Effects of Groundwater Management Strategies on the Greater Sacramento Area Water Supply

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Abstract

The groundwater basin below the Cosumnes River has changed dramatically since major development began in the 1950's. The river, which was once estimated to be able to support Chinook salmon runs of 17,000, has, since 1977, been observed to support fewer than 600 fish per year (Fleckenstein et al. 2006). The change is largely due to the decrease in groundwater stored below the Cosumnes River. Before development, groundwater provided baseflow to the river in October, when the Chinook salmon need it to migrate to their spawning grounds in the Upper Cosumnes River. This study examines the water supply delivery and financial implications of different groundwater management strategies aimed at improving groundwater conditions below the Cosumnes River.

The first step was to determine the most economically efficient way to operate the existing water system surrounding the Cosumnes River, comprising the area above the Sacramento County groundwater basin, inflows from Folsom and Oroville Reservoirs, and outflows to the Delta. To do this, a hydro-economic model was created that represents water as a commodity and conveys it to the highest bidder via existing infrastructure. The model showed that water purveyors in the area might be able to save millions of dollars by 1) conjunctively using ground and surface water in the area more efficiently, 2) managing Folsom and Oroville Reservoirs together to minimize evaporative losses and 3) making more economically beneficial use of higher quality American River water. With flexible reservoir operation of this kind, and more conjunctive use, it would be possible to meet 99% of all water demands in 2030, compared with 97% met with the current operating policy (approximately a 15 TAF/yr increase in water supply deliveries on average and up to 18 TAF/yr during the '76-77 and '87-92 drought years).

The model also showed, in the next step, that if a groundwater management policy were implemented that required groundwater levels to restore baseflow at the end of an extended period of time (72 years in this study), agricultural water supply deliveries would only be reduced by approximately 12 TAF/yr (3.8% of the total agricultural demand), and urban water supply deliveries would not be affected, even though such a policy required that approximately 50 TAF/yr more water be stored as groundwater. If such a policy were implemented, 76% of the additional water could be attained by more effectively managing system flows to reduce surplus Delta outflows[1]. Even with such an ambitious groundwater management policy, 97% of total demands would still be met - the same as with the current operating policy.

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[1] Surplus Delta flows are those in excess of the minimum flows required to meet required Delta outflow, exports, in-Delta deliveries and in-Delta consumptive use after accounting for San Joaquin River and in-Delta precipitation contributions.

1 Introduction

Historically, the Cosumnes River has been observed to support up to 5,000 returning Chinook salmon per year, while the basin has been estimated to have the capacity to support 17,000 fish under ideal conditions – an important contribution to California's multi-million dollar salmon industry (Fleckenstein et al. 2006). Salmon populations in the Cosumnes River basin have declined from changes in water use and hydrologic conditions. In nine out of ten water years[2], the Fall Run Chinook are unable to return to their upstream spawning grounds without human intervention (Robertson-Bryan 2006). Since 1997, less than 600 Chinook salmon have been observed in any given year (Fleckenstein et al. 2006).

This low flow condition exists in part because of groundwater overdraft: water is being pumped out of the groundwater in areas surrounding the river faster than the groundwater can recharge. Historically, in the lower Cosumnes, groundwater has provided baseflow to the river in dry periods. Increased groundwater pumping has practically eliminated base flows in the lower Cosumnes River by drawing the groundwater down far enough that the river is no longer supplied by groundwater baseflow(Fleckenstein et al. 2006). Now, the river is losing water to the groundwater all year round, causing the river to stay dry longer into late fall and causing longer reaches of the river to dry up (Robertson-Bryan 2006).

Figure 1.1 UC Davis Professor Jeff Mount and the director of The Nature Conservancy's 40,000 acre Cosumnes River Preserve, Mike Eaton, walk on the dry Cosumnes River Bed

The effect of lost access to spawning grounds in the Cosumnes and other spawning areas combined with current poor ocean conditions was strongly felt in April of 2008 when Governor Arnold Schwarzenegger declared California to be in a State of Emergency because of the declining salmon populations. He provisionally closed California's recreational and commercial salmon fisheries. The move was expected to cost the state over $255 million and result in the loss of over 2,200 jobs (Schwarzenegger 2008).

To try to improve the situation in the Cosumnes River for the Chinook salmon, and to restore the native riparian vegetation and other native wildlife, the Nature Conservancy is currently working with seven governmental and non-profit organizations to manage the Cosumnes River Preserve. The

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[2] A water year is the 12 month period from October through September and is identified by the calendar year in which it ends.

projects they are undertaking to maintain and restore the Cosumnes River Preserve include:

1. Breeching levees to create more natural floodplains (Fleckenstein et al. 2006).

2. Encouraging local land owners to manage their land in a way that helps recharge the groundwater when they are not planting and harvesting crops (TheNatureConservancy 2008)

3. Forming the Cosumnes River Research Group at UC Davis to explore restoration in the area from a research perspective (CosumnesResearchGroup 2008).

4. Improving the Chinook salmon migration via the Cosumnes River Flow Augmentation Project. This program explored the benefits of putting pumped groundwater in the Cosumnes River and evaluated groundwater recharge rates to guide future groundwater management (Robertson-Bryan 2006)

Through such efforts, the Cosumnes River Preserve has grown to include approximately 40,000 acres. More details on efforts to restore the preserve appear in Chapter 2.

This study focuses on how groundwater management strategies to improve flows in the Cosumnes River would affect water supply operations and deliveries. The primary question being examined is: if more aggressive groundwater management policies required over an extended time that there to be no further overdraft beyond the 1993 condition, or that groundwater storage levels to be those such that groundwater baseflows were restored, then how would the water supply deliveries and associated costs be affected? The first phase of this investigation examines how inefficiencies in the current operating policy could be reduced by operating the system more flexibly. The second and third phases explore how different long-term groundwater management policies would affect the water supply if the system was operating more flexibly.

The hydro-economic optimization model CALVIN (CALifornia Value Integrated Network) was used to explore the re-operation of the major infrastructure in the Sacramento Area as well as the potential economic benefits of operating the existing system more flexibly. Flexible system operations are driven by water markets in which water is traded as a commodity. Although there are some issues with water markets including: ill defined water rights, the potential for externalities[3], and difficulties in communication between willing buyers and sellers, they are currently being widely implemented in California (Tanaka 2007). The CALVIN model of the Sacramento area assumes the water markets to be ideal, so there are no risks to the buyers or sellers when making a trade. Additionally, CALVIN assumes that buyers and sellers have very good knowledge of the hydrology. These assumptions yield idealized theoretical results, but these results can provide insights into how the reservoirs and conveyance facilities represented in the model can be operated more flexibly to minimize economic costs

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[3] Externalities are impacts to external parties, for example farm workers may be laid off as a result of less agriculture occurring because urban areas are willing to pay more for water than agricultural areas.

system wide. The only constraints this flexibly operated system is required to meet are that the physical capacities of infrastructure are not exceeded, and that minimum environmental flows are met.

The model shows that there are substantial economic benefits to be gained by operating the system more flexibly, including conjunctively using ground and surface water in the area more efficiently and by managing Folsom and Oroville Reservoirs together to minimize evaporative losses and make more economically beneficial usage of higher quality American River water. With flexible reservoir operation and more conjunctive management 99% of all water demands in 2030 can be met, as compared with only 97% of the total demands that are met with the current operating policy. Results from this model show that if the system is allowed to operate more flexibly, it is possible to restore groundwater baseflows, over a long period of time, and have substantial economic benefits to the system, while not increasing overall scarcity in the system.

One way to increase end of period[4] groundwater storage is to operate Folsom and Oroville Reservoirs to minimize evaporative losses and reduce surplus Delta flows. Water conserved from more efficient reservoir management can then be diverted via the Folsom South Canal, or down the American River to the Sacramento and through the Freeport Pipeline[5] to major groundwater pumpers such as Elk Grove, as well as the agricultural areas of Galt ID and Omochumne-Hartnell. In other words, the reservoir water would be exchanged for groundwater via an *in-lieu* transfer in which surface water would be used *in-lieu* of groundwater. This would give groundwater levels a chance to recover. Re-operating Folsom and Oroville Dams in this way could have other potential benefits in addition to recharging the groundwater levels and creating better conditions for Chinook salmon. These include:

- Expanding underground water storage that could be used during dry periods, thereby increasing the overall water supply reliability.

- Drawing down the Folsom flood pool sooner. This would create more flood space earlier in the season, which would be increasingly valuable should climate change cause flood events to become larger and less predictable (TheNatureConservancy 2008).

- Supporting the natural habitat of tundra swans, great blue herons, egrets, pintails, sandhill cranes, and the native riparian vegetation such as the threatened Valley Oak (Viers et al. 2006).

Output from the Sac CALVIN model will be used to determine the following (a more comprehensive list of objectives appears in Section 5.1):

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[4] The period would be an extended period of time, determined by the policy makers, in this case the period is 72 years since that is the period for which hydrologic data is available

[5] The route that is used will be dependent on not exceeding current operating policy flows on the Folsom South Canal, and meeting minimum environmental flow requirements in the Lower American River

- The amount of extra water that is available to the Sacramento area if Folsom and Oroville Reservoirs are re-operated, as well as the most economical way to operate the Sacramento Area water system

- Whether conjunctive use would occur if the system was optimally operated.

- How water supply deliveries would be affected if a policy required there to be no net groundwater depletion over an extended period of time[6].

- How water supply deliveries would be affected if a policy required that Cosumnes River baseflow be provided by the groundwater.

These objectives motivate this work and their answers will be discussed in Chapter 7. The study area and previous restoration in the area are discussed in Chapter 2. Chapter 3 provides background on the techniques used in this study and explains basic principles of conjunctive use, focusing on both its physical and economic aspects. The mathematical model used in this study is explained in Chapter 4. Chapter 5 then answers the above questions, and Chapter 6 comments on limitations of the study, and makes recommendations for future work. The final Chapter summarizes the conclusions of this study.

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[6] In this study "an extended period of time" refers to the 72 year period being modeled. In other words, this objective examines optimal operation if the end of period storage is required to equal or exceed the initial storage.

2 Study Area

2.1 Location

The Sacramento County Groundwater Basin, the basin under the Cosumnes River, lies below the surface watersheds of the Lower Sacramento, Lower Cosumnes and Lower American Rivers (shown in Figure 2.1 in different shades of blue). Each surface watershed provides a major source of recharge for the Sacramento County Groundwater Basin (outlined by the bold black line in Figure 2.1). This groundwater basin is a sub-region of the political boundary of Sacramento County, which includes the entire area outlined by the bold black line, as well as the area shown in yellow.

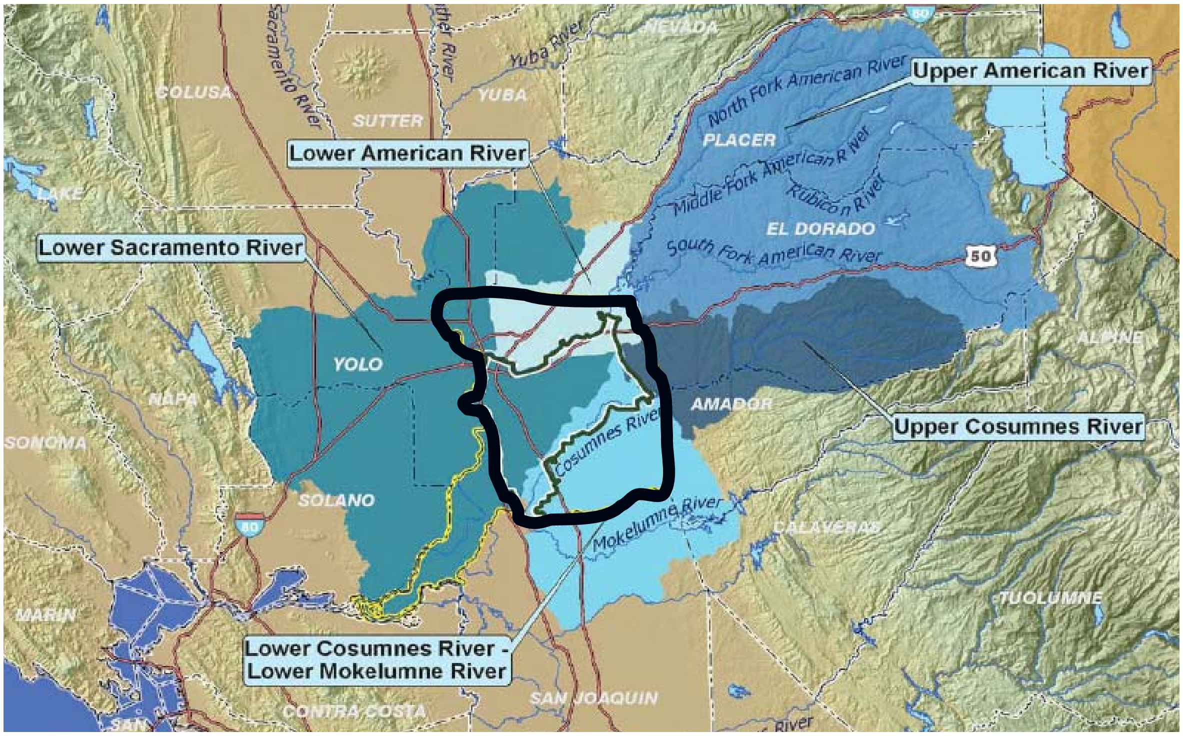

Figure 2.1 Major surface watersheds above the Sacramento County Groundwater Basin (Water_Forum 2006)

The Sacramento County Groundwater Basin has three subbasins - North, Central and South - as illustrated in Figure 2.2. These subbasins are hydraulically disconnected from each other, meaning that water from one of the subbasins does not mix with water in the adjacent subbasin (Water_Forum 2006). This hydraulic property of the subbasins justifies some simplifications made in how groundwater was modeled in this study (see Chapter 3). The Central and South groundwater basins are of particular interest in this investigation since they border the Cosumnes River below the area where the river typically runs dry.

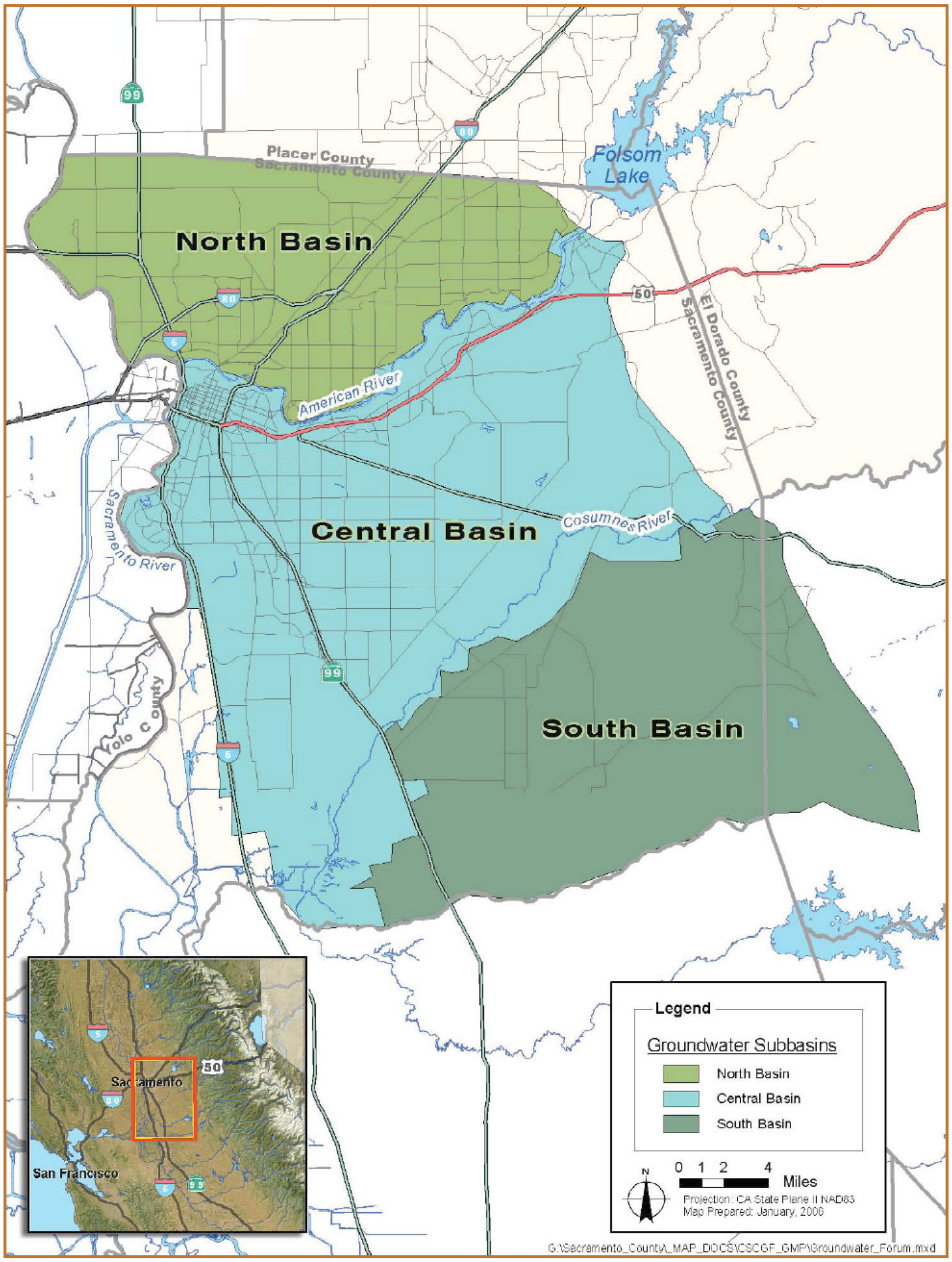

Figure 2.2 Sacramento County Groundwater Basins (WaterForum 2006)

2.2 Current Groundwater Profile

As mentioned in the introduction, historically the Cosumnes River was hydraulically connected to the groundwater table. An illustration of what it means to be hydraulically connected is shown in the pre-1950 historical condition illustration in Figure 2.3. With lowered groundwater levels due to pumping and changing hydrologic conditions, the current situation causes surface water from the river to drain into the groundwater all year round, depleting the river, and eliminating baseflow.

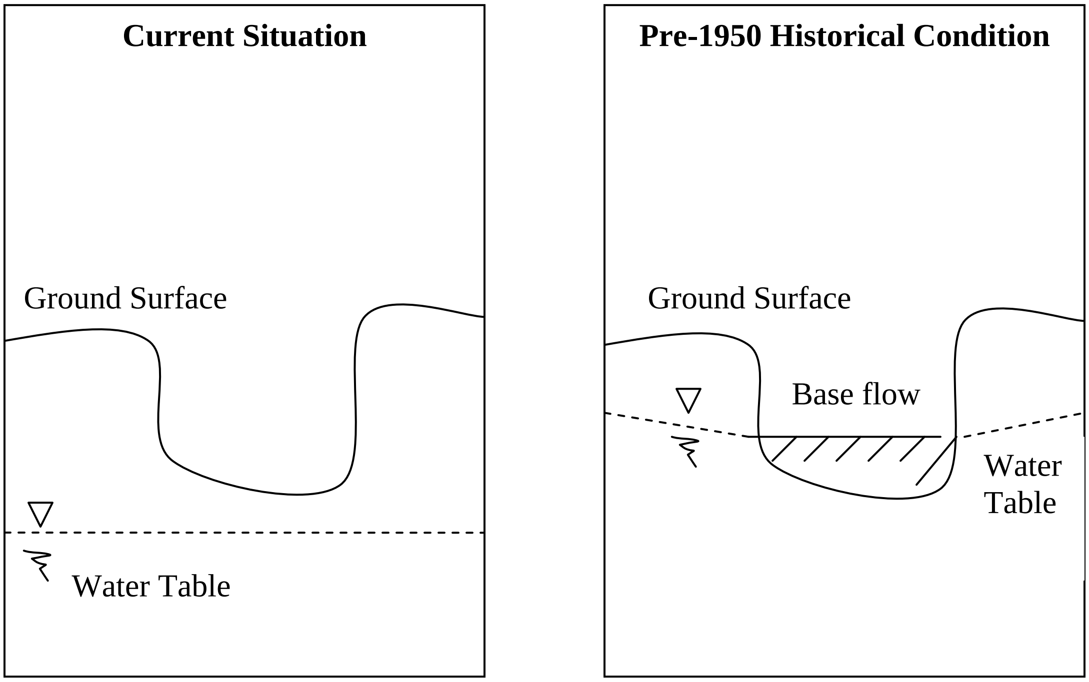

Figure 2.3 Current and desired groundwater table levels

(The triangle and squiggle are used to indicate the water surface)

The areas where depth from the surface to the groundwater table are greatest are shown in Figure 2.4. Some of the major cones of depression[7] are below the City of Galt (6) and Elk Grove Water Service area (38). However, there is extensive drawdown on both sides of the Cosumnes River, including below the Sacramento County Water Agency's delivery area (12-14, 23, 36-42) and agricultural areas in the South Basin, Clay ID (9) and Galt ID (5). A complete list of the 43 demand areas and a map of their locations appears in Appendix A.

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[7] A cone of depression occurs when groundwater is pumped faster than it is recharged. When this occurs, groundwater flow changes direction in a portion of the watershed. Instead of moving toward the natural discharge area (which previously would have been the Cosumnes River) the groundwater within the influence of the pump flows toward the well from every direction.

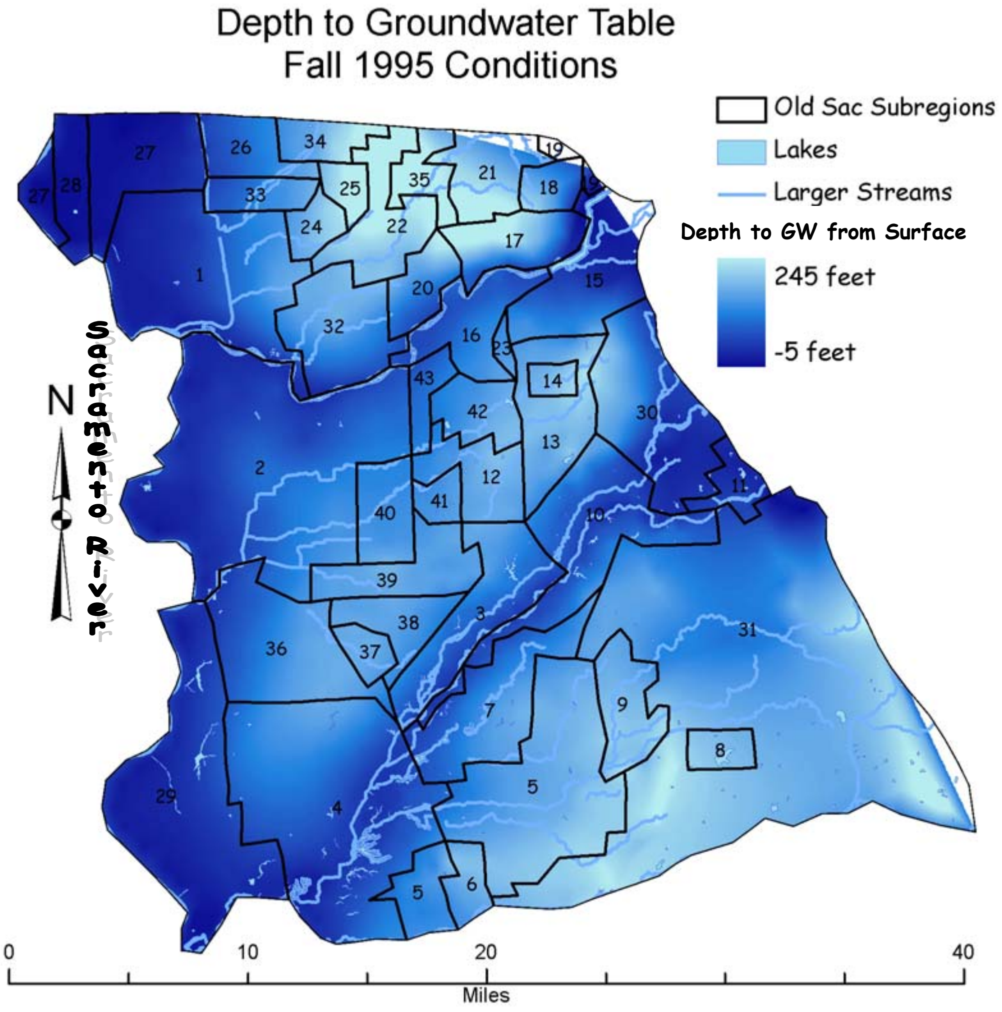

Figure 2.4 Fall 1995 Depth To Groundwater from Ground Surface Map (created by Aaron King based on data provided by WRIME)

2.3 Geology

The Central Sacramento Groundwater Management Plan describes the hydro- geology of the Sacramento County Groundwater Basin (WaterForum 2006). The aquifers of most importance to this investigation are the shallow aquifer, commonly referred to as the Modesto Formation, and a deep aquifer called the Mehrten Formation. The two layers are shown in Figure 2.5, a cross section of the Sacramento County Subbasin, as layers 1 and 2.

The Modesto Formation starts at the ground surface and typically goes to a depth of 150 to 200 ft, but can extend as deep as 300 ft within the study area. The Modesto Formation is geologically heterogeneous in composition (WRIME 2005). Groundwater in the Modesto Formation typically starts 20 – 100 ft below the ground surface (WaterForum 2006; Underwood 2007). The Modesto Formation is commonly used for private domestic wells, and usually does not need treatment (WRIME 2005).

A discontinuous clay layer separates the shallow Modesto Formation (layer 1 in Figure 2.5) from the deep aquifer, or Mehrten Formation (layer 2 in Figure 2.5). Water from this deeper layer generally requires treatment for iron and manganese (WaterForum 2006). The Sacramento County Water Agency (SCWA) is the only water district included in this investigation that treats its water for iron and manganese (Underwood 2007). The deeper aquifer does not recharge from the Cosumnes River as does the upper aquifer, nor is the deeper aquifer as responsive to short term changes in hydrologic conditions or pumping as is the shallow aquifer (WRIME 2005).

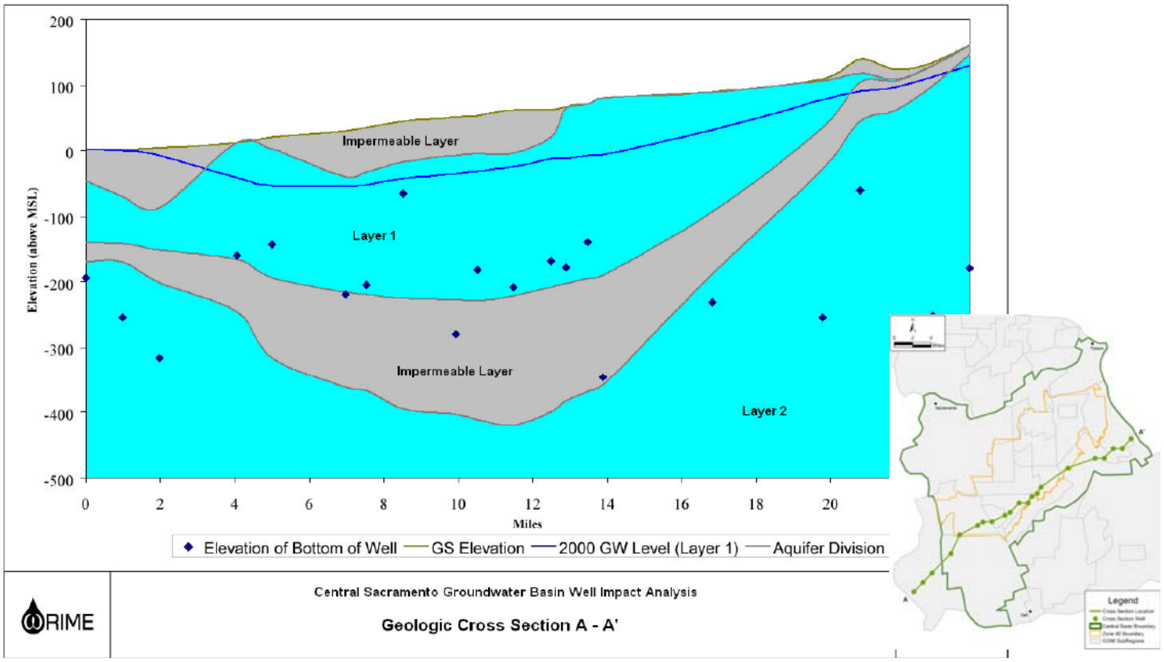

Figure 2.5 Hydrogeologic Cross Section from A –A’ (WRIME 2006)

2.4 Water Supplies and Demands

The major water sources for the Sacramento County area modeled in this study are the Feather River, the Sacramento River, the American River, the Cosumnes River, groundwater, and precipitation. Releases from the Feather River (which flow to the Sacramento River) are regulated by Oroville Dam. Releases from the American River (tributary to the Sacramento River) are regulated by Folsom Dam. Another important piece of infrastructure is the Freeport Pipeline (shown in green above the SCWA label in Figure 2.6), which runs from the Sacramento River at Freeport to the Folsom South Canal. Attached to the pipeline is the Sacramento County Water Agency's water treatment plant. The pipeline is currently scheduled for completion in 2009**.** By operating Folsom and Oroville dams differently, and using the Freeport Pipeline to transport water to areas other than SCWA and EBMUD, it may be possible to reduce costs and create net recharge to the Cosumnes River groundwater table.

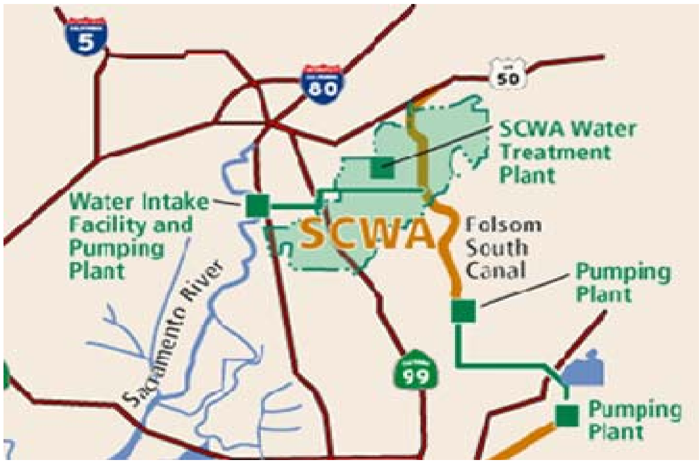

Figure 2.6 Map illustrating the location of the Freeport Pipeline and SCWA treatment plant (Freeport_Regional_Water_Authority 2008)

Costs are reduced by minimizing projected shortages to demand areas and by providing demand areas with as much water as possible from the least expensive available source. Most water demands in the Sacramento County Groundwater Basin are for urban and agricultural purposes. A map of major water purveyors within the study area appears in Appendix A. For the purposes of this model, several purveyors were grouped together based on their water sources, as shown in Appendix A. Purveyors are grouped by the area numbers used in the SacIGSM study. See Figure 2.4 for a map of the SacIGSM study areas.

2.5 Restoration Efforts in the Cosumnes River Area

Background

The Cosumnes River Preserve was created by The Nature Conservancy and seven governmental and non-profit partners to manage and restore the Cosumnes River area. The project has grown from the original 6,000 acres to approximately 40,000 acres today. The Cosumnes River is the last major undammed river on the western slope of the Sierra Nevada Mountain Range (Fleckenstein et al. 2006). Before 1995 it had an extensive levee system, until an accidental levee breach led to more riparian restoration and restored the geomorphic function of the nearby floodplain. After the environmental success of the breech in 1995, the Army Corps of Engineers intentionally breeched the levee further upstream. Together, these breeches helped restore some of the floodplain along the Cosumnes River (Mount et al. 2000). Naturally functioning floodplains provide benefits such as fishing and recreation, ecosystem services, and habitat for a wide range of species providing ecological diversity (Moyle et al. 2003). No single major river in the California has an entirely naturally functioning floodplain. All major rivers in California have extensive levee systems, and most have at least one dam to manage floods, improve the reliability of the water supply, or provide hydropower. While entirely natural floodplain systems do not exist on major rivers in the United States, it is possible to operate existing dams and levees to create naturally functioning floodplain systems. Because of the Cosumnes River's unique situation as the last undammed river on the western slope of the Sierra, it has been of interest for many researchers and restoration efforts.

Chinook Salmon

A major concern for the Cosumnes River is the native fish population. By April of 2008, the Chinook population had experienced such a steep decline that governor Schwarzenegger declared California to be in a State of Emergency.

The CALFED Bay-Delta Program has been trying to identify ways to increase the native fish population. One primary goal of the CALFED Bay-Delta Program is to "improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species" (CalfedBayDeltaProgram 2008). One way to increase Chinook salmon in the Delta is to have more fish enter the Delta from the Cosumnes River. CALFED listed actions to maintain the Fall Run Chinook salmon population in the Cosumnes River:

1. Increase stream flow at critical periods
2. Improve channel and floodplain morphology
3. Improve spawning and rearing habitat through gravel recruitment
4. Improve fish passage at diversion dams
5. Reduce losses to unscreened diversions
6. Remove existing levees and construct set back levees
7. Implement improved land management and livestock grazing practices along stream/riparian zones
8. Make fish passage improvements at small dams

(Robertson-Bryan 2006)

The Cosumnes River Flow Augmentation Project

The Cosumnes River Flow Augmentation Project has provided some important advances in the knowledge of the inner workings of the Cosumnes River ecosystem. The project found that:

1. It is possible to re-create historical river channel conditions by transferring water from Folsom Reservoir via the Folsom South Canal to the Cosumnes River at key times of the year. This would pre-wet the channel and minimize seepage to groundwater.

2. Since 5 TAF have been allotted to improve Chinook salmon spawning success, this water can be most efficiently allocated by:
    a. Using it to only pre-wet the channel, as was done in 2005, when the upper reaches of the Cosumnes River (river mile 27.5 to 51) are unsuitable for spawning, or
    b. Using it to both pre-wet the channel and create a pulse flow when spawning habitat is available in the upper reaches of the Cosumnes River

3. Supplemental water will be needed to maintain minimum flows of 75 cfs at Michigan Bar in more than 90% of all water years (Robertson-Bryan 2006)

Ground-Surface Water Interactions

Part of the research being done in the Cosumnes River area involves investigating how to best manage surface water and groundwater to restore fall flows. Interactions between ground and surface water can become complex quickly and are time consuming to model. One model of these ground-surface water interactions is SacIGSM through which a detailed accounting of groundwater in the Sacramento Area groundwater basin has been completed. The groundwater represented in the Sac CALVIN model is calibrated to the detailed results from the SacIGSM model. The SacIGSM model has been used for other analyses in the Cosumnes River area to quantify the stream losses. Some important conclusions from these studies are:

1. An increase in channel losses between 1941 and 1981 coincided with a significant decrease in groundwater levels, further confirming that declining groundwater levels caused declining fall flows,

2. Before substantial groundwater development occurred in the 1950’s and 1960’s the Cosumnes River was probably receiving base flow from the aquifer and was sustaining perennial flows,

3. Aside from no-pumping, flow augmentation was an essential part of any scenario that could ensure average fall flows above the minimum flow requirement (Fleckenstein et al. 2004).

3 Conjunctive Use

This investigation focuses on how to optimally operate the Sacramento Area system to achieve both an environmental goal (increasing groundwater levels) and an economic goal (minimizing net economic costs to water system users as a whole). This model examines using existing infrastructure in more flexible ways to minimize costs and detect new operating patterns and will be used to spur discussions as the South Sacramento County Groundwater Management Plan is being written. Both physical and economic considerations are required to make a conjunctively managed system work effectivenly and smoothly. These physical and economic considerations are discussed below along with several common modeling techniques. Conjunctive use is already used in many areas of California with mixed results. The most promising trends are highlighted here as well as the common practices to avoid.

3.1 Physical Considerations of Conjunctive Use

Conjunctive use involves operating surface and groundwater storage facilities and flows together to meet demands. A key element when evaluating a conjunctive use strategy is how water will be transferred between ground and surface storage. This transfer can be broken into recharge and withdrawal components.

Recharge can be done by:

1. Delivering surface water to customers that would have otherwise been pumping groundwater. Since the surface water is used *in-lieu* of the groundwater, the groundwater basin recharges from the normal deep percolation due to precipitation, water applied for irrigation, seepage from streams, rivers or unlined channels. *In-lieu* recharge is the focus of this study.

2. Allowing deep percolation to occur after using the water to satisfy a surface water purpose. For example, in California much of the water recharged to the groundwater table and later used for conjunctive use schemes deep percolates to the groundwater table after being applied to wetlands or agricultural lands in the off season (Pulido-Velazquez et al. 2008). Water applied to wetlands creates more environmental habitat, and the water applied to agricultural lands in the off-season serves to pre-irrigate the land, making the soil more productive during the harvest season.

3. Taking advantage of deep percolation that occurs in unlined channels, natural streams and rivers and reservoirs. Rivers and channels are sometimes operated to enhance such recharge.

4. Applying water over spreading basins and infiltration ponds. Spreading basins and infiltration ponds are most effective if located on highly permeable soils. For example, Kern Water Bank infiltration ponds are on 7,000 acres of sandy soil

which can percolate 3 TAF per day (Purkey et al. 2001). The Arvin Edison Water Storage District has 500 acres of spreading ponds which percolate excess irrigation water (Purkey et al. 2001). In San Jacinito in Riverside, California percolation rates averaged 1.9 meters/day in the recharge ponds (Lee et al. 1992).

5. Inducing seepage to groundwater from a river or stream bed by placing a series of wells along the body of water and then pumping alongside the river or stream to lower the pieziometric head and induce infiltration.

6. Injecting water into the ground using injection wells. Semitropic Water Storage District in the Central Valley of California uses injection wells to facilitate infiltration (Purkey et al. 2001).

Withdrawals are made using one of three techniques:

1. Pumped well withdrawals are used in most conjunctive use schemes in California (Purkey et al. 2001).

2. Water exchanges are when an area that would normally have a right to surface water exchanges their surface water right and agrees to pump groundwater. This was attempted in the Semitropic Water Storage District, where the Department of Water Resources (DWR) agreed to deliver more Central Valley Project (CVP) surface water to the storage area during wet years in exchange for the area's contractual right to CVP water in dry years. The problem with the exchange arose in the drought of 1990 when DWR wanted to call upon their contractual right to Semitropic's CVP water, but unable to because Semitropic were not actually allotted any water in 1990 due to the low priority of their water right (Purkey et al. 2001).

3. If the groundwater table is higher than the water level in an adjacent river or stream, water flows from the groundwater table into the stream. As additional water is allowed to seep into the ground raising the groundwater level further, the flow rate of groundwater to the surface stream increases.

The above recharge and withdrawal techniques can be managed actively or passively. When actively managed, frequent decisions are needed to operate the facilities for conjunctive use. Recharge facilities such as infiltration ponds and injection wells require active management. Flow augmentation is another example of ground and surface water interactions that requires active management. Flow augmentation is used to meet minimum instream flows and involves pumping groundwater or importing surface water and then running it down the stream or river to meet the minimum instream flow. This water is allowed to deep percolate back to the groundwater table. In the Cosumnes River region, a pilot flow augmentation project was run. This project used natural flows from the Cosumnes River together with supplemental releases from the Folsom South Canal to re-wet the Cosumnes River channel and generated flow in the normally dry late fall and summer months (Robertson-Bryan 2006). However, not all systems require active management. In passively managed systems, demand areas naturally choose to pump groundwater during times of drought because it is what is available, and they use surface water during wet periods because it is less expensive (Jenkins 1992). Few management decisions are needed in this case, and often existing infrastructure is sufficient to convey water. Sometimes minimal construction is needed. One example of a conjunctive use system that is passively managed is the City of Phoenix which supports a population of 3.5 million and has three principle water sources, the Salt Verde River, the Colorado River, and the Salt River Valley Aquifer System. During wet periods, the Salt Verde and the Colorado Rivers are relied upon to supply water to the City because that is less expensive than pumping groundwater; during droughts the surface water is supplemented with groundwater (Llamas et al. 2003).

3.2 Advantages and Disadvantages of Conjunctive Use

Advantages

One advantage of conjunctive use is that groundwater basins often have enormous underexploited storage capacities. For example, in California alone, groundwater basins have been estimated to be able to hold as much as 850,000 TAF of water, orders of magnitude larger than the surface water storage facilities (Pulido-Velazquez et al. 2008). Groundwater storage areas are not subject to evaporation, unless the water is stored in very shallow aquifers, although the recovery rate from groundwater storage facilities is sometimes less than that from surface water storage facilities. Groundwater typically needs less treatment than surface water and, historically, passing the water through the ground has been sufficient to filter the water (Huisman et al. 1974). Additional benefits from storing more water in the ground can include: 1) increased streamflows typically from gaining? water from the groundwater, which can aid restoration efforts, 2) increased flood protection, because less water is being stored in surface water facilities where it poses a flood risk, 3) decreased saline intrusion, and 4) increased water supply reliability.

An economic strength of conjunctive use is that storing water in a depleted groundwater table, even if new infrastructure is needed to recharge/withdraw the water and to transport it, is often less expensive than creating more surface water storage space (Fisher et al. 1995). If the storage aquifer is below the demand area, then distribution infrastructure does not need to be built for the groundwater portions of the conjunctive use system. The aquifer serves as a natural distribution system. There can also be additional value from the increased water supply reliability of a conjunctive use system. A numerical value can be assigned to this added benefit. This additional value has been termed the “buffer value” and can be calculated by subtracting the maximum value of the value of an uncertain water supply from the maximum value of a certain water supply (Tsur et al. 1991).

Disadvantages

Groundwater contamination can be more difficult to contain and remediate than surface water contamination. Additionally more reliance on groundwater may require more groundwater monitoring (Pulido-Velazquez et al. 2008). If more groundwater is being used then higher pumping costs and energy requirements will be incurred, although these are typically offset by the greater treatment costs needed for surface water.

There also can be political drawbacks to conjunctive use. For example, if water is stored in the ground and then exported out of the region, this often upsets local groundwater pumpers. Monitoring wells and financial incentives to those who may be affected are sometimes needed.

Potential economic drawbacks of conjunctive use include decreased hydropower generation, decreased recreational activities in surface water reservoirs, and if the groundwater basin is not near the demand area being serviced by the conjunctive use project, increased operating costs (Pulido-Velazquez et al. 2008).

3.3 Modeling Techniques

To address the wide range of problems involving water supply systems, a range of modeling techniques have been previously used. This study uses a linear programming optimization model called Sac CALVIN. The reasons for using a linear programming optimization model will be best understood by understanding the different modeling techniques which could have been employed.

Simulation Models

Simulation models set up relationships between different known conditions in an attempt to predict unknown conditions. Figure 3.1 shows different known conditions that could be entered into to a simulation model. The simulation model then employs a relationship using the known conditions to predict an unknown final state. The relationship is refined by calibrating the model. During calibration, known inputs are used, and typically one or more parameter values within the model are changed to try to simulate, as closely as possible, the known final state. Once a satisfactory relationship has been established by modifying parameter values in the simulation model, the model is then tested by putting in different inputs. The established relationship is used to determine the predicted output. This output is then compared to the known output. If they are close enough, or there are acceptable reasons for any discrepancies, then the model is considered to be calibrated.

