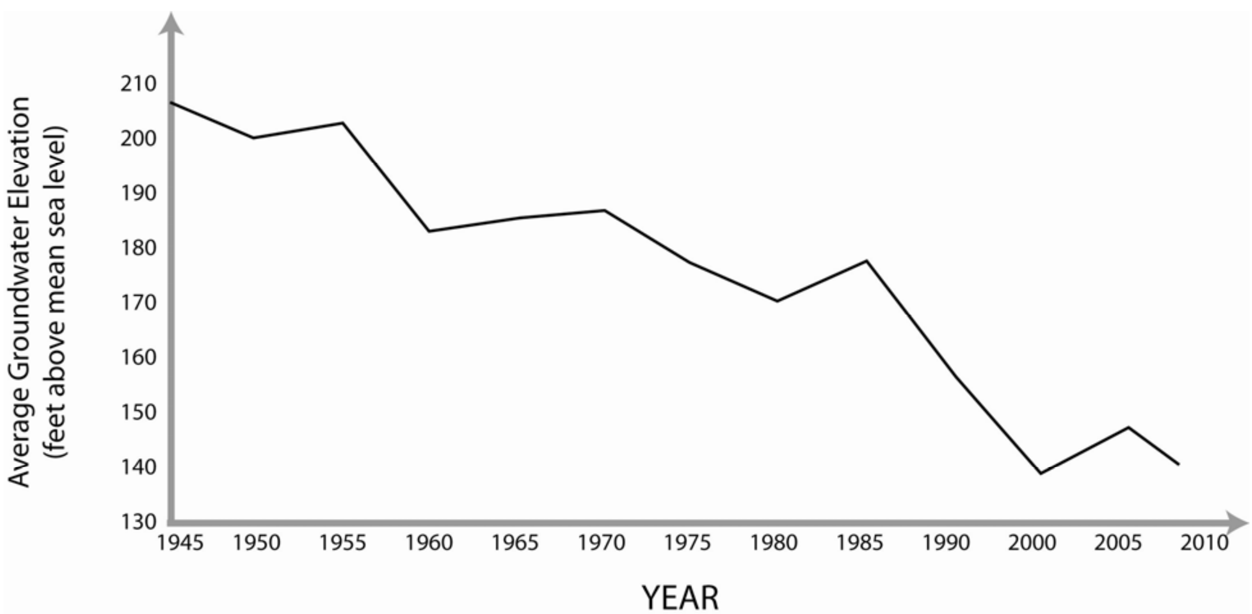


Figure 7.4: Average Madera Basin Groundwater Levels (based on Bureau of Reclamation, 2008)

7.2.3 Agriculture, Land Use, and the Border Problem

Agriculture is the largest single land use in Madera County, making up 47% or 648,300 acres of the total county area (Bureau of Reclamation, 2008). Considering that a sizable portion of Madera County extends into the foothills of the Sierra Nevada Range, where soils and topography are not conducive to irrigated agriculture, by far the majority of the county on the valley floor is used for agriculture.

The top five crops in the county in 2007 were almonds and nuts, grapes, pistachios, and cattle for milk and meat. About 86% of the cultivated land in Madera County is in permanent crops, including almonds and nuts, grapes, and pistachios, which cannot be easily fallowed or abandoned from one year to another (Bureau of Reclamation, 2008).The high percentage of permanent crops means that the region depends on a consistent source of water to prevent damage to the permanent crops.

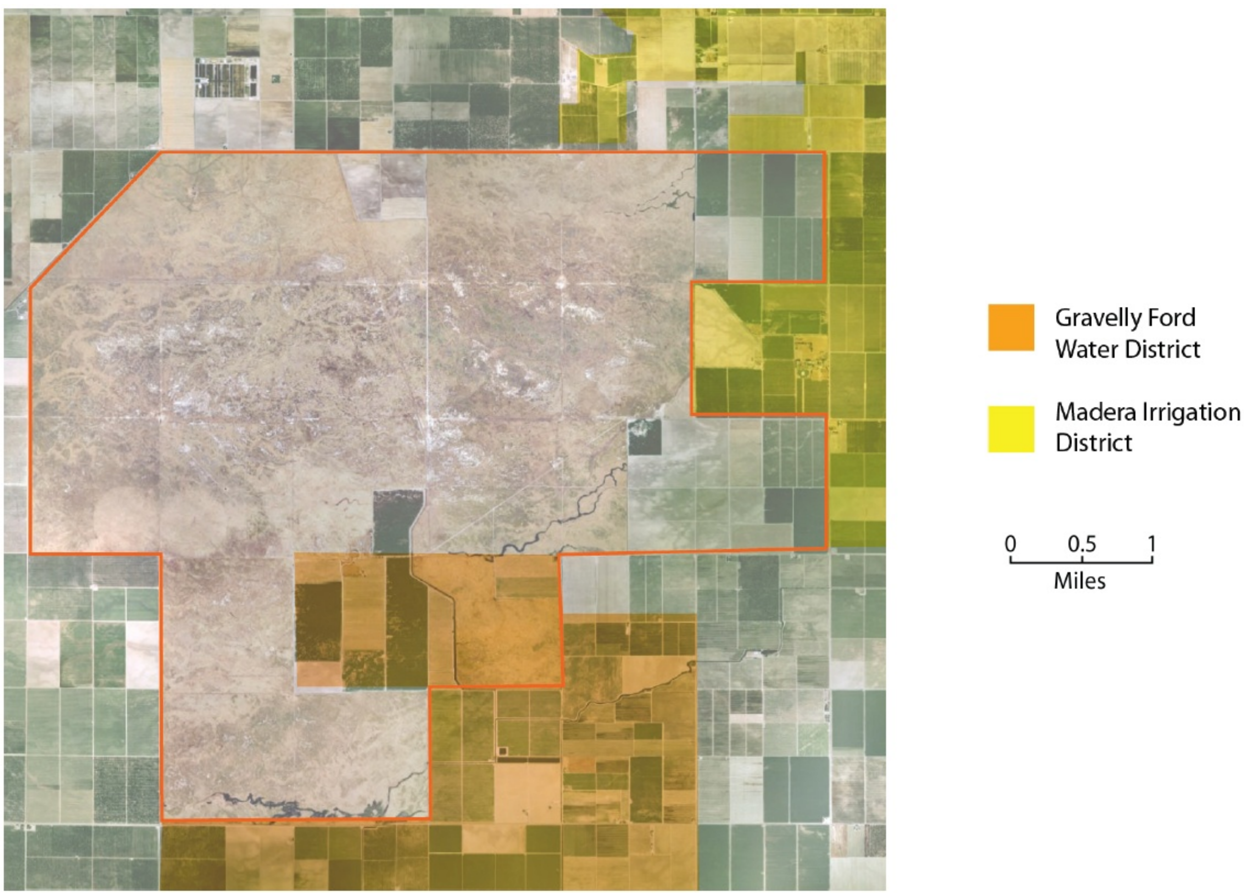


Figure 7.5: Site Aerial with Madera Ranch Property Delineated

On the Madera Ranch site, the vast majority of the land is used for grazing, with a small portion of the area used for crop production. Nearly all the land bordering the Madera Ranch site is in agricultural production. The contrast between the grazing land and the agricultural production is evident in Figure 7.5. Figure 7.6 shows the specific crop types and land use in and adjacent to Madera Ranch.

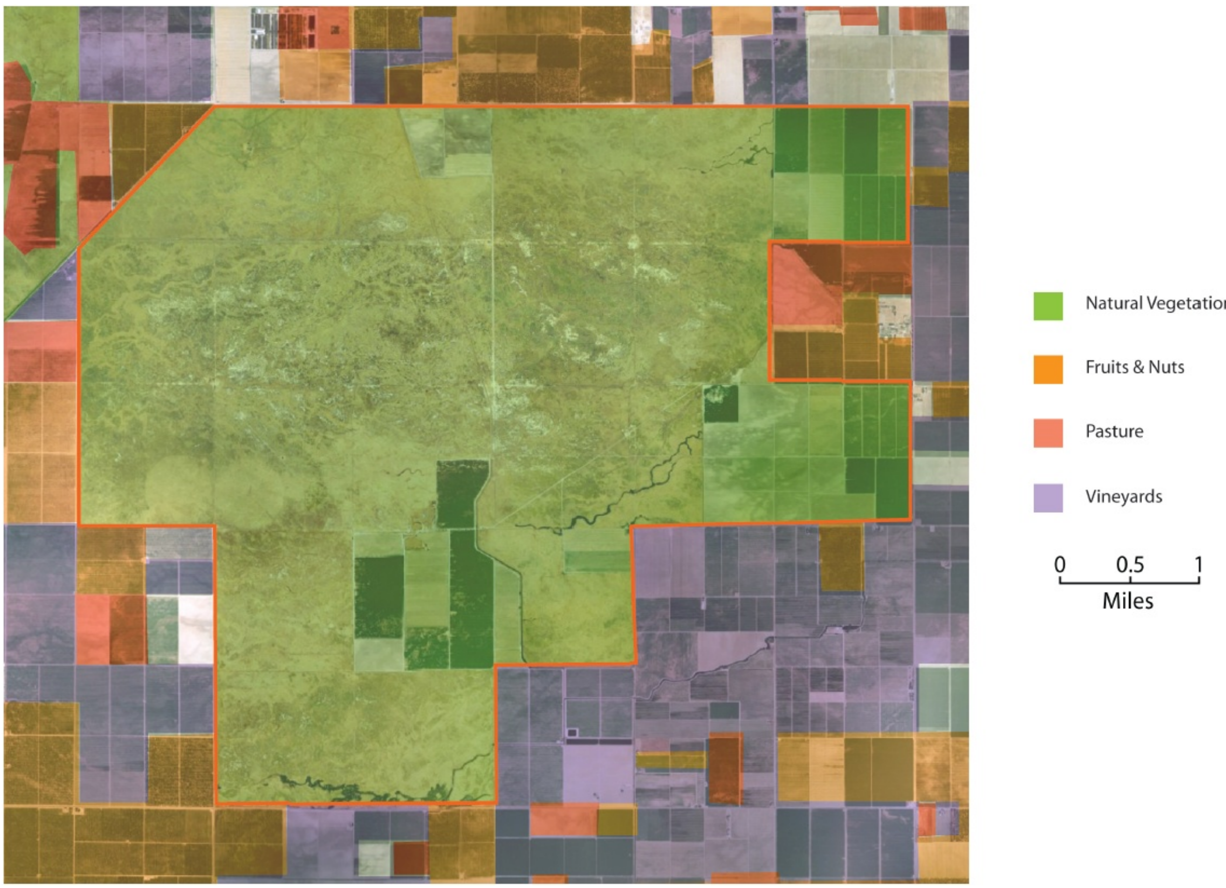


Figure 7.6: Land Uses Adjacent to Madera Ranch
(based on Bureau of Reclamation, 2008)

A portion of the south eastern corner of the property is in Gravelly Ford Water District and the eastern edge of the property is in the Madera Irrigation District (Figure 7.5). Both of these districts are partners in the proposed Madera Water Bank. The entire western border and most of the northern border separates Madera Ranch from private farmers who are not affiliated with either Gravelly Ford Water District or Madera Irrigation District. Since most of the farmers adjacent to the project who are not part of the irrigation districts will not benefit from the project, they could be opposed to the project on the grounds that they could be exposed to the risks—from a lowered groundwater table due to project pumping, or root flooding from infiltrated water—without having any direct benefits.

7.2.4 Soils

The San Joaquin Valley is a large structural trough filled with a thick layer of alluvial sediment that is generally highly permeable (Bailey, 1966). Figure 7.7 shows the Madera Ranch site soils and geology in a larger regional context. The site sits on top of basin and alluvial fan deposits consisting of gravels, sands, silts, and clays deposited by rivers and streams.

Figure 7.8 shows the soils on the Madera Ranch site from a survey done by the Natural Resources Conservation Service (NRCS) in the 1950s. The survey, however, was completed before much of the area in and around Madera Ranch was cultivated. Agricultural practices may have altered the composition and distribution of the soils.

Soil composition played an important role in deciding the location of the recharge swales for the proposed Madera Water Bank. The recharge swales are generally over soil from more recent alluvial flood deposits, which have lower salt content and relatively high permeability. The swales are mostly underlain by the Pachappa Series soils, which usually consist of fine sand loams and sand loams. Pachappa soils are moderately rapidly permeable and are well-drained. Designing the infiltration swales over the Pachappa soils allows water to soak into the ground more rapidly than less permeable soils and can allow water to be pumped out with less energy expended than would be used for extraction from less permeable soils.

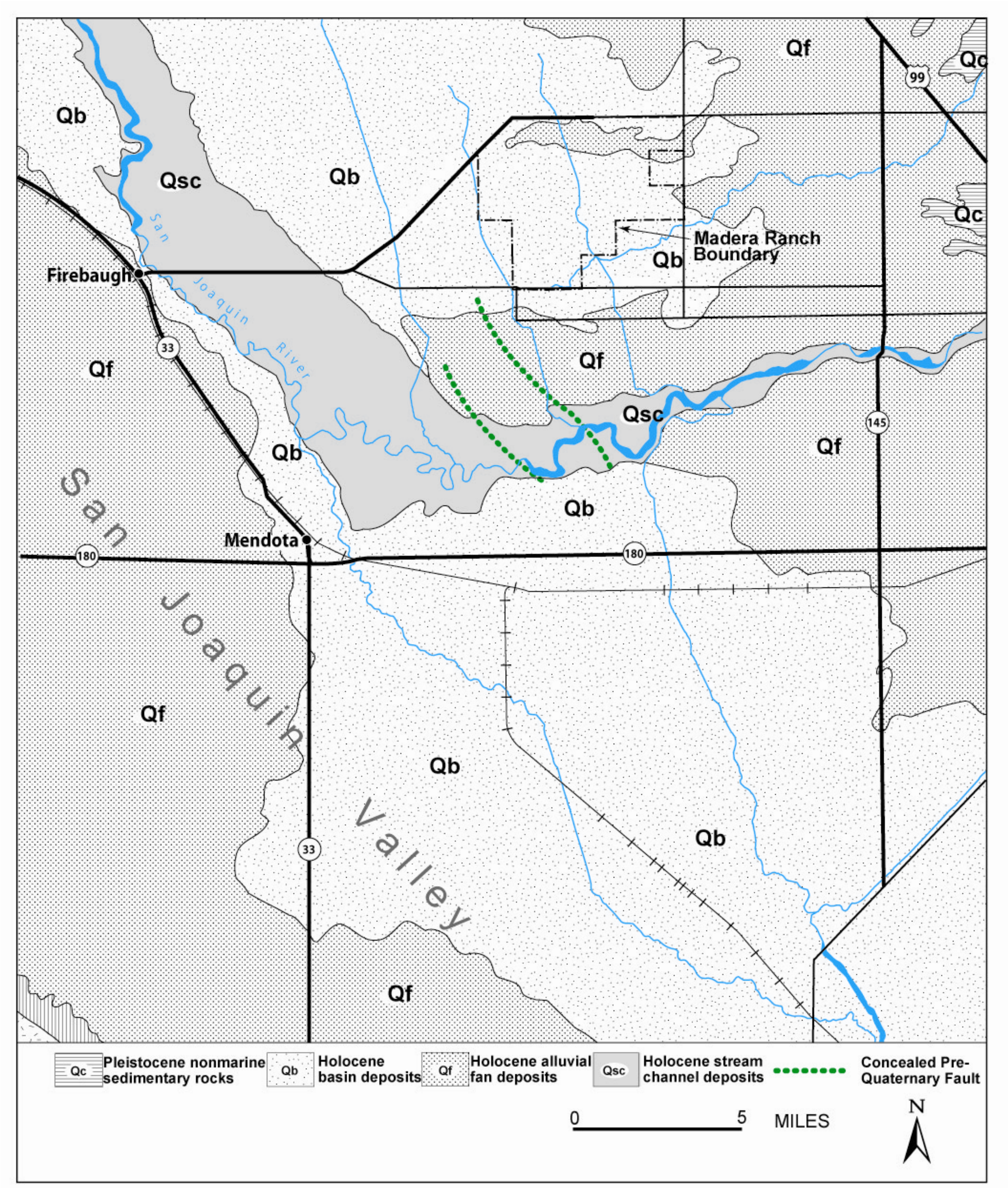


Figure 7.7: Regional Geology (Bureau of Reclamation, 2008)

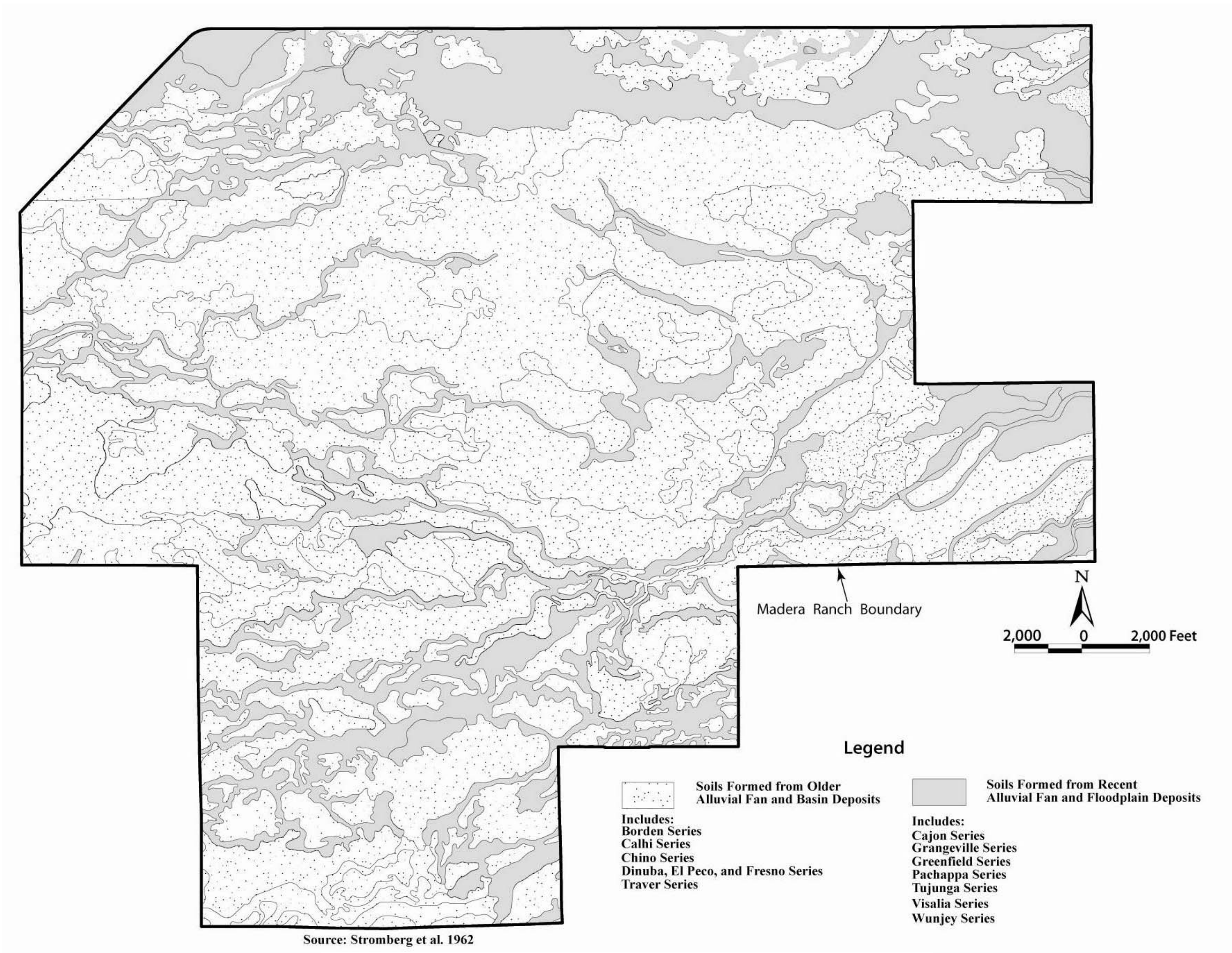


Figure 7.8: Madera Ranch Soil Survey (Bureau of Reclamation, 2008)