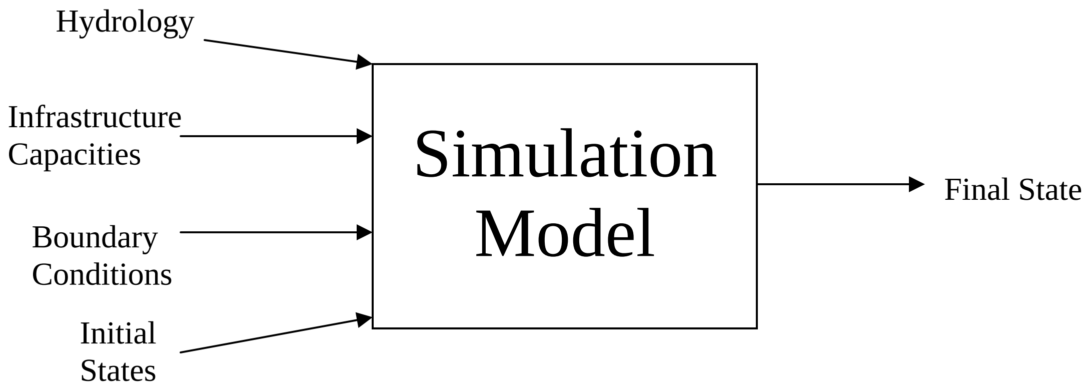

Figure 3.1 Diagram of a Simulation Model

Some basic examples of questions that may be addressed using a simulation model are:

- If 1 inch of rain is uniformly distributed across a watershed, and there are 500 TAF in the reservoir to begin with, what will the final storage in the reservoir be after the event?

- If a groundwater basin has 300 TAF of storage, a nearby surface reservoir has 50 TAF, precipitation time series data is available from 1940 to 1990, historical releases are made from the reservoir, and it is known how much water was used, what was the final groundwater storage in the groundwater basin in 1990?

- If historical delivery patterns are continued into 2050, what will be the predicted shortage experienced by urban and agricultural demand areas if the current groundwater and surface water storages are known and a given predicted precipitation is applied?

Optimization Models

Optimization models, like the Sac CALVIN model being used in this study, answer entirely different types of questions than simulation models. Optimization models can answer questions such as:

- What is the most economically efficient reservoir operating procedure for a given objective?

- What is the most profitable cropping pattern?

- To minimize costs, which demand areas should take water from ground and which from surface water storage, and how much would they take from each?

There are several types of optimization models. Optimization models applied to conjunctive use problems fall into four categories: dynamic programming, linear programming, non-linear programming, and hierarchal optimization. Figure 3.2 below illustrates the types of model used to model water resource problems.

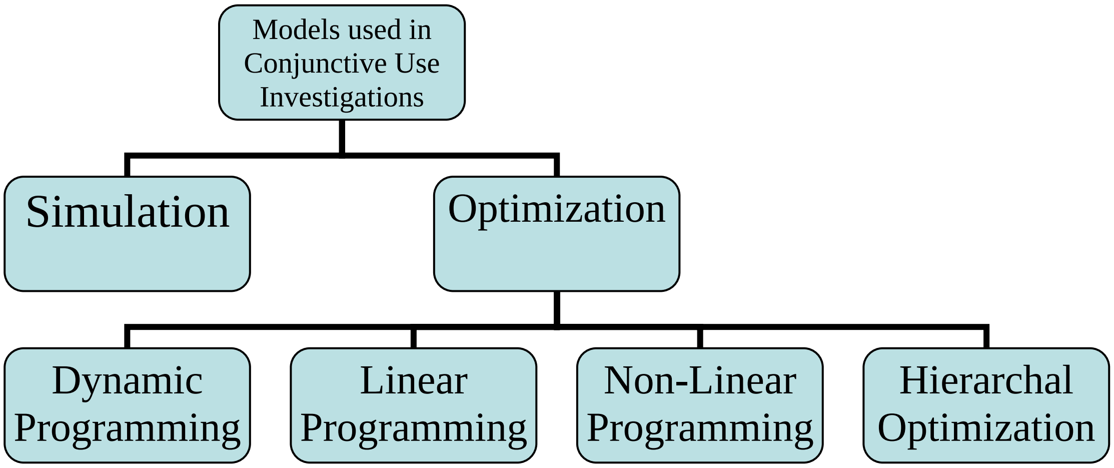

Figure 3.2 Types of mathematical models used in conjunctive use investigations

Dynamic Programming is based on Bellman's Principle of Optimality which states that, "An optimal sequence of decisions has the property that whatever the initial state and decisions are the remaining decisions must be optimal with respect to the state resulting from the initial decision (Bellman 1957)." In dynamic programming, the problem is broken down into small, solvable pieces that are interconnected, each piece is solved, and the optimal[8] solution is the one in which each previous step contributing to that solution is optimal. Linear programming involves maximizing or minimizing a linear objective function subject to a linear set of constraints. Non-linear programming is the same as linear programming except that the objective function, a constraint, or both are non-linear. In a hierarchal optimization model, competing objectives are given a priority weighting. Higher priority objectives are optimized first. After each ranking, inferior solutions are eliminated. With hierarchal optimization there is no direct comparison of different criteria, so no standardized criteria scores are needed (Carver 1991).

The Sac CALVIN model is a linear programming model. Since the functions being used in the model are all linear, it is the most intuitive and least computationally intensive. If non-linear penalty functions were to be entered in the model then a non-linear or dynamic programming model would be needed. However, the added benefit that would be gained from having non-linear input functions is minimal compared to the added complexity that would be added to the problem (Draper 2001).

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[8] Optimal refers to the solution which maximizes or minimizes the objective function. For an example, see Section 4.1 for the mathematical representation of the equations used in CALVIN. For further explanation see Section 5.2.

Combined Simulation-Optimization Models

Simulation and optimization techniques can be combined in a variety of ways to provide new insights into problems. For example, a simulation-optimization approach was used to develop operational plans for the main stem Missouri River system. The system has multiple uses and multiple reservoirs whose operations need to be coordinated to optimize the use of the storage throughout the whole system. The model incorporated the uncertainty, or stochastic properties, of inflow hydrology into the model by using a 92 year period of historic data. This implicit stochastic optimization technique was used to optimize reservoir storages. Simulation models were then used to refine and test the "optimal" operating rules (Lund et al. 1996).

Optimization and simulation techniques can also be used together when a simulation model is created, run many times, calculating the value of the objective function for each run (for example, the cost of that scenario), and then a maximum or minimum objective function value is identified and the scenario associated with the optimal value is the optimal solution. For example, a reservoir is going to be built in an arid region and the size of the reservoir needs to be determined. The inflow hydrology, the amount used by demand areas in the watershed, the evaporation and the cost of building a reservoir of a certain size are known. A simulation model could be built to determine the cost of building a reservoir of a given size. This simulation model could then be run many times, and the run that had the smallest cost would be the recommended design size. In this simple example, it would be possible to run the simulation model for a range of possible sizes. However, if the modeler wanted to take into account that the inflow hydrology, upstream demands, and evaporation are known only by their probability distributions, then it would not be possible to enumerate all the possible combinations of variables. In this case a Monte Carlo approach could be used. One study successfully used Monte Carlo simulation together with a hierarchal optimization model to determine the optimal reservoir operating policy for a multi-reservoir system in the Yaqui Valley in Mexico (Schoups et al. 2006).

A simulation model also can be built using optimization techniques. For example, CALSIM II, which is used to calibrate the surface water portion of the Sac CALVIN model, is a well-known water resource simulation model designed to simulate State Water Project (SWP) and Central Valley Project (CVP) operations by assigning priority weights to given flows and requiring minimum instream flows. The priority weights ensure that senior water rights holders will receive their water before those with junior water rights. Simulation is used in CALSIM II when inputs are translated into constraints that are then applied to a linear optimization model which determines flows. All optimization problems consist of an objective function and a set of constraints. The objective function in CALSIM II ensures that water is allocated to different users in the correct order based on their water right priority. In CALSIM II, flows in each reach being modeled are determined by solving a linear optimization model (DWR 2000).

Modeling Techniques used in Sac CALVIN

Sac CALVIN is a linear programming optimization model. An optimization model (as opposed to a simulation model) had to be used to determine the most economically efficient way to operate the Sacramento Area water system. A linear programming model (as opposed to a dynamic programming, non-linear programming, or hierarchal optimization model) was selected for its relative simplicity, intuitive formulation, computational speed, and because it allows for a direct comparison of evaluation criteria (this study used cost to make this comparison).[9] The Sac CALVIN model's objective function is to minimize system costs (mathematically equivalent to maximizing benefits), such that minimum instream flows are met, physical infrastructure capacities are not exceeded, and the mass balance of the water in the system is maintained (Section 4.1). Penalty functions are used to represent the cost of scarcity in the various demand areas (Figure 4.6).

3.4 Conjunctive Use in California

There have been numerous attempts to apply conjunctive use in the Central Valley. Many, such as those in the North Sacramento Area, the Eastern San Joaquin Area, Semitropic Water Storage District, Arvin Edison Water Storage District, and the Kern Water Bank, have been successful. These successful projects had several things in common: they 1) all kept stakeholders informed, 2) mitigated potential environmental impacts and complied with CEQA when appropriate, 3) avoided federal government involvement so they would not need to satisfy the NEPA requirements, and 4) most project expenses were covered by the agencies or individuals benefitting from the project.

Two unsuccessful attempts at groundwater banking include Butte County and Madera Ranch. These unsuccessful projects also had several things in common: 1) distrust by local landowners, 2) concern about third party impacts, 3) a perceived lack of communication with the locals, and 4) unaddressed concerns about banked water being used outside of the region. Seven regionally significant conjunctive use attempts are described in Appendix C.

The significant lessons learned from these attempts to use groundwater and surface water conjunctively are:

- Third party concerns must be addressed. Local groundwater pumpers have many concerns regarding exporting water. For a program to be successful these concerns should be heard and locals ensured that third party impacts will

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[9] To address the objectives of this study the less intuitive, but often computationally faster dynamic programming method was not needed. A non-linear programming model was not needed because all functions being input in the model (penalty and persuasion functions) were able to be linearly approximated. (A non-linear programming technique is needed when functions used in the model cannot be linearly approximated, or the function being used is an exact non-linear function (as opposed to an approximation) and the result is dependent on the level of accuracy contributed by the non-linear function. Non-linear programming models are computationally much more time intensive to run.) A hierarchal optimization model does not have a direct comparison of criteria, which was required since the least cost operation of the system was to be determined.

be mitigated against (see Eastern San Joaquin County conjunctive use program in Appendix C). The success of a program can be aided by holding the agency implementing the program accountable for negative impacts incurred by third parties (see Madera Ranch conjunctive use program in Appendix C).

- The higher the cost of water, the higher the interest in creating a conjunctive use system. If the price of water is perceived as high, individuals are more likely to consider paying for new infrastructure, including injection and extraction facilities, recharge ponds, or re-operating existing facilities to more efficiently manage ground and surface water resources. High water prices contributed to the success of the Semitropic Water District (see Appendix C).

- When water from a conjunctive use program benefits an area outside the groundwater basin, local pumpers need to be consulted and compensated. A project in the Eastern San Joaquin County was embroiled in two years of controversy because East Bay MUD was to export the extracted water from the project. The project was allowed to proceed on the condition that it maintained or improved current groundwater conditions. The Arvin Edison Water Storage District was successful because the Metropolitan Water District, which benefits from the project, offered enough money to make the project cost-free, and ensured that the groundwater banking would help mitigate against overdraft (see Appendix C).

Based on an analysis of seven of the prominent conjunctive use programs in California, success of a project is heavily dependent on the local public's perception of the project and their perceived involvement and compensation. The most significant setbacks to conjunctive use programs occurred because of a perceived lack of communication between the beneficiaries of the conjunctive use programs and the local groundwater pumpers.

4 The Sacramento Region Sac CALVIN Model

4.1 CALVIN Overview

In Chapter 3 the models for investigating conjunctive use were classified as either simulation or optimization models. Simulation models explore events and can answer questions such as, “What would happen if a 100-year event occurred in the watershed above Folsom Reservoir?” The goal of the optimization model is not to explore an event, but rather to identify the most promising decisions or operations. In the CALVIN model, the amount of water delivered to each demand area, flowing through the rivers and streams, pumped from the aquifers and reservoir releases in each time step is a decision variable. The decision variables are adjusted to satisfy the objective function, which in CALVIN is to minimize overall costs. Costs are associated with delivering less than the target amount of water to any of the demands and with pumping, treating, and distributing water. A detailed description of the costs in this model can be found in Table D.3. CALVIN determines the optimal operation of reservoirs and the optimal water delivery to each demand area. A basic schematic for the CALVIN model is shown in Figure 4.1.

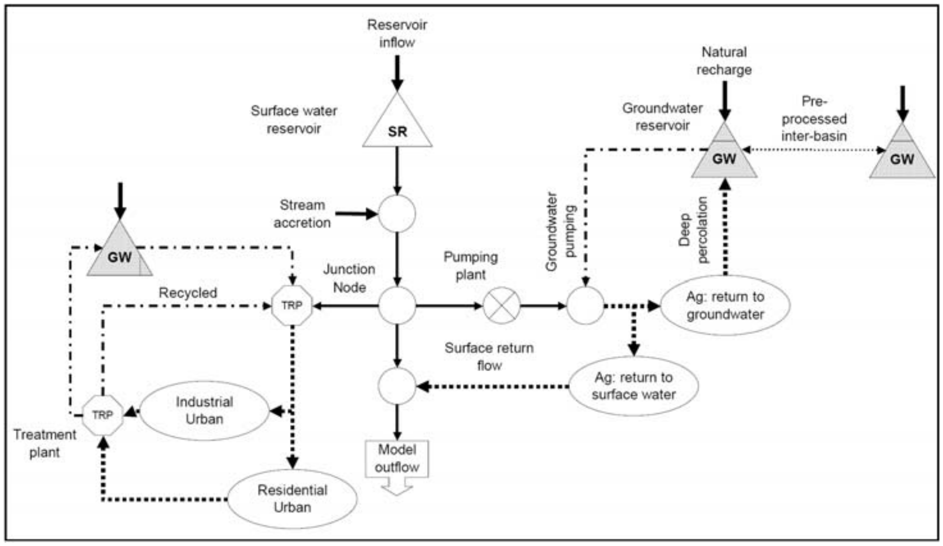

Figure 4.1 A Generic Portion of the CALVIN Schematic (Draper 2001)

Triangles represent storage facilities, These include both groundwater (shaded triangles) and surface water (unshaded triangles) storage facilities. The octagons are treatment plants including water treatment, wastewater treatment and recycled water treatment plants. Ovals are demand areas, either urban or agricultural demands. The water not consumed in the demand area will re-enter the system as a return flow.

Surface inflows are classified as either boundary flows (rim flows) or local accretions. Boundary flows generated outside of the study area and flow into the study area, such as inflows from major rivers or streams entering the study area. Accretions originate within the study area and then deep-percolate to groundwater or create streams that originate within the study area.

The inputs into the CALVIN model can be divided into: inflows, links and nodes. These are depicted in Figure 4.2 and are then described in more detail.

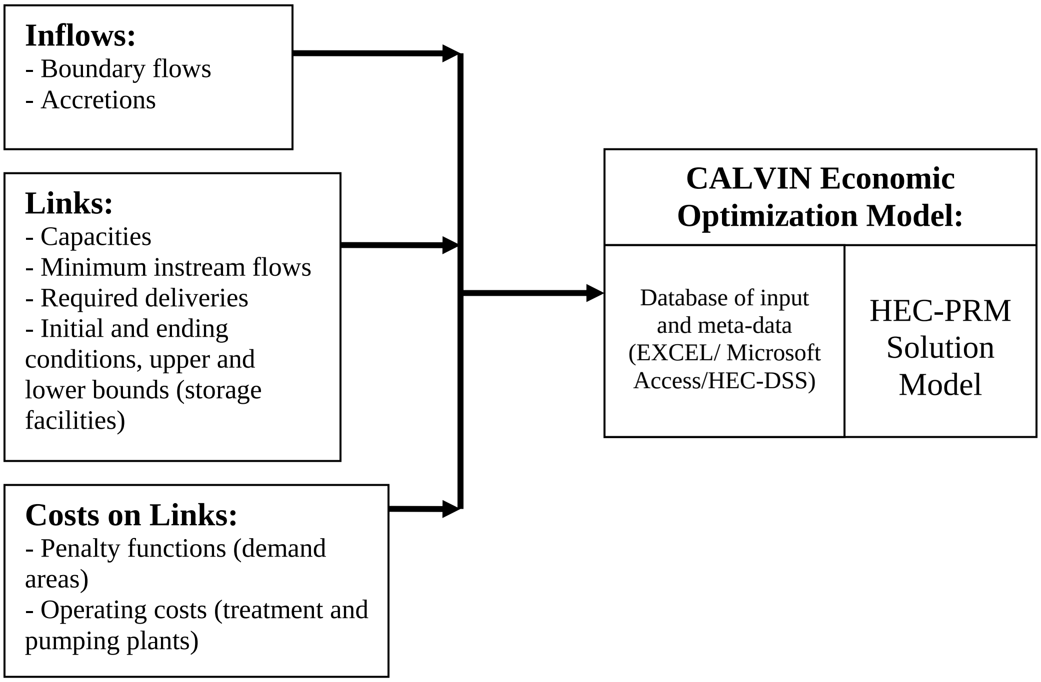

Figure 4.2 CALVIN inputs (modified from (Draper 2001))

CALVIN formulates the economic optimization problem as a network flow problem, a specific way of formulating a linear programming optimization problem (see Figure 3.2). The network flow formulation solves the problem by connecting a series of nodes with links (arcs). Any optimization problem consists of an objective function and a set of constraints. The objective is met by changing the decision variables. In the CALVIN model, the objective is to minimize the cost flows in all links, subject to the constraint that the water that enters each node must leave the node or be otherwise accounted for (such as a consumptive loss in a demand node, or a channel loss in an unlined channel), and the upper and lower bounds on each link cannot be violated.

The basic mathematical formulation of the CALVIN model is:

Minimize: Z= $\sum_i \sum_j C_{ij} x_{ij}$ (The cost of water flowing through each link)

Subject To: $\sum_i x_{ji} = \sum_i A_{ij} x_{ij} + B_j$ (conservation of mass at each node)

$x_{ij} \leq U_{ij}$ (upper bound on each link)

$x_{ij} \leq L_{ij}$ (lower bound on each link)

Where: *Z= the total costs of flows through the network [K$]*

x_{ij}= the amount of flow across link i-j [TAF]

C_{ij}=the cost of having one TAF of water flow across link i-j[K$/TAF]

A_{ij}=the amplitude on link i-j[dimensionless]

B_j=the external inflow to node j [TAF]

Figure 4.3 lists four categories of useful results that can be derived from the outputs of the CALVIN model: optimal flows, the added expense or cost reduction of different policy alternatives, the value of expanding infrastructure, and the demand area's willingness to pay for water and reliability. Since the decision variable in the CALVIN model is the amount of water flowing through each link, CALVIN determines the optimal flows that minimize costs for the network. These optimal outflows can be used to determine optimal reservoir operating rules, optimal demand area deliveries, and the potential beneficiaries of conjunctive use operations.

By comparing a run in which deliveries are constrained to current operating policy deliveries, and an unconstrained run, the value of flexible operations can be deduced, including the value of a conjunctive use program. As an added benefit to formulating the problem as a linear programming problem, the solution includes shadow values (Lagrange multipliers) for capacities or flow requirement on each link. The shadow values indicate the value of relaxing the constraint on that link by one unit. For example, if the shadow value on a link from the Freeport Pipeline to Omochumne-Hartnell Agricultural Water District (OHWD) was -$42 in October of 1942, that means that if one more unit (in this case one more AF) of water was allowed to flow from the Freeport Pipeline to OHWD the overall cost to the system would be reduced by $42.

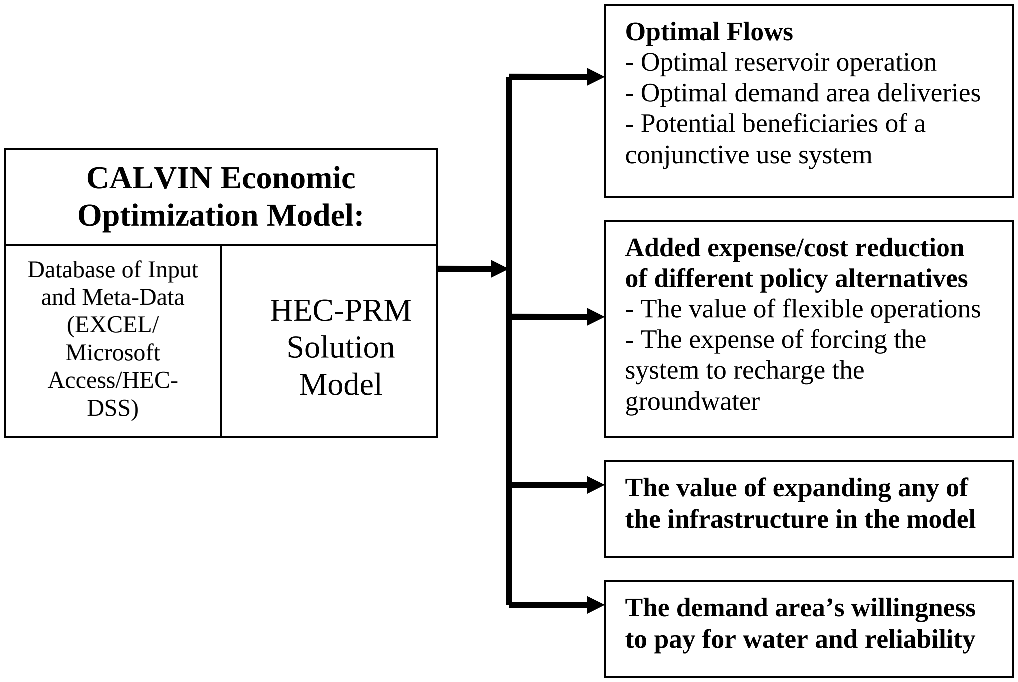

Figure 4.3 CALVIN outputs (modified from Draper, 2001)

4.2 Schematic of the Sacramento Region

The CALVIN model is the most extensive water optimization model in California with over 1,200 spatial elements including 51 surface reservoirs, 28 groundwater reservoirs, and over 600 conveyance links. The model accounts for 88% of the irrigated acreage in California and 92% of the population (Lund 2003). Areas of California that are modeled by the CALVIN model are shown in Figure 4.4.

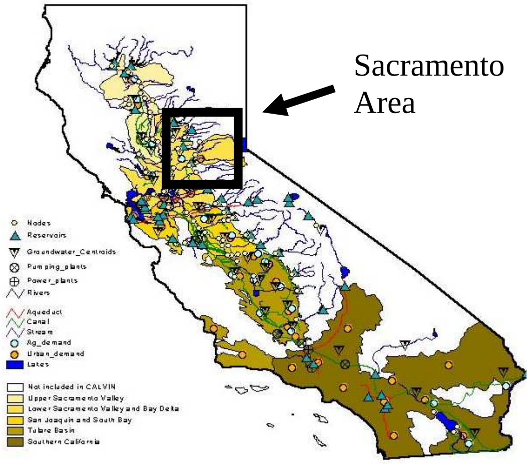

Figure 4.4 Coverage of the CALVIN model in California (Lund 2003).

The original statewide CALVIN model, has relatively little refinement in the Sacramento Area as illustrated by the schematic in Appendix A. One objective of this study is to find the most promising operations of the facilities in the Sacramento County area to operate ground and surface water together in the Central and South Sacramento County Groundwater Basins to lower system operating costs. For this question, a more refined schematic was needed. The refined schematic:

1. Accounts for the North, Central and South Sacramento County Groundwater Basins separately and uses Sac CALVIN to find optimal deliveries to each demand area from the groundwater (except rural residential estates and SMUD, which are supplied using a fixed time series)

2. Explicitly accounts for the North Sacramento County and Placer Areas, the City of Sacramento, Cal-Am Parkway, Cal-Am Rosemont, Rancho Murieta, City of Folsom, Golden State, the Sacramento County Water Agency (SCWA), Cal-Am Security Park, and SMUD. Each of these areas was mapped to the 43 different areas modeled by WRIME using the SacIGSM model (see Table A.1)

3. Disaggregates agricultural demand areas from the previous model by grouping agricultural demand areas together based on their available ground and surface sources (see Table A.2).

4. Represents deliveries to East Bay Municipal Utility District (EBMUD) as a fixed time series because EBMUDSim is a proprietary model and as such the 2030 predicted deliveries from Pardee Reservoir are unavailable. The Folsom South Canal Deliveries to EBMUD were reported in the Freeport EIR, and the annual average was found to be the same as that modeled by CALSIM II OCAP study. The monthly pattern used by EBMUDSim and CALSIM II differ, so for consistency, and to calibrate the model, the CALSIM II deliveries were used.

5. Includes the Aerojet Groundwater Treatment Plant and Rancho Murieta's surface water reservoirs

The updated schematic for this region can be found in Appendix B. A Microsoft Access database, which is used by PRM NetBuilder to solve the network flow problem, was created to represent the Sac CALVIN schematic.

4.3 Data Sources

The SacIGSM general study was used for much of the groundwater – surface water interaction including estimating maximum pumping capacities, natural deep percolation, and deliveries to demand areas not modeled dynamically (for example, the rural estates were modeled with a fixed time series of demands). SacIGSM is the most comprehensive groundwater model available to describe ground-surface water interaction for the Sacramento County Groundwater Basin. The groundwater in the Sac CALVIN model was calibrated using the SacIGSM model. Calibrating to SacIGSM has two advantages. First, it avoids duplicating the extensive effort and detailed data collection needed to build a reliable ground-surface water model. Secondly, since the SacIGSM model is already widely accepted[10] by both groundwater modelers and policy makers who will be interested in the outputs from the Sac CALVIN model, it provides some continuity between the models and allows accounting for discrepancies between the models.

A more recent SacIGSM refined study was not used because it modeled a shorter time period (Oct '69 – Sept '95). It would have needed to be used together with the general study which did model the entire period of interest (Oct '21 – Sept '93), and the starting and ending groundwater storages for the central and south groundwater basins did not match (see Figure 4.7) (WRIME 2005).

The CALSIM OCAP 4a Study assumptions for the minimum instream flows, and surface water accretions and depletions that were not dynamically modeled were used. For the base case surface water deliveries to Res:NE Co Sac Placer, Res: Folsom+GS, the Folsom South Canal, Res: SacCity+Cal-Am Parkway and Rosemont, Res: SCWA + Cal-Am Security Park were fixed at deliveries observed in the CALSIM OCAP 4a Study (see Table A.1 for a mapping of Sac CALVIN urban demands to water purveyors and SacIGSM areas, and see Figure 2.4 for areas corresponding to SacIGSM area numbers). Calibrating flows from the CALSIM OCAP 4a study were cross-checked with other modeling efforts whenever possible. The annual volumes that were modeled by the SCWA Allocation Model for the Sacramento County Water Agency (SCWA) Central Valley Project diversions at the Sacramento River Water Treatment Plant and the SCWA diversions at Freeport were the same as those modeled in the CALSIM OCAP 4a Study. The annual volume of Freeport water delivery to East Bay MUD as predicted by the EBMUDSIM Model, was cross-checked with the CALSIM OCAP 4a and was found to be approximately the same.

4.4 Demands

An extensive literature was reviewed and discussions were held to determine which demand areas receive water from the Central and South Sacramento County Groundwater Areas. The water districts represented in the model were also consulted and representatives at each agency have made available much of the data needed to make this study possible (see Acknowledgements). The results have been organized into a flow chart, which can be found in Figure B.2. The flow chart begins at the natural bodies of water of interest in this investigation (the blue areas). Any water treatment plants were identified and the SacIGSM areas were grouped together based on which sources of water they had access to. These became the Sac CALVIN demand areas. All SacIGSM

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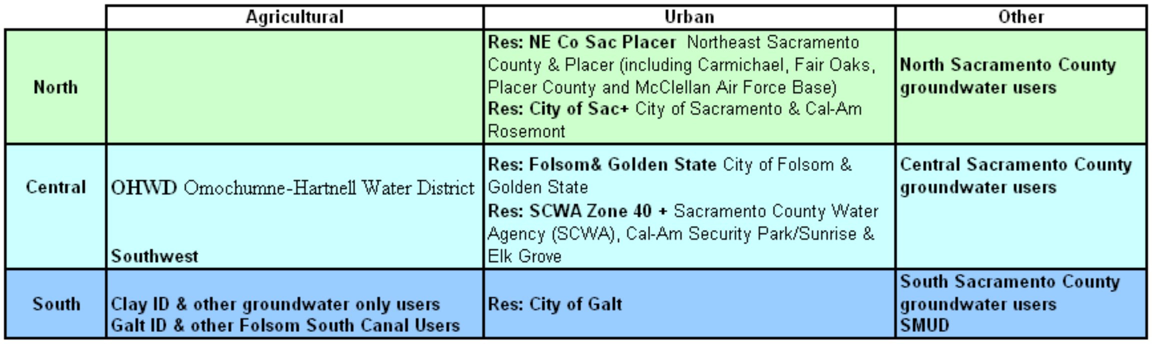
[10] "All models are wrong, but some are useful." (G.E.P. Box) Neither the original nor the refined Sac IGSM model will be correct, but the purpose of the Sac CALVIN model is to serve as a conversation piece for policy makers and water purveyors who already accept both SacIGSM models. The developers of the SacIGSM model have said that for the purposes of this study, the original Sac IGSM will at least be consistent in the error it introduces over the 72 year period of hydrology and since we are most interested in long term trends and annual average values, this should be sufficient.

regions are illustrated in Figure 2.4, and the Sacramento CALVIN areas that they are mapped to are documented in Tables A.1 and A.2 of Appendix A. Each SacIGSM area can be mapped to a section of the region being modeled, ensuring that all water entering the demand areas above the Sacramento County Groundwater Basin is accounted for and can be traced from its source to its recipient, which can be connected with a piece of land. A summary of the agricultural, urban and other demand areas represented in the Sacramento area CALVIN model are appear in Figure 4.5. The other areas are primarily rural residential estates (North, Central and South Sacramento County groundwater users) that have significantly different water use patterns from either the agricultural or the urban areas. They are represented as fixed diversions in the model. The SMUD Rancho Secho facility is also represented as a fixed diversion in the Sacramento Area CALVIN model; the facility consumes water in the cooling towers of its power plant.



	Agricultural	Urban	Other
North		**Res: NE Co Sac Placer** Northeast Sacramento County & Placer (including Carmichael, Fair Oaks, Placer County and McClellan Air Force Base) **Res: City of Sac+** City of Sacramento & Cal-Am Rosemont	**North Sacramento County groundwater users**
Central	OHWD Omochumne-Hartnell Water District **Southwest**	**Res: Folsom& Golden State** City of Folsom & Golden State **Res: SCWA Zone 40 +** Sacramento County Water Agency (SCWA), Cal-Am Security Park/Sunrise & Elk Grove	**Central Sacramento County groundwater users**
South	**Clay ID & other groundwater only users** **Galt ID & other Folsom South Canal Users**	**Res: City of Galt**	**South Sacramento County groundwater users** **SMUD**

Figure 4.5 Summary of demand areas represented in the Sacramento Area CALVIN model

Once the mapping was done, target demands for each Sac CALVIN region were needed. All major water districts in the model were called and asked for current per capita useage for their area and predicted population in their demand area in 2030. These estimates were used to set target values for each of the demand nodes. The target value is the value for which there is no penalty cost for delivering that amount of water (or more), but for which there would be no cost benefit for delivering more water. A typical penalty function is depicted in Figure 4.6. All specific penalty functions can be found in the .dss files associated with any of the modeling scenarios which can be found by contacting Professor Lund (all penalty functions are the same in all four modeling scenarios used in this project.)

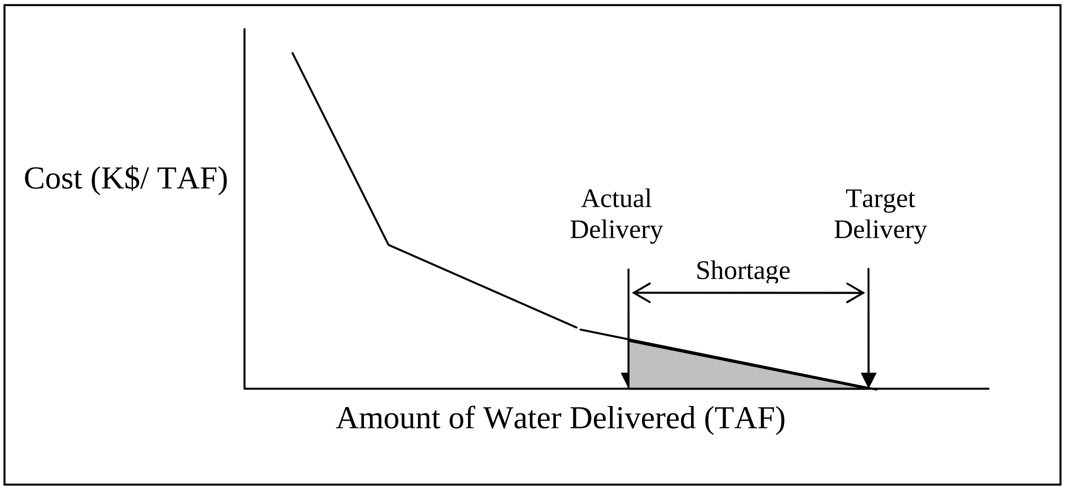


Figure 4.6 Typical Penalty Function

Much of the analysis discussed in the results of this report focuses on water scarcity costs. Scarcity costs occur when less water is delivered to a demand area then the target delivery. Figure 3.6 illustrates an example in which the actual delivery is less than the target delivery. The difference between the target delivery and the actual delivery is the shortage, or the water scarcity to that demand area. The cost of creating that shortage, or the scarcity cost, can be calculated by finding the area of the shaded region shown in Figure 3.6. Since Sac CALVIN is an optimization model, and there is no additional benefit to delivering another unit of water past the target amount, the model will never allocate more than the target amount.

One problem in calibrating the model was that the demand estimates derived using populations projected by the water districts and their reported current per capita use were significantly higher than those used in WRIME’s SacIGSM model, but they were significantly less than the demands assumed in the CALSIM II 2020 OCAP model. One reason for this discrepancy is that the CALSIM II model is a policy model used for planning. When agencies report their predicted water usages to the US Bureau of Reclamations - which are then input into CALSIM II - they tend to report that they will be using their entire water right. Since it cannot be proven otherwise, this is what is modeled in CALSIM II, even though this may not accurately represent water demand in 2030. Once the target demands were identified, the Black& Veatch Price Survey of 2006 was used to create the penalty functions.

4.5 Calibration

Since the Sac CALVIN model does not do any detailed modeling of the surface and ground water interactions, it relies on the SacIGSM model to represent that interaction, as well as all the other detailed groundwater modeling. Inflow hydrology from areas outside the modeled area, and local accretions and depletions were taken from the CALSIM II model. Since the predicted future demands are fundamentally different in Sac IGSM, and CALSIM II, both of which are different from the predicted future demands as reported by the water purveyors themselves, calibration flows were needed to ensure that the system had access to the right amount of water in any given month (and to create a feasible model that wouldn't crash).

Calibration flows were added at key locations in the water system (see Table D.6 in the Appendix D for the details on these calibration flows). The most significant calibration flow that was needed to adjust a delivery at a demand area was at Northeast Sacramento County and Placer where the CALSIM II model had grouped both the agricultural and urban areas together. Flows to the agricultural area (CVPM-7) were removed from the system as a calibration flow.

Calibration flows were also needed to correct for discrepancies in the evaporation rates in the reservoirs. Average calibration flows and an explanation of why they were needed appears in Table D.6 in Appendix D.

4.6 Water Sources and Infrastructure

The major water sources represented in the Sacramento Area CALVIN model are the Sacramento River, Feather River, American River, Cosumnes River, and the North, Central and South Sacramento County Groundwater Basins. A simplified schematic which illustrates the recipients of water from each of these major sources appears in Figure B.2. Demand areas that receive water from the same sources are grouped together in the Sac CALVIN demand nodes represented in the simplified schematic. A complete version of the Sacramento Region CALVIN model schematic is based on this and is included in Figure B.3.

The inflow hydrology for each of these water sources used in this study is from the historic period of record from October 1921 – September 1993. This implicitly stochastic, or statistically random, hydrology is used to meet 2030 demands. Using historic hydrology to model future conditions is a widely accepted practice and the California Department of Water Resources, as well as numerous consulting firms that conduct groundwater modeling. Occasionally, scenarios are examined where the historic period is adjusted, amplified for extreme precipitation scenarios, or scaled down for drought scenarios. Since a projection is being made 20 years into the future, it is assumed that the hydrology will be much the same, and that the types of droughts experienced in the last 72 years will be similar to the droughts experienced in the future.

The major infrastructure included in the model include Folsom and Oroville Reservoirs, the Freeport Pipeline, and the Folsom South Canal. In the model, each of these pieces of infrastructure has an upper and lower bounds applied to them to ensure the system is modeled in a feasible way. The upper bounds represent physical capacities. These capacities were determined by consulting literature published by the water districts or by consulting directly with the water agencies. The upper bound constraints are summarized in Appendix D. The lower bound constraints represent minimum environmental flow requirements. The minimum instream flow requirements were kept consistent with previous CALVIN studies, and detailed documentation for each application of a minimum flow can be found in the PRM NetBuilder database.

4.7 Groundwater

One of the most detailed groundwater modeling efforts of the Sacramento County Groundwater Basin is that done by WRIME using the SacIGSM model. The SacIGSM 2030 Baseline Run was used to set the initial and final groundwater storage values for the Sacramento Area CALVIN model. This was done by aggregating the time series from all of the 43 subbasins into north, central and south subbasins. The initial and ending storage values were fixed for the base case and the unconstrained case. To create a fair comparison between the base case and the unconstrained case, initial and ending ground and surface water storage values were fixed in both runs; however, in the base case the entire time series for the groundwater storage levels was constrained. The natural deep percolation that was applied to all model runs was determined by processing the output from the SacIGSM model. The deep percolation due to agricultural and urban runoff is dynamically modeled in the Sac CALVIN model.

The Sacramento County Integrated Ground and Surface water Model (SacIGSM) was used to establish the pumping capacities, the return flow and the proportion of the water returning to the groundwater after being used demand areas dynamically represented in the model. The SacIGSM model also was used to calibrate the model used in this study. SacIGSM models both the Modesto Formation and the Mehrten Formation (see Section 1.2).

The original SacIGSM study, which models the entire period being analyzed by this study, was used. A more refined study, also done by WRIME using the SacIGSM model, has been conducted since the original study; however, it only spans from October 1969 – September 1995. Using the first half of the time period from the original study and the second half from the more refined study was not an option, because the October 1969 storage values in the Central and South Sacramento County Groundwater Basins did not match, as shown in Figure 4.7. For consistency, only the original SacIGSM data was used in this model. The resolution offered by the original SacIGSM study was found to be sufficient for the question of whether reservoir re-operation is economically beneficial.

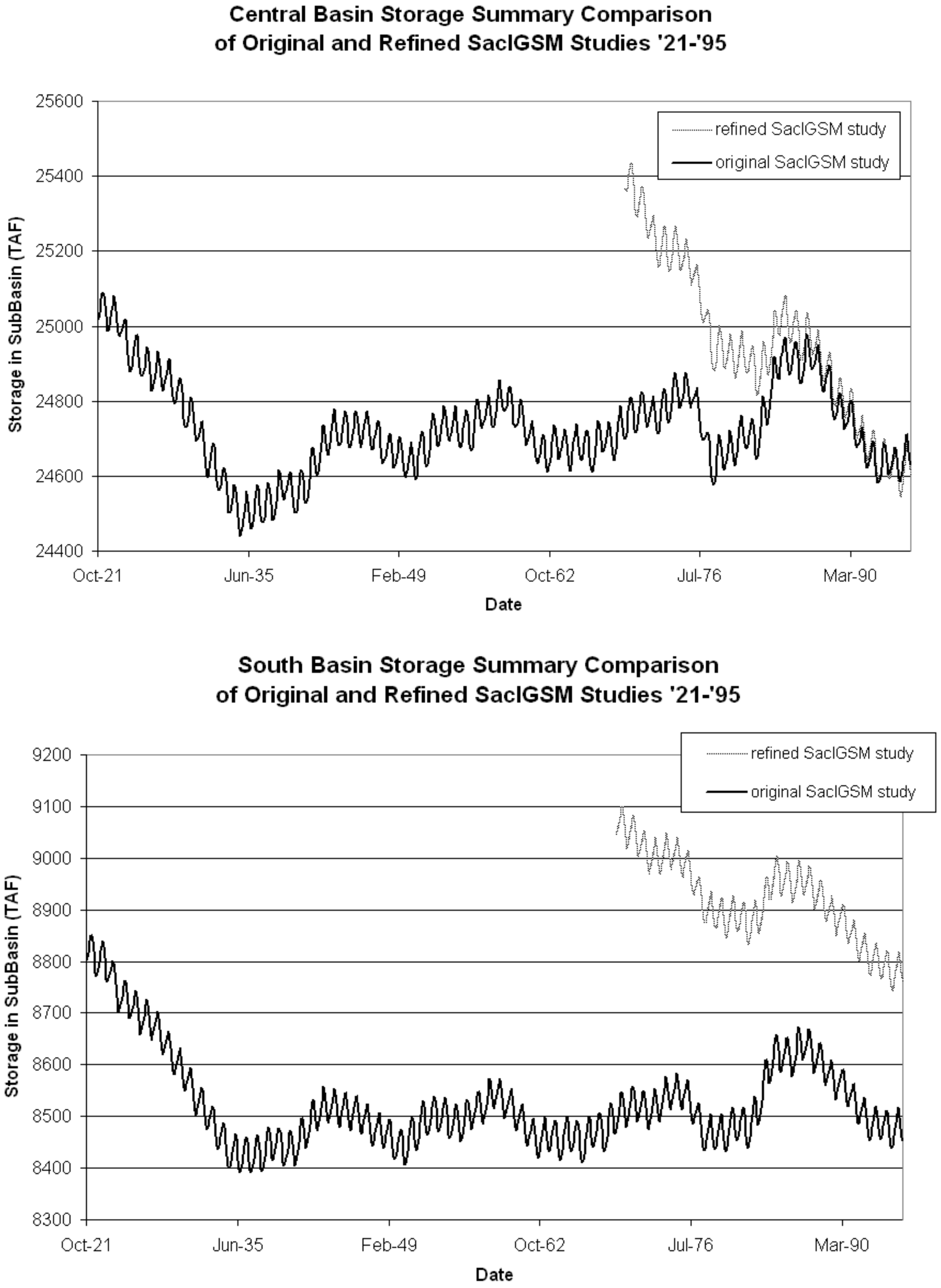


Figure 4.7 Central and South Basin Storage Summary Comparison of the SacIGSM original and refined studies.

Figure 4.7 also illustrates that much more water is stored in the Central Sacramento County Groundwater Basin than in the South Sacramento County Groundwater Basin. The Central Sacramento County Groundwater Basin stores approximately 25,000 TAF as compared to the South Sacramento County Groundwater Basin that stores approximately 9,000 TAF.

4.8 Surface Water

The surface water in the Sac CALVIN model uses the reservoir starting and ending conditions from the CALSIM II 2020 OCAP Study. In the base case, storage in the surface water reservoirs are constrained to those modeled by CALSIM II. Originally, the operations of Pardee and Comanche Reservoirs were to be modeled, but since EBMUDSim is a proprietary model, the way EBMUD plans to operate these reservoirs was not reported in the Freeport Draft EIR vol. 3. The Mokelumne River system was therefore omitted from this study, and the deliveries to East Bay MUD were modeled as a fixed timeseries rather than dynamically. For consistency, the deliveries modeled by CALSIM II were used in this study. The annual average of these deliveries is the same as those reported in the Freeport EIR, although the monthly pattern is different.

The accretions (surface water flows that originate within the boundary of the area being modeled) were also calculated based on the CALSIM II 2020 OCAP Study. The depletions were calculated similarly. The boundary flows (flows that originate outside of the study area) were calculated from the CALSIM II 2020 OCAP model run results.