7.3 Project History

7.3.1 Perrett and the USBR (1996-1999)

Mr. Herbert Perrett, former owner of the Madera Ranch site, presented the idea of developing a groundwater bank on the property in 1996 to the United States Bureau of Reclamation (the Bureau). The Bureau was interested in the site to provide supplies for drought years and to help meet the requirements of the Central Valley Project Improvement Act (Thomas et al., 2008).

The Bureau completed a number of studies to explore the viability of a groundwater banking project and decided the Madera Water Bank was a viable project to pursue. Local farmers, particularly those adjacent to the site, were concerned that pumping from a groundwater bank would lower the levels of the groundwater table during droughts, thereby making it more difficult to pump groundwater for surrounding farmers. There was also concern that water banked during the rainy season would raise the groundwater table and could drown out the root zone of their crops, damaging the crops of adjacent farmers.

Figure 7.9 shows a project timeline obtained from the Thomas et al. (2001) report. Opposition from local landowners stalled the project. The Madera County supervisors were concerned that a water banking project would lead to water being exported outside of the area, and passed a groundwater ordinance forbidding groundwater to be moved outside the county. The supervisors also passed a resolution opposing the project in 1999. The Bureau sold the Madera Ranch site to the Azurix Corporation in 1999, thereby ending the first attempt to implement the Madera Water Bank.

MADERA RANCH GROUNDWATER BANKING PROJECT CHRONOLOGY 1996–1999	
EVENT	**DATE**
Mr. Heber Perrett purchases the Madera Ranch property	May 1991
USBR receives Madera Ranch Groundwater Banking Project Proposal	August 1996
Preliminary evaluation is completed (fatal flaws analysis, capacity analysis)	July 1997
Agreement for two-phase investigation is made	November 1997
Phase 1 Investigation starts	December 1997
USBR issues press release and holds two public briefings	January 1998
Bookman-Edmonston provides study results to Perrett and USBR	February 1998
Phase 1 Report completed (field tests, technical issues identified)	April 1998
Perrett conducts on-site tour of Madera Ranch for local landowners	May 1998
Area farmers and representatives of local water districts form grassroots Madera Ranch Oversight Committee to monitor project	August 1998
Oversight Committee gathers information and makes presentations opposing the project	September1998–March 1999
USBR releases Bookman-Edmonston study to the general public	September 1998
Emergency congressional appropriation attempts to fund land acquisition of Madera Ranch	September 1998
Various local agencies voice concerns and opposition to land acquisition prior to the completion of comprehensive studies	September/Oct 1998
CALFED rejects $14.5 million funding request by USBR due to local opposition	October 1998
USBR extends project timeline by 18 to 24 months due to local opposition	October 1998
USBR meets with Friant Users Authority and Oversight Committee	October 1998
Freedom of Information Act request is filed	December 1998
Madera County Supervisors pass groundwater ordinance and resolution opposing project	March 1999
Landowner sets deadline for USBR action	1999
Azurix purchases Madera Ranch site from landowner	October 1999

Figure 7.9: Timeline of Madera Ranch Groundwater Banking Project, 1996-1999 (Thomas et al., 2001)

7.3.2 Azurix Madera Corporation (1999-2001)

The Madera Ranch property was purchased by Azurix, a subsidiary of Enron in 1999. Azurix intended to expand its holdings to included water supply distribution and water treatment in the western United States. Azurix intended to use the Madera Ranch property for a water bank to help create a speculative market for water. The company established a web forum, www.water2water.com, in which investors could purchase holdings in the water bank. An announcement in the Wall Street Journal in February 2000 explained how the online market would work: “Azurix Corp., a Houston-based water company, is launching an exchange on the Internet for buying, selling, storing and transporting water in the West, hoping to make water a traded commodity much like natural gas or electricity (CBC News, 2004)." Azurix's then CEO, Rebecca Mark, explained the concept behind water2water.com: "until now, who gets water has been a government decision. It's time to assign more economic value to the resource, and that's what a market can do. What we're after is the creation of a market (Public Citizen, 2002)." Local farmers were concerned about how the proposed online speculative water market would work and how it would impact the groundwater table, and the opposition encountered previously against the Madera Water Bank was revived (Figure 7.10). Farmers mounted a campaign against the Azurix Corporation. Eventually, the project was abandoned as a result of the collapse of Enron and the failure of the online forum to generate sufficient profit. Azurix was sold in 2001 and the Madera Water Bank was again put on hold (CBC News, 2004).

Figure 7.10: A Sign in Local Campaign Against Azurix
(from http://www.cbc.ca/fifth/deadinthewater/california.html)

7.4 Current Project Development

The Madera Irrigation District revived the Madera Water Bank project in 2006, and completed a pilot groundwater banking study on the site from February 2007 to April 2009. The Bureau of

Reclamation published a draft Environmental Impact Statement in 2008 because the project requires storing Central Valley Project water outside the service area of the Madera Irrigation District. The agencies involved in the project are the Bureau of Reclamation, the Madera Irrigation District, who currently owns the Madera Ranch property, and the Gravelly Ford Water District.

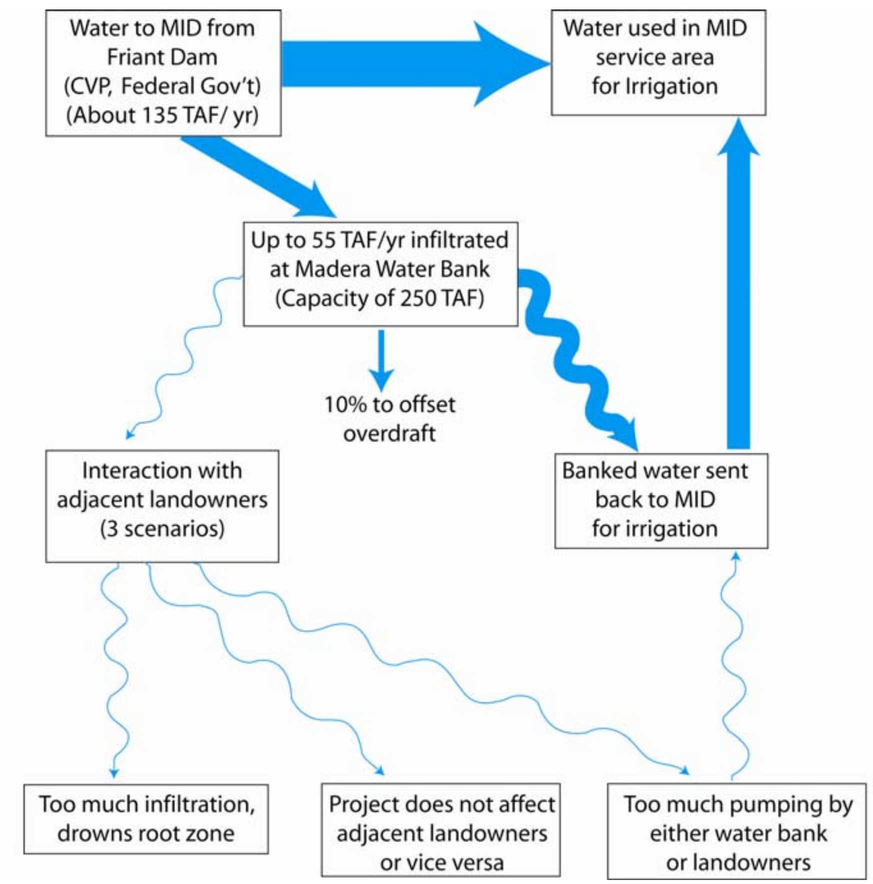


Figure 7.11: Conceptual Model of Madera Water Bank
(thin blue lines indicate sources of uncertainty)

7.5 Conceptual Model

Figure 7.11 is a conceptual model of the operation of the proposed Madera Water Bank and the sources of uncertainty. The source of the banked water for the Madera Irrigation District is water from Friant Dam, which is part of the Central Valley Project, managed by the Bureau of

Reclamation. Friant Dam delivers about 135,000 acre-ft per year to the Madera Irrigation District. Up to 55,000 acre-ft per year would be sent to be infiltrated in the Madera Water Bank. Ten percent of the water would be set aside to reverse overdraft. The banked water could be recovered later and sent back to customers in Madera Irrigation District or the Gravelly Ford Irrigation District.

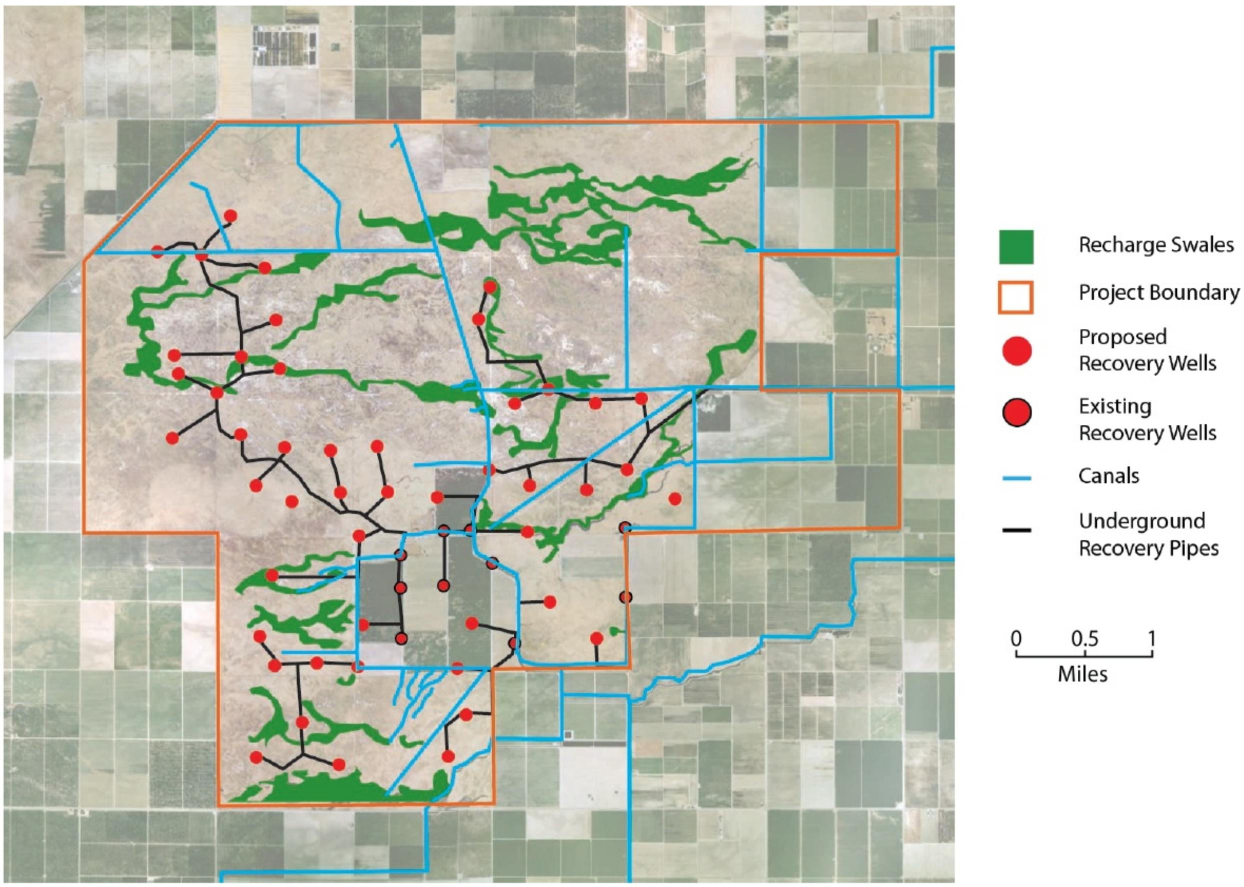


Figure 7.12: Proposed Project Operations of Madera Water Bank (based on Bureau of Reclamation, 2008)

There are, however, three different scenarios of how the water bank operations could interact with the adjacent landowners. First, if too much water is infiltrated, it could drown the out the root zone and kill permanent crops. Second, if the Madera Water Bank operators pump too much water, it could lower the groundwater levels for the adjacent landowners. It is also possible that the adjacent landowners could extract large amounts of groundwater, which could affect the project operations. The third possibility is that the project operations would not affect the adjacent landowners, or vice versa. Figure 7.12 shows the preferred alternative for recharge swales, recovery wells, canals, and underground recovery pipes for the Madera Water Bank. The recovery wells are located either adjacent to or overlying the recharge swales.

7.6 Model Predictions and Managing Uncertainty

Despite a detailed understanding of the geology, there is still a significant amount of uncertainty about what will happen to the water once it infiltrates into the ground. The MID modeled groundwater and surface water interactions for the project, and found that the modeled predictions "would not provide sufficient security" for the adjacent property owners who were concerned that the operations of the water bank could either flood the root zone of their crops during times when water is infiltrating or could lower the water table significantly when the banked water is being recovered (Bureau of Reclamation, 2008).

The EIS describes a monitoring program established partially in response to concerns of adjacent landowners. In order to monitor groundwater levels, the Monitoring and Operational Constraints Program (MOCP) was proposed. The MOCP is a group with 10 members, including 5 MID board members, 3 independent members who represent the interests of the surrounding landowners, a county supervisor, and a board member from the adjacent Gravelly Ford Water District. The MCOP meets monthly during periods of recharge and prepares an annual monitoring report. The MOCP reviews monitoring data to protect the adjacent landowners from risks and would make recommendations on how to adjust operations if impacts do occur, as well as make suggestions for how to improve monitoring. The MID is responsible for the operation of the monitoring wells themselves as the water bank operates (Bureau of Reclamation, 2008).

Overall, the Madera Water Bank project can provide a source of local supply and address issues of overdraft. The project design takes the local hydrogeology into account. The monitoring program may address the local concerns over the effects of project operations on adjacent landowners. However, since there is no control or information about adjacent landowner pumping, management becomes more difficult. The lack of control over groundwater pumping creates mutual frustration: for the adjacent landowners, who aren't sure how their groundwater levels will be impacted by the project, and for the project managers, who can't make informed predictions without a basic understanding of pumping by adjacent landowners. The next chapter addresses how implementing a locally-run groundwater permitting system can overcome this mutual frustration.

References

Bailey, G.W. 1966. "Proceedings of Symposium on Agricultural Waste Waters." Water Resources Center, University of California, Davis. Report 10, pg. 94.

Bureau of Reclamation. 2008 "Madera Irrigation District Water Supply Enhancement Project Draft EIS." Web. 01 Sept. 2009 < http://www.usbr.gov/mp/nepa/nepa_projdetails .cfm?Project_ID=3128>.

CBC News. 2004. "California: Enron and the Dot Com Bubble that Burst" Web. 23 Apr. 2009. <http://www.cbc.ca/fifth/deadinthewater/california.html>.

Grossi, Mark. 2010. "San Joaquin River's Flow Extends to the Pacific Again." Fresno Bee. Web. 24 Mar. 2010 < http://www.fresnobee.com/2010/03/24/1871224/san-joaquin-river-flows-to-pacific.html>.

Public Citizen. 2002. "Liquid Assets: Enron's Dip into Water Business Highlights Pitfalls of Privatization." Public Citizen's Critical Mass Energy and Environment Program. Web. 16 Nov. 2009. <http://www.citizen.org/cmep>.

Thomas, Gregory, David Brown, Nicholas Pinhey, Jennifer Spaletta, and Peter Kiel. 2001. "Designing Successful Groundwater Banking Programs in the Central Valley: Lessons from Experience." Natural Heritage Institute. Web. 07 Feb. 2009 <http://www.n-h-i.org/uploads/tx _rtgfiles/7550_Conjusefinal.PDF >.

Western Regional Climate Center. 2009. "Madera, California Period of Record General Climate Summary." From: http://www.wrcc.dri.edu/cgi-bin/cliGCStP.pl?ca5233.

8.0 Conclusions & Recommendations

The case study analyses in the previous chapters show that groundwater management is a prerequisite to implementing conjunctive management. A common thread running through each case study is the issue of control over groundwater pumping—a type of groundwater management. The Tehachapi Basin adjudication is a successful arrangement because there is a high degree of control on landowner pumping to address the overdraft that occurred when landowners pumped water without any limitation. In the Kern Water Bank, the Memorandum of Understanding among the project participants clearly defines how water pumped from the project is divided among participants. In addition, the geology of the site allows nearly all of the infiltrated water to be extracted by recovery wells. The heart of the adjacent landowner opposition to the proposed Madera Water Bank is the uncertainty about how the project will affect them. However, the reason for the uncertainty about project operations is not knowing or having control over the pumping rates of adjacent landowners.

Although the Tehachapi Basin and the Kern Water Bank have developed mechanisms to allow an element of control over groundwater extractions, the proposed Madera Water Bank shows the difficulties of developing a conjunctive management project in a realm fraught with uncertainty due to a lack of understanding or predictability of pumping by adjacent landowners. Under current California law, where groundwater can be extracted without limits and the ownership of water infiltrated into an aquifer is nebulous, there exists little incentive to develop conjunctive management projects—a cheaper, more environmentally-beneficial form of storage closer to the point of use than dams. Why would an irrigation district or municipality invest in a project when a very basic question is unanswered: If my agency develops this project, will we be able to guarantee that the water we infiltrate can be recovered? In order to encourage the development of conjunctive management projects, the legislature must quantify the rights to pump groundwater in areas that need management the most.

In this chapter, I outline a continuum of groundwater management, compare the three conjunctive management case studies, evaluate current groundwater management practices and the recently passed groundwater reform. Finally, to address the uncertainty inherent in current groundwater management, I develop a locally-run groundwater permitting system that can encourage conjunctive management projects by providing better information and a mechanism to control groundwater extraction.