4.9 Costs

Since Sac CALVIN is a hydro-economic model, operations are driven by costs. The costs in the model were found by consulting with the water districts being modeled. A detailed report of costs used in this model appears in Appendix D. All groundwater pumping costs were estimated using depth-to-groundwater data for the fall of 1995 provided by WRIME. These data was reported for approximately 2000 nodes. An average depth-to-groundwater value for Fall of 1995 was found for each of the 43 regions modeled by the SacIGSM model. This value was used to calculate a weighted depth-to-groundwater value for each region in Sac CALVIN. The average was weighted using the pumping the SacIGSM model predicts in 2030 for each of the 43 regions. To these weighted average depths, 30 feet of drawdown was added (Newlin et al. 2001). In GW-7 the change in lift in 2030 was estimated to be 19 ft and in GW-8 (GW-CSC and GW-SSC) it was estimated to be 3 ft (Newlin et al. 2001). To calculate the cost, the total pumping head was multiplied by \$0.30 / AF / foot of lift. This value was derived from the 1995 statewide average as reported in the CALVIN Operating Costs Appendix G (Newlin et al. 2001), by adjusting it for inflation to a 2008 cost (Appendix D). Table 4.2 summarizes the costs and ranks them by demand area from least expensive to most expensive. Groundwater is least expensive source of water for Res: SCWA + Cal-Am Security Park, and for Res: City of Sacramento + Cal-Am Parkway + Cal-Am Suburban

Rosemont, as well as for the Res: City of Galt and Ag: Southwest, which only have access to groundwater.

Table 4.1 Cost Ranking of Water Sources By Demand Area

Sac CALVIN Demand Node	Water Source	Total Cost ($/AF in 2008 Prices)
Res: NE Sac Placer	N&M Forks American R	35
	Folsom Reservoir	35
	GW-7	51
Res: SCWA + Cal-Am Security Park	GW-CSC (Untreated)	41
	GW-CSC (Treated)	56
	Sac R via Freeport Pipeline & Vine WTP	70+FRPT (12 to 24)
	Lower American R via Fairbairn WTP	98
	Sac R via Sac City R WTP	108
	Recycled Water	400.8
Res: Rancho Murieta	Cosumnes R	35
	Recycled Water	400.8
Res: Folsom + Golden State	Folsom Reservoir via Folsom WTP	35
	GW-CSC	65.55
	American R via Folsom South Canal and Coloma WTP	77.90
Res: City of Sac +Cal-Am Parkway + Cal-Am Suburban Rosemont	GW-7	28
	GW-CSC	51
	Lower American R via Fairbairn WTP	60
	Sac R via Sac City WTP	70
	Recycled Water	400.8
Res: City of Galt	GW-SSC	45
	Recycled Water	400.8
Ag: Southwest	GW-CSC	28
Ag: OHWD	Cosumnes River	0
	GW-CSC	31
Ag: Galt ID + Other Folsom South Canal Users	Laguna & Badger Creeks	0
	GW-SSC	42
Ag: Clay ID + Other Ground Water Only Users in the South Basin	SMUD Water	0
	Folsom South Canal	0
	GW-SSC	45
Ag: CVPM-7	Sacramento River	0
	GW-7	17
(Unconstrained Case) Ag: OHWD, Galt ID, Clay ID	Sacramento River via Freeport	29.25 to 43

5 Results

5.1 Project Goals

The goals of this study are to:

- Determine the maximum amount of increased water delivery that would be economically efficient for the Sacramento Area to obtain if the system is: a) allowed to operate flexibly, b) driven only by economic objectives, and c) constrained only by physical capacities and environmental flows[11]. Identify how increased deliveries are made possible, and how all major infrastructure (including operation of Folsom and Oroville Dams and the Freeport Pipeline) is operated under optimal conditions. Determine other major benefits associated with this re-operation. Identify where there is economic benefit to changing current operating policy or expanding infrastructure.

- Determine if seasonal or inter-annual conjunctive use opportunities are predicted if the Sacramento Area water system is flexibly operated, and economic costs to the entire Sacramento area are minimized.

- Determine how water supply deliveries would be affected if a policy required groundwater levels to equal or exceed the 1993reference condition by the end of an extended period of time (in this case the 72 year period being modeled). Determine the additional cost of such a policy.

- Determine the affect on water supply deliveries if a policy required groundwater levels to restore Cosumnes River baseflows by the end of an extended period of time (in this case the 72 year period being modeled). Determine the additional cost of such a policy. If there were less water in the system (such as that modeled under a scenario where baseflows were required to be restored) determine which infrastructure would be the most economically beneficial to expand its capacity.

5.2 "Optimal" Operation

To meet these objectives, an optimization model was used to determine the optimal way to operate the system and then that optimized scenario was modified to examine different groundwater management strategies. Attempting to find the "optimal" way to operate a system implies an overarching goal dictates the operations. The "optimal" operations examined in this model involve maximizing net economic benefit to the entire system. Environmental considerations are taken into account through minimum instream flows,

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[11] A few institutional policies were also included, such as limiting Folsom South Canal diversions from the American River to the diversions predicted by CALSIM II limiting diversions from the Folsom South Canal to agricultural areas to 10% more than the maximum value predicted in CALSIM II simulated operations.

for example, required flows on the Lower American River and the Mokulemne River. Disagreements between water purveyors, preferences for specific water sources, and political tendencies are initially not included in the Sac CALVIN model. The results from optimizations show, if political differences and social preferences for some water sources could be overlooked, how an idealized system would be operated to maximize economic benefits. This can give insights into how to more efficiently operate the existing water system, and point to sometimes unexpected opportunities where inefficiencies in the system can be eliminated and resources expanded.

5.3 Modeling Scenarios Evaluated

To answer the questions being explored in this study, four modeling scenarios were developed and run, and their results compared: a base case, an unconstrained case, a case that required groundwater levels at the end of the 72 year period to equal or exceed the initial groundwater level, and a case which required groundwater baseflow to be restored at the end of the 72 year period. Each model run is described below.

Base Case

In the base case, the model was forced to operate according to the existing operating policy. This involved calibrating the surface water flows to those modeled by CALSIM II OCAP 4a modeling run with 2020 level of development, the Department of Water Resource model used to answer policy questions relating to managing Sacramento River system surface water infrastructure and supplies. Since the surface water flows were constrained, so were the reservoir operations. Groundwater was forced to mimic the operations predicted in the SacIGSM model Baseline model run with 2030 level of development. Outflows to the Delta were required to equal or exceed the minimum required flows from the corresponding CALSIM II locations, including prescribing the contributions from the Sacramento River and the East Side Streams according to CALSIM II.

Unconstrained Scenario (Flexible Operation Scenario)

The unconstrained scenario allowed deliveries to demand areas to be optimized based on economic efficiency and existing infrastructure capacities, with only a few operating policies imposed. In the unconstrained run the total outflow to the Delta from the Sacramento River and East Side Streams was maintained as the same level as the Base Case but the proportion contributed from the Sacramento River and from the East Side Streams was allowed to vary, within limits imposed by minimum instream environmental flow constraints represented on the Sacramento and Mokelumne Rivers. Additionally, Feather River and American River outflows that had been forced to mimic monthly flow patterns observed in CALSIM II were allowed to vary as long as they met the minimum instream flow requirements from the CALSIM II study. Reservoir operations also were relaxed from policies represented in the Base Case, and as long as reservoirs did not exceed their rule curve for the flood pool or fall below their dead pool, were allowed to operate to maximize net economic benefit. Groundwater initial and ending storages were required to meet those observed in the base case at the beginning and the end of the 72 year analysis period (essentially the same as those observed in the SacIGSM study). Demand areas were allowed to pump groundwater or take surface water, limited only by groundwater and surface water pumping, diversion, conveyance, and water treatment plant capacities.

In an initial run of the unconstrained scenario, even with the minimum instream flow on the Lower American River, much more water was diverted down the Folsom South Canal than was modeled by CALSIM II (equal to the base case, in Figure 5.1).

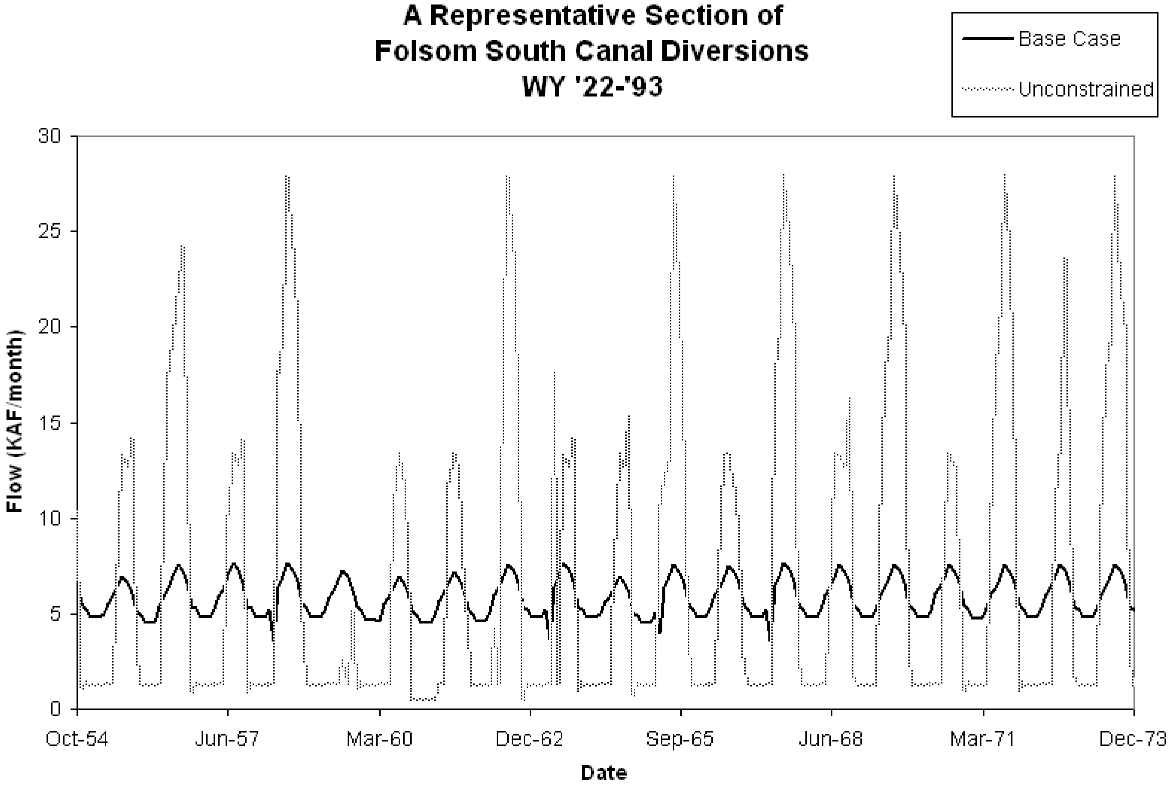


Figure 5.1 Water Diverted Down Folsom South Canal in the Unconstrained Case Before Limiting Folsom South Canal Diversions

Diverting more water down the Folsom South Canal than is allowed for in the current policy is a major controversy and was the reason that SCWA and East Bay MUD had to build the Freeport Pipeline, since advocates for the Lower American Chinook Salmons and Steelhead point out that diverting water from the American River near Lake Natomas deprives fish in the Lower American River of the use of that water. Since this political issue is not the focus of this investigation, an operating constraint was imposed on the final unconstrained model run to restrict diversions into the Folsom South Canal to be at or below those modeled in the base case.

No Net Groundwater Overdraft (Flexible Operation Scenario with No Net Groundwater Depletion)

Setting the groundwater ending storage greater than or equal to the initial storage scenario could also be called the no-net groundwater depletion scenario. It modified the calibrated unconstrained scenario by raising ending groundwater storages in each basin to be at or above the initial level observed at the beginning of the 72 year period (25,021 TAF in the Central Basin and 8,801 TAF in the South Basin). These initial groundwater storage levels are the 1993 final groundwater level modeled by the SacIGSM calibration model (Traum 2008).

Restore Groundwater Baseflows Scenario (Flexible Operation Scenario with Required Restoration or Groundwater Baseflows)

This scenario further modified the calibrated unconstrained scenario by increasing ending groundwater storage levels in the central and south basins to be at or above the calculated levels required to restore groundwater baseflow to the Cosumnes River by the end of the 72 year period being modeled (36,510 TAF) (see Tables D.7 and D.8 in Appendix D for details on how the storage level needed to restore baseflows was calculated.)

These four modeling scenarios represent different water management strategies to satisfy different objectives. The base case represents the current economic analysis and disaggregated behavior of system operations and water allocations under the current operating policy. The unconstrained scenario represents the economically optimal way to allocate water resources and operate the system for maximum economic benefits, and reveals management strategies that generate such optimal results including reservoir operation and conjunctive groundwater management. The no further depletion scenario represents how the system could be optimally operated if a policy was implemented to avoid any further net depletion over the long-term from the 1993 reference condition agreed upon by the Water Forum. The scenario which requires increasing groundwater aquifer levels aimed at re-establishing historic baseflow to the Cosumnes by the end of the modeling period shows the economically optimal operation, ideal water allocations, and the maximum economic benefits that could be expected if this policy were to be implemented.

5.4 Steps used in Sac CALVIN Modeling Effort

The four project goals were met using the four scenarios described above by following the steps outlined in Figure 5.2 below.

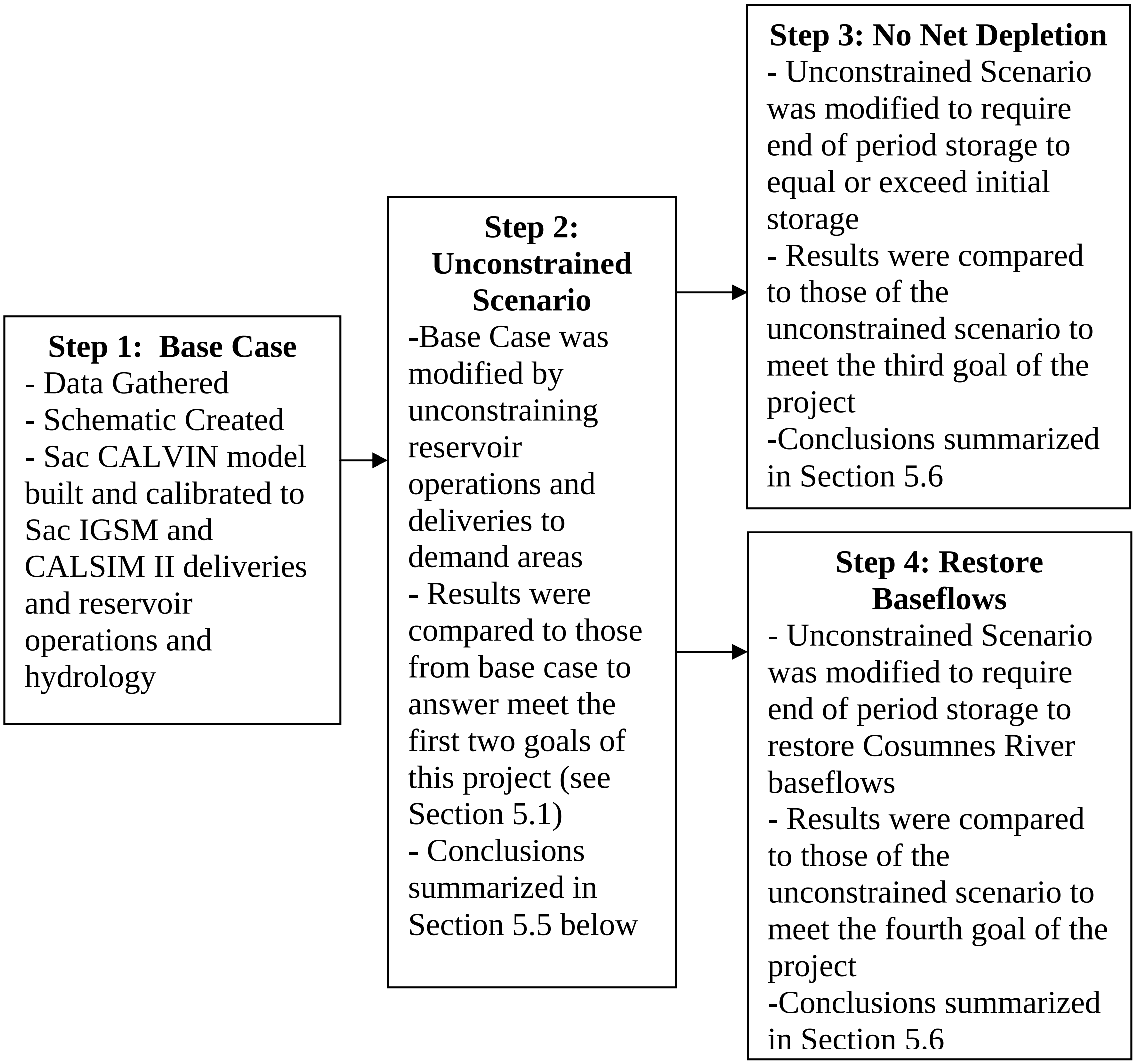


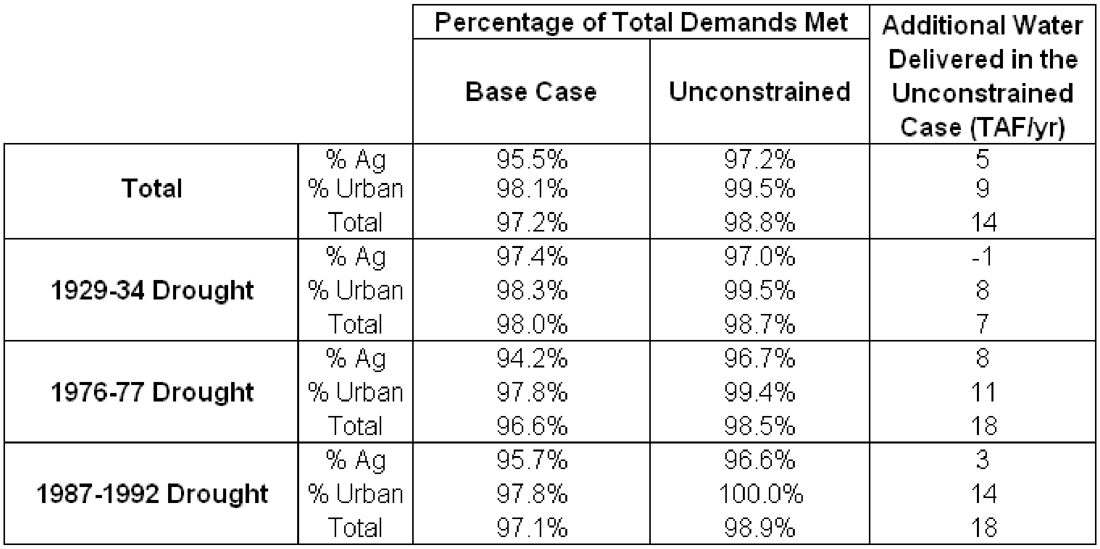
Figure 5.2 Steps used in the Sac CALVIN modeling project to meet the project goals explained in Section 5.1

5.5 Optimal Operation of Reservoirs and Conveyance Facilities

Maximum Flexible Operation Benefits

The major benefits to the system from more flexible optimized operation are 1) reduced scarcity, 2) increased water supply deliveries, and 3) decreased scarcity and operating costs. First, with flexible system operations, scarcity is nearly eliminated, 99% of all water demands in 2030 are met, as compared with only 97% of future water demands met by the current operating policy. Reductions in scarcity are greater during two of the historic droughts. Table 5.1 shows the percentage of the total target water demand that can be met in the unconstrained case as compared with the base case. Over the 72 year period being modeled, approximately 1.5% more deliveries occur in the unconstrained case, with 1.7% more deliveries to agricultural users and 1.4% more delivered to urban users. In severe droughts, such as the 76-77 drought and the 87-92 drought, greater scarcity reductions are observed. For example, there was nearly a 2% total increase in deliveries during each of those extreme events. This amounts to a total reduction in scarcity of nearly 55%.

Table 5.1 Percentage of Water Demands Met



		Percentage of Total Demands Met		Additional Water Delivered in the Unconstrained Case (TAF/yr)
		Base Case	Unconstrained	
Total	% Ag	95.5%	97.2%	5
	% Urban	98.1%	99.5%	9
	Total	97.2%	98.8%	14
1929-34 Drought	% Ag	97.4%	97.0%	-1
	% Urban	98.3%	99.5%	8
	Total	98.0%	98.7%	7
1976-77 Drought	% Ag	94.2%	96.7%	8
	% Urban	97.8%	99.4%	11
	Total	96.6%	98.5%	18
1987-1992 Drought	% Ag	95.7%	96.6%	3
	% Urban	97.8%	100.0%	14
	Total	97.1%	98.9%	18

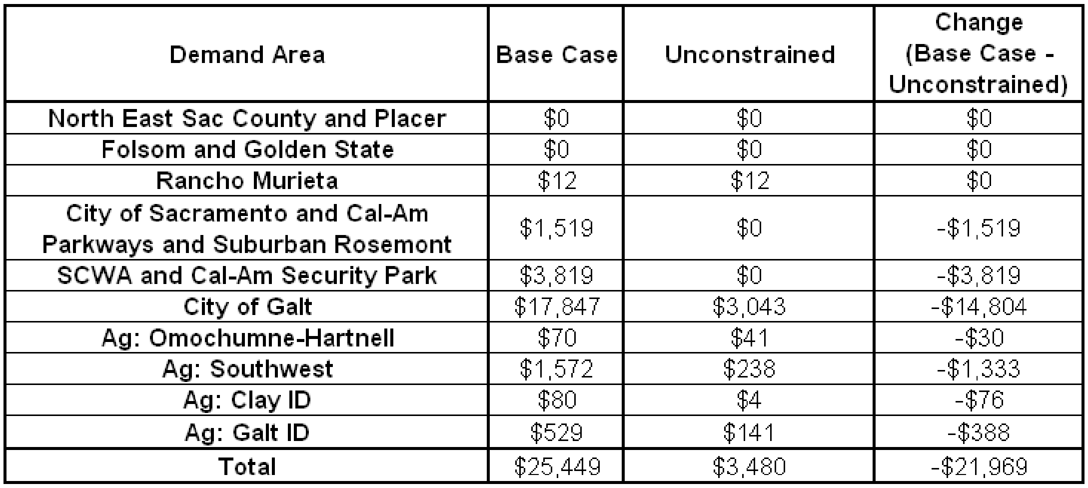
This increased water delivery occurs as a result of more flexible institutional operations. More efficient water management practices in the unconstrained case led to an annual average scarcity reduction of approximately 14.5 TAF (see Table 5.2), with 60% of this reduction in scarcity benefiting urban areas and approximately 40% benefiting agricultural areas.

Table 5.2 Scarcity Reduction from Flexible Operation (TAF/yr)

	Annual Base Case (BC)	**Average Scarcity** Unconstrained Case (UC)	**Scarcity Reduction from Flexible Operation** (UC-BC)
Urban	12.08	3.11	-8.97
Agricultural	14.24	8.76	-5.48
Total	26.32	11.87	-14.45
Percentage of Total Demands Met	97%	99%	

The economic value of flexible water supply operations to water users can be measured in terms of reduced economic costs of scarcity, equivalent to the value of satisfying incrementally more customers' water demands, and reduced operating costs associated with the changed operations. The negative values indicate the scarcity reduction. For example, with flexible system operations, urban and agricultural areas combined experienced 14.45 TAF/yr more deliveries (and therefore 14.45 TAF/yr less scarcity).

Table 5.3 Annual Average Scarcity Cost Reduction by Demand Area From Flexible Operation ($K/yr)



Demand Area	Base Case	Unconstrained	Change (Base Case - Unconstrained)
North East Sac County and Placer	$0	$0	$0
Folsom and Golden State	$0	$0	$0
Rancho Murieta	$12	$12	$0
City of Sacramento and Cal-Am Parkways and Suburban Rosemont	$1,519	$0	-$1,519
SCWA and Cal-Am Security Park	$3,819	$0	-$3,819
City of Galt	$17,847	$3,043	-$14,804
Ag: Omochumne-Hartnell	$70	$41	-$30
Ag: Southwest	$1,572	$238	-$1,333
Ag: Clay ID	$80	$4	-$76
Ag: Galt ID	$529	$141	-$388
Total	$25,449	$3,480	-$21,969

As shown by Table 5.3, the greatest reductions in economic scarcity costs are experienced by the City of Galt, SCWA, the City of Sacramento, and the independent agricultural residents in the southwest portion of the Central Sacramento County Groundwater Basin. These reductions in scarcity arise from flexible system operations which yield an annual average of approximately 15 TAF more water supply for productive uses per year that generates an estimated average $22 million/year in increased economic value. Although the annual average amount of water pumped by each of these demand areas increases, the end of period groundwater storage at the end of the 72 years is the same as in the base case. This occurs because more efficient water management allows more water to be available to the Sacramento Area in the unconstrained case. This additional water in the unconstrained run comes from 1) increased surface water diversions during months when there is surplus Delta outflow from the Sacramento River system (15%) 2) operating Oroville and Folsom reservoirs so as to minimize evaporation (45%) and 3) increasing return flows from demand areas, thereby increasing re-use in the system (40%) (Figure 5.3).

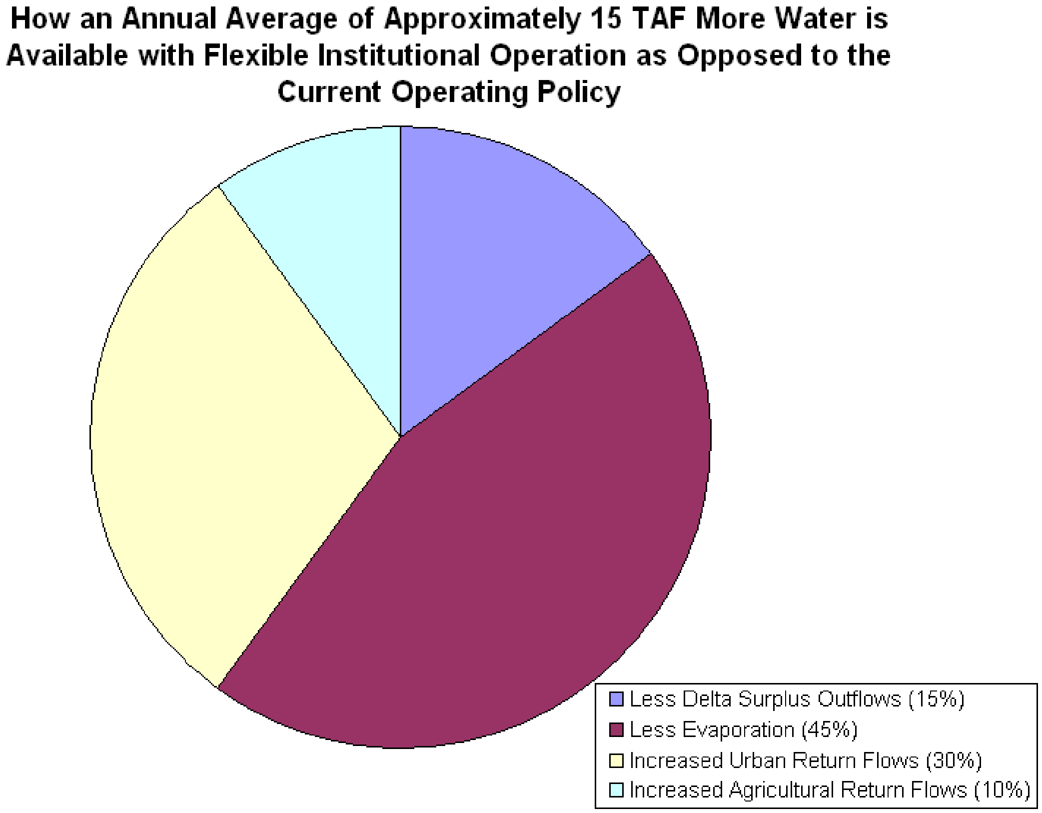


Figure 5.3 Where New Water Supply Delivery Comes From

Increased deliveries from less Delta outflows and less evaporation result in greater return flows to the surface and groundwater system from urban and agricultural areas where it can then be re-used. Urban areas have much lower consumptive use rates than agricultural areas where much of the water is used for crops. Of the additional water made available by productively used return flows, 75% came from urban areas with the rest was from agricultural return flows.

Not only are scarcity costs reduced with more flexible system operations, but operating costs are also reduced, by an estimated $7.5 million/yr, on average. Total net economic benefits of optimized operation are thus potentially almost $30 million/yr.

Table 5.4 Annual Average Operating Cost Reduction by Demand Area ($K/yr)

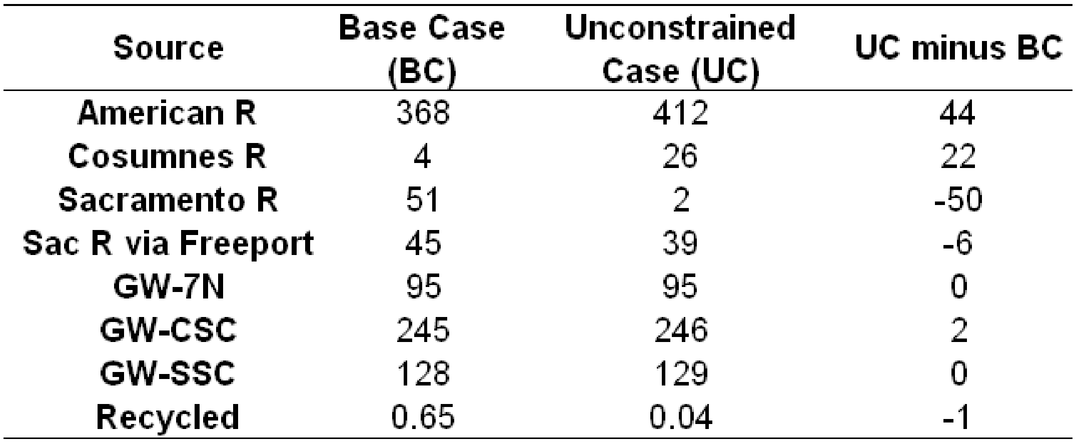
Demand Area	Base Case (BC)	Unconstrained (UC)	UC minus BC
North East Sac County and Placer	$19,150	$19,538	$389
Folsom and Golden State	$4,552	$4,574	$22
Rancho Murieta	$301	$301	$0
City of Sacramento and Cal-Am Parkways and Suburban Rosemont	$14,523	$10,959	-$3,563
SCWA and Cal-Am Security Park	$10,722	$7,539	-$3,183
City of Galt	$274	$462	$188
Ag: Omochumne-Hartnell	$1,439	$191	-$1,248
Ag: Southwest	$2,381	$2,493	$113
Ag: Clay ID	$2,293	$1,569	-$724
Ag: Galt ID	$2,997	$3,512	$515
Ag Areas w access to Freeport water	$0	$2,558	$2,558
Total	$58,631	$53,697	-$4,934

The most significant operating cost reductions in the unconstrained case are for the City of Sacramento and the SCWA demand areas, where higher cost Sacramento River diversions in the Base Case are replaced with lower cost American River diversions and lower cost groundwater pumping. Driven by economic efficiency, the City of Sacramento demand area for example, meets its demands without any Sacramento River water in the unconstrained run and saves an estimated $3.6 million/year in operating costs. While this may be institutionally impossible or challenging to implement the unconstrained model highlights that it is both physically and cheaper to re-operate the system to meet City of Sacramento demand area requirements from increased American River and north basin groundwater pumping. This is consistent with predictions made by an engineer for the City of Sacramento that there will be future expansion of wells in the North Sacramento County Groundwater Basin (Peifer 2007). The most economically efficient operations for SCWA also involved reducing deliveries from the Sacramento River and nearly doubling groundwater use. Reductions in deliveries from the Sacramento River to SCWA translate into less water pumped through the Freeport Pipeline, which relative to other urban supply sources, is the most expensive water supply in this system. The City of Sacramento and SCWA can rely more heavily on groundwater under flexible operation because Northeast Sacramento and Placer County, the City of Folsom and Golden State, Omochumne-Hartnell and Clay ID all rely less on groundwater in the unconstrained case, and more on American and Sacramento River flows instead.

Supply Source Analysis

Scarcity reduction and reduced operating costs in the unconstrained case are possible because of a shift in the allocation of available water supplies to the demand areas, driven by economic efficiency. The major shift is a reduction in diversions from the Sacramento River to urban users, via the Sacramento River Water Treatment Plant, and through the Freeport Pipeline, both of which are the most expensive water supplies in the system, aside from recycled water. More American River diversions (73 TAF/yr), as well as more diversions via the Cosumnes River (22 TAF/yr) are used, some of the latter comprising return flows from SMUD and agricultural applications. With additional water made available to the system through reoperation and re-allocation, less of the very expensive recycled water is also needed (0.61 TAF/yr less, amounting to an approximately $250,000 cost reduction).

Table 5.5 Water Supply Source Analysis (Annual Average Values in TAF/yr)



Source	Base Case (BC)	Unconstrained Case (UC)	UC minus BC
American R	368	412	44
Cosumnes R	4	26	22
Sacramento R	51	2	-50
Sac R via Freeport	45	39	-6
GW-7N	95	95	0
GW-CSC	245	246	2
GW-SSC	128	129	0
Recycled	0.65	0.04	-1

The approximately 73 TAF/yr of additional American River deliveries in the unconstrained case are broken down in Figure 5.4. The darkest bar shows the average net change in total deliveries made from the American River in the unconstrained case compared to the base case, broken out by month. To the left, the net change is broken down into net change for each demand area that uses American River water. For example, 16.5 TAF more total deliveries were made in May of American River water in the unconstrained versus base case, from at or below Folsom Reservoir, with most of that additional water going to Clay ID, to Northeast Sacramento and Placer Counties urban demand area, and then to City of Sacramento urban demand area. Between September and March, the City of Sacramento takes less American River water in the unconstrained, because north basin groundwater is cheaper compared to its other supply options and is more available for meeting its demands. During this time of year target demands are greatest and it is most economically efficient for Folsom Reservoir storage values to remain lower than current policy to minimize evaporative losses. Additional North Basin groundwater availability for the City of Sacramento demand area occurs because it is more economically efficient for urban (and potentially agricultural users) in the areas north of the American River who normally pump groundwater, such as Northeast Sacramento and Placer Counties agencies, to use more surface water from the American River, taken at and above Folsom Reservoir, in the unconstrained case.

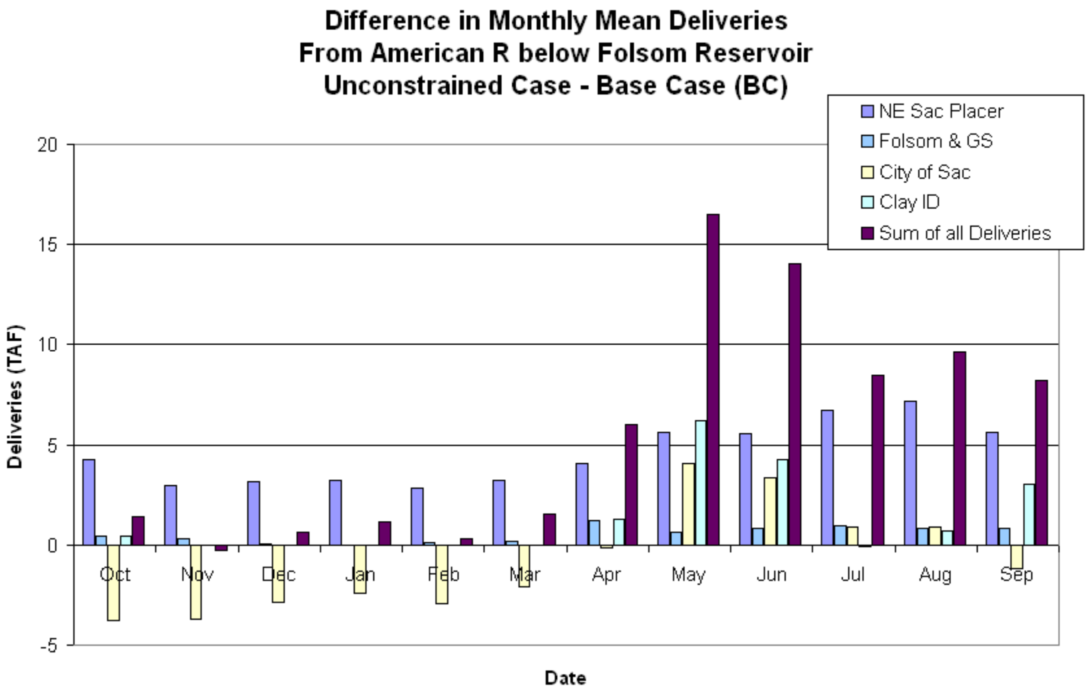


Figure 5.4 Difference in Monthly Mean Deliveries From the American River below Folsom Reservoir between the Unconstrained Case and the Base Case

Conjunctive Management

More efficiently managing the ground and surface water resources conjunctively to handle multi-year droughts was key to reducing scarcity and costs in the unconstrained run. As shown in Figure 5.5, groundwater storage in the North Sacramento County Groundwater Basin can be drawn down lower than they have been in the past (approximately 150 TAF lower), and the groundwater basin can still recover over extended periods.

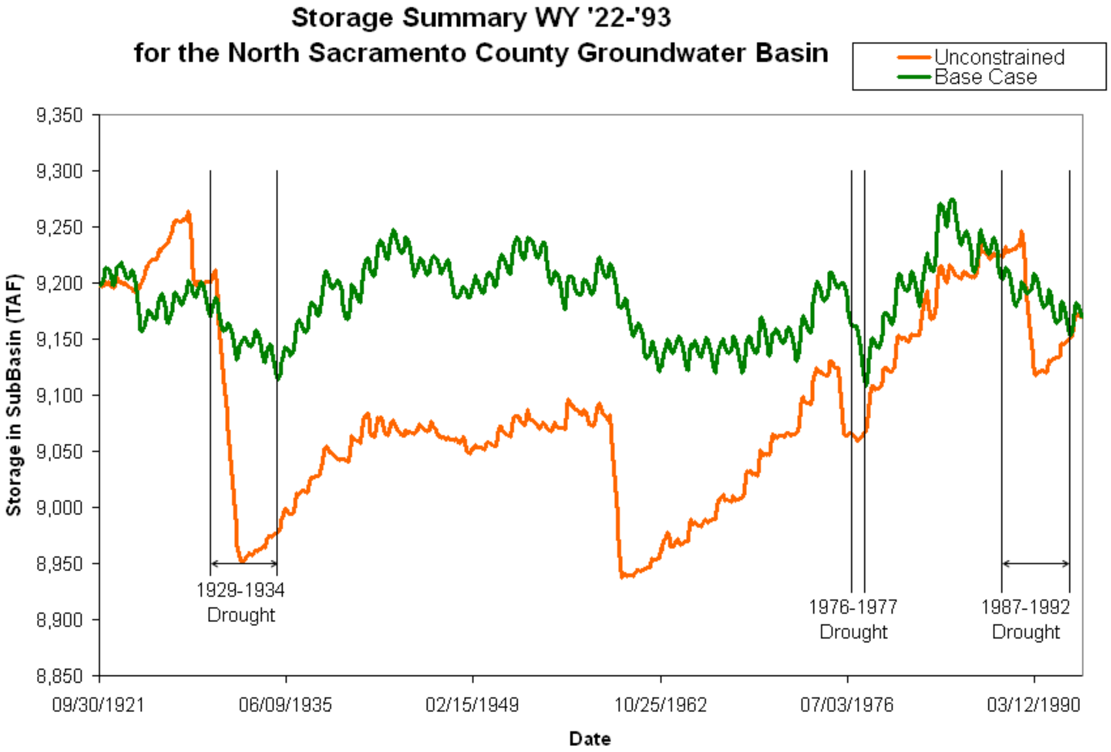


Figure 5.5 North Sacramento County Groundwater Storage Summary

During droughts (1929-1934, 1976-1977 and 1987-1992), groundwater resources in the north basin were relied on heavily to meet demands by the City of Sacramento. The major North Basin groundwater users represented dynamically in the Sac CALVIN model are Northeast Sacramento and Placer County and the City of Sacramento. Agricultural water uses in this part of the system were represented as pre-processed fixed surface and groundwater withdrawals. Over the 72 year period being modeled, it was most economically efficient for 54 TAF/yr of North Basin groundwater to switch from serving Northeast Sacramento and Placer County demands to the City of Sacramento demands. This is because Northeast Sacramento County has access to higher quality, less expensive American River water. The City of Sacramento switched entirely off Sacramento River water to rely more heavily (54 TAF/yr more) on North Groundwater Basin resources.

Although the annual average amount of water being used by major urban demand areas in the North Basin remained the same, during drought periods the basin became more depleted than in the base case, particularly during the ’29-’34 year drought when 33 TAF/yr more was removed from the basin in the unconstrained case than in the base case. These results suggest the most economically efficient way to manage the ground and surface water resources in the Sacramento County Area to maintain high reliability during multi-year prolonged droughts is to take full advantage and potential of the North Groundwater Basin as a multi-year storage area to deliver stored water to the demand area with the greatest need and willingness to pay. Already, there are signs that there are plans to further develop groundwater resources in the north basin. Currently, there is a conjunctive use program in place in the north basin, and the City of Sacramento, one of the major groundwater users in the north basin, is predicted to close the two wells that it currently operates in the central basin and expand its pumping capacity in the north basin (Peifer 2007).

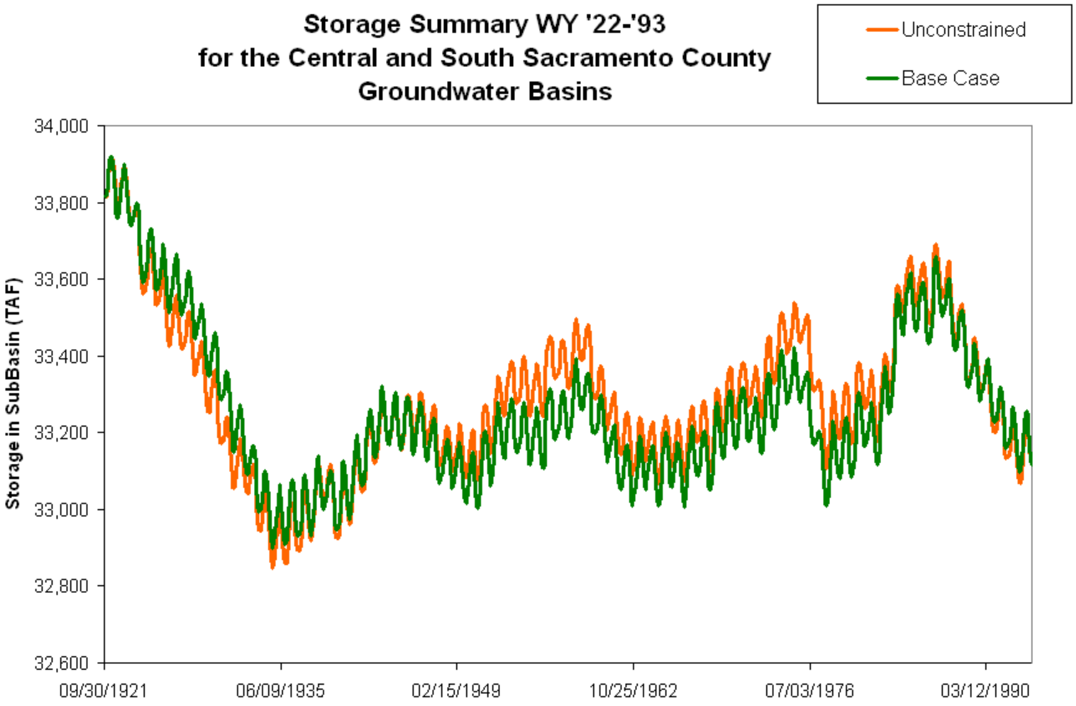


Figure 5.6 Central and South Sacramento County Groundwater Basins Storage Summary

The groundwater storage in the central and south basins also is used more conjunctively under flexible economic operations in the unconstrained case. During the 1929 – 1934 drought a greater quantity of groundwater was extracted during that period in the unconstrained scenario than in the base case (approximately 34 TAF/yr more). Although more groundwater was used, groundwater provided the same portion of total deliveries during the 1929 – 1934 year drought (42%), because overall more deliveries occurred during the drought in the unconstrained case. Between 1943 and 1953, a wetter period, approximately 1 TAF/yr more recharge occurred (from increased agricultural return flows) than in the base case, preparing the basin for future droughts. Apart from prolonged droughts, groundwater levels are higher for the unconstrained case than with the current operating policy. The median monthly storage values in the unconstrained case in the Central and South Sacramento County Groundwater Basins are approximately 47 TAF higher than those predicted with the current operating policy, over the 72 year analysis period.

One indicator of how much conjunctive management is occurring in an area is the how much variation there is in the percent reliance on groundwater in that area, as seen in Figure 5.7 comparing the percent reliance on ground water supply in the base case to that in the unconstrained case. The greater the variation across the hydrologic record, the more conjunctively surface and ground water resources are managed in an area. When water resources are being conjunctively managed to take advantage of groundwater storage facilities, then in a small percentage of years, a large percentage of the supply will be met by groundwater. Heavy reliance on groundwater will occur during severe and prolonged multi-year droughts when there is little surface water supply and multi-year surface storage runs out. The percentage of demands met by groundwater in the unconstrained exceeds the percentage met in the base case in at least 1 out of every 6 years (more than 15% of the time). In close to 10% of years, over 50% of the annual water supply needs are met by groundwater, compared with the base case where groundwater supplies never exceed 50% of water demands (Figure 5.7). Although there is more overall reliance on groundwater in the unconstrained case, end of period storage levels in the north, central and south basins are the same in both cases. This is due to the increased annual recharge to groundwater from applied agricultural water, which effectively provides more groundwater for productive uses.

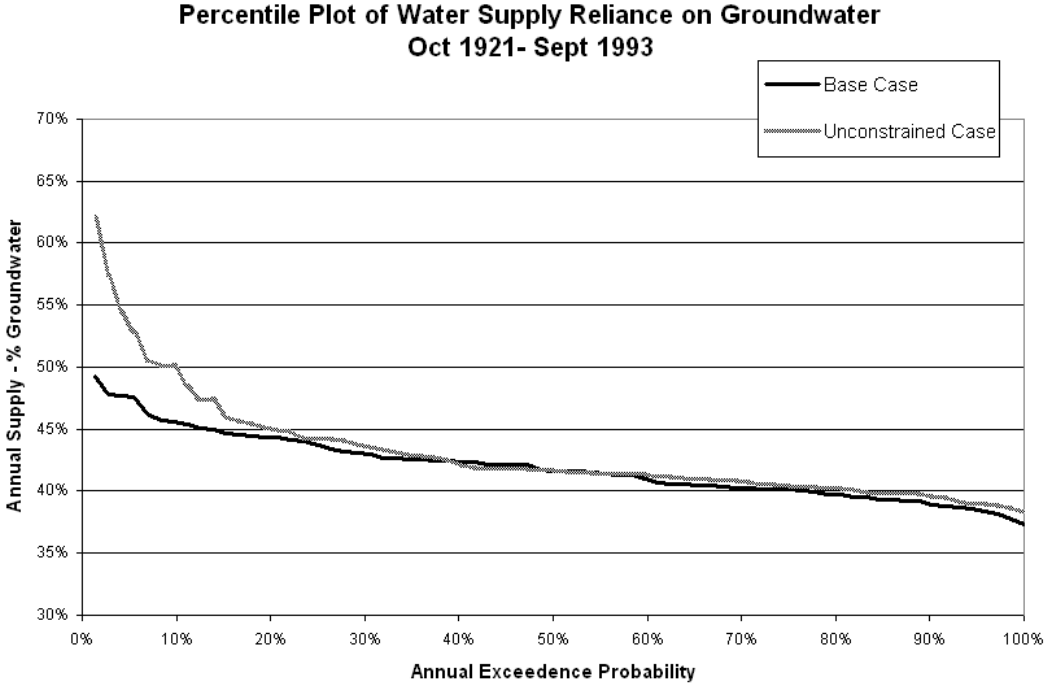


Figure 5.7 Percentile Plot of Water Supply Reliance on Groundwater

Another indicator of how much conjunctive use is the spread between the highest and lowest groundwater storage levels observed. In the base case the spread between highest and lowest observed groundwater storage levels in the North Basin was 166 TAF. In the unconstrained case it more than doubled to 327 TAF. In the central and south basins the contrast was less dramatic, but there was still more conjunctive use occurring. In the base case the difference between the highest and lowest combined groundwater storage level for the central and south basin was 879 TAF and in the unconstrained case it was 939 TAF (Table 5.13).

Folsom and Oroville Reservoir Operations

Re-operating Folsom and Oroville reservoir played a key role in making it possible to maximize net benefits by: 1) reducing evaporative losses (making it possible to deliver an annual average of 6.2 KAF more water) and 2) delivering more of the higher quality American River water which is less expensive to treat.

Evaporative losses were minimized by coordinating operation of the two reservoirs. Folsom Reservoir was kept much emptier in the summer (Figure 5.10), so much less water was lost to evaporation (an annual average of 9.3 KAF/yr) and Oroville Reservoir levels were kept higher (Figure 5.12), with only slightly more evaporative losses (an annual average of 3.1 KAF/yr). This occurred because annual average loss rates per unit of stored water at Folsom Reservoir are 7 times those at Oroville. Figure E.13 compares the average monthly evaporation in the base case and in the unconstrained case. However, lower surface water levels could have dramatic implications for recreation at Folsom Reservoir which would keep such a policy from being implemented. The most dramatic difference in surface water levels occurs in June, July, August and September when, on average reservoir levels are approximately 150 TAF lower than with the current operating policy (Figure 5.10). Although less water was stored in Folsom, combined, more surface water is stored in the two reservoirs on average in any given month all year round in the unconstrained scenario (Figure 5.8). Between May and November combined surface water levels are kept higher in the unconstrained scenario because surplus surface water in the system is stored in the reservoirs, and the water that is not stored in Folsom is stored in Oroville Reservoir (Figure 5.12). More combined surface water storage occurs because of the slightly higher persuasion value placed on maintaining system surface water in storage than on releasing it as surplus Delta outflow, when there is extra or excess surface water in the system relative to economic demands and required flows. These results confirm that the increased supply produced from flexible economic operations arises from more efficient use of existing water within the system, and not from reducing reservoir storage levels.

Another reason why less water was stored in Folsom Reservoir in the unconstrained run is because American River water of a higher quality than Sacramento River water and thus less expensive to treat, so there are more American River water deliveries with flexible operations (Figure 5.4).

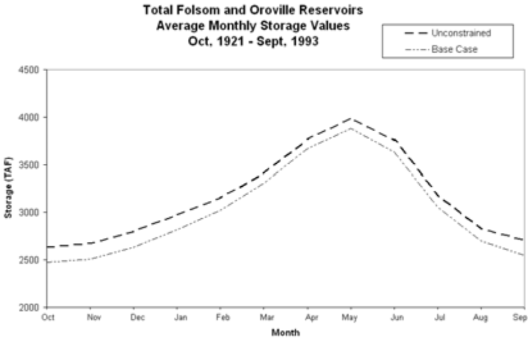


Figure 5.8 Combined Folsom and Oroville Reservoirs Mean Monthly Storage Values

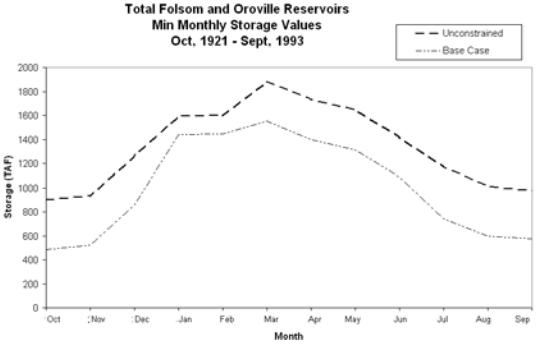


Figure 5.9 Combined Folsom and Oroville Reservoirs Minimum Monthly Storage Values

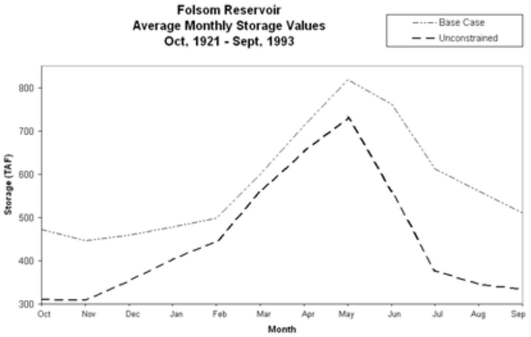


Figure 5.10 Folsom Reservoir Mean Monthly Storage Values

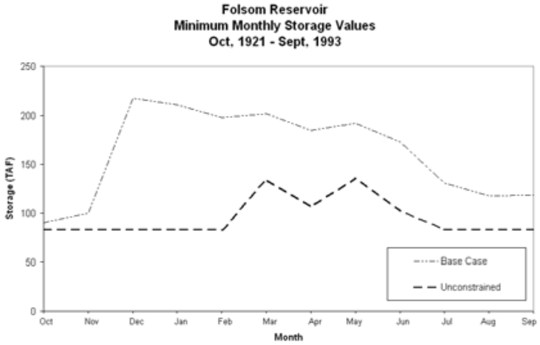


Figure 5.11 Folsom Reservoir Minimum Monthly Storage Values

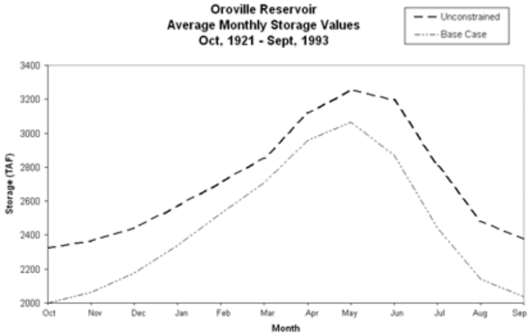


Figure 5.12 Oroville Reservoir Mean Monthly Storage Values

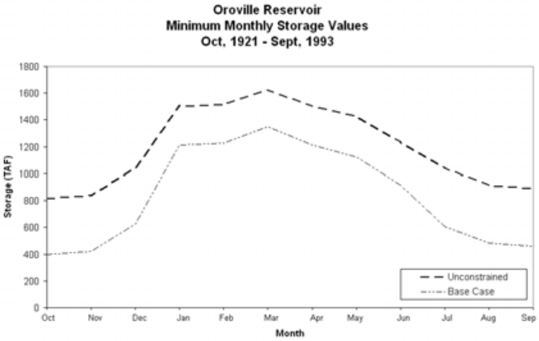
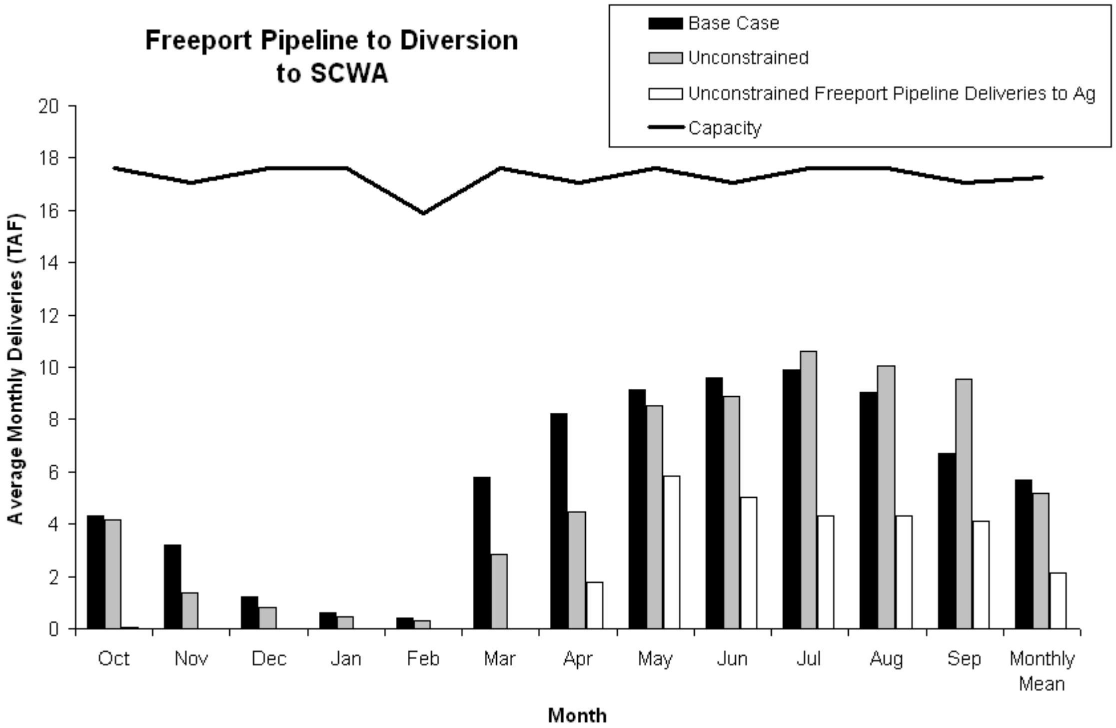


Figure 5.13 Oroville Reservoir Minimum Monthly Storage Values

Freeport Pipeline Operation

With flexible system operation it appears economically efficient for SCWA to take less water than currently planned from the Freeport Pipeline because of the high operating expense incurred in conveying and treating Sacramento River water via this facility. Figure 5.14 compares the average monthly amounts of water transported via the Freeport Pipeline along the portion from Freeport to the diversion to SCWA in the base case (black bars) to that which occurs in the unconstrained case (grey bars). Overall, approximately 6 TAF/yr less water is diverted down the Freeport Pipeline in the unconstrained case compared to the base case. Economically Freeport Pipeline diversions cost between $12 and $24/AF along this segment, and it is the most expensive natural surface water source for urban users to treat. In the base case, with current operating policy, no water is diverted through the pipeline to agricultural users. However, in the unconstrained case, agricultural users (white bars) in the south county area (Omochumne-Hartnell, Clay ID and Galt ID) use an average of 24 TAF/yr of water delivered through the Freeport Pipeline into the Folsom South Canal and diverted from the canal or via turn-outs into the Consumnes R. The model shows south county agricultural users are willing to pay the cost of transporting the water through the pipeline up to the Folsom South Canal, which at its cheapest costs almost $30/AF. Agricultural users are motivated to pay for this water because of the scarcity cost that they would incur without this water and because often when the pipeline is empty or nearly so, the conveyance costs are lower than estimated agricultural groundwater pumping costs in the central basin and always lower than costs from the south basin, making the Freeport Pipeline water supply source more economical than groundwater to agricultural users at those times (Table 4.2). They are motivated to pay even when the Freeport pipeline is operating at higher capacities and pumping costs are higher (86% of the time that agricultural users diverted water through the Freeport Pipeline they pay close to $40/AF) as these still are less than the variable cost of groundwater pumping from the south basin.

Figure 5.14 Average Monthly Deliveries via the Freeport Pipeline Portion from the Sacramento River to the Diversion to SCWA



Under current operating policy, water diversions through the Freeport Pipeline go exclusively to SCWA and EBMUD, so in the second segment of the pipeline from the point where SCWA diverts its water to the point where the pipeline meets the Folsom South Canal, water that is conveyed in the base case all goes to EBMUD (Figure 5.15). However, in the unconstrained case, a large increase in water transported along this section of the pipeline occurs from April to September for delivery to agricultural users in the south county (Figure 5.15).

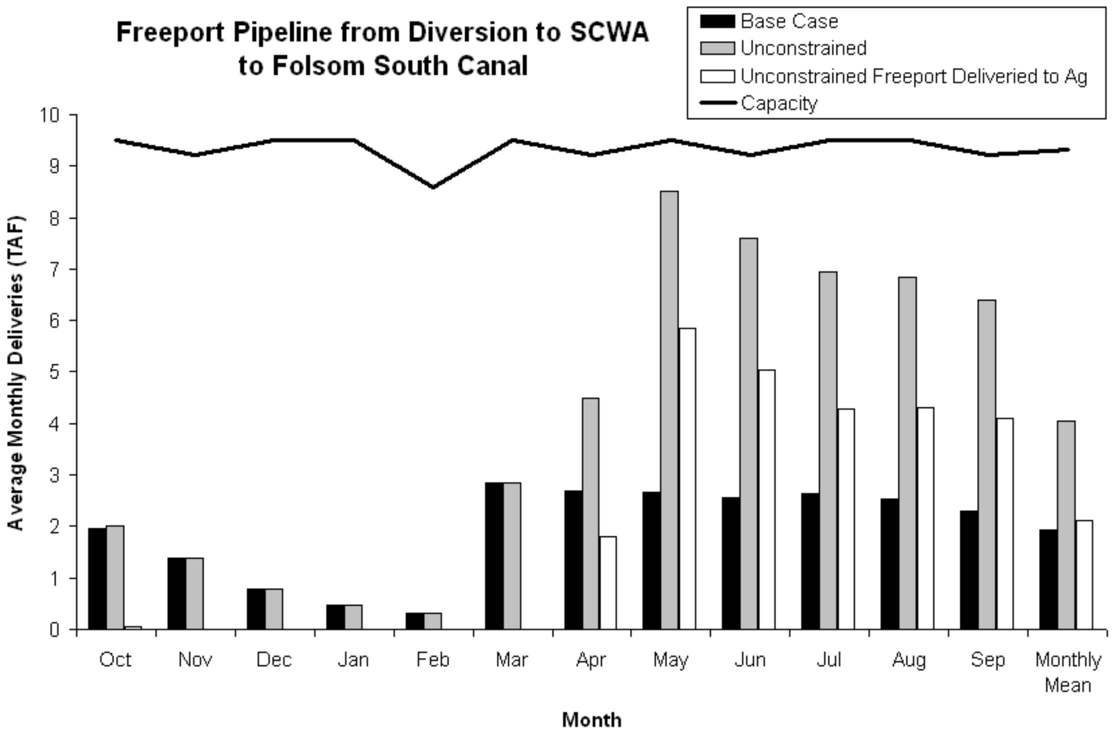


Figure 5.15 Average Monthly Deliveries via the Freeport Pipeline from the SCWA diversion to the Folsom South Canal

System Costs of Flexible Operation

Economically optimal operations that occur in the unconstrained case result in a savings in total system-wide scarcity and operating costs of approximately $29.6 million over the current operating policy. These savings arise primarily from reduced water scarcity (approximately $22 million dollars) to both agricultural and urban water users, with the rest from operating cost savings. The demand areas with most reduced scarcity costs are the City of Galt (saved $15 million/yr) and the Southwest Agricultural Users (saved $1.3 million). The demand areas that saved the most in operating costs were the City of Sacramento ($3.5 million) and SCWA ($3.2 million). An additional $3.6 million dollars less is spent operating the Freeport Pipeline, by reducing total deliveries and by changing the pattern of deliveries across months and years so as to operate the pipeline more often with some water compared to the base case, but with an 8.5 cfs (0.5 TAF/month) lower average flow rate than in the base case, avoiding the increasing marginal costs of conveying higher volumes of water through the pipeline. However, for a few droughts, more water is pumped per month through the Freeport Pipeline than in the base case. This type of operation of the facility with more even but lower flows in most years and greater flows only when needed in drought years, minimizes pumping costs through the facility (averaging $116/AF in the base case vs $40/AF in the unconstrained case) while increasing benefits of this newly created source of water for the south county. A summary of the costs incurred to the system by operating facilities (water treatment plants, recycling plants, and pumping facilities) associated with each major natural water source and conveyance route is found in Table 5.6. A more detailed summary of the costs broken down by demand area and water supply source and diversion point appears in Appendix E.

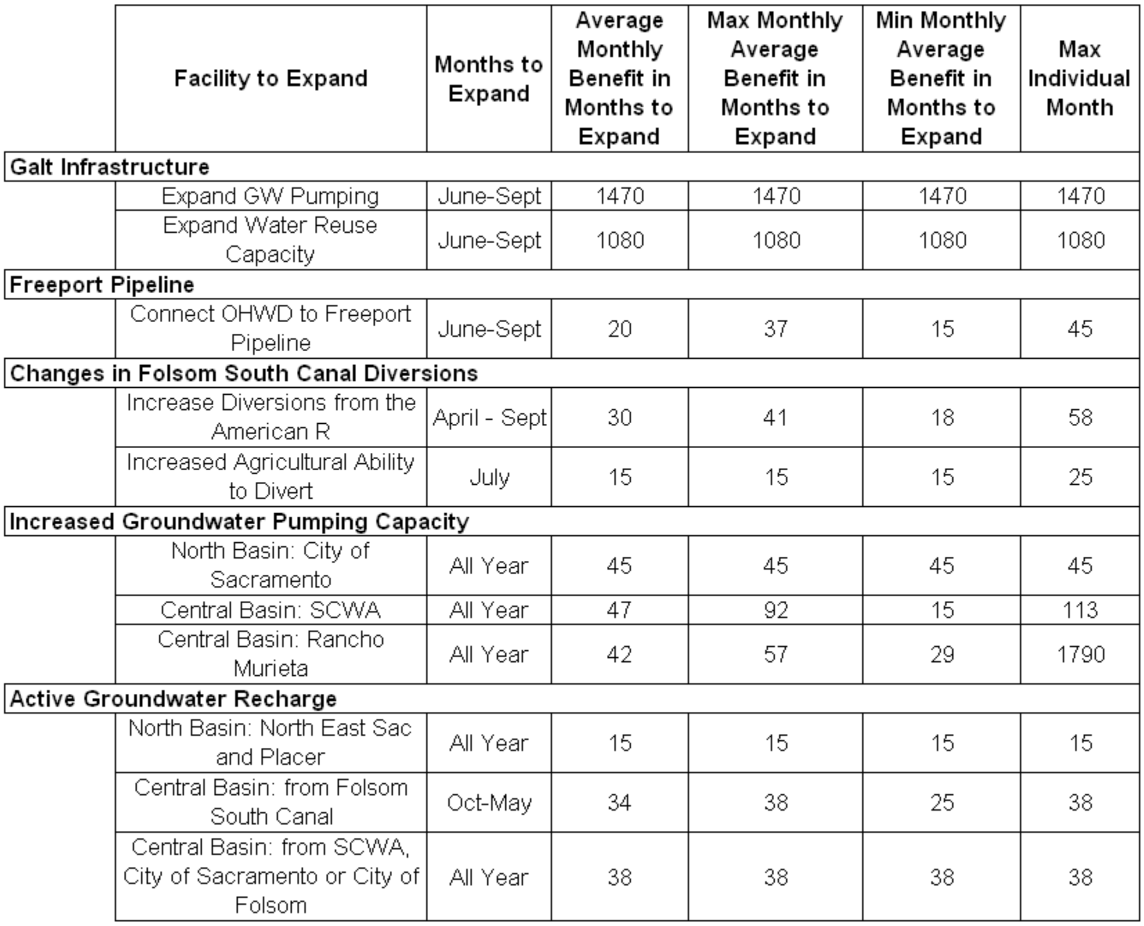
Table 5.6 Total Cost of Operating the System by Water Source ($K)

Natural Source	**Totals** **Base Case**	 **Unconstrained**	**Unconstrained Minus Base Case**
American River	$27,995	$30,502	$2,507
Cosumnes River	$286	$286	$0
Sacramento River	$11,102	$1,810	-$9,291
Sac R via Freeport	$5,213	$1,574	-$3,639
North GW Basin	$4,173	$2,929	-$1,244
Central GW Basin	$9,256	$10,054	$798
South GW Basin	$5,564	$5,543	-$21
Recycled Water	$261	$15	-$246
Operating Costs ($K)	$63,971	$55,271	-$8,700
Shortage (KAF)	26.6	11.9	-15
Scarcity Costs ($K)	$25,449	$3,360	-$22,089
Total Cost ($K)	$84,080	$54,499	-$29,581

Conveyance Facilities and Treatment Facilities to Consider Expanding

One output from a linear programming optimization model such as CALVIN is the Lagrange multiplier, or the marginal benefit or cost from relaxing a facility, conveyance, or policy restriction by one unit, representing a change equivalent to requiring one more unit of water be allocated to a fixed delivery or fixed flow constraint, expanding an existing facility or conveyance by one unit more, or examining the first unit of capacity of a proposed new conveyance or facility that as yet does not exist.   For example, the monthly average marginal benefit of expanding the City of Galt's groundwater pumping capacity between June and September is $1,470 per AF/month of additional capacity. That means that for the first acre-foot of additional GW pumping capacity for the City of Galt beyond its current projected capacity (1 TAF/month) in the south groundwater basin, the net benefit generated per year, on average over the 72 year hydrologic record, would be $1,470/month times 4 months/year = $5.9 million/yr. Table 5.7 summarizes the capacity and policy restriction expansions that produce a significant marginal benefit in the unconstrained scenario. These capacity expansions or policy relaxations fell under five general categories, those associated with 1) expanding the water supply infrastructure of the City of Galt, 2) adding new connections to the Freeport Pipeline, 3) relaxing operational restrictions on Folsom South Canal Diversions from the American R and on turnout flows into the Cosumnes River, 4) expanding groundwater pumping capacities and 5) creating new active groundwater recharge facilities in the Central or South Groundwater Basins. The most significant marginal benefits were those from expanding the City of Galt's access to additional water supplies. This is because the City of Galt currently only has access to groundwater and is projected to have significant shortages if their water portfolio and groundwater pumping capacity remains unchanged in 2030. The period of the year when this expanded capacity would be needed is between June and September. Water reuse facilities are being used at full capacity during those months, with a net marginal benefit of $1,080/AF from expanding urban recycling beyond the current capacity of 0.04 TAF/month (0.43 mgd) (Gianquinto et al. 2005). These marginal benefit estimates only include costs that vary with the amount of water pumped or treated through the facility and do not include any sunk or capital costs that must be paid regardless of how much the facility is used or for the cost of building the expansion. Fixed and sunk costs include: administrative costs, water quality testing costs, and amortized capital costs of constructing or expanding facilities, etc.

Table 5.7 Marginal Benefit Associated with Capacity Expansion ($/AF)



	Facility to Expand	Months to Expand	Average Monthly Benefit in Months to Expand	Max Monthly Average Benefit in Months to Expand	Min Monthly Average Benefit in Months to Expand	Max Individual Month
Galt Infrastructure						
	Expand GW Pumping	June-Sept	1470	1470	1470	1470
	Expand Water Reuse Capacity	June-Sept	1080	1080	1080	1080
Freeport Pipeline						
	Connect OHWD to Freeport Pipeline	June-Sept	20	37	15	45
Changes in Folsom South Canal Diversions						
	Increase Diversions from the American R	April - Sept	30	41	18	58
	Increased Agricultural Ability to Divert	July	15	15	15	25
Increased Groundwater Pumping Capacity						
	North Basin: City of Sacramento	All Year	45	45	45	45
	Central Basin: SCWA	All Year	47	92	15	113
	Central Basin: Rancho Murieta	All Year	42	57	29	1790
Active Groundwater Recharge						
	North Basin: North East Sac and Placer	All Year	15	15	15	15
	Central Basin: from Folsom South Canal	Oct-May	34	38	25	38
	Central Basin: from SCWA, City of Sacramento or City of Folsom	All Year	38	38	38	38

There is a marginal benefit in directly connecting Omochumne-Hartnell to the Freeport Pipeline at the SCWA diversion point (assuming this location would provide sufficient elevation for gravity flow). In the irrigation months of June – Sept, when the capacity of the pipeline is not filled with water going to SCWA or EBMUD, there is an average monthly additional benefit of $20/AF. Transporting water through the Freeport Pipeline is relatively expensive, but at its cheapest pumping cost to the point of the SCWA turnout of $12/AF, Omochumne-Hartnell has sufficient unmet agricultural water demands to pay this cost and still generate a net benefit of $20/AF in productive agricultural use of the water.

When the model was originally constructed without an operational restriction on the amount of Folsom South Canal Diversions from the American River at well below the canal's physical capacity, the most economical way to operate the system was to transport larger volumes of American River water via the Folsom South Canal to agricultural users such as Clay ID, Omochumne-Hartnell and Galt ID. Because it is not institutionally possible to operate the system in this way, an operating limit was imposed to restrict American River diversions into the Folsom South Canal to current operating policy limits. The monthly average additional net value to the system of allowing one more acre-foot of American River water diverted into the Folsom South Canal and delivered to downstream users is approximately $30/AF between April and September, and reflects the net productive value to south county agricultural users. Furthermore, agricultural user's ability to divert water from the Folsom South Canal via Consumnes River turn-outs was limited, also for institutional reasons, but there was only a marginal net benefit to relaxing that constraint in July, at which point the marginal benefit was approximately $15/AF of additional turn-out capacity to Clay ID and to Laguna and Badger Creeks.

There is economic value to expanding current capacity to pump groundwater and creating new artificial groundwater recharge facilities for recharging urban return flows and surplus surface water. There is net economic benefit to expanding groundwater pumping capabilities of SCWA in the central basin, City of Sacramento in the north basin, and to creating pumping capacity for Rancho Murieta to access groundwater in the central basin. Currently the City of Sacramento is predicted to be expanding its groundwater pumping capacities in the north basin, just as the model predicts is economically efficient.

The model also shows that there is a marginal benefit to actively recharging the groundwater aquifer. Logistics, costs, and actual locations of active recharge would need to be investigated in a more detailed surface-groundwater model, but this study shows economic value from such an activity, pointing to the potential value of doing such an investigation. Year round there would be an estimated average monthly marginal benefit of $38/AF to be able to recharge the central groundwater basin with urban surface return flows from areas such as SCWA, the City of Sacramento, and the City of Folsom. This estimate does not include the cost of constructing or operating such recharge facilities (operating costs for basin spreading have been estimated to be about $5/AF in 1995 dollars (Newlin et al. 2001)). Additionally, there is a marginal benefit to using excess American River water transported via the Folsom South Canal within the limit of current operating restrictions of FSC diversions, to artificially recharge the Central Groundwater Basin in non-irrigation months when south county agricultural areas have no need for this excess system water. The monthly average marginal benefits (for the months in which there is a marginal benefit) are summarized in Table 5.7 along with the overall maximum monthly benefit observed in any month over the 72 year period. These marginal benefits include the cost of getting water to the artificial recharge location, and the costs of later pumping it out and delivering it to unmet future demands, but do not include operating costs or capital costs required to build and operate the new facilities and any new connecting conveyance that might be required. Graphs showing the average monthly marginal benefits can be found in Appendix E.

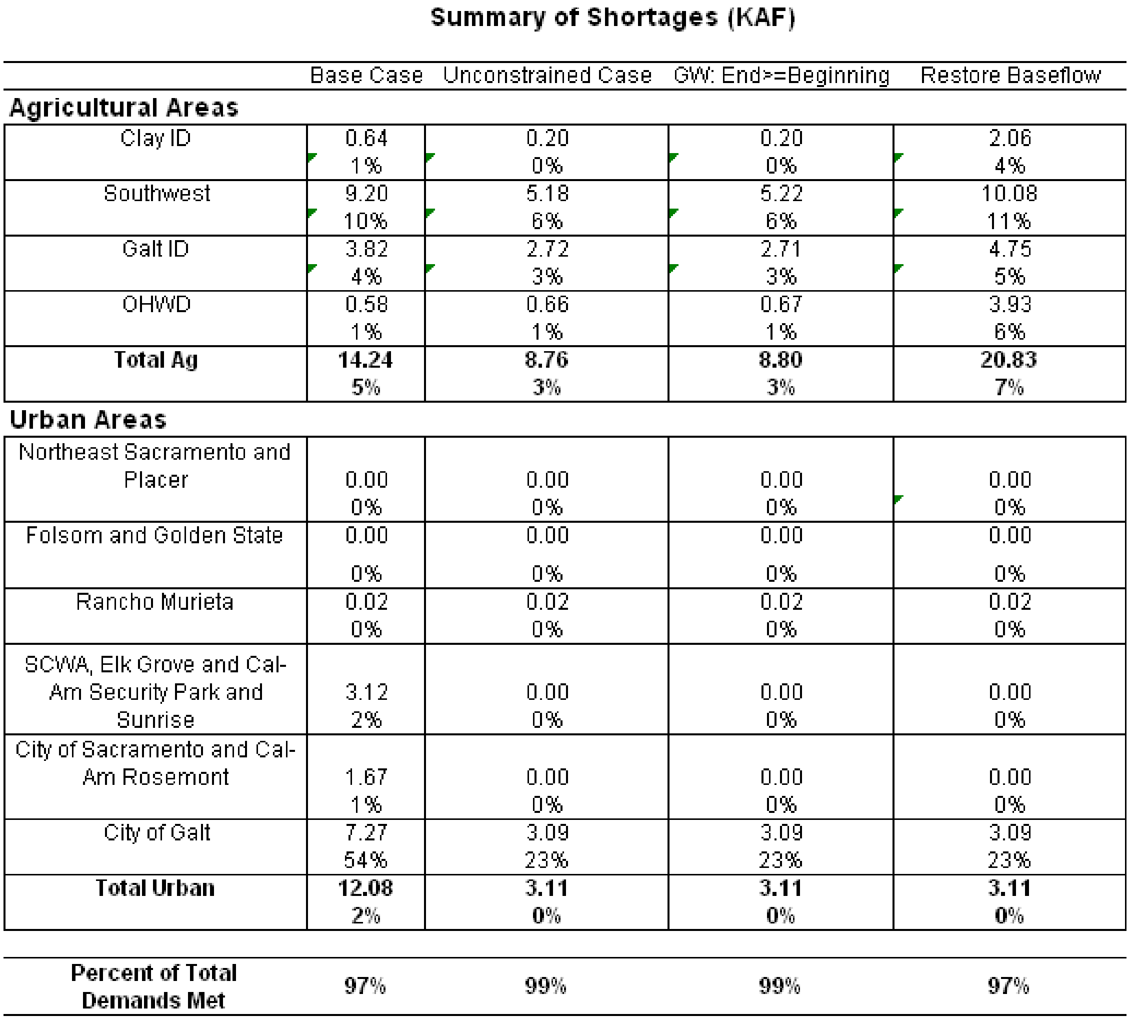
5.6 Groundwater Recovery Results

If a groundwater management policy was put in place that required the end of period groundwater storage to exceed or equal the beginning groundwater storage levels, the Sacramento Area water supply system is robust enough to be able to accommodate this additional restriction with relatively little economic impact to users in the system. As compared with the unconstrained scenario, there was only 0.04 TAF more shortage per year to disassociated agricultural users (Southwest Agricultural demand area) in the southwest corner of Central Sacramento County Groundwater Basin (see Table 5.8). No other demand area experienced an increase in shortage. Additionally, there was no significant change in water deliveries during drought years. The largest effect was in the ’87-’92 drought when 0.2% (0.06 TAF/yr) less water for agricultural users, and 0.5% (3.2 TAF/yr) less water for urban users was available as compared with the base case. However, in the ’29-’34 and ’76-’77 years droughts, no more than a 0.1% (0.31 TAF) increase in agricultural scarcity was observed, with no change to urban scarcity (see Appendix E). There was no significant increase in scarcity costs, and a $568,000/yr increase in operating costs, see Table 5.11 and 5.12 for estimates of the total scarcity cost, operating cost and overall cost. Appendix E provides a more detailed break down of estimated costs by demand area and water source. The groundwater management policy of no net long-term depletion in which the end of period storage is required to equal or exceed initial storage requires a build up of approximately 10 TAF per year of aquifer storage that would otherwise have been delivered to users in the base and unconstrained scenarios. Of this “lost” system water, 94% came from less Delta outflows (as compared with the unconstrained run), 5% from increasing shortages to agricultural areas, and 1% from re-operating Folsom and Oroville reservoirs to minimize evaporation even further (Figure 5.16).

Under a groundwater management policy requiring groundwater baseflows be restored to the Consumnes at the end of an extended period of time (in this case the 72 year analysis period), impacts to system water supply delivery and economic costs would be more significant, but shortages and scarcity costs would still be less than those anticipated to occur in 2030 with the current operating policy. Requiring groundwater storage to increase to support baseflows results in an estimated 12 TAF/yr increase in shortage to the agricultural areas when compared with the base case, while shortage to urban areas remains unchanged from the unconstrainted scenario. Overall 97% of total system demands were met, the same percentage predicted with the current operating policy. During multi-year droughts, such as the ’87 to ’92 drought, urban areas experienced approximately 3 TAF/yr more shortage than in the unconstrained case with current groundwater management, but still received 11 TAF/yr more supply during this drought than under the current operating policy. Even with less central and south basin groundwater available as water supply, urban areas were allocated more water than with the current operating policy during all droughts, while the largest reduction in supply delivery to agricultural areas relative to what they received under the current operating policy was 15 TAF/yr, during the 1929-’34 drought.

Overall, while costs significantly increased above those in the unconstrained case with the restoration of baseflows in the Cosumnes River, by $789,000/year in scarcity cost and $3,203,000/year in operating costs, they were still $21,180,000/yr lower in scarcity costs and $ 1,731,000 lower in operating costs than under the current operating policy.

Table 5.8 Summary of Shortages (TAF)



Summary of Shortages (KAF)

	Base Case	Unconstrained Case	GW: End>=Beginning	Restore Baseflow
Agricultural Areas				
Clay ID	0.64 1%	0.20 0%	0.20 0%	2.06 4%
Southwest	9.20 10%	5.18 6%	5.22 6%	10.08 11%
Galt ID	3.82 4%	2.72 3%	2.71 3%	4.75 5%
OHWD	0.58 1%	0.66 1%	0.67 1%	3.93 6%
Total Ag	**14.24** **5%**	**8.76** **3%**	**8.80** **3%**	**20.83** **7%**
Urban Areas				
Northeast Sacramento and Placer	0.00 0%	0.00 0%	0.00 0%	0.00 0%
Folsom and Golden State	0.00 0%	0.00 0%	0.00 0%	0.00 0%
Rancho Murieta	0.02 0%	0.02 0%	0.02 0%	0.02 0%
SCWA, Elk Grove and Cal-Am Security Park and Sunrise	3.12 2%	0.00 0%	0.00 0%	0.00 0%
City of Sacramento and Cal-Am Rosemont	1.67 1%	0.00 0%	0.00 0%	0.00 0%
City of Galt	7.27 54%	3.09 23%	3.09 23%	3.09 23%
Total Urban	**12.08** **2%**	**3.11** **0%**	**3.11** **0%**	**3.11** **0%**
Percent of Total Demands Met	**97%**	**99%**	**99%**	**97%**

Table 5.8 illustrates the anticipated changes to in water supply delivery and shortages under the different groundwater management strategies examined. The most important points are:

1. If baseflow in the Cosumnes River was required to be restored over a long time period, total water deliveries could be maintained at the same level as the current operating policy (97% of all demands met),
2. Neither groundwater management scenario that required more water to be stored in the aquifers below the Cosumnes River increased shortages to urban demand areas,

3. Reductions in groundwater pumping to demand areas (in the net recharge and restore baseflow scenarios) resulted in less system water delivered to agricultural areas that have a lower willingnes to pay, and
4. In the restore baseflow scenario, the agricultural area that experienced the greatest increase in shortages was the unaffiliated agricultural users in the southwest portion of the Central Groundwater Basin who have access only to this water supply source (11% shortage, approx 5 TAF increase from the unconstrained case), followed by Omochumne-Hartnell (6% shortage, approximately a 3 TAF increase from the unconstrained case).

With either the no net depletion or the restore baseflow groundwater management strategies, additional water is required to be stored over time as groundwater. Some of this additional water comes from delivering less water to agricultural areas, but the most of the additional water comes from more effectively and efficiently managing and allocating resources in the system so that there are less surplus Delta outflows and less evaporation in Folsom and Oroville Reservoirs (about one percent of the additional water) from managing storage to minimize surface water evaporation (Figure 5.16 and Figure 5.17).

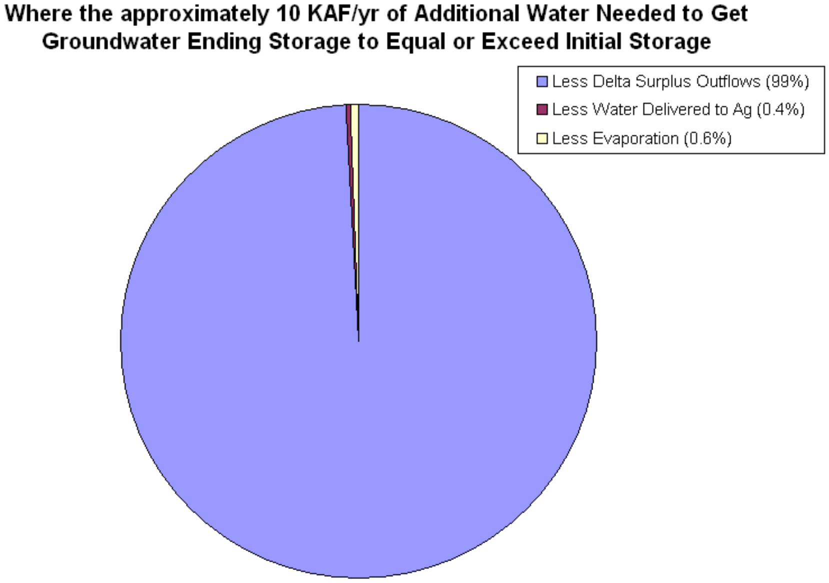


Figure 5.16 Accounting for the Approximately 10 TAF/yr of Additional Water Needed to Get the End of Period Groundwater Storage Greater Than or Equal to the Initial Groundwater Storage

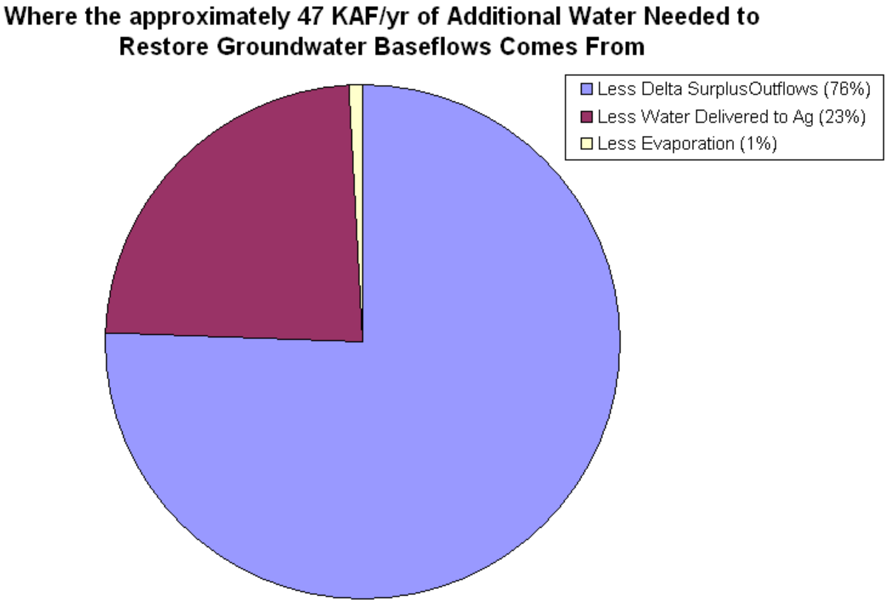


Figure 5.17 Accounting for the Approximately 47 TAF/yr of Additional Water Needed to Restore Groundwater Baseflows

Supply Source Analysis

More water was made available to store as groundwater in the Central and South Basins in the no net depletion and restore baseflow groundwater management scenarios by more efficiently managing the existing surface water resources to decrease surplus Delta outflows. In the modeling scenarios that require more water to be stored in the ground, several trends are apparent: 1) more water is taken from the American River for delivery to users as less groundwater is available for extraction, 2) Sacramento River water is the most expensive surface water source for urban users to treat and as such is used sparingly, 3) Freeport diverted Sacramento River water is even more expensive for urban users than directly diverted Sacramento River water because it must be pumped through the Freeport Pipeline, but when agricultural areas are faced with the prospect of increasing shortages from restricted groundwater extraction, they are willing to pay for Freeport water (see

Figure 5.14, Figure 5.15, Figure 5.21, Figure 5.22 and
Table 5.9). An initially surprising finding from the supply source analysis is that the amount of water recycled does not increase with either groundwater management policy - 0.61 TAF/yr less water is recycled in the unconstrained case compared to the base case, and the same amount is recycled in each of the three unconstrained cases. The reduction occurs because it is not economically beneficial for SCWA to recycle water. Their recycled water program is significantly subsidized and they continue recycling because they believe it is a good thing to do and that if they perfect their technique now it will provide more opportunities in the future (Underwood 2007). Rancho Murieta is the only demand area to regularly use its recycled water program in the unconstrained case (0.04 TAF/yr). The City of Galt's water treatment plant capacity is so small (0.04TAF/month) that the recycled water is regionally insignificant.