8.1 The Groundwater Management Continuum

Based on my review of groundwater management practices and the three conjunctive management projects, I developed a conceptual diagram of groundwater management (Figure 8.1). The lower the strength of groundwater management, the higher freedom there is for individuals to pump. In the weakest form of management—essentially no management at all—the law of capture allows overlying landowners to pump as much water as desired without regard to impacts on adjacent landowners. In California, groundwater must be extracted reasonably and used beneficially, which is a slightly stronger form of management. Reasonable extraction means that landowners cannot take unlimited amounts without regard to affects on adjacent landowners (BLM, 2001). Each landowner has a shared or correlative right to groundwater use (BLM, 2001). "Beneficial" use is a broadly defined term and includes industrial, agricultural, and municipal uses (BLM, 2001).

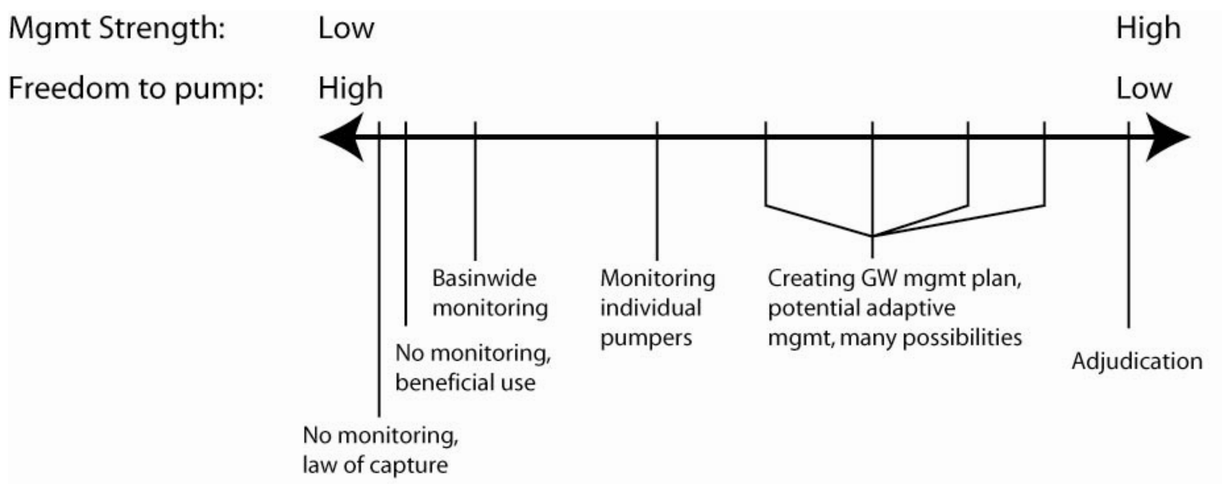


Figure 8.1: Conceptual Diagram of Groundwater Management

Either the law of capture or beneficial use may be coupled with basin-wide monitoring of groundwater levels. This provides a stronger form of management since managers can estimate the amount of water stored in an aquifer and, over time, can develop estimates of aquifer extraction. Developing a groundwater management plan is a significant step in improving groundwater management, but there can be a wide variety in the strength and effectiveness of a groundwater management plan. The most stringent form of groundwater management is adjudication, a legally binding arrangement where landowners agree to extract only a certain amount of groundwater and are generally monitored individually to ensure that landowners stay within their pumping limits.

8.2 Case Study Comparison

A comparison of the size, maximum amount recharged and recovered, and the estimated storage of the proposed Madera Water Bank, the Tehachapi Basin, and the Kern Water Bank shows there is no general relationship between these factors (Figure 8.2). The three different projects range in size from 13,600 acres to 38,000 acres. The Kern Water Bank has the largest recharge and recovery rates, at 450,000 and 240,000 acre-ft per year, respectively. The Kern Water Bank also has the largest estimated storage at 1,000,000 acre-feet. The safe yield of 5,500 acre-feet in the Tehachapi basin is by far the lowest of the three, an order of magnitude less than the Madera Water Bank and about one-fiftieth of the maximum recovery of the Kern Water Bank. The amount of water recharged and recovered and the maximum amount of water are highly dependent on the local geology and aquifer properties underlying the project site, which differs for the three locations. Also, the amount of water available for recharge is another important factor and varies between the three projects.

Project Name	**Project Size**	**Maximum Amount Recharged/Recovered (acre-ft per year)**	**Maximum Storage (acre-ft)**
Madera Water Bank (Proposed)	13,600 acre project	55,000 recharge 55,000 recovery	250,000
Tehachapi Basin	38,000 acre basin	5,500 safe yield	375,000
Kern Water Bank	20,000 acre project	450,000 recharge 240,000 recovery	1,000,000

Figure 8.2: Case Study Comparison

The Tehachapi Basin has a much lower recovery rate since most of the water infiltrated comes from local rainfall, compared to the Kern Water Bank and Madera Water Bank, which receive water from outside sources. In addition, the adjudication was specifically intended to address overdraft issues so the safe yield was set lower than the annual natural recharge to allow aquifer levels to recover. This strategy has worked, since the groundwater levels rose over 70 feet since the basin was adjudicated.

Despite the success of the Tehachapi Basin adjudication in reversing overdraft problems and arriving at clearly defined pumping rates that overlying landowners agreed to, adjudication may not be an applicable model for many other groundwater basins in California. The Tehachapi Basin is a geologically contained and well-defined groundwater basin, has about 100 landowners, and is entirely within the Tehachapi-Cummings County Water District. The groundwater pumped in the Tehachapi Basin is only allowed to be used within the basin. Many groundwater basins in the Central Valley are much larger, cross multiple jurisdictions, and involve a large number of landowners. Also, many conjunctive management arrangements involve moving banked groundwater outside of a basin. Although California law allows any groundwater user to initiate a groundwater adjudication, the difficulty in terms of time and cost of initiating an adjudication is daunting. For example, in the entire Tulare Basin, there are at least 10,000 individual pumpers. Determining pumping rates based on historic data in a groundwater adjudication is a formidable task.

The Kern Water Bank bears the most similarities to the proposed Madera Water Bank in terms of acreage, recharge and recovery, the maximum project storage, and management arrangements. Unlike the Tehachapi Basin project, both the Madera Water Bank and Kern Water Bank deliver water to users outside the project boundary. A major element that allowed the Kern Water Bank to be successful was the adoption of a Memorandum of Understanding among the parties involved that included extensive monitoring of groundwater levels and allowed an element of adaptive management.

A major difference between the Kern Water Bank and the Madera Water Bank is that the all of the surrounding irrigation districts and landowners are beneficiaries of the Kern Water Bank, while the Madera Water Bank benefits landowners in the Madera and Gravelly Ford Irrigation Districts, but not some landowners immediately adjacent to the project site.

Overall, my findings about factors that lead to the success of conjunctive management projects are consistent with those of Thomas et al. (2001), namely that successful projects are locally managed, and have trust among parties, good information for management, quantified pumping rates, financial rewards, and minimal legal and hydrologic risk. It is possible to institutionalize and manage the uncertainties in hydrogeology. California's lack of effective groundwater management, however, presents a number of barriers for implementing conjunctive management.

8.3 Current Groundwater Management and Recent Reforms

8.3.1 How is groundwater currently managed?

Groundwater plays an important role in the state's water supply, especially during droughts. According to a USGS study, the lack of groundwater management in the San Joaquin Basin has lead to an overdraft of 61 MAF since 1961 (Faunt, 2009). The Department of Water Resources (DWR) has a monitoring network of 35,000 wells to measure water quality and aquifer levels. Many of these wells have large gaps in their records, have only operated for a few years, or were only active in the past. The DWR has sporadically released Bulletin 118 to characterize the state's groundwater resources. The most recent Bulletin 118 was released in 2003 and the prior

Bulletin 118 was released 23 years before that, in 1980. The state does not monitor individual pumpers. There is no statewide regulation of groundwater.

Since groundwater is an important source of water supply and it is not managed by the state, the Legislature should make a number of changes to its current policies, outlined in greater detail in the following sections. However, it is possible that the legislature will not address groundwater management in the near future, so it is important to understand how groundwater is currently (however poorly) managed.

As explained in Chapter 4 on the economics of conjunctive management, absent regulations on groundwater pumping, landowners have an incentive to pump groundwater if no surface water is available or as long as the cost of pumping groundwater is less that the cost landowners pay for surface water. In many parts of the San Joaquin Basin, inexpensive surface water has made it not economical to pump groundwater, and landowners tend to only pump groundwater if no surface water is available. The recent reductions in surface water deliveries many indicate more pressure for landowners to extract groundwater.

AB 3030 and SBX7-6 are two relatively recent bills that address groundwater issues in California. The Legislature passed AB 3030 in 1992, which allows local agencies to develop a groundwater management plan in groundwater basins as defined by DWR's Bulletin 118. AB 3030 provides a framework for developing a groundwater management plan. The bill sets out a list of procedures for adopting a groundwater management plan. It also suggests a number of components that may be in a groundwater management plan, including:

- Monitoring groundwater levels and groundwater storage
- Mitigating conditions of overdraft
- Identification of well recharge areas
- Replenishing extracted groundwater and
- Facilitating conjunctive management

There are some key limitations to AB 3030. First, if a majority (defined as over 50% of the value of land) protests the formation of a plan, the plan is not adopted. Second, creating a plan is voluntary to begin with. Third, there are no required elements in the groundwater plan, only suggested ones.