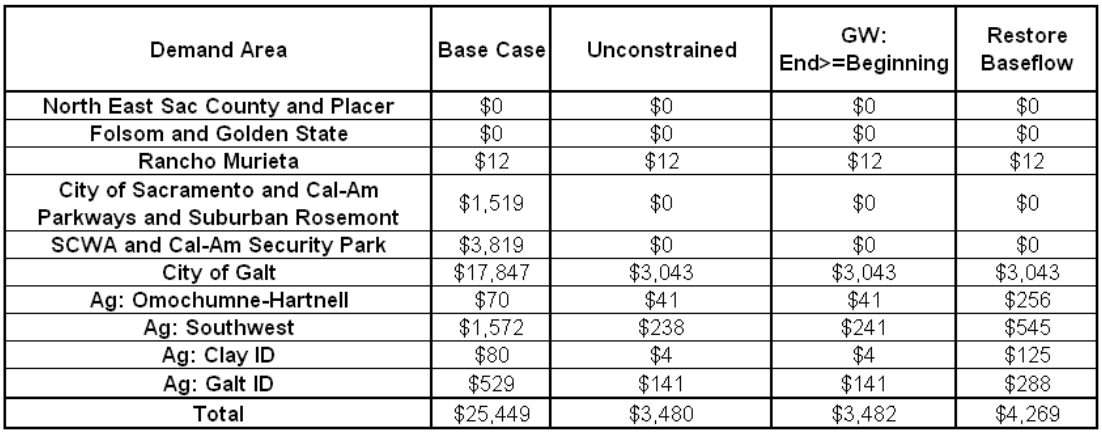
Table 5.9 Supply Sources (TAF/yr)

Source	Base Case	Unconstrained Case	Net Recharge	Restore Baseflow
American R	368	412	417	434
Cosumnes R	4	26	26	25
Sacramento R	51	2	2	12
Sac R via Freeport	45	39	44	46
GW-7N	95	95	95	95
GW-CSC	245	246	241	213
GW-SSC	128	129	124	113
Recycled	0.65	0.04	0.04	0.04
Total	938	949	949	937

System Costs of Different Groundwater Management Strategies

More economically efficient use of water in all unconstrained runs resulted in substantially lower scarcity costs compared to current operating policy. Scarcity costs decrease dramatically (by $22 million/year) with flexible operations, and increase only about $1 million/year over current policies when baseflow is required to be restored over the 72 year analysis period (Table 5.10). There appears to be enough water in the system to accommodate stricter groundwater management strategies without incurring a large increase in total shortage over the current policy, while at the same time through flexible and increased conjunctive operation, re-allocating available resources to reduce scarcity costs.

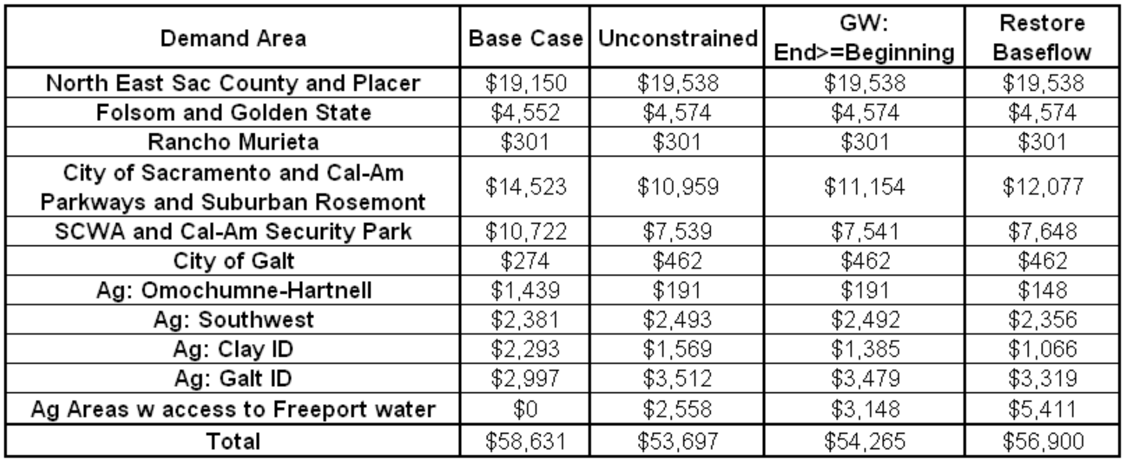
Table 5.10 Annual Average Scarcity by Demand Area ($K/yr)



Demand Area	Base Case	Unconstrained	GW: End>=Beginning	Restore Baseflow
North East Sac County and Placer	$0	$0	$0	$0
Folsom and Golden State	$0	$0	$0	$0
Rancho Murieta	$12	$12	$12	$12
City of Sacramento and Cal-Am Parkways and Suburban Rosemont	$1,519	$0	$0	$0
SCWA and Cal-Am Security Park	$3,819	$0	$0	$0
City of Galt	$17,847	$3,043	$3,043	$3,043
Ag: Omochumne-Hartnell	$70	$41	$41	$256
Ag: Southwest	$1,572	$238	$241	$545
Ag: Clay ID	$80	$4	$4	$125
Ag: Galt ID	$529	$141	$141	$288
Total	$25,449	$3,480	$3,482	$4,269

Operating costs also decrease substantially with flexible operation ($5 million/year, for current groundwater management policies). These operating costs do not include administrative costs, or capital costs, but even so they indicate trends worth examining, for example, giving agricultural areas the opportunity to purchase Freeport Pipeline water when the pipeline capacity is not full lowers operating and scarcity costs, and having the City of Sacramento and SCWA shift off of Sacramento River water and replace some of these supplies with increased groundwater pumping lowers operating costs since less expense is needed to treat the water (Table 5.11).

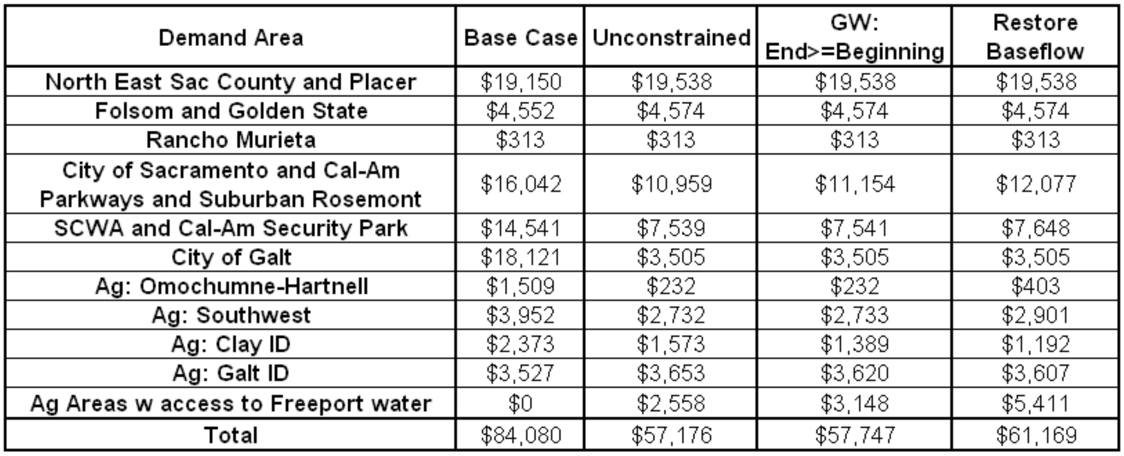
Table 5.11 Annual Average Operating Cost Summary by Demand Area ($K/yr)



Demand Area	Base Case	Unconstrained	GW: End>=Beginning	Restore Baseflow
North East Sac County and Placer	$19,150	$19,538	$19,538	$19,538
Folsom and Golden State	$4,552	$4,574	$4,574	$4,574
Rancho Murieta	$301	$301	$301	$301
City of Sacramento and Cal-Am Parkways and Suburban Rosemont	$14,523	$10,959	$11,154	$12,077
SCWA and Cal-Am Security Park	$10,722	$7,539	$7,541	$7,648
City of Galt	$274	$462	$462	$462
Ag: Omochumne-Hartnell	$1,439	$191	$191	$148
Ag: Southwest	$2,381	$2,493	$2,492	$2,356
Ag: Clay ID	$2,293	$1,569	$1,385	$1,066
Ag: Galt ID	$2,997	$3,512	$3,479	$3,319
Ag Areas w access to Freeport water	$0	$2,558	$3,148	$5,411
Total	$58,631	$53,697	$54,265	$56,900

Lower scarcity and operating costs reduce total cost to the system substantially for the unconstrained runs as compared with the base case (over $22 million dollars/year). The increased cost to the system, relative to the unconstrained scenario with current groundwater water management policy, of requiring the end of period groundwater storage to be equal to the initial storage is less than $0.6 million dollars. The relative cost of a groundwater management policy that requires no net long-term depletion is small. Implementing a policy that requires groundwater to be sufficiently high to provide baseflow to the lower Cosumnes River is more costly (approximately $4 million dollars more expensive than current groundwater management in the unconstrained case). Most of the additional cost of implementing such groundwater management policies falls on the City of Sacramento, SCWA, and agricultural users in paying for Freeport Pipeline water to avoid additional shortages (Table 5.12). With the current operating policy (base case), agricultural areas do not have access to the Freeport Pipeline. However, in the unconstrained cases more water is delivered to urban areas who are willing to pay more for it and agricultural areas are left facing shortages or paying to have higher priced Freeport Pipeline water pumped to them via the pipeline, the Folsom South Canal and down the Cosumnes River.

Table 5.12 Combined Annual Average Scarcity and Operating Cost by Demand Area ($K/yr)



Demand Area	Base Case	Unconstrained	GW: End>=Beginning	Restore Baseflow
North East Sac County and Placer	$19,150	$19,538	$19,538	$19,538
Folsom and Golden State	$4,552	$4,574	$4,574	$4,574
Rancho Murieta	$313	$313	$313	$313
City of Sacramento and Cal-Am Parkways and Suburban Rosemont	$16,042	$10,959	$11,154	$12,077
SCWA and Cal-Am Security Park	$14,541	$7,539	$7,541	$7,648
City of Galt	$18,121	$3,505	$3,505	$3,505
Ag: Omochumne-Hartnell	$1,509	$232	$232	$403
Ag: Southwest	$3,952	$2,732	$2,733	$2,901
Ag: Clay ID	$2,373	$1,573	$1,389	$1,192
Ag: Galt ID	$3,527	$3,653	$3,620	$3,607
Ag Areas w access to Freeport water	$0	$2,558	$3,148	$5,411
Total	$84,080	$57,176	$57,747	$61,169

Conjunctive Management

One way that scarcity and operating costs were able to be kept lower in the unconstrained cases is by operating groundwater basins to incorporate more conjunctive use, especially for the north basin. This can be seen in Figure 5.18 and Figure 5.19.

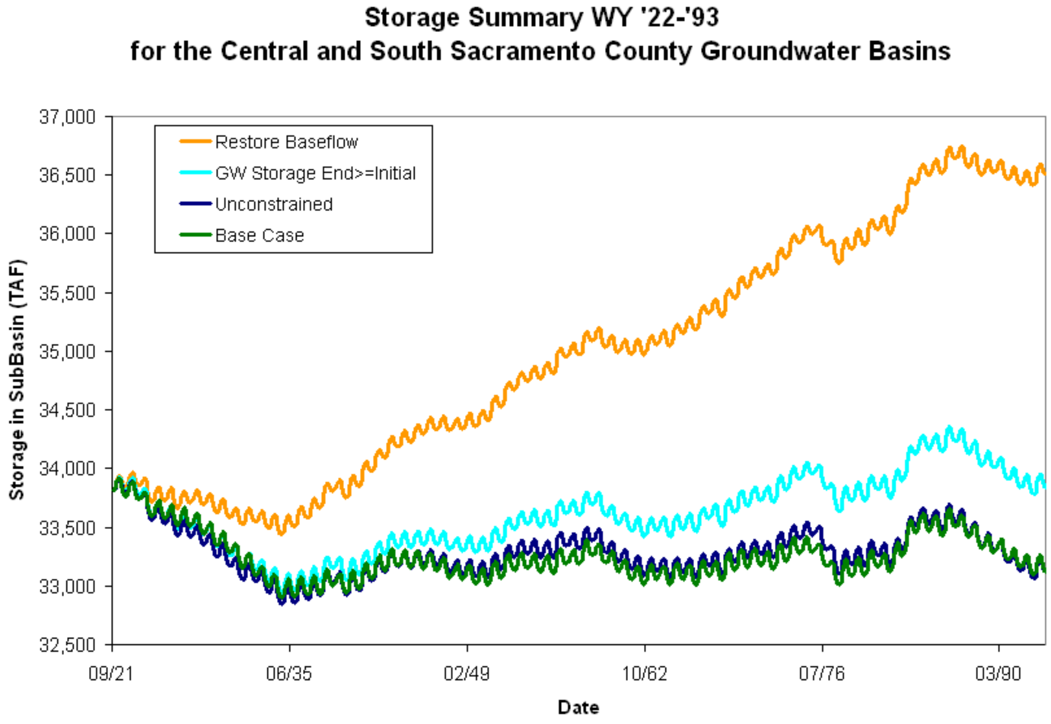


Figure 5.18 Central and South Sacramento County Groundwater Basin Storage

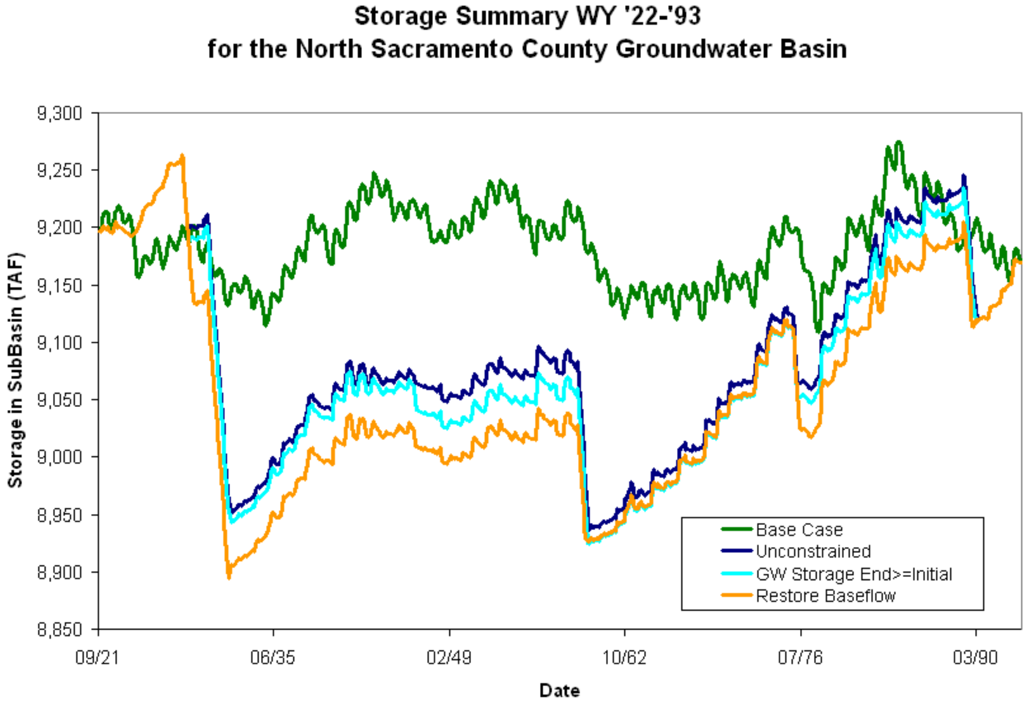
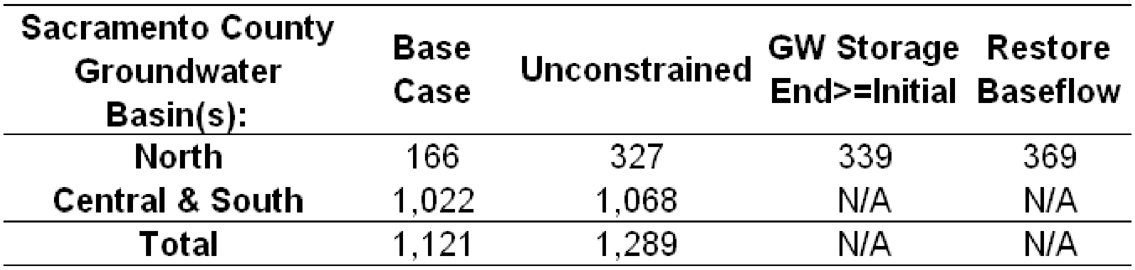


Figure 5.19 North Sacramento County Groundwater Basin Storage

One indication of more conjunctive use is a wider range between the maximum and the minimum monthly storages as groundwater recharge increases during extended periods via in-lieu mechanisms and then is drawn down lower during droughts when surface water is scare. Table 5.13 summarizes the variation observed in the Central and South Basins, as well as the North Basin. The indicators of conjunctive management for the Central and South Basins in the restricted groundwater management scenarios are not particularly meaningful because of the very high ending storage value imposed in these scenarios. However, in the Central and South Basins when the unconstrained case is compared with the base case there is a noticeable increase in the amount of conjunctive use, and in the North Basin, conjunctive use increases with each scenario of increasing restriction on central and south basin groundwater extraction. These observations are consistent the direction of operational changes that the North Sacramento County Groundwater Basin has begun to implement as part of a conjunctive use program that aims to take advantage of the basin's groundwater storage resources (Purkey et al. 2001).

Table 5.13 Active Groundwater Storage Use

(Monthly Max Storage Level – Monthly Min Storage Level in TAF)[12]



Sacramento County Groundwater Basin(s):	Base Case	Unconstrained	GW Storage End>=Initial	Restore Baseflow
North	166	327	339	369
Central & South	1,022	1,068	N/A	N/A
Total	1,121	1,289	N/A	N/A

In the scenario with no net depletion, on average 37% of the total water supply was from groundwater in contrast to an average of 38% in the unconstrained case. In the scenario where baseflow was restored, the average portion of total supplies from groundwater decreased to 35%.

However, with flexible operation and more conjunctive management, much more supply comes from groundwater during droughts when surface water is less available than under current operating policies and when groundwater policies limit average extraction (restricted ground water management scenarios) than when groundwater is more readily available (unconstrained case) (Figure 5.20). This indicates that even when the system has lower average amounts of water resources to operate with (because more recharge on average must to left in the aquifer), the system reserves groundwater for the few extended very dry periods much more than with the current operating policy, and aquifer levels can still recover over the medium to long-term without causing long-term aquifer overdraft. If groundwater supplies are managed effectively and much less of the total annual average water supply comes from groundwater in 90% of the years, then aquifer levels can recover over the medium to long-term without causing aquifer overdraft (Figure 5.20).

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[12] The Central and South Basin spread of groundwater storage values is not applicable because the groundwater storage is required to meet a higher value, therefore forcing the spread to be greater.

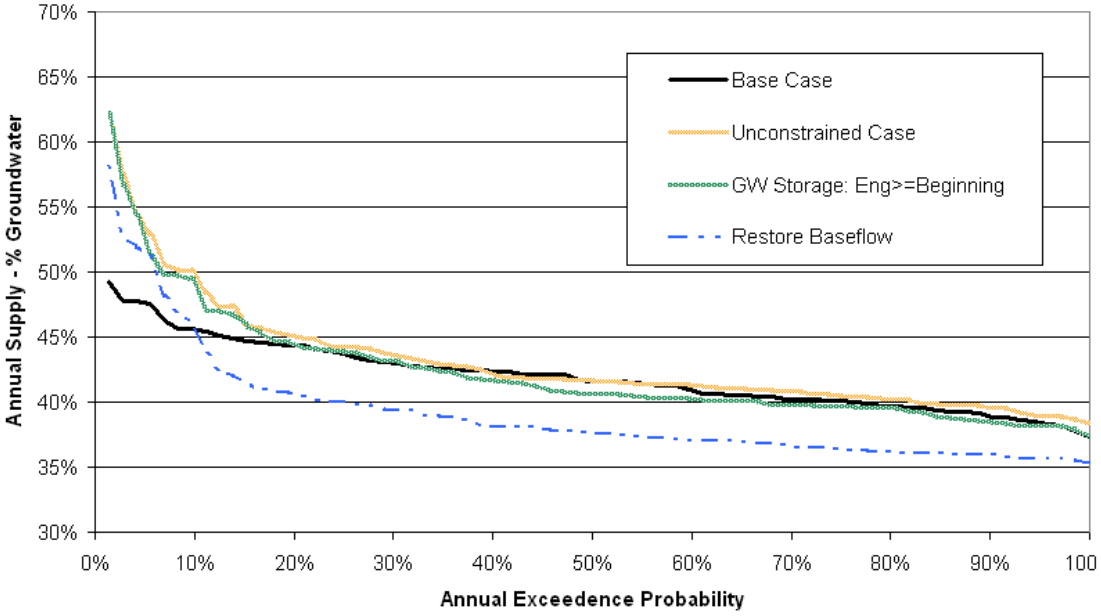

Figure 5.20 Percentile Plot of Water Supply Reliance on Groundwater (Oct 1921 – Sept 1993)

Folsom and Oroville Reservoir Operation

Folsom and Oroville Reservoir operations in the scenarios examining different groundwater management policies were essentially the same as the unconstrained case. Slight modifications in operations made it possible reduce evaporation in the reservoir by one more TAF/year over the unconstrained scenario (with current groundwater management). On average surface water levels were kept slightly higher in the restrictive compared to the current groundwater management unconstrained scenarios, with the increase occurring entirely in Oroville reservoir to minimize evaporative losses. Oroville's minimum storage values were higher, particularly in January and February, but aside from those minor changes, the reservoir was operated similarly to the unconstrained case. See Appendix E for graphs of Folsom, Oroville and combined minimum and average storage values.

Freeport Pipeline Operation

With less groundwater available for use by demand areas in the restricted groundwater management scenarios, Freeport Pipeline usage by agricultural areas increased from the unconstrained case (
Table 5.9). In contrast, the SCWA demand area decreased its use of the pipeline by approximately 4.28 TAF/yr while increasing the amount it wheels through the Sacramento River Water Treatment Plant by the same amount, to most efficiently accommodate the increased agricultural Freeport pipeline deliveries from a system-wide perspective. In the restore baseflow scenario, the second portion of the pipeline from the SCWA diversion to the Folsom South Canal intersection operates at full capacity

between May and September, even though having the maximum amount of water run through the pipe incurs the highest average operating cost per unit of pipeline through-put water. Agricultural areas, affected most by the restrictions on groundwater extraction, have more costly water shortages and are willing to pay to avoid these economic losses (see Figure 5.21 and Figure 5.22).

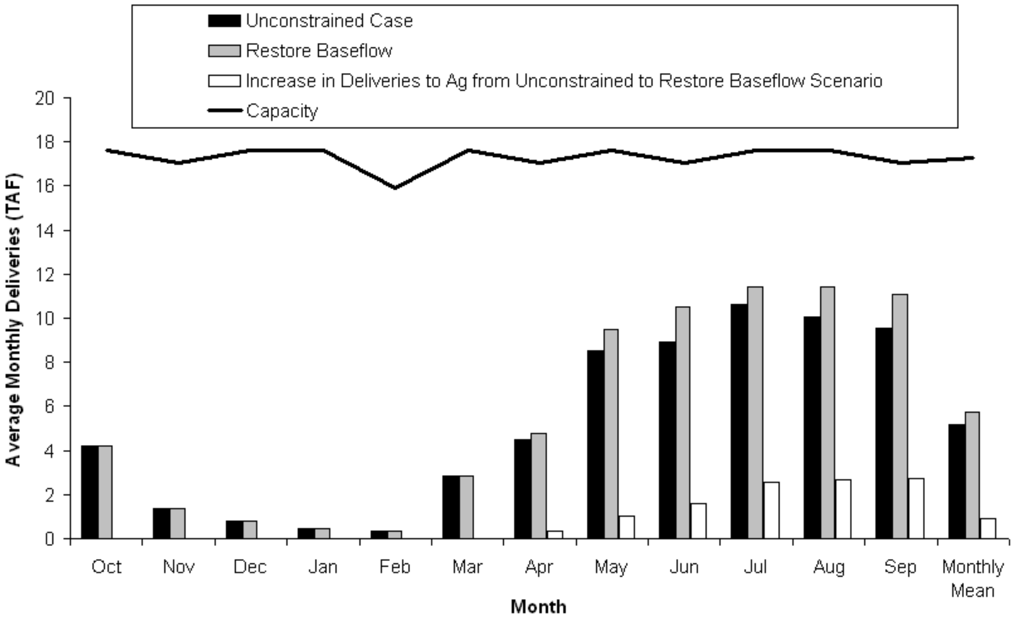

Figure 5.21 Monthly Average Freeport Pipeline Flows Between Freeport and SCWA Diversion Point

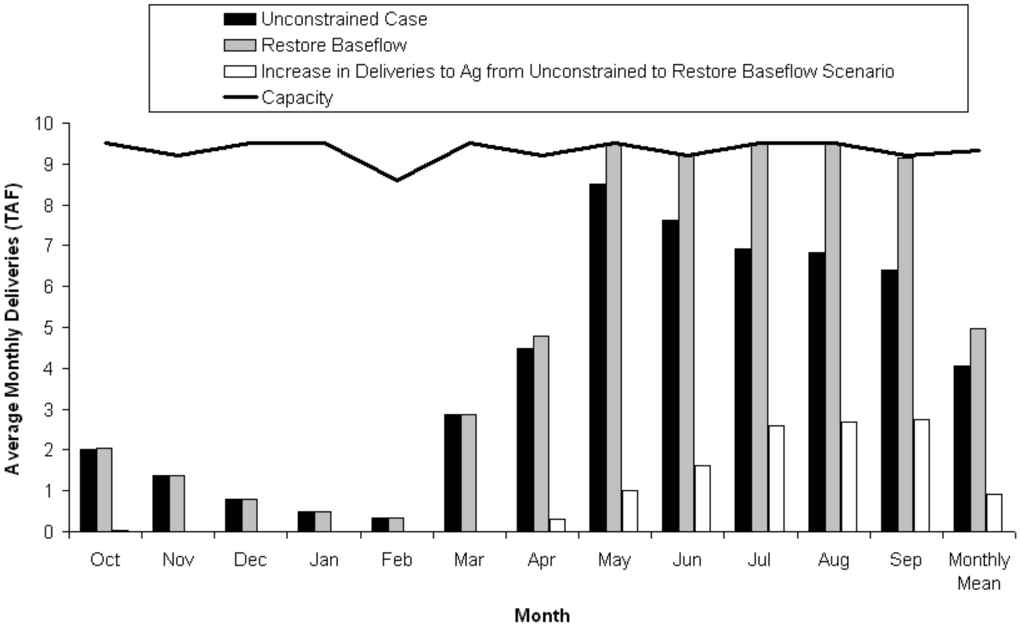

Figure 5.22 Monthly Average Freeport Pipeline Flows from the SCWA Diversion Point to the Folsom South Canal

Values for Expanding Facilities and Relaxing Groundwater Recovery Restrictions

If the Sacramento area water supply system had to operate with approximately 50 TAF/year less groundwater extraction than is currently projected to occur (such as in restore baseflow scenario), then several conveyance facilities have a positive marginal benefit of expansion. Those with the highest marginal net benefits are associated with the City of Galt which has the highest willingness to pay since it is predicted to have approximately 3 TAF/year of shortage even in the unconstrained case. The only ways represented in the model that the City of Galt could get more water is to either expand groundwater pumping or wastewater reuse capacities; both of these links have marginal net benefits exceeding $1,000/month per AF/month of expanded capacity during the peak demand months of June through September.

Another facility to consider re-operating is the Folsom South Canal. In this modeling effort American River diversions into the Folsom South Canal were restricted to levels modeled for the current operating policy due to potential political issues regarding diverting more American River water. However, were more water allowed to be diverted via the Folsom South Canal from April through September, an average net benefit of $60/AF would be produced for additional diversion.

There is also a net marginal benefit for new conveyance facility from the Freeport Pipeline to Omochumne-Hartnell, between June and September equivalent to an average $40/AF of new conveyance capacity created, while in some of these months the benefit would be as great as $60/AF for this additional capacity. There is also an average net benefit to expanding the capacity of the portion of the Freeport Pipeline from the SCWA diversion to the Folsom South Canal equivalent to $25/AF during May - Sept. These net benefits of expansion include operating costs of moving water through the pipeline, but do not include administrative or fixed maintenance costs, nor capital costs required to build the new facilities and any connecting conveyances.

Several areas that would benefit from increasing groundwater pumping capacities include the City of Sacramento from the North Basin, resulting in an average net marginal benefit of $50/AF of additional capacity, SCWA from the Central Basin, resulting in average net marginal benefit of $40/AF to the system all year round (except in Jan), and Rancho Murieta from the Central Basin, resulting in an average net marginal benefit of $30/AF with some months reaching as high as $1,790/AF.

Rancho Murieta has such a high marginal benefit to establishing groundwater wells in the Central Basin because currently its only source is the Cosumnes River, which it stores in a series of surface reservoirs. When the river is dry, or instream flows fall below 70 cfs at Michigan Bar, Rancho Murieta cannot divert water. Rancho Murieta would benefit from relaxing this instream flow restriction in October and allow it to divert more water from the Cosumnes River, averaging $40/AF of additional diversion allowed in October, with a maximum net marginal benefit of $1,685/AF in some Octobers. However, October is crucial for salmon who need the flows needed in the lower Cosumnes to migrate to the upper Cosumnes. Allowing more diversions in October is not environmentally or politically feasible.

Another such politically and environmentally infeasible diversion that the model suggests is an increase in City of Sacramento’s American River diversions, particularly in the months of June – August. This will not be feasible because environmentalists will protest that Chinook and Steelhead on the Lower American river are being deprived of that water.

In the restore baseflow scenario, several demand areas are located in all three groundwater basins for which a net economic benefit could be produced by actively recharging the basin with urban surface water return flows. Average monthly net benefits of such active groundwater recharge range from $15 to $50/AF all year urban return flow active groundwater recharge capacity (see Table 5.14).

Table 5.14 Average Marginal Benefit for restoring Groundwater Baseflow Scenario

Facility to Expand	Months to Expand	Monthly Average Benefit in Months to Expand	Max Monthly Average Benefit in Months to Expand	Min Monthly Average Benefit in Months to Expand	Max Individual Month
Galt Infrastructure					
Expand GW Pumping	June-Sept	1,350	1,400	1,335	1,400
Expand Water Reuse Capacity	June - Sept	1,025	1,075	995	1,080
Freeport Pipeline					
Increase Capacity of Pipeline from SCWA diversion to Folsom South Canal	May-Sept	25	30	15	35
Connect OHWD to Freeport Pipeline	June - Sept	40	45	40	60
Changes in Folsom South Canal Diversions					
Increase Diversions from the American River	April – Sept	60	70	30	70
Increased Groundwater Pumping Capacity					
North Basin: City of Sacramento	All Year	50	60	45	60
Central Basin: SCWA	All Year (except Jan)	40	80	15	85
Central Basin: Rancho Murieta	All Year	30	45	15	1,790
Active Groundwater Recharge					
North Basin: Northeast Sac and Placer	All Year	15	15	15	50
Central Basin: from Folsom South Canal	Oct-May	45	50	25	50
Central Basin: SCWA	All Year	50	50	50	50
Central Basin: City of Sac	Oct-May	30	30	25	50
Central Basin: Rancho Murieta	All Year	50	50	50	50
South Basin: City of Galt	Oct-April, July	30	30	30	30
South Basin: from Folsom South Canal	Oct-Mar	30	30	30	30
City of Sacramento					
Increased Diversions from American River	June- Aug	15	15	15	15
Rancho Murieta					
Increased Diversions from Cosumnes	Oct	40	40	40	1,685

6

Limitations and Recommendations for Future Studies

6.1 Limitations

This is a "proof of concept" study to see what the water supply implications would be of implementing groundwater management strategies that could improve groundwater conditions below the Cosumnes River and even restore baseflow. The Sac CALVIN optimization model's purpose is not to model the surface and groundwater interactions in detail, nor to serve as a surface water model, or a groundwater model, but rather to take an accepted surface water model (CALSIM II), an accepted groundwater model (SacIGSM) and use previously done work to investigate the water supply, operational, and economic implications of different water management policies. There are several limitations to this study which can be categorized as 1) limitations on how ground and surface water are represented, 2) limitations of the quality and quantity of data employed, and 3) institutional limitations.

Ground and Surface Water Representation

Since the Sac CALVIN model has difficulty representing surface-groundwater interaction, infiltration loss rates on the Cosumnes River were not included. Loss rates range from 0.2 cfs/mile below Rooney Dam to 3.5 cfs/mile below Mahon Dam. Water infiltrating from the Cosumnes River goes to the Central and South Groundwater Basins, and thus is not lost to the system, but is stored in the ground and available for later use. For a rough approximation of the most economically efficient way to operate the system, it was sufficient to not include the loss rates (less than 3 % of the total deliveries to the Greater Sacramento Area pass through the Cosumnes River). However, this means that with the recommended economically efficient operations, the Cosumnes River may be becoming drier even more often than the model results predict. A minimum flow of 1.95 TAF/month (0.93 cms) is needed at the McConnell gage during October, November and December for salmon to migrate to their upper Cosumnes River spawning grounds (Anderson et al. 2004). In November and December in the base case and the unconstrained case this minimum flow was met 100% of the time. However, in October, flows in the Cosumnes River are less than the required flow for salmon migration in 69% of all years modeled in the unconstrained case (as compared with only 7% in the base case), both of these figures would be higher if Cosumnes River loss rates were included. This is occurring because there is no policy limiting agricultural diversions in October and surface water is free to agricultural users, while they must pay to pump groundwater, and October is still a month when agricultural water demand is somewhat high. Relatively little water is at stake (1.77 TAF/month). A policy that required agricultural users to not divert water from the Cosumnes River in October would help. This will have an insignificant effect on the overall operation of the system, but will ensure that minimum flows in the Cosumnes River occur in more years.

The aquifers in the area are perched, implying that localized pumping will have a more significant effect on flows in the river than groundwater pumped further away. This is not accounted for in the Sac CALVIN model.

Additionally, infiltration losses from the canals, rivers and reservoirs while represented as losses from deliveries are not represented as gains to the groundwater basins below. This implies that the system may have access to more water than is represented in this model. The effect is likely to be similar in the base case and the unconstrained case, and since this study is most interested in the difference between cases, is not anticipated to be a significant limitation.

Another limitation related to how ground and surface water were represented is that the demands reported by demand areas (calculated using their current average per capita use and their 2030 population projections) differ significantly from those modeled in CALSIM II, which significantly differ from those assumed in the Sac IGSM model (discussed in section 4.4 on Demands). When calibrating the model, flows were added at the demand nodes to add or remove water from the system as needed to make these differing sets of data work together in this model. These flows were typically not more than 3 TAF/yr, except for Northeast Sacramento County and Placer, in which the CALSIM II model grouped deliveries to that area together with agricultural deliveries in the area making them much higher than this study's representation, so that approximately 78 TAF/yr had to be removed from the Sac CALVIN model.

Additionally, the original Sac IGSM model was used for consistency because it modeled the entire 72 year period of hydrology that this model is examining. The refined Sac IGSM model had a more detailed accounting of the groundwater areas near the Cosumnes River. The refined Sac IGSM model predicts that at the end of the modeling period there will be approximately 300 TAF more groundwater in the Central and South Basins than the original Sac IGSM model is predicting. This means that the Sac CALVIN model may be over estimating the cost of restoring baseflow. The largest discrepancy between the original and the refined Sac IGSM results is in the initial Central and South Basin combined groundwater storage value represented in the refined model (a 1969 groundwater storage value), which is 1150 TAF greater than the same value in the original model (and just 2000 TAF less than what was calculated in this study as the combined groundwater storage level needed to restore hydraulic connectivity.) This large discrepancy indicates that the Sac CALVIN results may have been quite different if the refined SacIGSM values were used. Differences would have been heavily dependent on what the refined studies groundwater storages values were between October of 1921 and September of 1969 (a period which was not modeled in the refined study). If the same initial storage values were used as those used in the original study, then the refined Sac IGSM model would likely indicate that there is more groundwater storage in the Central and South Basins than the original Sac IGSM model predicted. Water purveyors would then likely rely more heavily on groundwater than they did in these model runs and that would significantly reduce costs.

Furthermore, groundwater return flows from urban areas were fixed based on the projected deliveries made with the current operating policy. Since there were 9 TAF/yr more deliveries to urban areas in the unconstrained cases, than in the base case, slightly more water should have been returned to groundwater from urban areas. In this model, that water was returned instead to surface water where it unable to be reused by demand areas. This implies that some more water would have been able to be re-used as groundwater in the unconstrained case, although the percentage of extra water from urban area return flows (both surface and deep percolation) is accurate (Figure 5.3, Figure 5.16 and Figure 5.17).

Another instance where the flows through a link were fixed, but were meant to represent a percentage of the entire flow, was with SCWA's groundwater. Currently 66% of SCWA's groundwater is treated with Iron and Mg at an additional cost of approximately $15/AF, which is added to the approximately $41/AF cost of pumping the water (see Appendix D). In the base case 76% of the flow was modeled as untreated, and 24% modeled as treated, and in the unconstrained case 52% of the flow was modeled as untreated, and 48% as treated. This means that the $3 million per year benefit that SCWA would experience by flexible operations in actually a conservative estimate.

Since ground and surface water interactions were not modeled in detail, the variable cost of groundwater pumping was not accounted for in the model. As groundwater was depleted in a certain area, the cost of pumping the groundwater in that area should have increased, but in this model a rough estimate of the cost of pumping groundwater was fixed for each demand area for the entire 72 year period being modeled.

Data Limitations

When gathering data from demand areas, not all demand areas provided us with information on their per capita use and 2030 projected populations. Some of the information could be found in water management plans, but when that was not available, there were several water agencies about which information could not be gathered and estimates were made based on what similar demand areas had reported. Since demand projections are based on predicted development, all of the demands in the model are just estimates. If actual demands are higher than those used in the model, then more scarcity will be encountered and overall costs will be higher. However, since the same demands are used in all four scenarios, and the key results are found by comparing the modeling scenarios, the error in the demand estimates will be subtracted out, and the predominate trends will remain the same.

When penalty functions were being put together for each of the demand areas, it was noted that the current Black and Veatch urban residential water price survey information (B&V 2006) was less comprehensive than that of the 1995 survey, and some reported prices that were expected to have gone up significantly had remained the same or were even lower. However, since this was the best information available, this was used.

Institutional Limitations

Sac CALVIN is a hydo-economic optimization model where its sole goal is to maximize net benefits to the system. However, some results are probably institutionally infeasible. These include:

- Drying the Cosumnes River more during critical periods with flexible operation than with the current operating policy (in October, 7% of flows in the base case are below critical flows, in the unconstrained case 69% of flows are subcritical).

- Pumping groundwater from the North Sacramento County Groundwater Basin at full pumping capacity every month for 72 years by the City of Sacramento. This action allowed the City to stop taking Sacramento River water entirely which was much more costly to treat. Other areas that had been pumping groundwater shifted off groundwater to make this possible so that the same amount of groundwater would still be extracted over the 72 year period (such as Northeast Sacramento County and Placer).

- Having extensive conjunctive use draws down groundwater far below what is predicted with the current operating policy (see Figure 5.19). This has potential negative consequences for drying wells, among others.

- Not drawing down the reservoir as much during floods. Since the model has perfect hydrologic foresight, it knows exactly how much to draw the reservoirs down in the flood months and keeps storage levels as high as possible, but still lower than the required flood control pools.

6.2 Recommendations for Future Studies

In future studies done with Sac CALVIN to explore ways to restore the Cosumnes River, It is recommend that:

1. Agricultural users are not allowed to divert water from the Cosumnes River in October.

2. The minimum instream flow below Nimbus, which currently represents Water Right Decision 893 be replaced with the new accepted Water Right Agreement for minimum instream flows below Nimbus. This minimum instream flow has been put into the version of CALSIM II that is being managed by the Bureau of Reclamations and the Executive Director of the Water Forum agrees that this is a sufficient minimum instream flow (Gohring 2008). Water Right Decision 893 is 60 years old and it is widely recognized that it does not provide sufficient minimum instream flow with a minimum of 500 cfs in the winter and 250 cfs in the summer, and at times relaxed as low as 195 cfs. The current minimum instream flow requirement on the American River above the confluence with the Sacramento River is Decision 1400 which was originally connected with Auburn

Dam, but which the Department of Water Resources has used in some of its planning studies. Both decisions are to protect the Fall Run Chinook salmon whose critical migration period is between October and December, and the Steelhead whose critical migration period is between June and September. In future studies, a persuasion penalty can be put on Lower American River flows for the critical migration periods of June through September, essentially saying that if there is extra water[13] in the system, run it through the Lower American River during these months, with the second highest persuasion priority to store it in the reservoirs, and the third to have the excess water go through the Delta.

3. A zero capacity link is connected from the Sacramento River above the confluence with the American River to Northeast Sacramento County and Placer and to the City of Sacramento, representing a potential water treatment plant that these two areas are considering building.

With these two changes, the unconstrained cases could be run again and more insight could be found to determine the ideal trade off between flows in the Lower American and flows in the Cosumnes River.

One of the nuances of the system that this model has highlighted is that there is a trade-off between October and December between flows in the Lower American River and flows in the Cosumnes River. Water in both these areas benefits the Fall Run Chinook Salmon. An environmental optimization model such as the one used by Sarah Null for her PhD dissertation on flows on the Shasta River, could be built to explore the most environmentally efficient use of the limited fall run water (Null 2008).

This model provides rough estimates of the additional economic cost of implementing various management strategies for improving groundwater conditions under the Cosumnes. Further economic analysis could be done to assess if the cost of the policy makes it worth trying to implement. Past studies have shown that flow augmentation is an essential part of restoring flows in the Cosumnes River (Fleckenstein et al. 2004). If a minimum instream flow constraint (representing a future policy decision) was put on the lower Cosumnes River, then a rough estimate of the cost of implementing such a policy could be determined. Before implementing such a policy, the ground and surface water interactions should be examined using a more detailed model, such as the one developed by Jan Fleckenstein. The perched aquifers could then be modeled more accurately and a more realistic idea of the effects of reduced groundwater pumping and required flow augmentation could be explored.