8.3.2 Groundwater Reform?

In November 2009, California passed a water reform bill. SBX7-6 was passed as part of the bill and changes how the state manages groundwater. According to SBX7-6, by January 1st, 2012, all groundwater basins as defined by the DWR need to release information about the groundwater levels within the basins, and do so in years ending with a 5 or 0. If a basin has multiple water agencies, the agencies must work together to produce a report on groundwater levels. If the state does not receive a report, the DWR can obtain its own information on groundwater levels and bill agencies in the basin and withhold state water grants and loans. Although SBX7-6 takes an important step by requiring agencies in a basin to cooperate and regularly report groundwater levels, the state still does not regulate groundwater withdrawals and does not monitor individual pumpers. The lack of significant progress of the state in groundwater management suggests that the legislature is either unwilling or unable to take an active role in groundwater management. A more viable option is to promote management on a local level, discussed in the final section.

Based on a rough estimation, the state is only using 0.5% of the total capacity of groundwater storage in the San Joaquin Basin as storage for conjunctive management projects. The lack of statewide groundwater management plays an important role in understanding why the potential for conjunctive management is so underutilized. Since agencies and managers cannot obtain information about local groundwater levels and pumping rates in unregulated groundwater basins, they are unable to present a clear or accurate picture about how a proposed conjunctive management projects might work. Landowners adjacent to or nearby a proposed conjunctive management project can rightly protest a project on the grounds that that the project operators are unsure how a project will operate—in part, because the project operators have no information about how much groundwater the landowners pump. Due to the legal and management uncertainties, many conjunctive management projects can take years to be implemented. For example, after a series of studies dating back to the 1970s, the Kern Water Bank was formally proposed by the Department of Water Resources in 1986. It took another 9 years for the project to begin operating in 1995. Barring a change in groundwater management, conjunctive management projects will probably continue to be established at a slow rate and will persist in underutilization of California's massive groundwater storage capacity.

8.4 Statewide Water Reform

A number of suggestions have been offered to reform how California's water management. The negotiations that led to the recently passed water legislation and the relatively small changes that emerged in terms of statewide water management suggest that any major changes in how water is currently managed on the state level will be met with political resistance.

California's Legislative Analyst's Office, a non-partisan office that provides fiscal and policy advice to the Legislature, wrote a report in 2009 (prior to the water reform bill) that highlights a number of issues affecting water management in the state and presents suggested changes to water management and water rights on the state level (Freeman, 2009). The issues include:

- **Over-allocation of surface water**: On almost every river system, water rights are greater than the actual water availability. Some of the water used is returned back to rivers, but in many cases, water rights are over-allocated.
- **Multiple institutions, limited resources**: Many separate institutions are involved in administering water rights, including the State Water Resources Control Board, Department of Water Resources, Department of Fish and Game, and the court system. The State Water Resources Control Board is in charge of enforcing water rights, but does not have the resources to seek out illegal diversions.
- **Importance of groundwater, lack of legal control**: Groundwater provides up to 30 percent of California's water supplies in an average year and up to 40 percent in drought years. There is no statewide groundwater rights system, although the state does support local groundwater management (Freeman, 2009).

The Legislative Analyst's Office presents a number of suggestions in the report to address these issues, including:

- **Water rights reform**: The state should "realign the water rights system to better reflect modern needs and circumstances" so that water rights reflect a more reasonable use of water. The Legislature could comprehensively define the reasonable and beneficial use of water.
- **Groundwater rights**: The Legislature should establish a water rights system for groundwater that is administered by the state. Local management of groundwater should be authorized and encouraged (Freeman, 2009).

Considering the non-partisan status of the Legislative Analyst's Office, and office's history of providing unbiased information to the Legislature, the Legislature should consider implementing these suggestions. More drastic changes to California's water policy beyond those suggested by the LAO—although they may be needed and beneficial to the state—may be unrealistic to implement.

8.5 Creating a Locally-Run Groundwater Permitting System

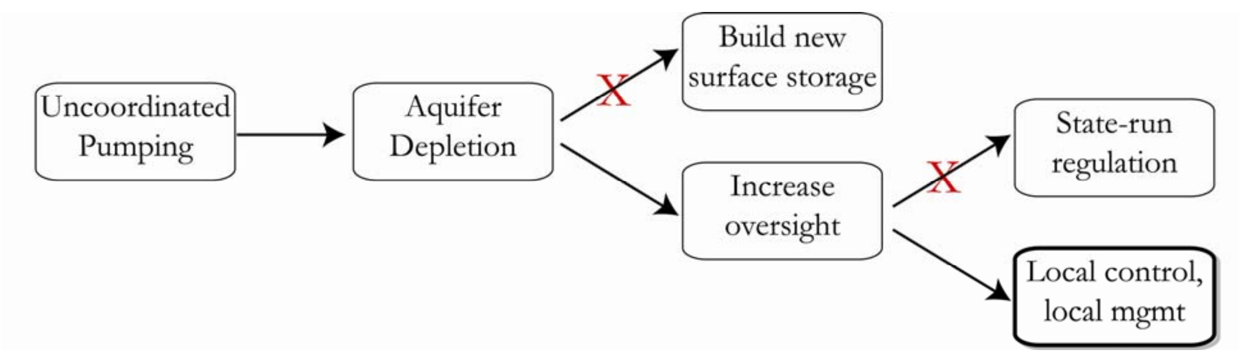


Figure 8.3: Decision tree leading to a locally managed groundwater permit system

This section develops a locally-run groundwater permitting system that the legislature can implement to address the inherent uncertainties in the current system. As outlined in the introductory chapters, uncoordinated pumping in the San Joaquin Basin has led to aquifer depletion. The State has historically built new surface water storage, including the Central Valley Project and the State Water Project, to address groundwater overdraft. Since this is no longer a viable option due to economic and ecological reasons, the alternative approach to address aquifer depletion is through increasing control over groundwater extraction (Figure 8.3).

Figure 8.4: Addressing Political Issues by Shifting Responsibility from the State to local groundwater basins

The local control of groundwater is a consistent theme in California's history. As discussed in Chapter 2, dating back to the development of the State Water Code of 1914, the state has been reluctant to regulate groundwater extraction. Current groundwater management in California developed through a series of court decisions rather than legislative action. Interest groups were opposed to the groundwater reforms proposed in the 1982 Water Resources Conservation and Efficiency Act on the grounds that it would reduce local control over water resources, which led to lack of support for the associated proposition and its ultimate defeat by the electorate.

The California Water Code (§ 10750 (a)) directly addresses the role of local agencies: "it is the intent of the legislature to encourage local agencies to work cooperatively to manage groundwater resources in their jurisdiction…" Considering political factors and the position of the legislature, the most palatable version of groundwater management is through local control of groundwater resources (Figure 8.4). In the following sections, I develop a locally-run groundwater permitting system with three general steps: 1) identifying decline 2) stabilizing decline and 3) groundwater level recovery.

8.5.1 Identifying groundwater decline

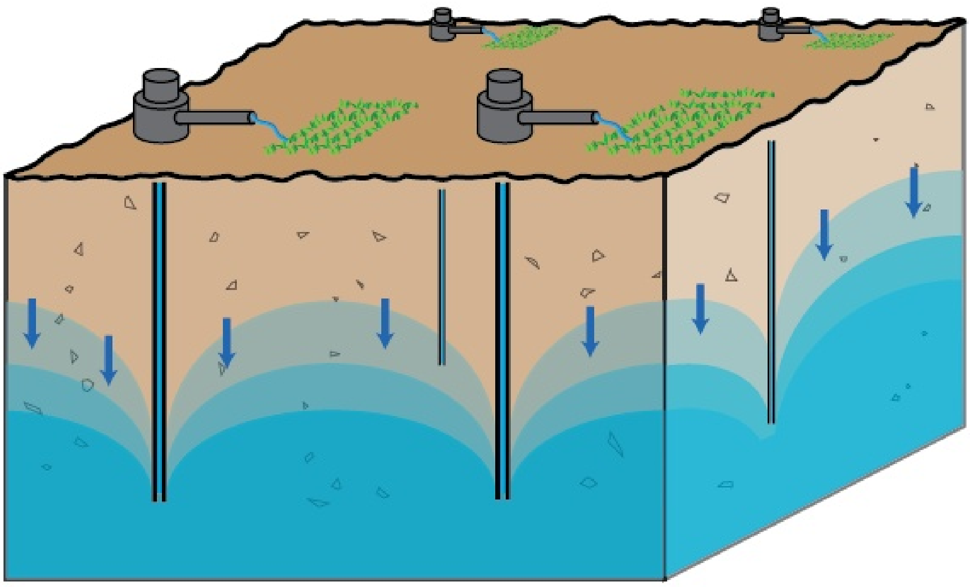


Figure 8.5: Identifying Groundwater Decline

In order to create a target groundwater management plan, areas with declining groundwater levels must first be identified (Figure 8.5). This is conceptually simple: use a system of monitoring wells, note the water elevation and record how groundwater levels change over time. A drop in groundwater levels over time beyond a certain threshold indicates a basin is in critical overdraft. The last comprehensive evaluation of basins in overdraft in California, however, happened in 1980 (Figure 8.6). The state defines a basin in critical overdraft as one in which the "continuation of present water management practice would probably result in significant adverse overdraft-related environmental, social, or economic impacts (DWR, 2003)." The Department of Water Resources or the legislature needs to develop a clearer definition of overdraft introducing a quantitative threshold, for example, a continuous decline of 10 percent per year for a 5 year period, or a qualitative one that is relatively easy to apply, such as impacts on vegetation or seasonal wetlands, for example.

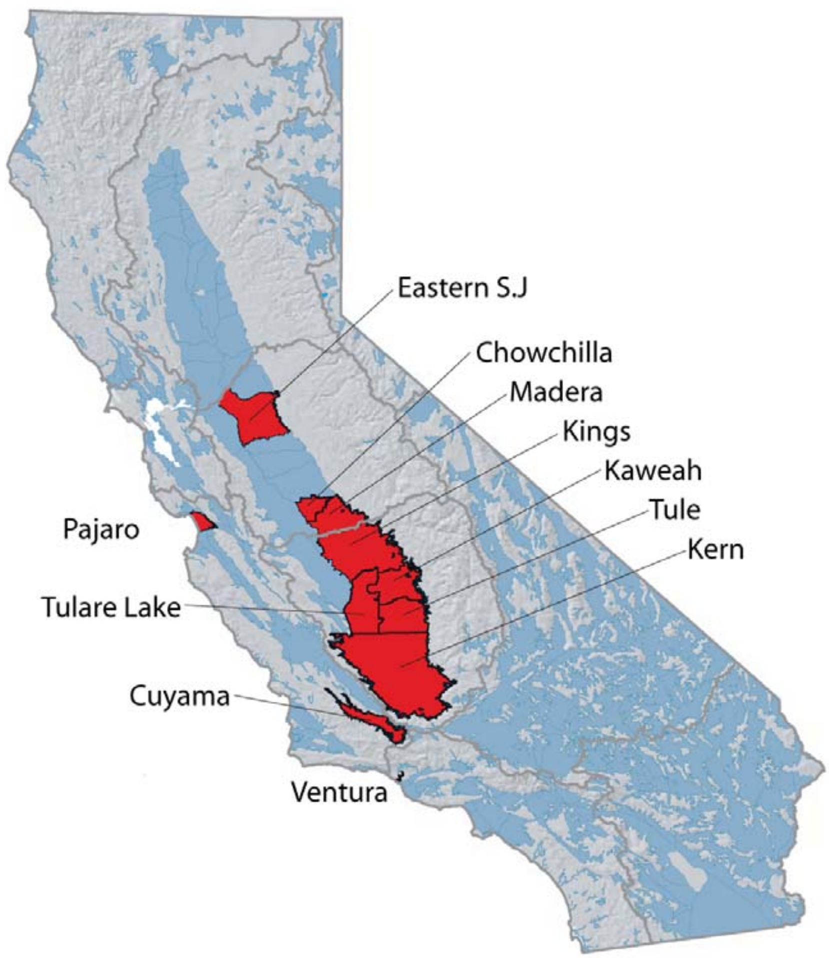


Figure 8.6: 11 Basins in Critical Overdraft
(data from DWR, 2003)

Until the passage of SBX7-6 in 2009, there was no legal requirement for basins to report groundwater levels. Under the recently passed bill, each of the 515 groundwater basins as defined by the Department of Water Resources (DWR) in Bulletin 118 must report groundwater levels and basin storage information to the DWR. The legislation requires each basin to select a monitoring entity or entities responsible for reporting groundwater levels to the Department of Water Resources. The monitoring entity can be a Watermaster, a groundwater management agency, a local agency, a water or irrigation district, a county, or a voluntary cooperative groundwater monitoring association. The monitoring entity must notify the DWR prior to January 2011 and must submit a map to the DWR that clearly delineates the spatial extent of the monitored area, whether it is an entire basin or a subbasin within a larger basin. If no monitoring entity notifies the DWR, the DWR may be required to perform monitoring of groundwater levels. The DWR can use the information on groundwater levels and basin storage reported by monitoring entities or collected by the DWR along with a clearer definition of overdraft to identify basins in severe overdraft.

8.5.2 Stabilizing Groundwater Decline

GW Mgmt Components	CA	AZ	TX	CO	NM
Statewide GW use permitting	-	X	-	X	X
Active Management Areas	-	X	X	X	X
Well data made public	-	X	X	X	X
Metering, measurement, and reporting	-	X	-	X	X

Figure 8.7: States Using Active Management Areas
(Based on LAO, 2010)

Once an area has been identified as in severe overdraft, I propose implementing a locally-run groundwater permitting system to stabilize groundwater decline (Figure 8.8). If a basin is not in severe overdraft, no action under this proposed permitting system is necessary. This both provides an incentive for basins to halt overdraft to prevent the introduction of a permit system and provides a targeted form of management that only applies to basins in which overdraft is an issue.

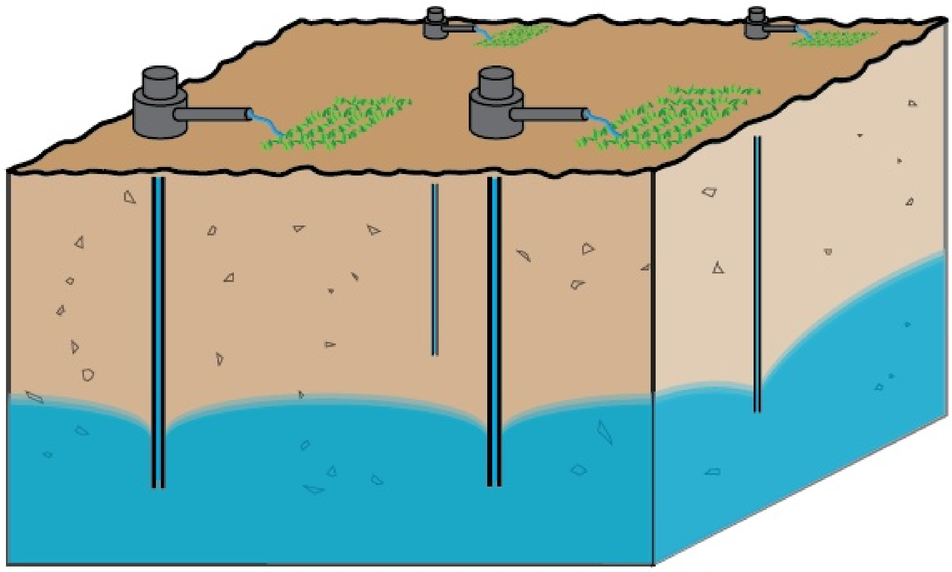


Figure 8.8: Stabilizing Groundwater Decline

Once the permitting system is introduced, the monitoring entities created in SBX7-6 identify Active Management Areas (AMAs) in the basins in severe overdraft. The monitoring entities would implement the locally-run groundwater permitting system in an AMA. If a number of monitoring entities share reporting responsibility in a basin in an AMA, then these entities should form a single groundwater agency responsible for administering a permit system within an AMA. Arizona, Texas, Colorado and New Mexico have all adopted AMAs in basins impacted by overdraft (Figure 8.7).

8.5.3 Water Table Recovery

Once the monitoring entities have established an AMA, a permit system can be developed. First, a safe yield, incorporating both the natural recharge rate and the recharge from the infiltration of imported water, is established by a certified hydrogeologist in accordance with hydrogeological principles. Next, groundwater pumping permits are allocated by the monitoring entity, respecting the safe yield. Allocating permits is potentially the most contentious step within establishing this permitting system. Permit can be allocated based on self-reported historic groundwater use. Many groundwater users, however, do not keep detailed records of groundwater pumping. If permits are allocated based on groundwater use over a period of a few years after the permit system is first announced, this could create a "race to the pumphouse," in which groundwater users have an incentive to pump more water than they would normally use in order to get a higher allocation of groundwater. However, groundwater pumping has associated energy costs, which could prevent egregious pumping rates. Another approach to allocate groundwater permits could be based on total irrigated land, potentially including crop choice. If all else fails, the State Water Resource Control Board can provide assistance in determining how to allocate groundwater permits.

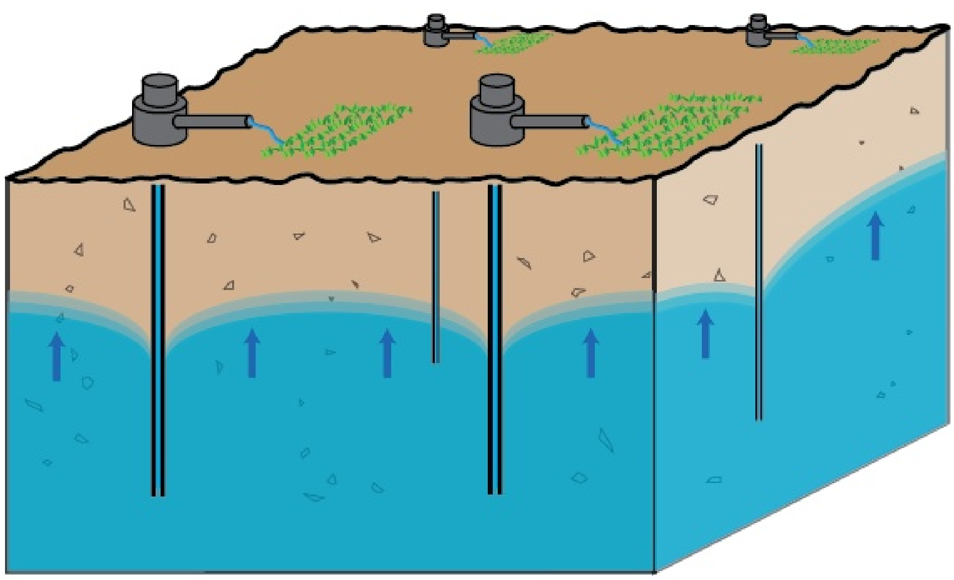


Figure 8.8: Groundwater Level Recovery

To keep the system flexible, groundwater pumping permits can be temporarily transferred or permanently sold from one user to another within the basin. As in the Tehachapi Basin case, pumping in excess of permitted amounts is allowed, but pump tax needs to be paid. The Tehachapi Basin case shows that pump taxes work well in discouraging overdraft. The funds from the pump tax could be used to run the management system and to purchase supplemental water.

The monitoring entities implementing the AMAs would maintain records on pumping to ensure that users adhere to permitted limits. This information could be kept only at a local level with the monitoring entity and would not need to be reported to the state. Although the monitoring entities are generally not staffed by local landowners, since they are locally-based organizations, including water districts and groundwater agencies, they can presumably be more responsive to the concerns of local landowners and can have a greater understanding of local conditions.