Modeling efforts could be supplemented with field work. The field work could extend the work done by Robertson-Bryan, Inc. of a pilot flow augmentation project in 2005. In the 2005 study, a proposal was made to begin flow augmentation to attract salmon up the Cosumnes River in November. Since this was not a part of the original plan and neither the CEQA nor NEPA documents accounted for such a request, the request was denied. It

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[13] Extra water in this instance refers to water not being used to meet: an urban or agricultural demand, a required delivery, or a required minimum instream flow.

is recommended that future studies prepare the proper environmental documentation and explore the benefits of such flow augmentation strategies.

7 Conclusions

This study has shown that there are several ways to manage the water resources of the Sacramento Area more efficiently than it is predicted to be operated in 2030 with current operating policies. Using the Sac CALVIN hydro-economic optimization model which assumes economically ideal and flexible infrastructure operation, the following preliminary conclusions are made. These conclusions, which are subject to further exploration, refinement and testing, are organized based on the objectives that they were meeting.

- **Objective:** To determine the maximum amount of increased water delivery that would be economically efficient for the Sacramento Area to obtain if the system is: a) allowed to operate flexibly, b) driven only by economic objectives, and c) constrained only by physical capacities and environmental flows[14]. Identify how increased deliveries are made possible, and how all major infrastructure (including operation of Folsom and Oroville Dams and the Freeport Pipeline) is operated under optimal conditions. Determine other major benefits associated with this re-operation. Identify where there is economic benefit to changing current operating policy or expanding infrastructure.

  Conclusions:
  1. The maximum amount of increased water delivery that it would be economically efficient for the Sacramento Area to obtain would be approximately 15 TAF/yr (1.6% of the total demands in the area). Approximately 60% of the increased delivery would be delivered to urban areas and the remaining 40% to agricultural areas (see Figure 5.2).

  2. This increased delivery is made possible by 1) operating Folsom and Oroville Reservoirs to minimize evaporative losses (up to 8 TAF/ yr or 45% of the increased delivery) 2) more effectively using water within the system to reduce surplus Delta outflows (up to 2.25 TAF or 15% of the increased delivery) and 3) by delivering this additional water to demand areas who then have increased return flows (up to 6 TAF or 40% of the increased delivery) (see Figure 5.3) Increased water supply is not from taking water from Folsom or Oroville Reservoirs; in all months, both median and average combined reservoir storage is higher than with the current operating policy (see Figure 5.7).

  3. The major changes in operation include: 1) more reliance on higher quality American River water to meet water supply needs, 2) less use of expensive Sacramento River water, 3) less use of expensive Freeport water, and 4)

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[14] A few institutional policies were also included, such as limiting Folsom South Canal diversions from the American River to the diversions predicted by CALSIM II limiting diversions from the Folsom South Canal to agricultural areas to 10% more than the maximum value predicted in CALSIM II simulated operations.

coordinated operation of Folsom and Oroville Reservoirs to minimize evaporative losses (see Table 5.5 and Figure E.13).

4. Flexible operation (as modeled by the unconstrained case) could have an economic benefit of as much as $27 million dollars, with as much as a $5 million coming from a reduction in operating costs and as much as $22 million from reducing scarcity costs (see Table 5.5 and 5.6). The reduction in scarcity comes from the increased water supply delivery described in conclusions 1 and 2. The decreased operating cost comes predominately from 1) using more higher quality American River water (approximately 73 TAF/yr more), 2) more use of Cosumnes River flows, some of which are from return flows, and most of which are at times that are not critical to salmon migration (approximately 22 TAF/yr more), 3) decreased Sacramento River urban diversions because that water is so much more expensive to treat than other sources (approximately 49 TAF/yr less), and 4) decreased urban use of the Freeport Pipeline because on top of being expensive to treat the water, it is expensive to pump (approximately 31 TAF/yr less).

5. There is significant physical flexibility in the Sacramento area water system. This is illustrated by meeting 15 TAF/yr more water demands at a lower cost than with the current operating policy (Figure 5.7 and Figure 5.8)

6. When the Freeport Pipeline is not being used to capacity by SCWA and EBMUD, there are times between April and September that agricultural areas are willing to pay for conveying surface water in the pipeline to avoid shortages. The maximum average monthly amount is in May when they are willing to pay for an average of approximately 6 TAF/month (Figure 5.14 and Figure 5.15). Omochumne-Hartnell is willing to pay as much as $45/AF at times to be connected to the Freeport Pipeline (see Table 5.7).

7. If any investments are to be made to increase the efficiency of the Sacramento Area water system, by far the most economically efficient investment would be in infrastructure to help the City of Galt diversify its water portfolio, increase its groundwater pumping capacity, or increase its water reuse capacity. The marginal benefit for any one of these improvements exceeds $1000/AF (Table 5.7).

8. It is worthwhile to investigate an operating policy for the Folsom South Canal that would allow more American River water to be diverted through the canal to provide flows for the Fall Run Chinook in the Cosumnes, or to deliver to agricultural areas who are willing to pay as much as $58/AF between April and September (Table 5.7).

- **Objective:** Determine if seasonal or inter-annual conjunctive use opportunities are predicted if the Sacramento Area water system is flexibly operated, and economic costs to the entire Sacramento area are minimized.

Conclusion:

1. More conjunctive management is economical for the Sacramento County Groundwater Basins. The North Sacramento County Groundwater Basin already has a program in place (Purkey et al. 2001). However, if the Northeast Sacramento County and Placer had active recharge facilities, and the City of Sacramento increased its ability to pump groundwater from the North Basin – which is planned to occur (Peifer 2007) –a marginal benefit could be as much as $60/AF of water exchanged (Table 5.7). Results from this study indicate that it would be possible for groundwater to be brought down lower than it has been historically and still have no long-term overdraft (for the 72 year period being modeled). In the Central and South Sacramento County Groundwater Basins, it would be economically efficient to have a greater portion of the annual water supply (more than 47%) come from groundwater in a small percentage of the years (less than 15%). In some of the more extreme droughts, more than 60% of the annual water supply could come from groundwater (see Figure 5.5 and Figure 5.7) There is an economic incentive to expand groundwater pumping facilities at SCWA, the average marginal benefit to expanding groundwater pumping is $47/AF in any given month. Rancho Murieta currently has no groundwater pumping facilities, but were they to acquire them, the average marginal benefit would be $42/AF and at times reach as high as $1,790/AF. There is also a marginal benefit to having active recharge facilities in the Central Groundwater Basin using return flow from the City of Sacramento, SCWA, and the City of Folsom, all of which would bring in a marginal benefit of $38/AF of water put in a recharge basin. Another way to recharge the Central Sacramento County Groundwater Basin would be to actively recharge the basin with water from the Folsom South Canal. There would be an average monthly marginal benefit of $34 to recharging in this way between the months of October and May (see Figure 5.8).

- **Objective:** To determine how water supply deliveries would be affected if a policy required groundwater levels to equal or exceed the 1993 reference condition by the end of an extended period of time (in this case the 72 year period being modeled). Determine the additional cost of such a policy.

Conclusions:

1. If a policy were to be implemented that required the end of period groundwater storage level to equal or exceed the initial storage, deliveries would only decrease by 0.04 TAF/ yr relative to the unconstrained run (0.004% of total deliveries – 1.3 % of total agricultural deliveries) (Table 5.8). Initially, it is surprising that deliveries were not more affected since the groundwater management policy required that approximately 10 TAF/yr more water was stored as groundwater. However, less than 1% of the additional water stored in the ground came from shorting the agricultural demand areas, 99% of the water came from using available surface water in the Sacramento Area by reducing surplus Delta

outflows, and the remaining portion (0.6%) came from decreasing surface reservoir evaporation (Figure 5.16).

2. The total average additional cost of ending overdraft would be $0.57 million/yr (less than 1% of the total operating cost) (Table 5.12).

- **Objective:** Determine the affect on water supply deliveries if a policy required groundwater levels to restore Cosumnes River baseflows by the end of an extended period of time (in this case the 72 year period being modeled). Determine the additional cost of such a policy. If there were less water in the system (such as that modeled under a scenario where baseflows were required to be restored) determine which infrastructure would be the most economically beneficial to expand its capacity.

  Conclusions:

  1. If a policy were to be implemented to require baseflow to be restored at the end of an extended period (such as the 72 year period being modeled in this study), then the decrease in agricultural deliveries would be approximately 12 AKF/yr (1.3% of the total deliveries - 3.8% of agricultural deliveries) (Table 5.8). This is a surprisingly small shortage considering that to implement such a policy requires 47 TAF/yr more water stored as groundwater. Most of the additional water stored in the ground (76%) comes from managing flows within the system to reduce surplus Delta outflows, mostly by increased conjunctive use (Figure 5.17).

  2. The total additional cost of restoring baseflow would be approximately $4 million/yr as compared with the unconstrained run (around 7 % of the total operating cost) (Table 5.12). $0.8 million came from increased scarcity costs (Table 5.10). $3.2 million came from increased operating costs which occurred in part because the City of Sacramento is forced to rely even more on American River surface water which is more expensive than pumping groundwater, in part because of SCWA's increase Sacramento River diversions, and because of all the agricultural area's increased use of the Freeport Pipeline (Appendix E).

  3. The Freeport Pipeline was a critical piece of infrastructure for implementing a groundwater management policy that required restoration of baseflow. Between May and September the portion of the pipeline from the SCWA diversion to the Folsom South Canal is operated at capacity. This is because agricultural areas were willing to pay the higher prices ($43/AF) for pumping water through the Freeport Pipeline.

  4. If a groundwater management policy were implemented to restore baseflow, then it would be worth considering expanding the areas mentioned that had marginal benefits in the unconstrained case, as well as considering expanding the portion of the Freeport Pipeline from the SCWA diversion to the Folsom South Canal and allowing agricultural areas to transport water via the pipeline because even after

paying $43/AF, they still experienced an additional benefit of $25/AF by putting that water to productive use (Table 5.14).

We reiterate that all conclusions are subject to the limitations noted in Chapter 6.

In conclusion, this work shows that implementing a groundwater management strategy that improves groundwater conditions under the Cosumnes River may not be as expensive or unmanageable as one might think. If the Sacramento Area Water system were able to operate flexibly and deliver water to the areas willing to pay the most for it, it would be possible to implement a groundwater management policy that required baseflow to be restored, and still meet 97% of all demands (the same percent of total demands anticipated to be met by the current operating policy) and keep costs much lower than those anticipated with the current operating policy (as much as $22 million lower). (Table 5.8, Table 5.12)

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Appendix A: Demands

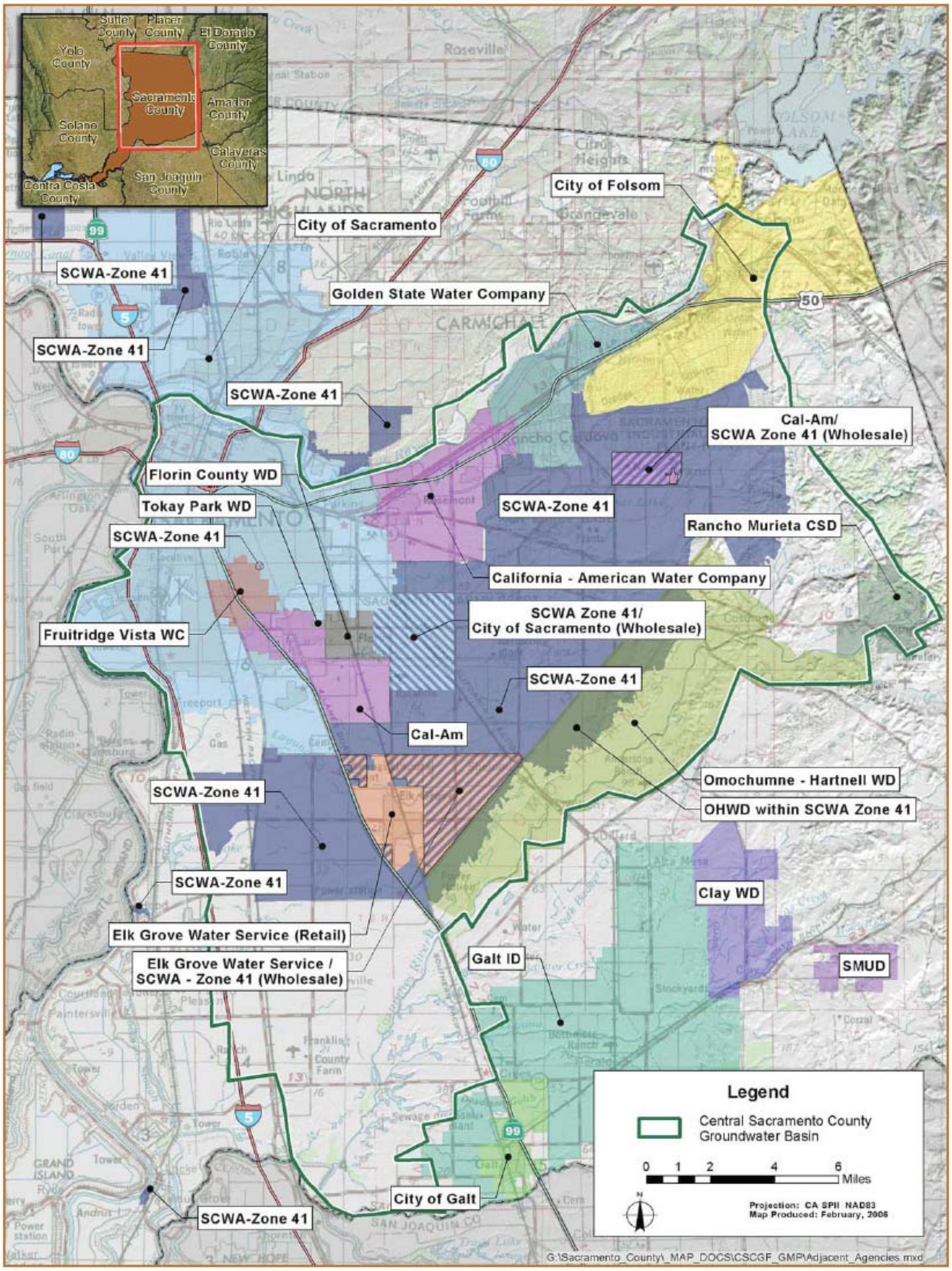


Figure A.1 Water Purveyors in the Central and South Sacramento County Groundwater Basins (WaterForum 2006)

Table A.1 Mapping of Sac CALVIN urban demands to water purveyors and SacIGSM areas (See Figure A.1 for areas corresponding to SacIGSM area numbers)

Sac CALVIN Urban Node	**Agency Name [1]**	**No.**	**SacIGSM Name**
Res:Folsom+GS	City of Folsom Folsom Prison Golden State WC (Cordova Section of Arden Cordova Region) California Parks and Recreation	15 16	City of Folsom Arden Cordova
Res: City of Sac +	City of Sacramento Cal-Am Parkway & Suburban Rosemont	43 1 2	Rosemont-Cal Am North Sacramento South Sac
CSC GWU	Omochumne-Hartnell (Rural Estates)	3	OHWD North
	Omochumne-Hartnell (Rural Estates) Southwest (Rural Estates) Foothills North (Rural Estates)	10 4 30	OHWD Southwest Foothills North
NWSacCo GWU	Natomas Mutual Metro Airport	27 28	Natomas Mutual Metro Airport
NE Co Sac. Placer	Mc Clellan AFB Sacramento International Airport Natomas Central MWC Rio Linda WD Sacramento Suburban WD SCWA Zone 41 (above American River) Del Paso Manor WD Golden States WC (Arden section of Arden Cordova Region) Fair Oaks WD Carmichael WD Citrus Heights ID Orangevale WC San Juan WD Cal-Am West Placer, Antelope, Lincoln Oaks & Antelope Placer County Water Agency El Dorado Irrigation District City of Roseville Arcarde WD	24 25 26 32 33 34 35 17 18 19 20 21 22	Mc Clellan AFB Arcade Rio Linda North Arcade WD-T&C Rio Linda South CUCC-Antelope CUCC-Lincoln/PO Fair Oaks Orangevale San Juan Carmichael Citrus Heights Northridge
Res: SCWA Zone 40+	SCWA (South of American River) Cal-Am (Security Park/Sunrise) Elk Grove Water Service	36 37 38 39 40 41 42 12 13 14 23	Laguna/Franklin EGWS SCWA/EGWS Retail Vineyard-SCWA N. Vineyard In Vineyard OUT PO Mather Sunrise "A" Sunrise Douglas – SCWA Security Park Cal-Am Sunrise SCWA
SSC GWU	Galt ID (Rural Estates) Clay ID (Rural Estates) Foothills South (Rural Estates)	5 7 9 31	Galt ID OFSCU Clay WD Foothills South
Res:City of Galt	City of Galt	6	City of Galt
Res:Rancho Murieta	Rancho Murieta	11	Rancho Murieta
SMUD	SMUD	8	SMUD
EBMUD	EBMUD		
Not Included		29	Courtland Area

[1] Agency deliveries to urban areas only are represented by Sac CALVIN Urban Demand Nodes

Table A.2 Mapping of Sac CALVIN Agricultural demands to water purveyors and SacIGSM areas (See Figure A.1 for areas corresponding to SacIGSM area numbers)

Sac CALVIN Ag Node	Agency Name [1]	No.	SacIGSM Name
Clay ID+GWOU	Clay ID	9	Clay WD
	Foothills South	31	Foothills South
CVPM 7	North Sac	1	North Sacramento
	Rio Linda WD	27	Natomas Mutual
	Metro Airport	28	Metro Airport
	Cal-Am West Placer, Antelope, Lincoln Oaks & Arden	26	Rio Linda North
		33	Rio Linda South
		34	CUCC-Antelope
		35	CUCC-Lincoln/PO
Galt ID+OFSC Ag	Galt ID	5	Galt ID
	Other Folsom South Canal Users	7	OFSCU
	City of Galt	6	City of Galt
OHWD Ag	Omochumne-Hartnell	16	Arden Cordova
	Golden State (Cordova Portion)	3	OHWD North
	Foothills North	10	OHWD
	SCWA (South of American River, except Laguna/Franklin Portion)	30	Foothills North
	Rancho Murieta	38	SCWA/EGWS Retail
		39	Vineyard-SCWA
		12	Sunrise "A"
		13	Sunrise Douglas – SCWA
		14	Security Park Cal-Am
		11	Rancho Murieta
Southwest Ag	City of Sacramento (South of American River)	2	South Sac
	Southwest	4	Southwest
	SCWA (Laguna/Franklin Portion)	36	Laguna/Franklin
No Ag WU		15	City of Folsom
		43	Rosemont-Cal Am
		24	Mc Clellan AFB
		25	Arcade
		32	Arcade WD-T&C
		17	Fair Oaks
		18	Orangevale
		19	San Juan
		20	Carmichael
		21	Citrus Heights
		22	Northridge
		37	EGWS
		40	N. Vineyard In
		41	Vineyard OUT PO
		42	Mather
		23	Sunrise SCWA
Excluded		29	Courtland Area

[1] Agency deliveries to agricultural areas only are represented by Sac CALVIN Ag Demand Nodes

Appendix B: Schematic

The original CALVIN model had less detail in the Sacramento Area as illustrated below.

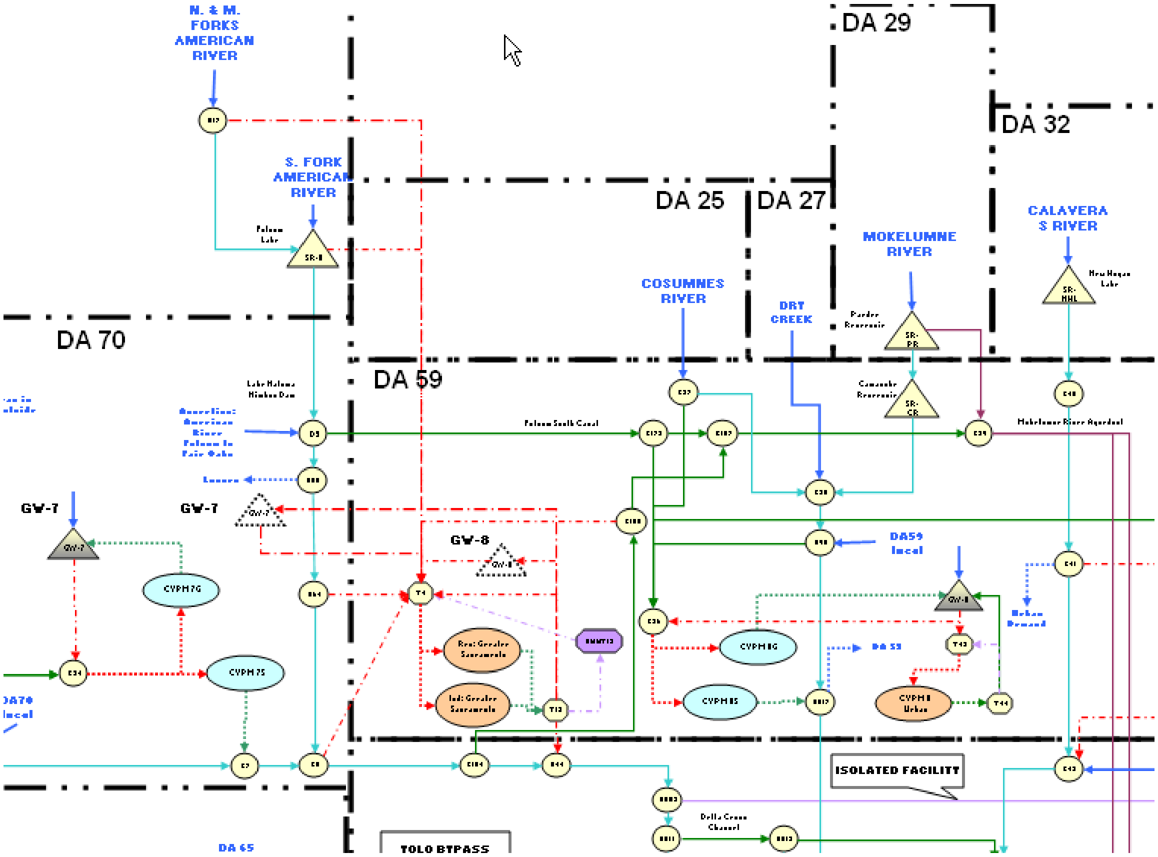


Figure B.1 Previous Schematic for the Sacramento Region

The urban demand areas in the previous Sac CALVIN schematic are shown in Figure B.1 as orange ovals and are: the residential portion of the greater Sacramento area, the industrial portion of the greater Sacramento area and CVPM 8 Urban which includes the City of Galt as well as of other areas that are not being investigated in this study. The agricultural areas included in the previous schematic include CVPM 7 and CVPM 8. Both of these regions include portions of areas not represented in this model, and CVPM 8 includes: Omochumne-Hartnell Water District, Clay ID & other independent groundwater only users that pump from the South Sacramento County Groundwater Basin, various unaffiliated groundwater only users that pump from the Central Sacramento County Groundwater Basin have been lumped together in the refined model as Southwest Ag, and Galt ID and other Folsom South Canal users. The objective of this study is to assess if operating ground and surface water together in the Central and South Sacramento County Groundwater Basins can reduce system operating costs, and if so, which demand areas could benefit from this combined operation.

To investigate this question required, a more refined schematic. For this study, the refined Sacramento Area Region of the model was not integrated into the entire Statewide CALVIN model. The questions being investigated here could be analyzed without running the entire California model, which can take days. However, the structure of the previous schematic was maintained while more detail was added to the Sacramento Region so future studies can incorporate the refined Sacramento Region Area into the Statewide CALVIN Model. The primary changes made to the previous schematic include:

1. Accounting for the Central and South Sacramento County Groundwater Basins (GW-CSC &GW-SSC) separately rather than simply as a portion of GW-8. The groundwater basins being modeled dynamically, as opposed to with a fixed time series, are GW-7, GW-CSC, and GW-SSC.
2. Groundwater only users in each groundwater subbasin are accounted for separately, and their usage is modeled as a fixed time-series
3. In the previous schematic the Greater Sacramento Area included: the North East Sacramento County and Placer Areas, the City of Sacramento, Cal-Am Parkway, Cal-Am Rosemont, Rancho Murieta, City of Folsom, Golden State, the Sacramento County Water Agency (SCWA), Cal-Am Security Park, and SMUD. All these areas have been accounted for explicitly in this model and mapped to the 43 different areas modeled by WRIME using SacIGSM (see Tables A.1 and A.2)
4. Only the portions of CVPM-8 that use water from GW-CSC or GW-SSC are included. This includes OHWD, Southwest who use water from the Central Sacramento County Groundwater Basin, and Clay ID & Other Groundwater Only Users, and Galt ID & Other Folsom South Canal Users who use water from the South Sacramento County Groundwater Basin.
5. After these areas had been disaggregated the entire Cosumnes River area including Laguna and Badger Creeks and Dry Creek had to be reconfigured to better represent the physical system.
6. All the infrastructure to connect the more disaggregated demand nodes was included.
7. Lake Oroville is represented and has been connected to the Sacramento Region in the most simplified way possible (omitting many of the details not pertinent to this investigation that can be found in the Statewide CALVIN model).
8. Deliveries to East Bay MUD (EBMUD) have been represented as a fixed time series because EBMUDSim is a proprietary model and as such the 2030 predicted deliveries from Pardee Reservoir are not available for public use. Folsom South Canal Deliveries to EBMUD were reported in the Freeport EIR, and the annual average was found to be the same as that modeled by CALSIM II OCAP study. The monthly patterns from EBMUDSim and CALSIM II were different, so for consistency and to calibrate the model, the CALSIM II deliveries were used.
9. The Aerojet Groundwater Treatment Plant was included on the new schematic.
10. Rancho Murieta’s reservoirs were included on the new schematic.

Figure B.2 Demand Area Water Sources (created by Yen Luong in the Mentor Engineering Program with information and guidance provided by Rachael Hersh-Burdick)

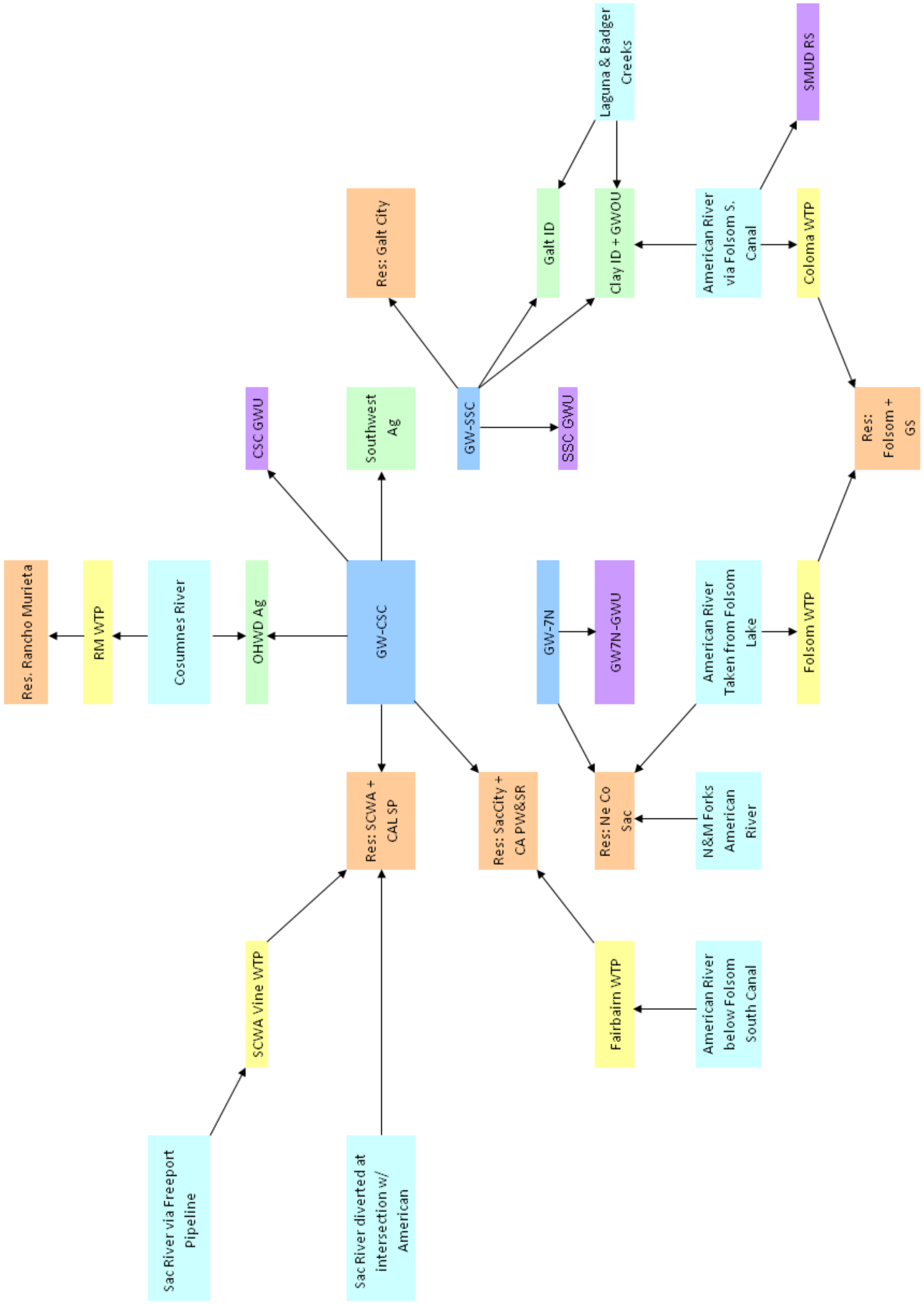


Figure B.3 Schematic of the Sacramento County CALVIN model used in this study

Appendix C: Conjunctive Use in California

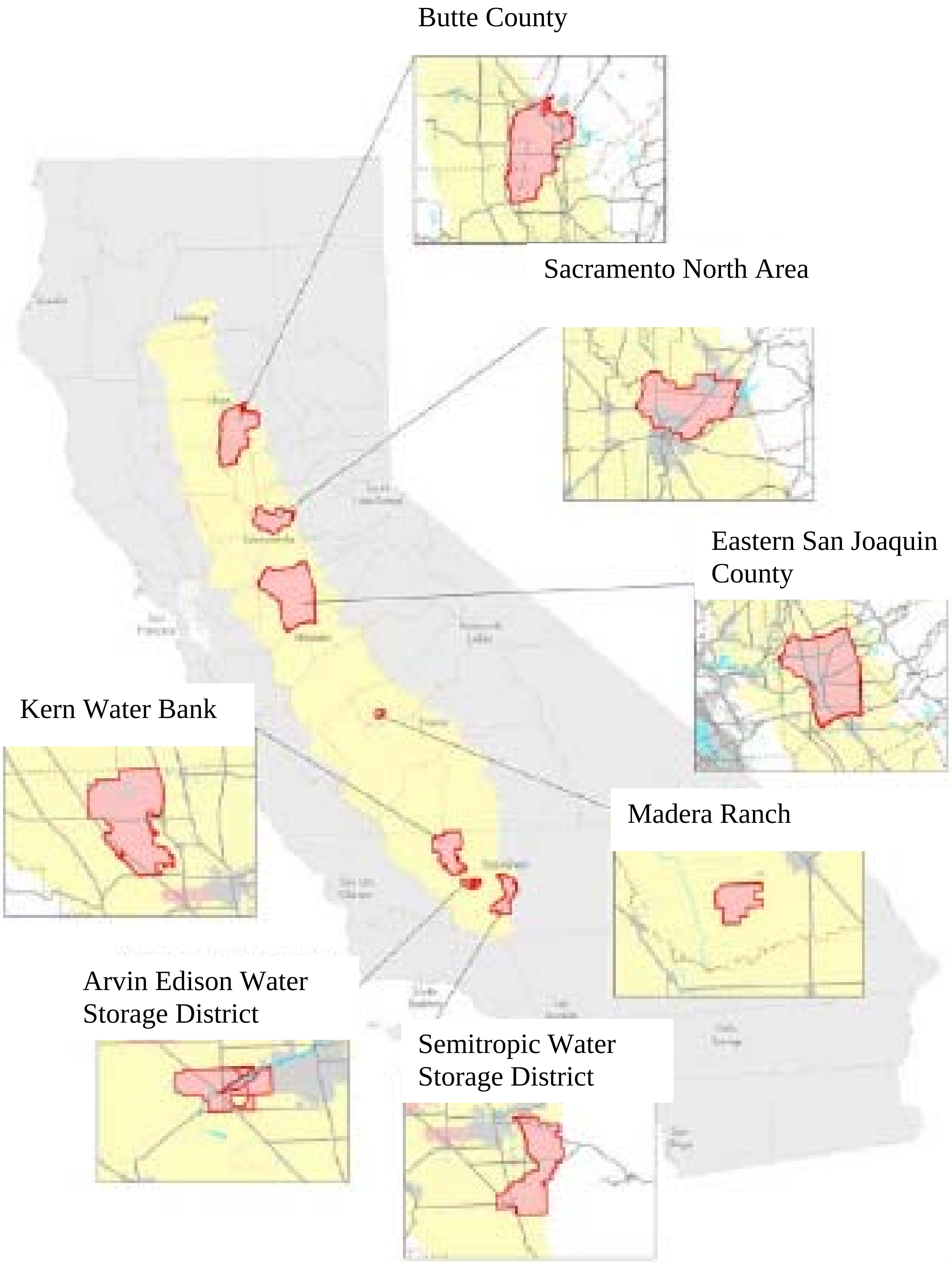


Figure C.1 Central Valley Water Project Conjunctive Use Sites (Purkey et al. 2001)

Location: Sacramento North Area

Current Local Water Demand: 320 TAF/yr; currently met by: (60% SW, 40% SW)

Storage Space for Banked Water: 400-600 TAF (near McClellan Air Force Base)

Project Description: The Water Forum Groundwater Management Element recommended an annual sustainable delivery of 131 TAF for the North Area (based on volume extracted in 1990). To comply with this the Sacramento North Area Groundwater Management Authority (SNAGMA) created the North Area Conjunctive Use Program. The program involves allowing the groundwater table to recharge in wet conditions, either through *in lieu* recharge (delivering surface water to users who would have pumped groundwater in exchange for them not pumping their groundwater and allowing the water table to recharge (Purkey et al. 2001)).

Location: Butte County

Water Use: 90% Agricultural, 10% Urban

Economic Characteristics: The State Drought Water Bank Program paid for itself by purchasing water and then selling it at a higher price.

Project Description: State Drought Water Bank Programs were implemented statewide, including Butte County, by Governor Wilson in 1991, 1992, 1993, and 1994. Water districts in Butte County that had water rights to 375 TAF/yr of Oroville Reservoir surface water were paid to take groundwater instead of surface water. The Department of Water Resources (DWR) acted as the water bank. The surface water was then delivered to users south of the area. The programs implemented between 1991 and 1993 were considered successful by both the recipients of the water, located predominately south of the Delta and the San Francisco Bay Area, as well as the inhabitants of Butte County. Increased stream flows helped maintain fisheries, and much of the funds from the State Water Bank Program were used to build a $9 million siphon project on Butte Creek to increase salmon populations.

However, by 1994 the increased groundwater pumping had noticeable adverse impacts on the water table and local wells. Dissatisfied third parties formed an alliance and considered pressing charges; the estimated legal fees were over $500,000, which was more than the dissatisfied parties were willing to pay, so no charges were pressed. One problem with the program was that the sellers, not DWR, controlled when and where they would pump, and DWR maintained all the liability as determined by the California Environmental Quality Act (CEQA).

The Department of Water Resources then developed a Supplemental Water Purchase Program to have a systematic way to handle future droughts. Initial groundwater substitution production targets were set at 400 TAF, but local opposition reduced the target to 200 TAF and the Supplemental Water Purchase

Program was replaced by the CALFED process. The conjunctive use program in Butte County was never successfully implemented. (Purkey et al. 2001)

Lessons: The agency held accountable for the negative impacts of the program must retain the power to limit pumping. Third party concerns must be addressed. Pumpers should be required to investigate and report any third party impacts.

Location: Eastern San Joaquin County

Current Local Water Demand: 1,231 TAF/yr (90% Agricultural, 10% Urban; 60% met by groundwater, 40% by surface water)

The Problem: Groundwater extractions exceeded recharge for 50 years; and have lowered groundwater levels as low as 75 feet below sea level, or 155 ft below pre-development levels. As a result, saline intrusion is occurring at a rate of approximately 150 lateral feet per year (see Figure C.2).

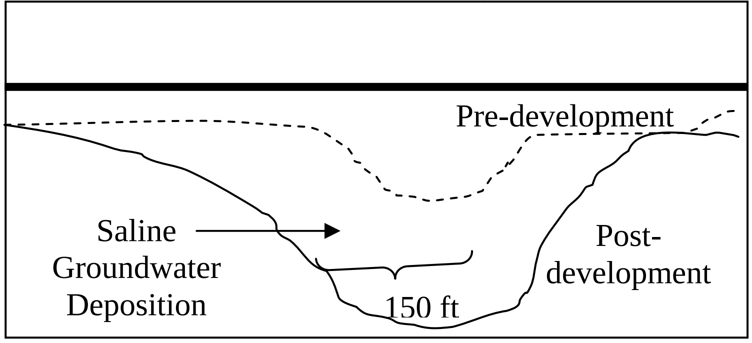


Figure C.2 Illustration of the problem caused by groundwater overdraft in the Eastern San Joaquin County where 150 lateral feet of saline intrusion was occurring each year in 1995

Space created by overdraft: 3,000 TAF

Project Description: Technical studies began in 1995 to assess optimal recharge and extraction volumes, as well as a cost analysis of the most cost effective way to execute the project. The studies recommended recharging 40 TAF in half of all water years and extracting 50 TAF in one out of four water years. A pilot project followed to test aquifer injection/extraction capacity. East Bay Municipal Utilities District (EBMUD) applied to export the extracted water which began two years of institutional controversy. A permit was granted after detailed project information was submitted, three monitoring wells were installed and limits were agreed upon for the amount of water to be exported, as well as extraction times. The permit was granted on the condition that the project maintains or improves the current groundwater conditions, and in 2000 it was decided that i*n lieu* and groundwater injection methods would be used to recharge an average of 7 TAF/yr of water from the Mokelumne River and extract 3.5 TAF/yr from the groundwater basin. Project costs were estimated at $25 million.

Beneficiaries: EBMUD which would use the additional storage and users in the Easter San Joaquin County who would benefit from higher groundwater levels (Purkey et al. 2001).

Lessons: Local groundwater pumpers have many concerns regarding exporting groundwater. Local interests must be assured that third party impacts will be mitigated for a conjunctive use project to succeed.

Location: Madera Ranch

Current Local Water Demand: 95 TAF/yr

Storage Space for Banked Water: 390 TAF

Project Description: The original project proposal was made by the US Bureau of Reclamation to take surplus Central Valley Project (CVP) water from the Delta to the Mendota Pool to recharge wetland ponds above the Madera Groundwater Basin. Then, when the water is needed, it would be extracted from groundwater and pumped back to the Mendota Pool. Significant local resistance prevented this and Matera Ranch was purchased by the Azurix Madera Corporation who intends to create the Groundwater Banking Project. Azurix (an Enron affiliate) later sold this to local interests.

Potential Beneficiaries: In the proposed project, local CVP users would have a more reliable water supply, and the US Bureau of Reclamation would have 100 TAF additional reserves during drought years. (Purkey et al. 2001)

Lessons: Communication between the public, stakeholders, and the water agencies from the outset of the project is important. Local knowledge and concerns must be addressed. In this case, locals wanted to maintain control of the groundwater banking program and were opposed to a federal agency implementing the program. Locals had knowledge about the salinity of the Mendota pool, concerns about the project's potential effects on flows in the San Joaquin River, and concerns about the potential for root zone flooding.

Location: Semitropic Water Storage District

Current Local Water Demand: 480 TAF/yr (primarily agricultural)

Storage Space for Banked Water: 2,000 TAF

Motivation for Groundwater Banking: Increasing groundwater overdraft, energy costs, water costs, and water supply unreliability

Project Description: Initially the project consisted of water exchange in which during wet years the Department of Water Resources (DWR) would deliver more State Water Project Water (SWP) than Semitropic's contractual amount to the area which Semitropic would use *in lieu* of their groundwater resources. In dry years, the Department of Water Resources would get the water they had stored back from Semitropic by not delivering their SWP contractual amount and requiring Semitropic to pump groundwater. This was attempted in 1990 when DWR delivered 92 TAF more than Semitropic's contractual amount and then in 1991 DWR called upon the exchange, but it was such a dry year that Semitropic did not have any SWP contractual rights and so could not return the water in that year. This indicated that for a groundwater banking project to be able to return banked groundwater in dry years in this area, facilities would need to be created to extract the groundwater. Currently Semitropic's Groundwater Banking Program involves the banking partners purchasing a share of the space in the aquifer underlying the district, and paying for a proportion of the facilities constructed to inject and extract the water. (Purkey et al. 2001)

Lessons: The project has benefited everyone involved because the price of water in the area is high enough that those wanting to use the groundwater banking program are willing to pay for a portion of the capital costs to build new faculties to inject and extract the water, as well as to store the water. This had led to increased operational flexibility for the Semitropic Water Storage District, as well as a reduced cost in the water costs to land owners. This project has not shown to have significant environmental impacts because it does not use any rivers or streams, and since no federal funding was received the project did not need to comply with NEPA. Other keys to the success of this project were 1) the land in the area is mainly agricultural land so the landowners had a common interest, 2) stakeholders were kept informed and involved, and 3) the district has maintained control of the project since the beginning.

Location: Arvin Edison Water Storage District

Current Local Water Demand: 160 TAF/yr (primarily agricultural)

Storage Space for Banked Water: 350 TAF

Project Description: Starting in 1966, the storage district has banked 1,500 TAF. In the 1950's average overdraft was 200 TAF/yr, current overdraft is 5-10 TAF/yr. The project consists of exchanging the district's highly variable Central Valley Project (CVP) class 1 priority water from Friant with non-Friant CVP water from the California Aqueduct that is available almost every year. Water in excess of the irrigation demand is deep percolated into the ground using recharge ponds. The Metropolitan Water District entered into an agreement with Arvin Edison Water Storage District for the use of their facilities. A pumpback facility, 500 acres of spreading ponds, 15 new wells and a 4.5 mile pipeline between the Arvin-Edison Canal and the California Aqueduct were built. (Purkey et al. 2001)

Lessons: This project was successful because 1) the groundwater banking helped to mitigate the effects of overdraft, 2)the basin is isolated and has not had effects on surrounding basins or districts, 3) few surrounding landowners have been effected, 4) the landowners all have a common interested in agriculture, 5) the district has maintained control of the project, and 6) Metropolitan Water District (they are using the water) offered enough money to make the project cost free for Arvin Edison Water Storage District and provide them with numerous benefits, and 7) Since the US Bureau of Reclamations was not involved, the project only had to comply with the California Environmental Quality Act (CEQA), not the National Environmental Policy Act (NEPA) which requires a time consuming and expensive Environmental Impact Statement (EIS).