There is a possibility that the monitoring entities responsible for implementing the permitting system within an AMA can either not enforce a permitting system or choose to not monitor the groundwater pumping of individual landowners to ensure they adhere to their permitted limits. If the basin continues to be in overdraft because of lax enforcement from the monitoring entity, the DWR can withhold funds for water grants or loans as provided in Section 10933.7 of the Water Code. If the monitoring entity continues to be unsuccessful in preventing groundwater overdraft, the DWR can condition the delivery of State Water Project water on compliance with the permitting system in basins with severe overdraft.

8.6 Advantages of Conjunctive Management through a Groundwater Permitting System

Creating a locally-run groundwater permitting system that is sensitive to political realities can provide palatable solution to the lack of groundwater management. Improving groundwater management can encourage conjunctive management projects by settling the uncertainty inherent under current California law. Conjunctive management through a locally-run groundwater permitting system has four main advantages: lower cost, environmental benefits, local supply, and local control.

8.6.1 Lower Cost Storage

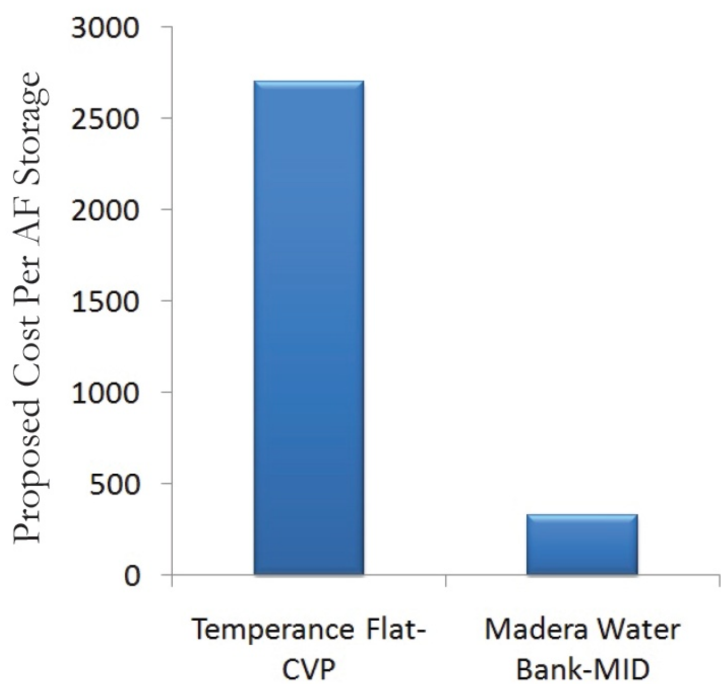


Figure 8.9: Cost Comparison

Based on construction costs, conjunctive management projects are a lower cost alternative than dams (Figure 8.9). The proposed Madera Water Bank costs approximately $330 per acre-foot of storage, while the proposed Temperance Flat Dam costs $2800 per acre-foot of storage. Operations and maintenance costs for dams can also be higher than conjunctive management projects.

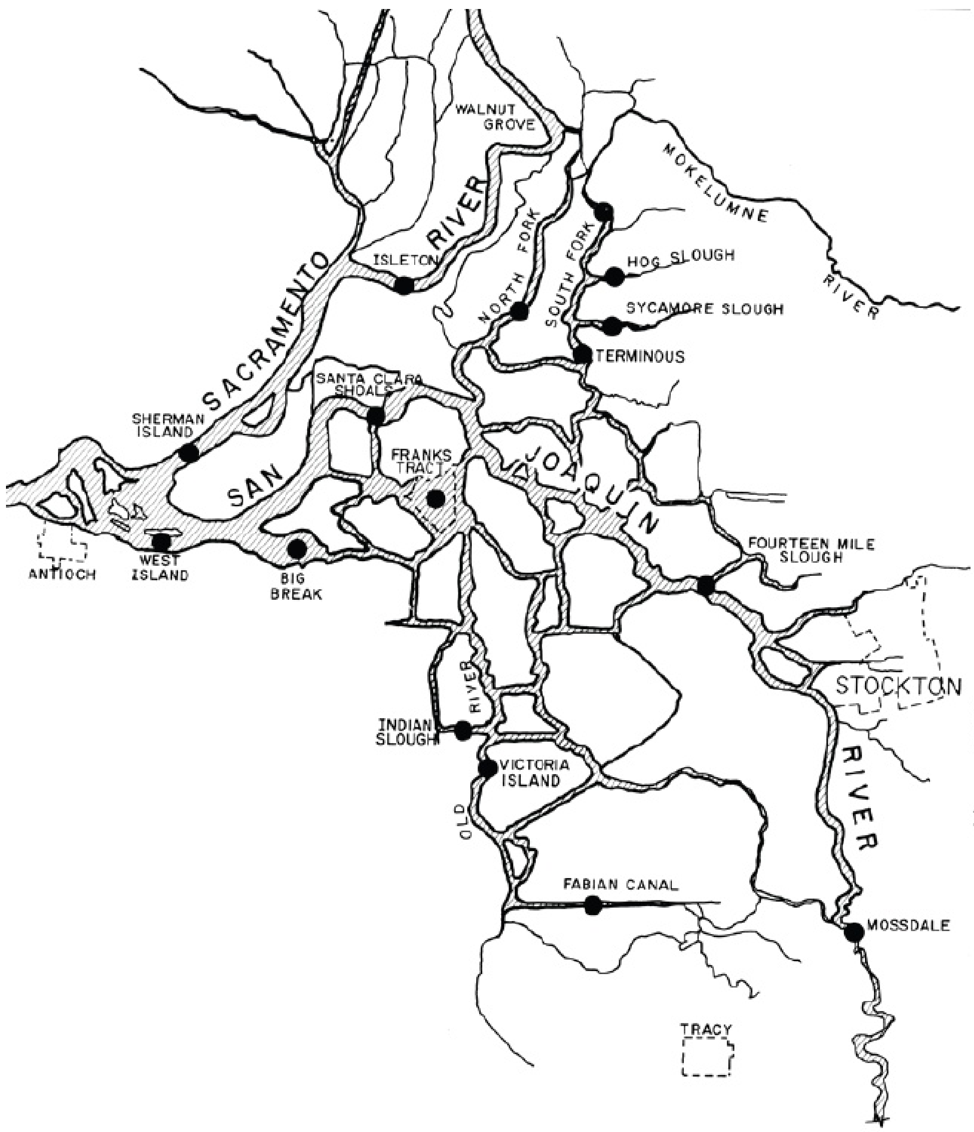
8.6.2 Environmental Benefits

Figure 8.10: Wetland Habitat at Yolo Bypass

Wetland habitat can be created during water infiltration in a conjunctive management project (Figure 8.10). The Kern Water Bank integrates its operations with the creation of seasonal wetlands. Utilizing conjunctive management projects to create wetland habitat can help to recreate the large seasonal wetlands lost during the development of large water projects in the Central Valley.

8.6.3 Reliability in Local Supply

Conjunctive management provides a method of storing water closer to where it is ultimately used. Recent restrictions on water pumped from the southern end of the Sacramento-San Joaquin Delta (Figure 8.11) to protect endangered fish species and the risks of levee failure from subsidence and seismic activity make the Delta unreliable as a source of water. Conjunctive management projects can increase local water supply reliability and reduce reductions in allocations through environmental restrictions.



Turner, 1966

Figure 8.11: The Sacramento-San Joaquin Delta,
The Hub of the Water Infrastructure in California

8.6.4 Local Control

The proposed groundwater permitting system allows permits to be allocated locally (Figure 8.12). It is ultimately up to a community how to allocate permits for groundwater pumping. By tasking local agencies with keeping records and enforcing the permitting system, the permitting system keeps control at a local level. The sooner groundwater management is addressed locally, the less likely it is that more restrictive solutions will be implemented.

Louise Mozingo

Figure 8.12: Self-Governance through Local Meetings

Overall, the need for water storage, the potential benefits from conjunctive management and the barriers presented by the current system of groundwater management point to a need to decrease uncertainty in groundwater rights. Implementing a locally-run groundwater permitting system can be a politically viable option to address the problems with current groundwater management and encourage conjunctive management projects.

References

Bureau of Land Management (BLM). 2001. "California: Water Rights Fact Sheet." Web. Dec. 2009. <http://www.blm.gov/nstc/WaterLaws/california.html>.

Department of Water Resources (DWR). 2004. "Water Facts No. 10: Components of a Groundwater Management Plan." Web. Nov. 2009. <http://www.water.ca.gov/pubs/conservation/waterfacts/components_of_a_groundwater_management_plan__water_facts_10_/water_facts_10.pdf>.

Faunt, Claudia C. (ed). 2009. "Groundwater Availability of the Central Valley Aquifer, California." United States Geological Survey. Web. Jan. 2010. <http://pubs.usgs.gov/pp/1766/.>

Freeman, Catherine. 2009. "Water Rights: Issues and Perspectives." Legislative Analyst's Office. Web. May 2009.< http://www.lao.ca.gov/handouts/resources/2009/water_rights _issues_ perspectives_031009.pdf>.

Thomas, Gregory, David Brown, Nicholas Pinhey, Jennifer Spaletta, and Peter Kiel. 2001. "Designing Successful Groundwater Banking Programs in the Central Valley: Lessons from Experience." Natural Heritage Institute. Web. 07 Feb. 2009 <www. waterexchange.com/market _ research/waterBanks/downloads/Designing_ Successful_Groundwater_Programs_2001.pdf >.