Location: Kern Water Bank

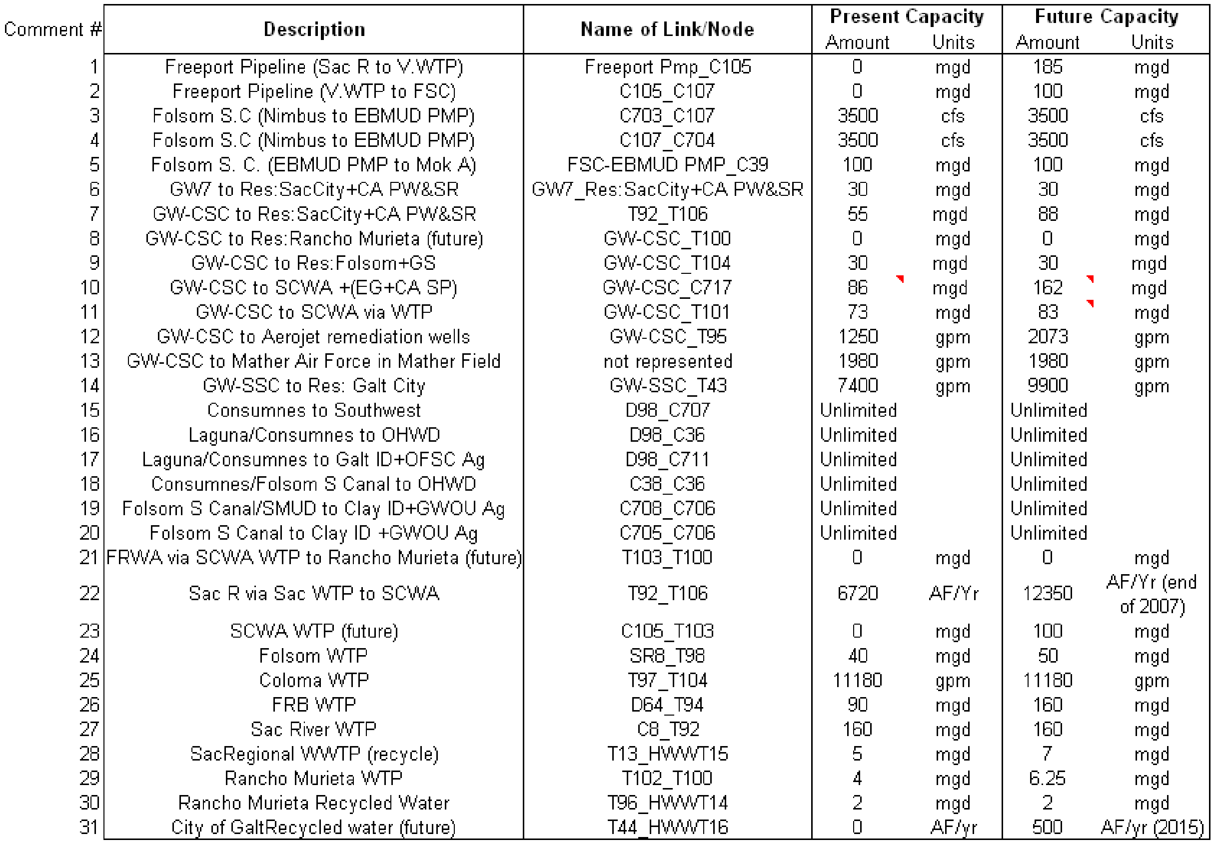
Storage Space for Banked Water: 1,000 TAF

Project Description: The Kern Water Bank property was transferred from DWR to Kern County in exchange for 40 TAF of State Water Project (SWP) entitlements. A water bank was then set up on the Kern Water Bank property capitalizing on the 7,000 acres consisting of sandy soil which can percolate 3 TAF per day. 60 shallow recharge basins were built. Water is recovered by 45 wells and transported using a pipeline that connects the Kern Water Bank and the SWP. (Purkey et al. 2001)

Lessons: The Kern Water Bank has been able to run a profitable and successful water bank because of the soil characteristics of the area, the fact the region is accustomed to conjunctive use and so landowners in the area were eager to cooperate, a monitoring system ensuring that the environment nor any third party suffers significant impacts, and the willingness of third parties outside Kern County to pay $350-$400 per AF of water.

Appendix D: Selected Model Metadata

Table D.1 Present and Future Capacities of Sacramento County Infrastructure



Comment #	Description	Name of Link/Node	Present Capacity		Future Capacity	
			Amount	Units	Amount	Units
1	Freeport Pipeline (Sac R to V.WTP)	Freeport Pmp_C105	0	mgd	185	mgd
2	Freeport Pipeline (V.WTP to FSC)	C105_C107	0	mgd	100	mgd
3	Folsom S.C (Nimbus to EBMUD PMP)	C703_C107	3500	cfs	3500	cfs
4	Folsom S.C (Nimbus to EBMUD PMP)	C107_C704	3500	cfs	3500	cfs
5	Folsom S. C. (EBMUD PMP to Mok A)	FSC-EBMUD PMP_C39	100	mgd	100	mgd
6	GW7 to Res:SacCity+CA PW&SR	GW7_Res:SacCity+CA PW&SR	30	mgd	30	mgd
7	GW-CSC to Res:SacCity+CA PW&SR	T92_T106	55	mgd	88	mgd
8	GW-CSC to Res:Rancho Murieta (future)	GW-CSC_T100	0	mgd	0	mgd
9	GW-CSC to Res:Folsom+GS	GW-CSC_T104	30	mgd	30	mgd
10	GW-CSC to SCWA +(EG+CA SP)	GW-CSC_C717	86	mgd	162	mgd
11	GW-CSC to SCWA via WTP	GW-CSC_T101	73	mgd	83	mgd
12	GW-CSC to Aerojet remediation wells	GW-CSC_T95	1250	gpm	2073	gpm
13	GW-CSC to Mather Air Force in Mather Field	not represented	1980	gpm	1980	gpm
14	GW-SSC to Res: Galt City	GW-SSC_T43	7400	gpm	9900	gpm
15	Consumnes to Southwest	D98_C707	Unlimited		Unlimited	
16	Laguna/Consumnes to OHWD	D98_C36	Unlimited		Unlimited	
17	Laguna/Consumnes to Galt ID+OFSC Ag	D98_C711	Unlimited		Unlimited	
18	Consumnes/Folsom S Canal to OHWD	C38_C36	Unlimited		Unlimited	
19	Folsom S Canal/SMUD to Clay ID+GWOU Ag	C708_C706	Unlimited		Unlimited	
20	Folsom S Canal to Clay ID +GWOU Ag	C705_C706	Unlimited		Unlimited	
21	FRWA via SCWA WTP to Rancho Murieta (future)	T103_T100	0	mgd	0	mgd
22	Sac R via Sac WTP to SCWA	T92_T106	6720	AF/Yr	12350	AF/Yr (end of 2007)
23	SCWA WTP (future)	C105_T103	0	mgd	100	mgd
24	Folsom WTP	SR8_T98	40	mgd	50	mgd
25	Coloma WTP	T97_T104	11180	gpm	11180	gpm
26	FRB WTP	D64_T94	90	mgd	160	mgd
27	Sac River WTP	C8_T92	160	mgd	160	mgd
28	SacRegional WWTP (recycle)	T13_HWWT15	5	mgd	7	mgd
29	Rancho Murieta WTP	T102_T100	4	mgd	6.25	mgd
30	Rancho Murieta Recycled Water	T96_HWWT14	2	mgd	2	mgd
31	City of GaltRecycled water (future)	T44_HWWT16	0	AF/yr	500	AF/yr (2015)

Comment #	**Reference**
1	05/23/07 Meeting with Larry Rodriguez, TNC, EBMUD, SCWA
2	05/23/07 Meeting with Larry Rodriguez, TNC, EBMUD, SCWA
3	Infrastructure capacity: 3,500 cfs Paper Document Central Valley Project Reference Manual 6/1/87 by DWR published by Resource Management International, Inc.
4	Infrastructure capacity: 3,500 cfs Paper Document Central Valley Project Reference Manual 6/1/87 by DWR published by Resource Management International, Inc., reapplied because Freeport Pipeline enters canal and therefore may exceed capacity
5	05/23/07 Meeting with Larry Rodriguez, TNC, EBMUD, SCWA, call with Mark Bluestein 08/16/07 says no plans to expand
6	Present capacity from p5-9 of Urban Water Management Plan for Sacramento (note that Cal-Am does not have wells in GW-7) e-mailed Jim Peifer at the City of Sacramento for 2030 capacity 081607
7	Cal- Am info from Gilfourthson Garcia at Cal-Am through e-mail 06/07, 08/07 (25.5 in Cal-Am Parkway and 27.89 in Rosemont Presently, 48 Rosemont & 40 Parkway future -Compiled in Data Request Responses) 1000gpm pumped in city of Sac as reported by Jim Peifer city engineer in e-mail 081607, in the future will be 0
8	Rancho Murieta IWMP says GW will likely be used in the future but does not state what the planned expansion will be, just that there are currently well fields that could be used. Attempted to contact Ed Crousse, never responded, no info available on website, assume future gw capacity to be 0 since we could not find out otherwise
9	Paul Schubert at Golden State reported in e-mail 07/07 (Compiled in Data Request Responses) Folsom has no GW pumping cap. Centaral Basin GMP - Folsom Reference for other info: Folsom Water Superintendent 355-8336)
10	Gilfourthson Garcia (Cal-Am) & Jean Young (SCWA) (Compiled in Data Request Responses), no written planned expansion by Cal-Am in Parkway the future, Elk Grove info from Scott Meyers (Elk Grove) 081707 (phone conversation)
11	2005 Zone 41 UWMP p2-22 Table 2-13
12	e-mail from Jean Young at SCWA 07/07 (Compiled in Data Request Responses)
13	e-mail from Jean Young at SCWA 07/07 (Compiled in Data Request Responses)
14	UWMP 2005 Update for Galt by BOYLE Table 5-1 Supply and Demand Comparison
15	Unlimited Riparian diversion
16	Unlimited Riparian diversion
17	Unlimited Riparian diversion
18	Unlimited Riparian diversion
19	Unlimited 215 diversion via Folsom S Canal
20	Unlimited 215 diversion via Folsom S Canal
21	Speculative connction - not mentioned on Freeport Pipeline Project Website or in Project Description in Freeport EIR
22	Jean Young from SCWA 07/07 (Compiled in Data Request Responses)
23	2005 Zone 41 UWMP p2-22 Table 2-12
24	05/23/07 Meeting with Larry Rodriguez, TNC, EBMUD, SCWA
25	Phone conversation with Paul Scubert 09/05/07, possible they will expand the treatment plant to treat another 5 TAF/Yr to accommodate the additional demand in the Westburough Area, but speculative
26	http://www.cityofsacramento.org/dsd/projects/65th-transit-village/documents/65ina_water.pdf University Transit Village Infrastructure Needs Assessment City of Sacramento 65th St
27	http://www.cityofsacramento.org/dsd/projects/65th-transit-village/documents/65ina_water.pdf University Transit Village Infrastructure Needs Assessment City of Sacramento 65th St
28	On p 6-13 of the SCWA Zone 40 Water Supply Mast Plan Table 6.3 water gets used by SCWA and maybe City of Sacramento; Projected use in previous CALFED study the capacity was set to a constant 0.56, this seems consistent with the recycling capability before expansion, it was entered by Jenkins and the source says to see Urbdem1.doc,
29	p8-9 Rancho Murieta Integrated Water Master Plan Nov 2006 by HDR
30	p15 IWMP for Rancho Murieta, assume no expansion since do not have information to indicate otherwise
31	05/23/07 Meeting with Larry Rodriguez, TNC, EBMUD, SCWA, and stated on p2-5 Galt UWMP

Table D.2 Sac CALVIN River Reaches with Environmental Flow Constraints

Comment #	River	CALVIN Links	Location	Data Source	Flow Values (cfs)		
					Min	Max	Avg
1	Feather	D37-D43	Above confluence with Sac R	CALSIM II OCAP 4a	756	1857	1237
2	American	D9-D85	Below Folsom South Canal diversion	CALSIM II OCAP 4a	188	3100	1695
3	American	D64-C8	Above confluence with Sac R	CALSIM II OCAP 4a	188	517	319
4	Cosumnes	C37-C38	Below Rancho Murieta diversion	Rancho Murieta IWMP	0	70	53
5	East Side Streams	D98-D517	Below Cosumnes R, Dry Creek, and Mokelumne confluence	CALSIM II OCAP 4a	0	467	118
6	Delta Outflow	C715-C712	Below East Side Streams (ESS) and Sacramento River (SR)confluence	CALSIM II OCAP 4a	0	33830	13018

Comment #

1 CALSIM OCAP 4A minimum instream flow (MIF) requirement below node 223

2 CALSIM OCAP 4A MIF

3 CALSIM OCAP 4A MIF

4 Minimum instream flow requirement to prevent Rancho Murieta from diverting from the Cosumnes River if flows are less than 70 cfs. The timeseries reflects a combination of this limit or, if natural Consumnes R inflow is below the limit (Source_C37), then the natural flow is the lower bound to prevent infeasabiliites.

5 Taken from CALSIM II OCAP 4a, and adjusted (lowered) in a few months (total of about 3 TAF reduced/yr on average) when this MIF is higher than actual ESS outflow.

6 CALSIM II OCAP 4A, representing the minimum required SR+ESS outflow to delta to meet required delta outflow, exports, in-delta deliveries and in-delta consumptive use after accounting for San Joaquin River and in-delta precipitation contributions.

Table D.3 Cost Summary Table ($/AF in 2008 prices)

CALVIN Demand Node	Water Source	CALVIN Link	Treatment	Local Distribution	Pumping	Pumping O&M	Wheeling	Total
Res: NE Sac Placer	N&M Forks American R[1]	HUSD17_T107	21.4	44.4				65.8
	Folsom Reservoir[2]	C716_T107	21.4	44.4				65.8
	GW-7[3]	GW-7_T107			51			51
	Lower American R[4]	D64A_T107	29.6	59.2				88.8
Res: SCWA + Cal-Am Security Park	Sac R via Sac City R WTP[5]	C8_T92 & T92_T106	44.4	59.2			38	141.6
	Sac R via Freeport Pipeline & Vine WTP[6]	C105_T103	44.4	59.2				103.6+FRPT (12 to 24)
	Recycled Water[7]	T13_HWWT15						400.8
	Lower American R via Fairbairn WTP[8]	T94_T106 &D64a_T94	29.6	59.2			38	126.8
	GW-CSC (Untreated)[9]	C717_T106			41			41
	GW-CSC (Treated)[10]	C717_T101	15		41			56
Res: Rancho Murieta	Cosumnes R[11]	SR-RM_T102	21.4	44.4				65.8
	Recycled Water[12]	T96_HWWT14						400.8
	GW-CSC[13]	GW-CSC_T100			18			18
Res: Folsom + Golden State	GW-CSC[14]	GW-CSC_T104						65.55
	Folsom Reservoir via Folsom WTP[15]	T98_T104	21.4	44.4				65.8
	American R via Folsom South Canal and Coloma WTP[16]	T97_T104	9.92+11.5 =21.4	43.5	13			77.90
Res: City of Sac +Cal-Am Parkway + Cal-Am Suburban Rosemont	Sac R via Sac City WTP[17]	C8_T92	44.4	59.2				103.6
	Recycled Water[18]	T13_HWWT15						400.8
	Lower American R via Fairbairn WTP[19]	D64a_T94	29.6	59.2				88.8
	GW-CSC[20]	GW-CSC_T93						51
	GW-7[21]	GW-7_T93			28			28
Res: City of Galt	Recycled Water[22]	T44_HWWT16						400.8
	GW-SSC[23]	GW-SSC_T43			45			45
Ag: Southwest	GW-CSC[24]	GW-CSC_C707			28			28
Ag: OHWD	GW-CSC[25]	GW-CSC_C36			31			31
Ag: Galt ID + Other Folsom South Canal Users	GW-SSC[26]	GW-SSC_C711			42			42

CALVIN Demand Node	Water Source	CALVIN Link	Treatment	Local Distribution	Pumping	Pumping O&M	Wheeling	Total
Ag: Clay ID + Other Ground Water Only Users in the South Basin	GW-SSC[27]	GW-SSC_C706			45			45
Aerojet remediation water	GW-CSC remediated[28]	GW-CSC_T95	200		29			229

[1] Taken to be the same as Folsom Lake; it was assumed that treatment costs would be similar to those experienced by Golden State, these were reported by Paul Schubert, General Manager at Golden State reported in an e-mail 04/08. Local distribution costs were taken from CALVIN Appendix G p G-9 Table G-5, which were multiplied by 1.48 to convert from 1995 prices to 2008 prices.

[2] It was assumed that treatment costs would be similar to those experienced by Golden State, these were reported by Paul Schubert, General Manager at Golden State reported in an e-mail 04/08. Local distribution costs were taken from CALVIN Appendix G p G-9 Table G-5, which were multiplied by 1.48 to convert from 1995 prices to 2008 prices.

[3] See Groundwater Pumping Cost Table

[4] CALVIN Appendix G p G-9 Table G-6 multiplied by 1.48 to convert from 1995 prices to 2008 prices

[5] Wheeling Cost reported by Jean Young from SCWA in the Data Request Response 05/07 and Appendix G CALVIN SW Operating Costs pG-5 (Lower American and Sac Rivers) multiplied by 1.48 to convert from 1995 prices to 2008 prices

[6] Appendix G CALVIN SW Operating Costs pG-5 (Lower American and Sac Rivers) multiplied by 1.48 to convert from 1995 prices to 2008 prices

[7] This value is the difference between the cost of treating to recycle the water ($2520 mg, which converts to $821.15/KAF) and the cost of treating to secondary effluent conditions ($1290 per mg which converts to $420.35/KAF), this information came from Sacramento Regional WWTP in an e-mail from Steve Nebozuk on 01/17/08, I was put in touch with him by Bob Seyfried 120607, Senior Civil Engineer, SRCSD SRWTP 2020 Master Plan Project Manager 916-876-6068 seyfriedr@saccounty.net (350 was the value from the previous CALFED Study)

[8] Wheeling Cost reported by Jean Young from SCWA in the Data Request Response 05/07

[9] See Groundwater Pumping Cost Table

[10] See Groundwater Pumping Cost Table, additional treatment cost of $15 from CALVIN Appendix G

[11] Taken to be the same as Folsom Lake water which requires minimal treatment; it was assumed that treatment costs would be similar to those experienced by Golden State, these were reported by Paul Schubert, General Manager at Golden State reported in an e-mail 04/08. Local distribution costs were taken from CALVIN Appendix G p G-9 Table G-5, which were multiplied by 1.48 to convert from 1995 prices to 2008 prices. Ed Crouse, the General Manager at Rancho Murieta (916)354-3700, was contacted several times in an attempt to get better information, but he did not return any calls

[12] Rancho Murieta Recycled water cost taken to be the same as that for Sac Regional WWTP. This value is the difference between the cost of treating to recycle the water ($2520 mg, which converts to $821.15/KAF) and the cost of treating to secondary effluent conditions ($1290 per mg which converts to $420.35/KAF), this information came from Sacramento Regional WWTP in an e-mail from Steve Nebozuk on 01/17/08, I was put in touch with him by Bob Seyfried 120607, Senior Civil Engineer, SRCSD SRWTP 2020 Master Plan Project Manager 916-876-6068 seyfriedr@saccounty.net (350 was the value from the previous CALFED Study)

[13] See Groundwater Pumping Cost Table

[14] The total cost was reported by Paul Schubert (District Manager of Northern Golden State Water Company) in an e-mail on July 6, 2007 as the power, chemical and direct labor cost for pumping groundwater, the pumping cost was calculated the same as the other groundwater pumping cost and is reported in the Groundwater Pumping Cost Table

[15] It was assumed that treatment costs would be similar to those experienced by Golden State, these were reported by Paul Schubert, General Manager at Golden State reported in an e-mail 04/08. Local distribution costs were taken from CALVIN Appendix G p G-9 Table G-5, which were multiplied by 1.48 to convert from 1995 prices to 2008 prices.

[16] Paul Schubert, General Manager at Golden State reported in an e-mail 04/08

[17] CALVIN Appendix G p G-9 Table G-5 multiplied by 1.48 to convert from 1995 prices to 2008 prices

[18] This value is the difference between the cost of treating to recycle the water ($2520 mg, which converts to $821.15/KAF) and the cost of treating to secondary effluent conditions ($1290 per mg which converts to $420.35/KAF), this information came from Sacramento Regional WWTP in an e-mail from Steve Nebozuk on 01/17/08, I was put in touch with him by Bob Seyfried 120607, Senior Civil Engineer, SRCSD SRWTP 2020 Master Plan Project Manager 916-876-6068 seyfriedr@saccounty.net (350 was the value from the previous CALFED Study)

[19] CALVIN Appendix G p G-9 Table G-6 multiplied by 1.48 to convert from 1995 prices to 2008 prices

[20] The total cost is an average weighted by the relative pumping of the two regions comprising the area (Jim Peifer, Engineer for the City of Sacramento who reported in a phone conversation with Rachael Hersh-Burdick 04/10/07 that the City of Sacramento operates two wells in the Central GW Basin area. He reported that one is $121 per mg, the other $129 per mg which means the average is $125 per mg but those values are just power costs and do not include operations and maintenance. He says standard procedure is to at 10% to the variable cost for operation and maintenance (this comes to $131/mgd or $45/AF) but he also reported that the future capacity of those wells in the Central GW Basin is predicted to be 0 mgd, this differs from what was modeled in the SacIGSM model, but estimates for 2030 pumping from each region were taken from the SacIGSM model as modeled by WRIME for consistency. Gilfourthson Garcia, Planning Engineer for Cal-Am reported 04/07 that the pumping costs for Cal-Am Parkway and Cal-Am Security Park are $0.192/ccf and the predicted 2030 pumping capacity will be 48mgd for Suburban Parkway and 40 mgd for Suburban Rosemont). The 22 for groundwater pumping was calculated the same as the other groundwater pumping costs and is reported in the Groundwater Pumping Cost Table, the difference between the reported and calculated values was assigned to pumping O&M

[21] See Groundwater Pumping Cost Table

[22] City of Galt recycled water cost taken to be the same as that for Sac Regional WWTP. This value is the difference between the cost of treating to recycle the water ($2520 mg, which converts to $821.15/KAF) and the cost of treating to secondary effluent conditions ($1290 per mg which converts to $420.35/KAF), this information came from Sacramento Regional WWTP in an e-mail from Steve Nebozuk on 01/17/08, I was put in touch with him by Bob Seyfried 120607, Senior Civil Engineer, SRCSD SRWTP 2020 Master Plan Project Manager 916-876-6068 seyfriedr@saccounty.net (350 was the value from the previous CALFED Study)

[23] See Groundwater Pumping Cost Table

[24] See Groundwater Pumping Cost Table; consistent with Larry Rodriguez at Robertson-Bryan Consulting who said that the average pumping cost per AF varies from $20-$25 for the power cost alone

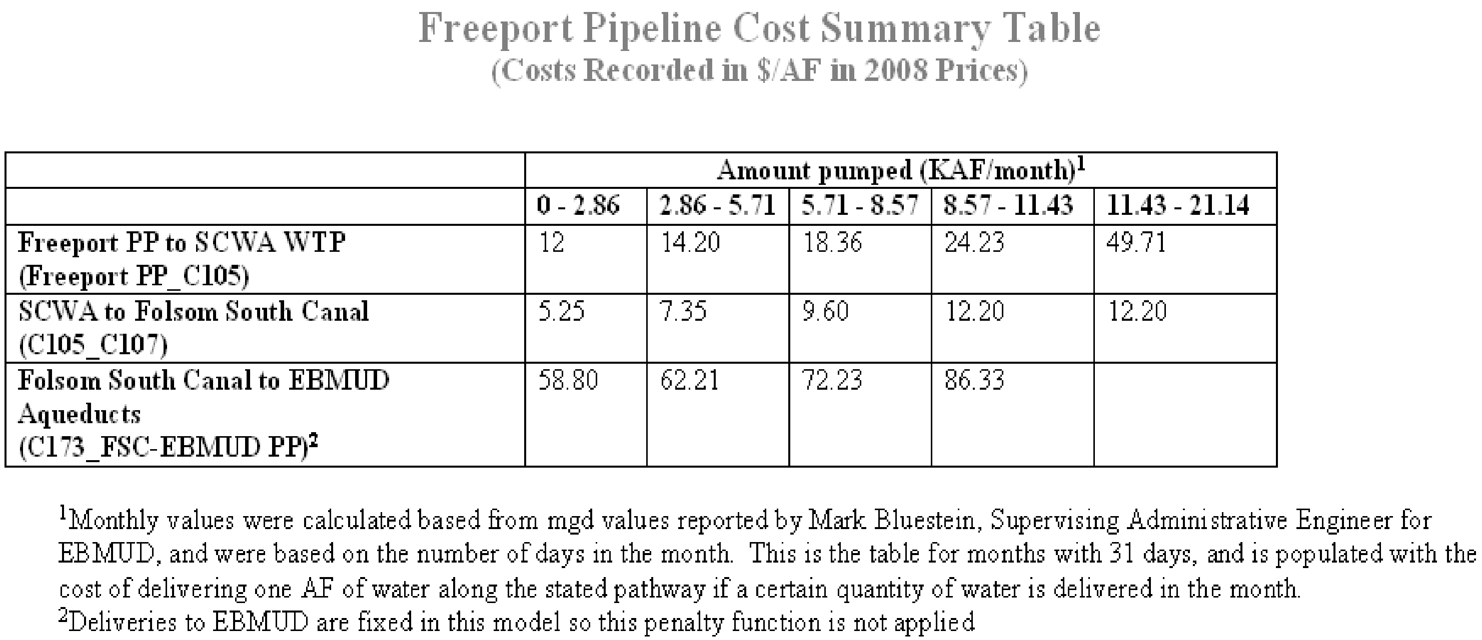
[25] See Groundwater Pumping Cost Table; consistent with Larry Rodriguez at Robertson-Bryan Consulting who said that the average pumping cost per AF varies from $20-$25 for the power cost alone

[26] See Groundwater Pumping Cost Table; consistent with Larry Rodriguez at Robertson-Bryan Consulting who said that the average pumping cost per AF varies from $20-$25 for the power cost alone

[27] See Groundwater Pumping Cost Table; consistent with Larry Rodriguez at Robertson-Bryan Consulting who said that the average pumping cost per AF varies from $20-$25 for the power cost alone

[28] See Groundwater Pumping Cost Table; MJ 3/3/08 $200 for treatment (very rough guess) since this is a super fund site and water is being treated at high level to remove hazardous chemicals/toxics·

Table D.4 Freeport Pipeline Cost Summary Table ($/AF 2008 Prices)



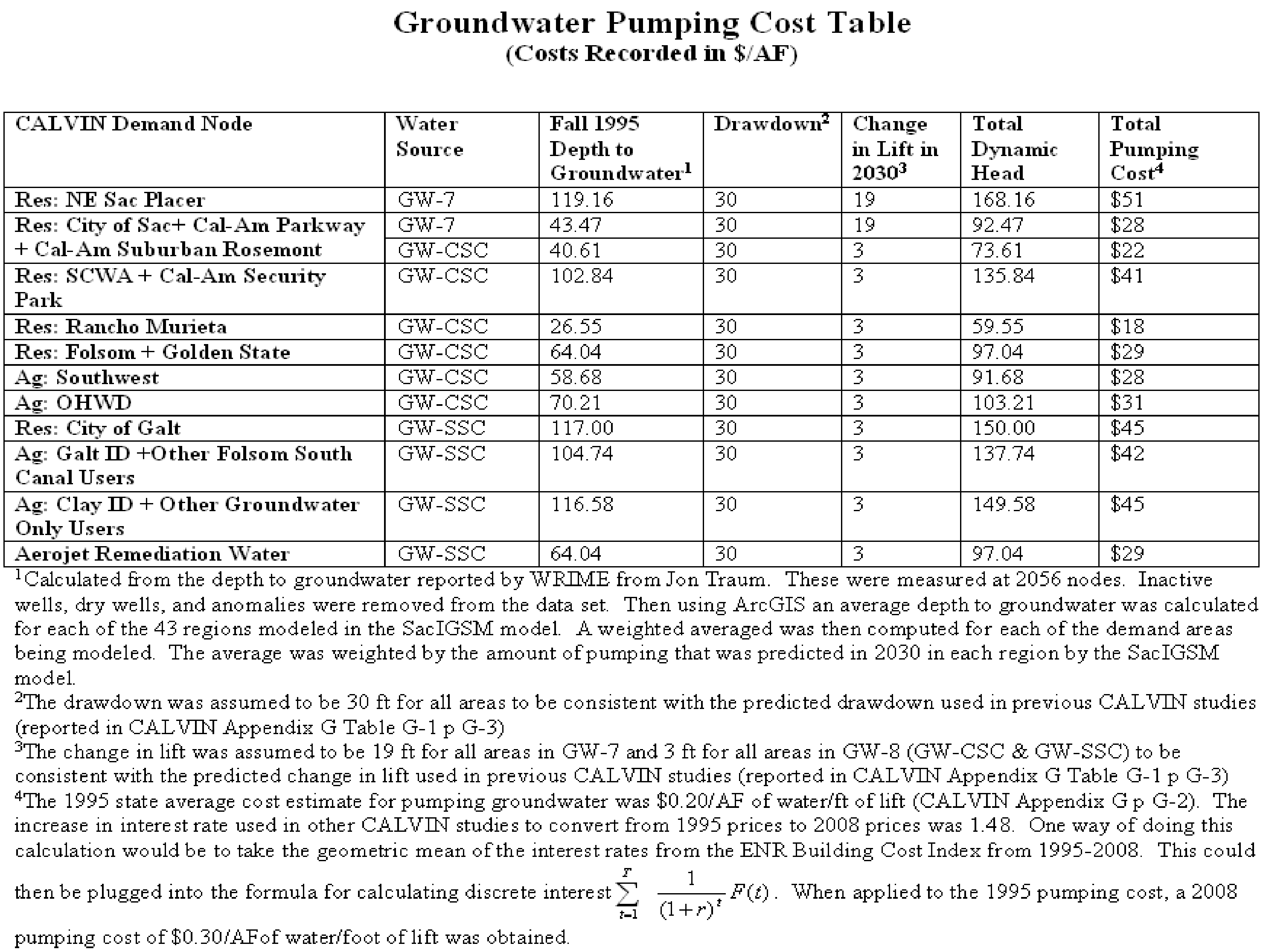
Freeport Pipeline Cost Summary Table
(Costs Recorded in $/AF in 2008 Prices)

	Amount pumped (KAF/month)[1]				
	0 - 2.86	**2.86 - 5.71**	**5.71 - 8.57**	**8.57 - 11.43**	**11.43 - 21.14**
Freeport PP to SCWA WTP (Freeport PP_C105)	12	14.20	18.36	24.23	49.71
SCWA to Folsom South Canal (C105_C107)	5.25	7.35	9.60	12.20	12.20
Folsom South Canal to EBMUD Aqueducts (C173_FSC-EBMUD PP)[2]	58.80	62.21	72.23	86.33	

[1] Monthly values were calculated based from mgd values reported by Mark Bluestein, Supervising Administrative Engineer for EBMUD, and were based on the number of days in the month. This is the table for months with 31 days, and is populated with the cost of delivering one AF of water along the stated pathway if a certain quantity of water is delivered in the month.

[2] Deliveries to EBMUD are fixed in this model so this penalty function is not applied

Table D.5 Groundwater Pumping Cost Summary Table ($/AF 2008 Prices)



Groundwater Pumping Cost Table
(Costs Recorded in $/AF)

CALVIN Demand Node	Water Source	Fall 1995 Depth to Groundwater[1]	Drawdown[2]	Change in Lift in 2030[3]	Total Dynamic Head	Total Pumping Cost[4]
Res: NE Sac Placer	GW-7	119.16	30	19	168.16	$51
Res: City of Sac+ Cal-Am Parkway + Cal-Am Suburban Rosemont	GW-7	43.47	30	19	92.47	$28
	GW-CSC	40.61	30	3	73.61	$22
Res: SCWA + Cal-Am Security Park	GW-CSC	102.84	30	3	135.84	$41
Res: Rancho Murieta	GW-CSC	26.55	30	3	59.55	$18
Res: Folsom + Golden State	GW-CSC	64.04	30	3	97.04	$29
Ag: Southwest	GW-CSC	58.68	30	3	91.68	$28
Ag: OHWD	GW-CSC	70.21	30	3	103.21	$31
Res: City of Galt	GW-SSC	117.00	30	3	150.00	$45
Ag: Galt ID +Other Folsom South Canal Users	GW-SSC	104.74	30	3	137.74	$42
Ag: Clay ID + Other Groundwater Only Users	GW-SSC	116.58	30	3	149.58	$45
Aerojet Remediation Water	GW-SSC	64.04	30	3	97.04	$29

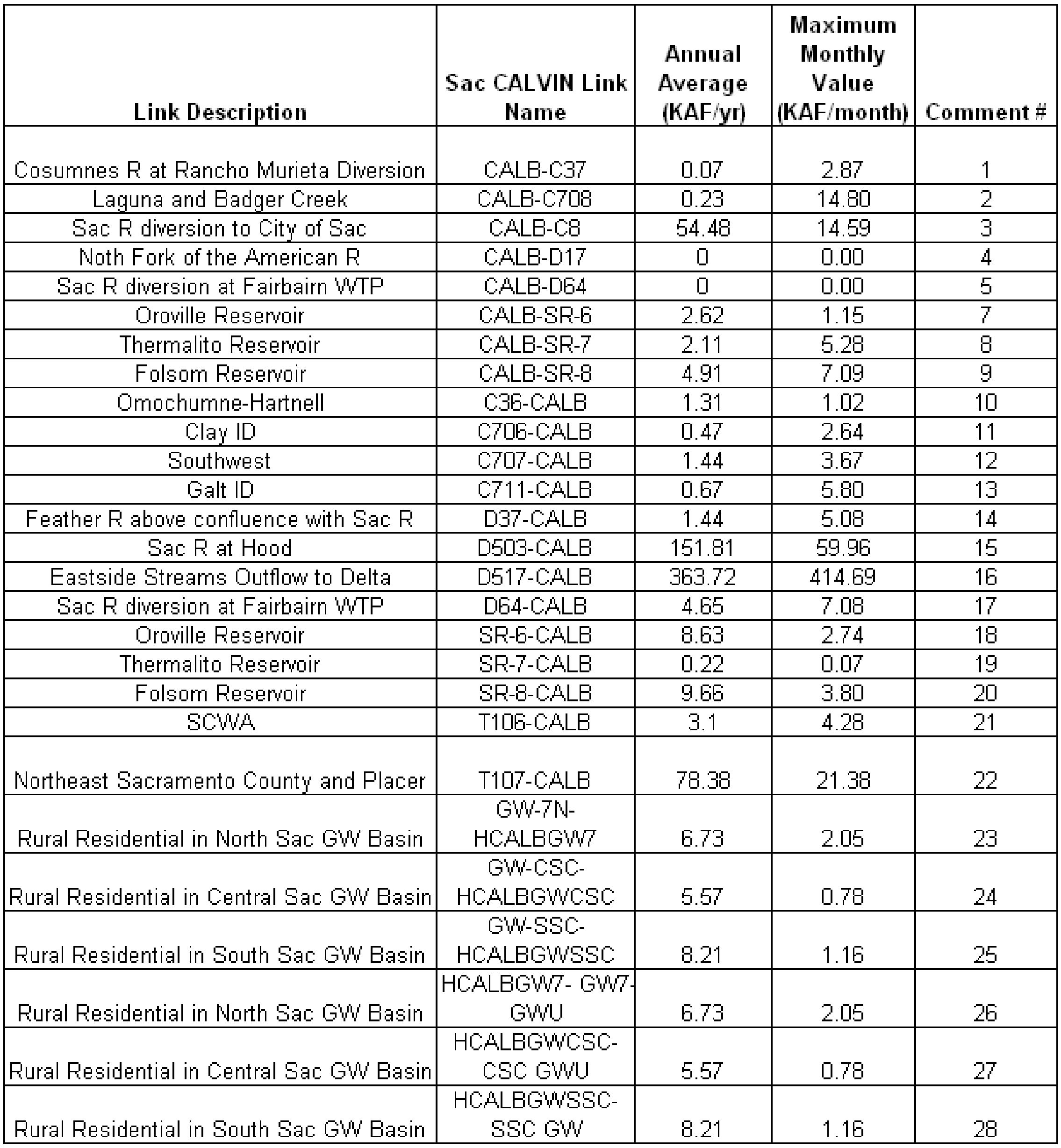
[1] Calculated from the depth to groundwater reported by WRIME from Jon Traum. These were measured at 2056 nodes. Inactive wells, dry wells, and anomalies were removed from the data set. Then using ArcGIS an average depth to groundwater was calculated for each of the 43 regions modeled in the SacIGSM model. A weighted averaged was then computed for each of the demand areas being modeled. The average was weighted by the amount of pumping that was predicted in 2030 in each region by the SacIGSM model.

[2] The drawdown was assumed to be 30 ft for all areas to be consistent with the predicted drawdown used in previous CALVIN studies (reported in CALVIN Appendix G Table G-1 p G-3)

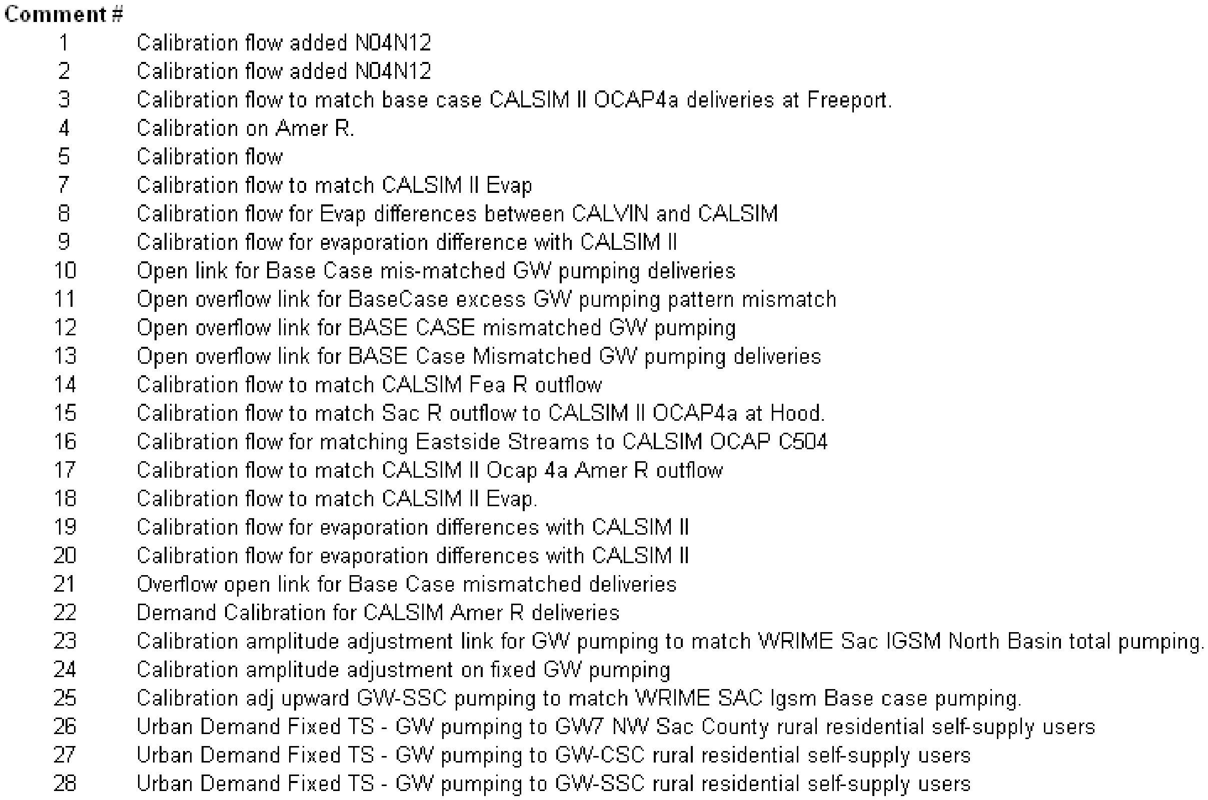
[3] The change in lift was assumed to be 19 ft for all areas in GW-7 and 3 ft for all areas in GW-8 (GW-CSC & GW-SSC) to be consistent with the predicted change in lift used in previous CALVIN studies (reported in CALVIN Appendix G Table G-1 p G-3)

[4] The 1995 state average cost estimate for pumping groundwater was $0.20/AF of water/ft of lift (CALVIN Appendix G p G-2). The increase in interest rate used in other CALVIN studies to convert from 1995 prices to 2008 prices was 1.48. One way of doing this calculation would be to take the geometric mean of the interest rates from the ENR Building Cost Index from 1995-2008. This could then be plugged into the formula for calculating discrete interest $\sum_{t=1}^{T} \frac{1}{(1+r)^t} F(t)$. When applied to the 1995 pumping cost, a 2008 pumping cost of $0.30/AFof water/foot of lift was obtained.

Table D.6 Calibration Flows



Link Description	Sac CALVIN Link Name	Annual Average (KAF/yr)	Maximum Monthly Value (KAF/month)	Comment #
Cosumnes R at Rancho Murieta Diversion	CALB-C37	0.07	2.87	1
Laguna and Badger Creek	CALB-C708	0.23	14.80	2
Sac R diversion to City of Sac	CALB-C8	54.48	14.59	3
Noth Fork of the American R	CALB-D17	0	0.00	4
Sac R diversion at Fairbairn WTP	CALB-D64	0	0.00	5
Oroville Reservoir	CALB-SR-6	2.62	1.15	7
Thermalito Reservoir	CALB-SR-7	2.11	5.28	8
Folsom Reservoir	CALB-SR-8	4.91	7.09	9
Omochumne-Hartnell	C36-CALB	1.31	1.02	10
Clay ID	C706-CALB	0.47	2.64	11
Southwest	C707-CALB	1.44	3.67	12
Galt ID	C711-CALB	0.67	5.80	13
Feather R above confluence with Sac R	D37-CALB	1.44	5.08	14
Sac R at Hood	D503-CALB	151.81	59.96	15
Eastside Streams Outflow to Delta	D517-CALB	363.72	414.69	16
Sac R diversion at Fairbairn WTP	D64-CALB	4.65	7.08	17
Oroville Reservoir	SR-6-CALB	8.63	2.74	18
Thermalito Reservoir	SR-7-CALB	0.22	0.07	19
Folsom Reservoir	SR-8-CALB	9.66	3.80	20
SCWA	T106-CALB	3.1	4.28	21
Northeast Sacramento County and Placer	T107-CALB	78.38	21.38	22
Rural Residential in North Sac GW Basin	GW-7N-HCALBGW7	6.73	2.05	23
Rural Residential in Central Sac GW Basin	GW-CSC-HCALBGWCSC	5.57	0.78	24
Rural Residential in South Sac GW Basin	GW-SSC-HCALBGWSSC	8.21	1.16	25
Rural Residential in North Sac GW Basin	HCALBGW7- GW7-GWU	6.73	2.05	26
Rural Residential in Central Sac GW Basin	HCALBGWCSC-CSC GWU	5.57	0.78	27
Rural Residential in South Sac GW Basin	HCALBGWSSC-SSC GW	8.21	1.16	28



Comment #	
1	Calibration flow added N04N12
2	Calibration flow added N04N12
3	Calibration flow to match base case CALSIM II OCAP4a deliveries at Freeport.
4	Calibration on Amer R.
5	Calibration flow
7	Calibration flow to match CALSIM II Evap
8	Calibration flow for Evap differences between CALVIN and CALSIM
9	Calibration flow for evaporation difference with CALSIM II
10	Open link for Base Case mis-matched GW pumping deliveries
11	Open overflow link for BaseCase excess GW pumping pattern mismatch
12	Open overflow link for BASE CASE mismatched GW pumping
13	Open overflow link for BASE Case Mismatched GW pumping deliveries
14	Calibration flow to match CALSIM Fea R outflow
15	Calibration flow to match Sac R outflow to CALSIM II OCAP4a at Hood.
16	Calibration flow for matching Eastside Streams to CALSIM OCAP C504
17	Calibration flow to match CALSIM II Ocap 4a Amer R outflow
18	Calibration flow to match CALSIM II Evap.
19	Calibration flow for evaporation differences with CALSIM II
20	Calibration flow for evaporation differences with CALSIM II
21	Overflow open link for Base Case mismatched deliveries
22	Demand Calibration for CALSIM Amer R deliveries
23	Calibration amplitude adjustment link for GW pumping to match WRIME Sac IGSM North Basin total pumping.
24	Calibration amplitude adjustment on fixed GW pumping
25	Calibration adj upward GW-SSC pumping to match WRIME SAC Igsm Base case pumping.
26	Urban Demand Fixed TS - GW pumping to GW7 NW Sac County rural residential self-supply users
27	Urban Demand Fixed TS - GW pumping to GW-CSC rural residential self-supply users
28	Urban Demand Fixed TS - GW pumping to GW-SSC rural residential self-supply users

Table D.7 Calculating Groundwater Levels Needed to Restore Groundwater Baseflows

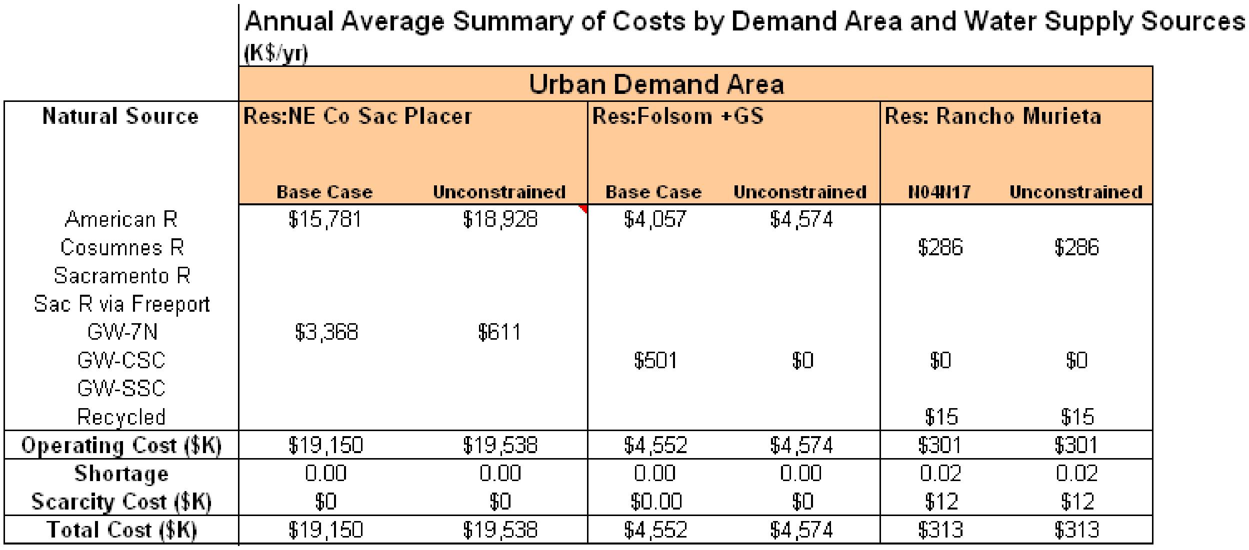
	Central	South
Sept 1995 level in refined SacIGSM	24,604 TAF	8,762 TAF
Ann. avg change in storage in refined (15 yr period)	-29 TAF/yr	-11 TAF/yr
Additional Ann Recharge needed to Restore Connectivity below McConnell Gage (15 yr period) (Fleckenstein 2004)	+184.59 TAF/yr	+65.12 TAF/yr
Total Storage Needed to Restore Connectivity	26,935 TAF	9,575.2 TAF

Table D.8 Putting Groundwater Levels Needed to Restore Groundwater Baseflow in Perspective

	Central	**South**
Total Storage Needed to Restore Connectivity	26,935 TAF	9,575.2 TAF
Starting Storage Sept 1921	25,021 TAF	8,801 TAF
SacIGSM Ending Storage Sept 1993	24,647 TAF	8,467 TAF
Total Storage	30,109 TAF	10,620 TAF

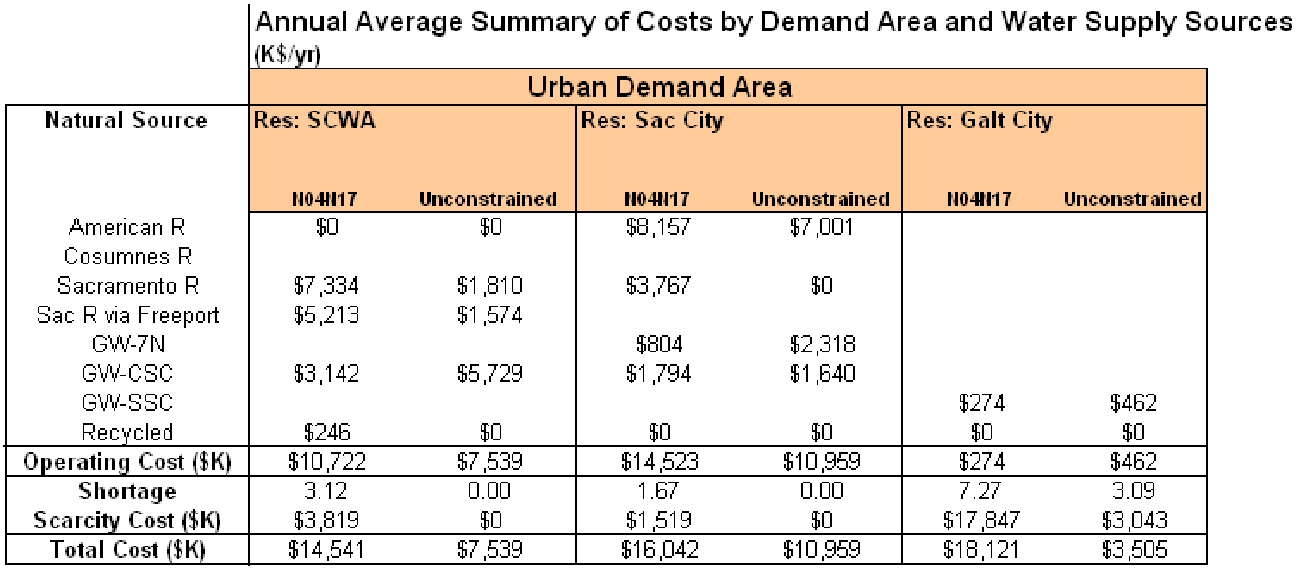
Appendix E: More Results

Table E.1 Annual Average Summary of Costs by Demand Area and Water Supply Source (Base Case vs Unconstrained Case)



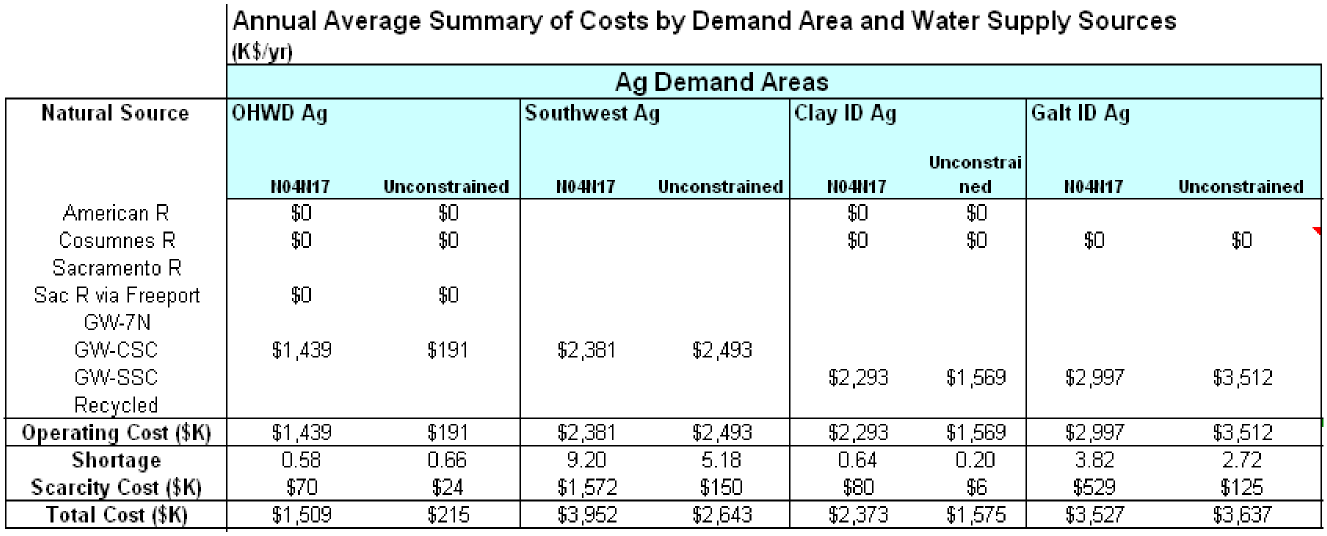
Annual Average Summary of Costs by Demand Area and Water Supply Sources (K$/yr)

Natural Source	Urban Demand Area					
	Res:NE Co Sac Placer		Res:Folsom +GS		Res: Rancho Murieta	
	Base Case	Unconstrained	Base Case	Unconstrained	N04N17	Unconstrained
American R	$15,781	$18,928	$4,057	$4,574		
Cosumnes R					$286	$286
Sacramento R						
Sac R via Freeport						
GW-7N	$3,368	$611				
GW-CSC			$501	$0	$0	$0
GW-SSC						
Recycled					$15	$15
Operating Cost ($K)	$19,150	$19,538	$4,552	$4,574	$301	$301
Shortage	0.00	0.00	0.00	0.00	0.02	0.02
Scarcity Cost ($K)	$0	$0	$0.00	$0	$12	$12
Total Cost ($K)	$19,150	$19,538	$4,552	$4,574	$313	$313



Annual Average Summary of Costs by Demand Area and Water Supply Sources (K$/yr)

Natural Source	Urban Demand Area					
	Res: SCWA		Res: Sac City		Res: Galt City	
	N04N17	Unconstrained	N04N17	Unconstrained	N04N17	Unconstrained
American R	$0	$0	$8,157	$7,001		
Cosumnes R						
Sacramento R	$7,334	$1,810	$3,767	$0		
Sac R via Freeport	$5,213	$1,574				
GW-7N			$804	$2,318		
GW-CSC	$3,142	$5,729	$1,794	$1,640		
GW-SSC					$274	$462
Recycled	$246	$0	$0	$0	$0	$0
Operating Cost ($K)	$10,722	$7,539	$14,523	$10,959	$274	$462
Shortage	3.12	0.00	1.67	0.00	7.27	3.09
Scarcity Cost ($K)	$3,819	$0	$1,519	$0	$17,847	$3,043
Total Cost ($K)	$14,541	$7,539	$16,042	$10,959	$18,121	$3,505



Annual Average Summary of Costs by Demand Area and Water Supply Sources
(K$/yr)

Natural Source	Ag Demand Areas							
	OHWD Ag		Southwest Ag		Clay ID Ag		Galt ID Ag	
	N04N17	Unconstrained	N04N17	Unconstrained	N04N17	Unconstrained	N04N17	Unconstrained
American R	$0	$0			$0	$0		
Cosumnes R	$0	$0			$0	$0	$0	$0
Sacramento R								
Sac R via Freeport	$0	$0						
GW-7N								
GW-CSC	$1,439	$191	$2,381	$2,493				
GW-SSC					$2,293	$1,569	$2,997	$3,512
Recycled								
Operating Cost ($K)	$1,439	$191	$2,381	$2,493	$2,293	$1,569	$2,997	$3,512
Shortage	0.58	0.66	9.20	5.18	0.64	0.20	3.82	2.72
Scarcity Cost ($K)	$70	$24	$1,572	$150	$80	$6	$529	$125
Total Cost ($K)	$1,509	$215	$3,952	$2,643	$2,373	$1,575	$3,527	$3,637

Table E.2 Cost Summary by Demand Area for all Scenarios

Natural Source	Urban Demand Area											
	Res:NE Co Sac Placer				Res:Folsom +GS				Res: Rancho Murieta			
	Base Case	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity
American R	$15,781	$18,928	$18,928	$18,928	$4,057	$4,574	$4,574	$4,574				
Cosumnes R									$286	$286	$286	$286
Sacramento R												
Sac R via Freeport												
GW-7N	$3,368	$611	$611	$611								
GW-CSC					$501	$0	$0	$0	$0	$0	$0	$0
GW-SSC												
Recycled									$15	$15	$15	$15
Operating Cost ($K)	$19,150	$19,538	$19,538	$19,538	$4,552	$4,574	$4,574	$4,574	$301	$301	$301	$301
Shortage	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.02	0.02	0.02	0.02
Scarcity Cost ($K)	$0	$0	$0	$0	$0	$0	$0	$0	$12	$12	$12	$12
Total Cost ($K)	$19,150	$19,538	$19,538	$19,538	$4,552	$4,574	$4,574	$4,574	$313	$313	$313	$313

Natural Source	Urban Demand Area												Ag Demand Areas			
	Res: SCWA				Res: Sac City				Res: Galt City				OHWD Ag			
	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity
American R	$0	$0	$0	$0	$8,157	$7,001	$7,459	$8,908					$0	$0	$0	$0
Cosumnes R													$0	$0	$0	$0
Sacramento R	$7,334	$1,810	$1,812	$1,919	$3,767	$0	$0	$602								
Sac R via Freeport	$5,213	$1,574	$1,576	$1,076									$0	$0	$0	$0
GW-7N					$804	$2,318	$2,318	$2,318								
GW-CSC	$3,142	$5,729	$5,729	$5,729	$1,794	$1,640	$1,377	$248					$1,439	$191	$191	$148
GW-SSC									$274	$462	$462	$462				
Recycled	$246	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0				
Operating Cost ($K)	$10,722	$7,539	$7,541	$7,648	$14,523	$10,959	$11,154	$12,077	$274	$462	$462	$462	$1,439	$191	$191	$148
Shortage	3.12	0.00	0.00	0.00	1.67	0.00	0.00	0.00	7.27	3.09	3.09	3.09	0.58	0.66	0.67	3.93
Scarcity Cost ($K)	$3,819	$0	$0	$0	$1,519	$0	$0	$0	$17,847	$3,043	$3,043	$3,043	$70	$41	$41	$256
Total Cost ($K)	$14,541	$7,539	$7,541	$7,648	$16,042	$10,959	$11,154	$12,077	$18,121	$3,505	$3,505	$3,505	$1,509	$232	$232	$403

Natural Source	Ag Demand Areas											
	Southwest Ag				Clay ID Ag				Galt ID Ag			
	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity	N04N17	Unconstrained	GW Storage End>Beg	Restore Hydraulic Connectivity
American R					$0	$0	$0	$0				
Cosumnes R					$0	$0	$0	$0	$0	$0	$0	$0
Sacramento R												
Sac R via Freeport												
GW-7N												
GW-CSC	$2,381	$2,493	$2,492	$2,356								
GW-SSC					$2,293	$1,569	$1,385	$1,066	$2,997	$3,512	$3,479	$3,319
Recycled												
Operating Cost ($K)	$2,381	$2,493	$2,492	$2,356	$2,293	$1,569	$1,385	$1,066	$2,997	$3,512	$3,479	$3,319
Shortage	9.20	5.18	5.22	10.08	0.64	0.20	0.20	2.06	3.82	2.72	2.71	4.75
Scarcity Cost ($K)	$1,572	$238	$241	$545	$80	$4	$4	$125	$529	$141	$141	$288
Total Cost ($K)	$3,952	$2,732	$2,733	$2,901	$2,373	$1,573	$1,389	$1,192	$3,527	$3,653	$3,620	$3,607

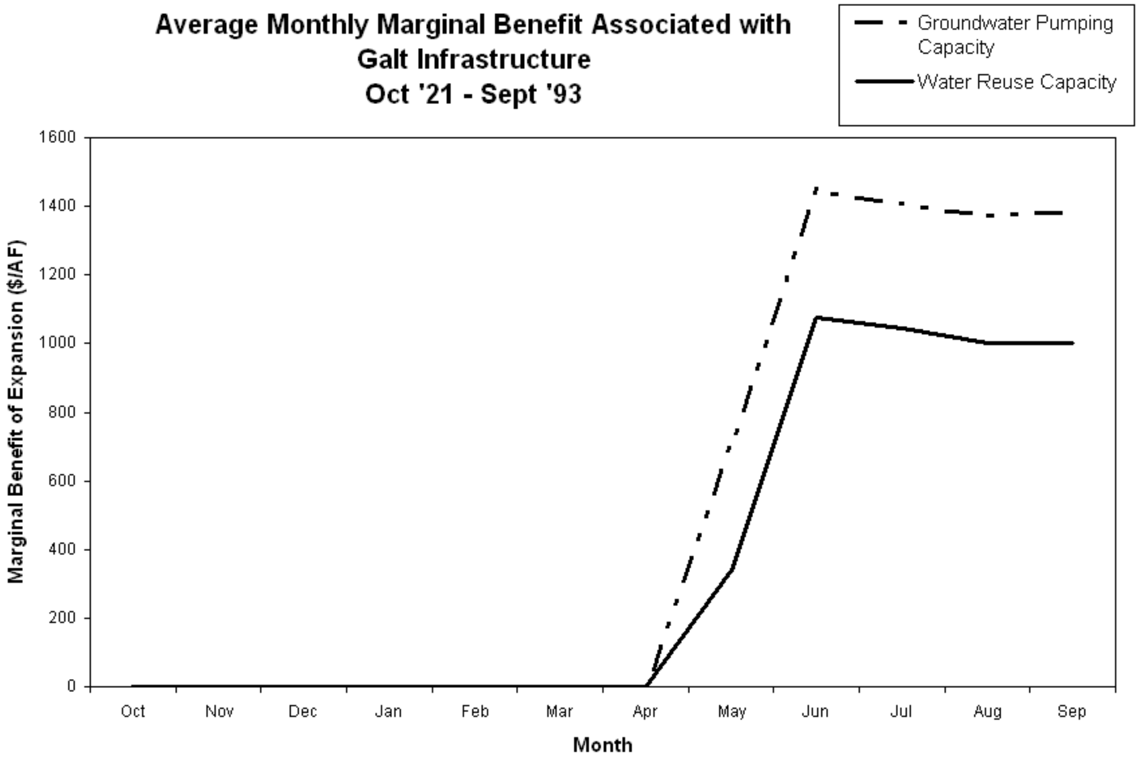


Figure E.1 Average Monthly Marginal Benefit Associated with Galt Infrastructure (Unconstrained Scenario)

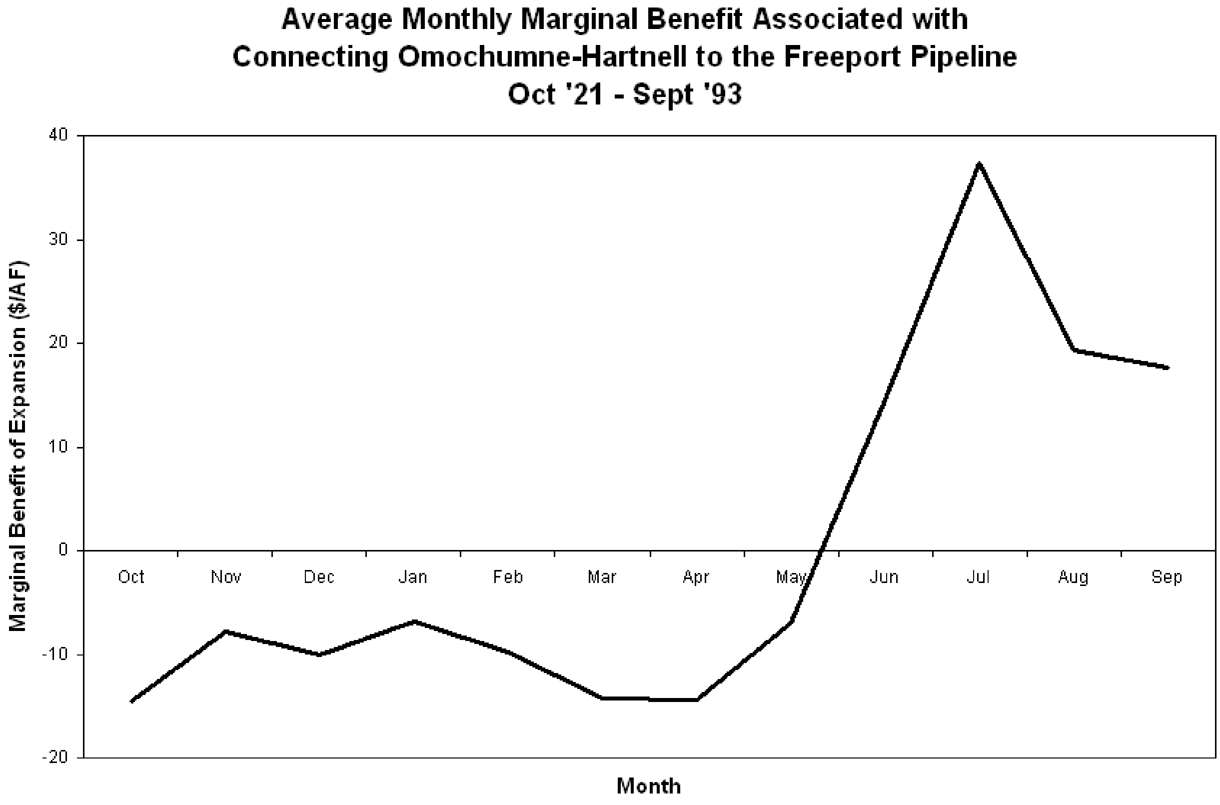


Figure E.2 Average Monthly Marginal Benefit Associated with Connecting OHWD to the Freeport Pipeline (Unconstrained Scenario)

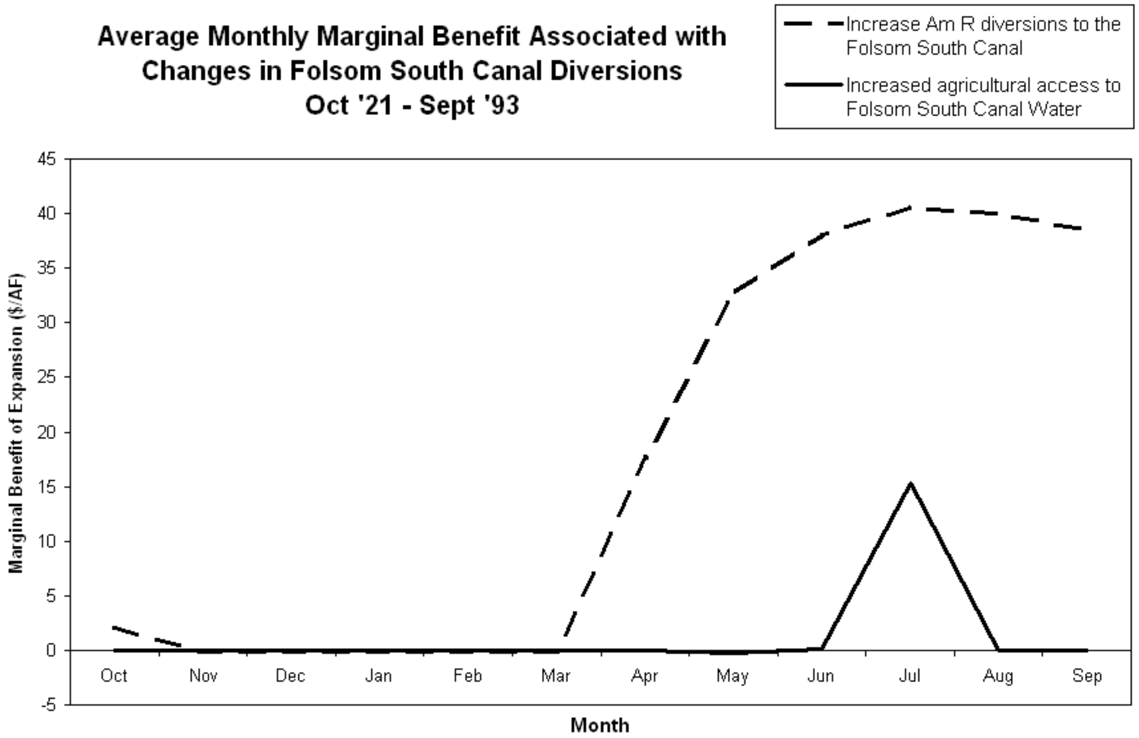


Figure E.3 Average Monthly Marginal Benefit Associated with Changes in Folsom South Canal Diversions (Unconstrained Scenario)

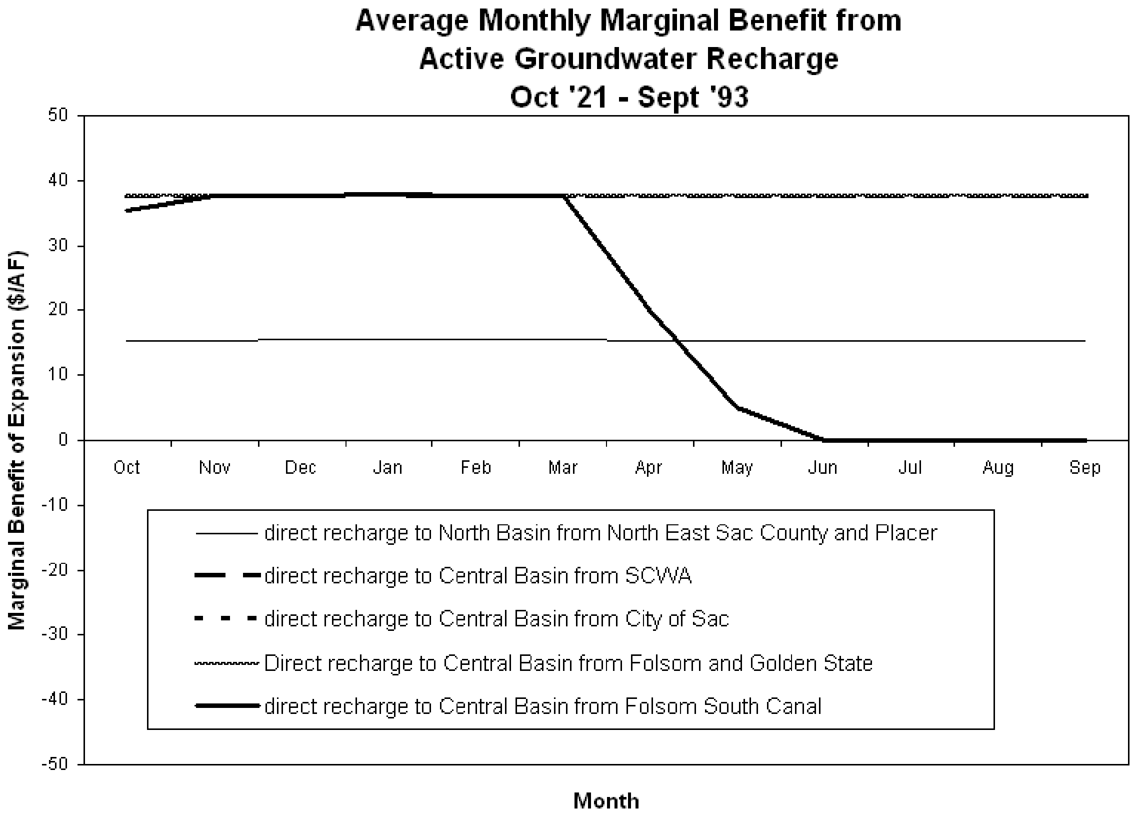


Figure E.4 Average Monthly Marginal Benefit Associated with Increasing Groundwater Pumping Capacities (Unconstrained Scenario)

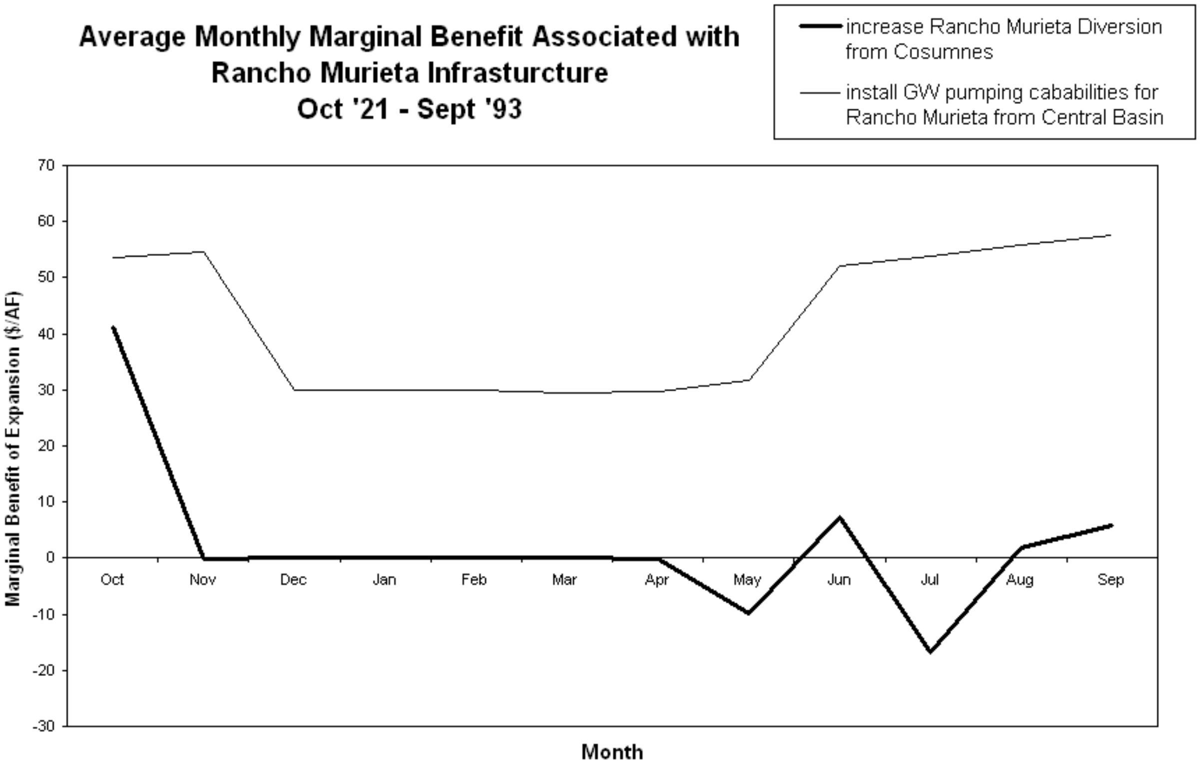


Figure E.5 Average Monthly Marginal Benefit Associated with Rancho Murieta Infrastructure (Unconstrained Scenario)

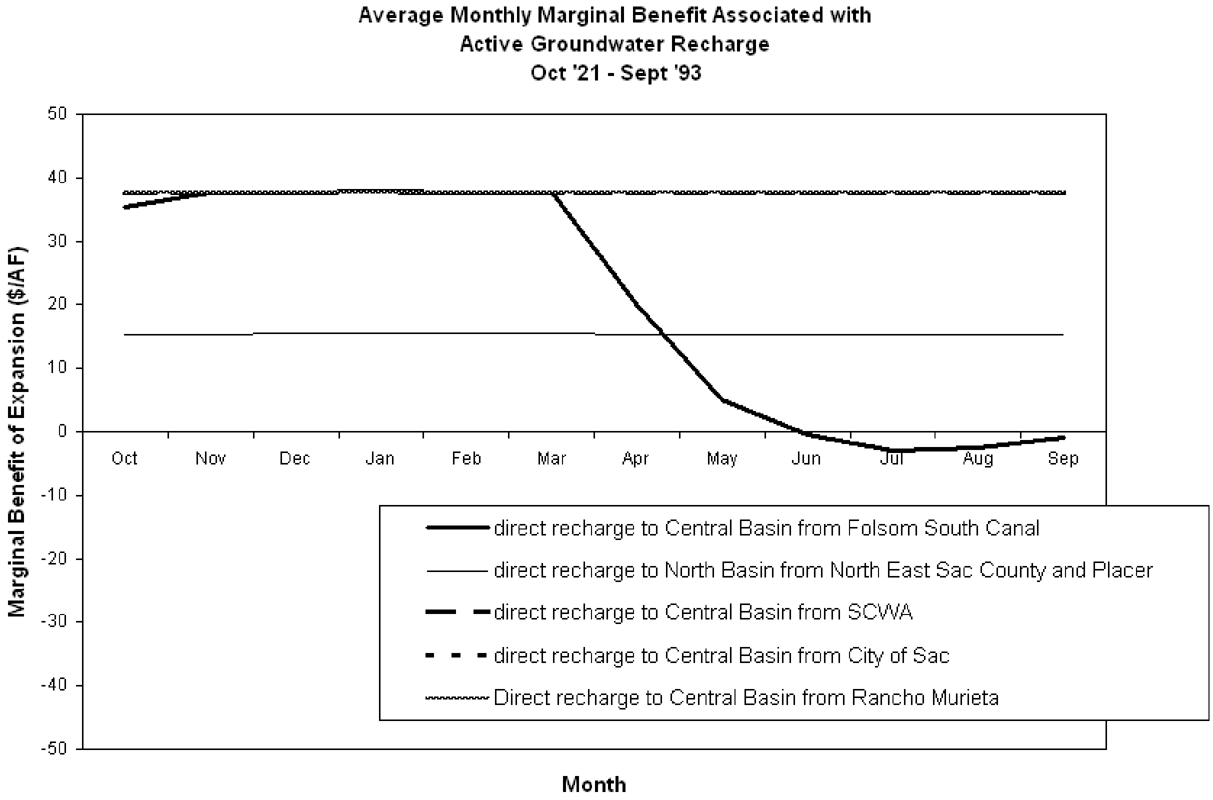


Figure E.6 Average Monthly Marginal Benefit Associated with Active Groundwater Recharge (Unconstrained Scenario)

Table E. 3 Percentage of Demands Met in Different Scenarios Overall and During Major Droughts

		Base Case	Unconstrained	Net Rechage	Restore Hydraulic Connectivity
Total	% Ag	95.5%	97.2%	97.2%	93.4%
	% Urban	98.1%	99.5%	99.5%	99.5%
	Total	97.2%	98.8%	98.7%	97.5%
1929-34 Drought	% Ag	97.4%	97.0%	96.9%	92.7%
	% Urban	98.3%	99.5%	99.5%	99.5%
	Total	98.0%	98.7%	98.7%	97.3%
1976-77 Drought	% Ag	94.2%	96.7%	96.6%	91.9%
	% Urban	97.8%	99.4%	99.4%	99.4%
	Total	96.6%	98.5%	98.5%	96.9%
1987-1992 Drought	% Ag	95.7%	96.6%	96.8%	92.5%
	% Urban	97.8%	100.0%	99.5%	99.5%
	Total	97.1%	98.9%	98.6%	97.2%

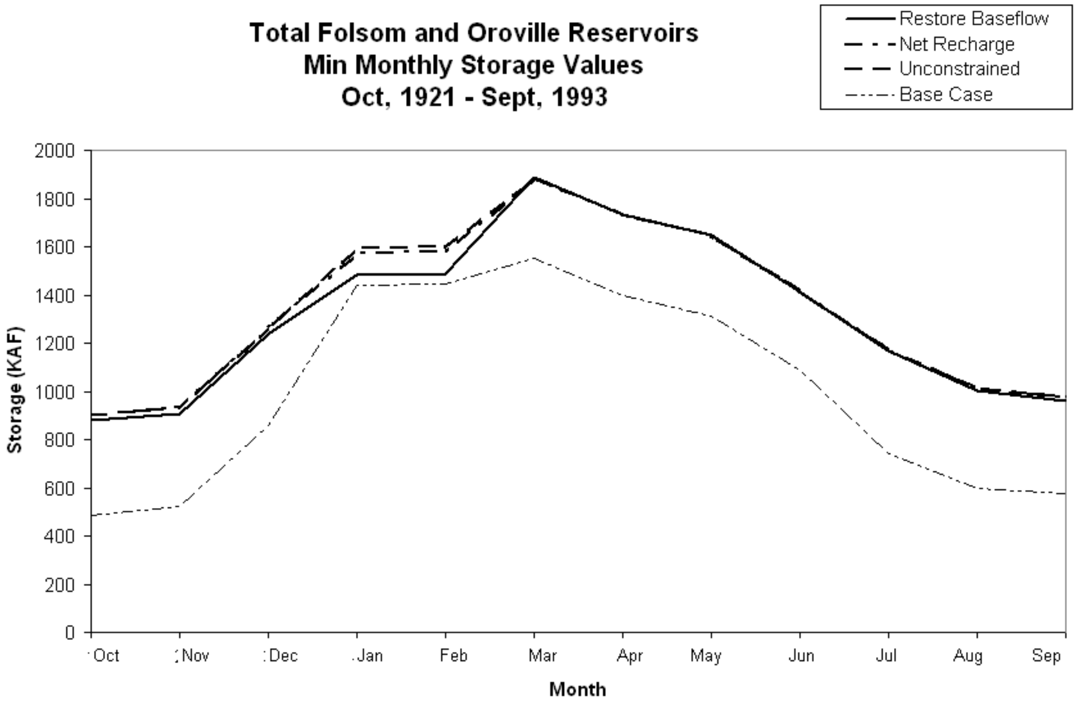


Figure E.7 Total Folsom and Oroville Reservoirs Minimum Monthly Storage Values

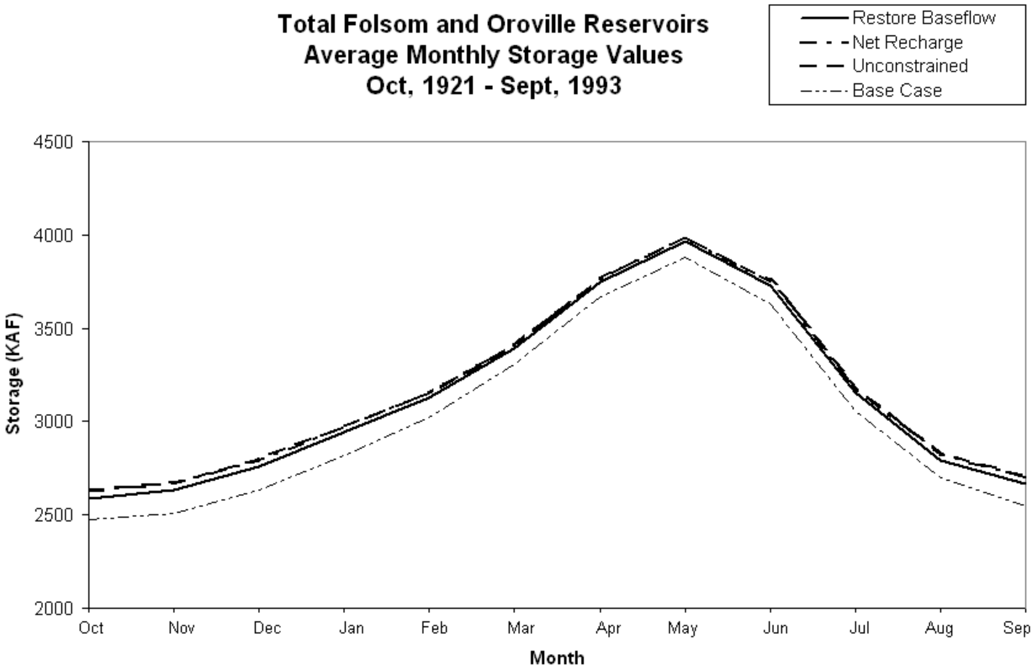


Figure E.8 Total Folsom and Oroville Reservoirs Average Monthly Storage Values

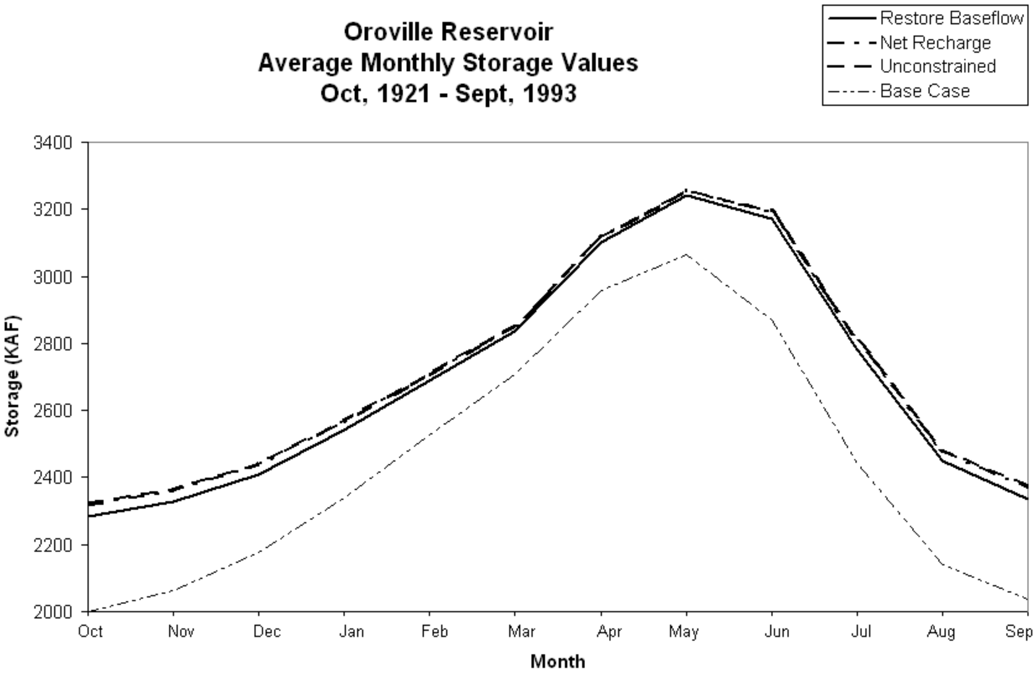


Figure E.9 Oroville Reservoir Average Monthly Storage Values

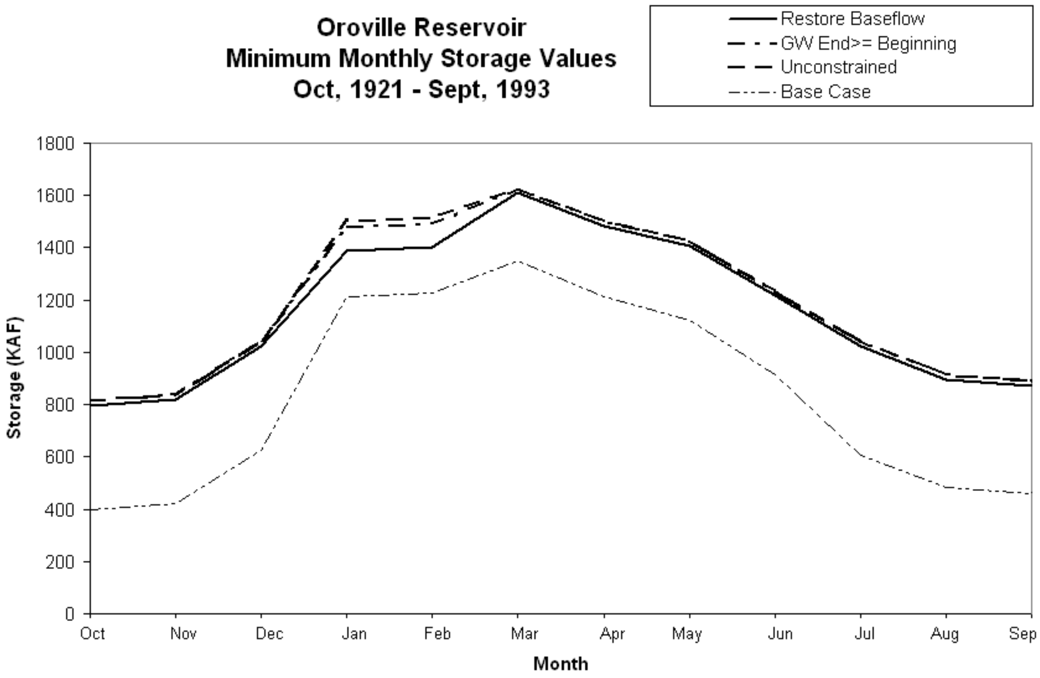


Figure E.10 Oroville Reservoir Minimum Monthly Storage Values

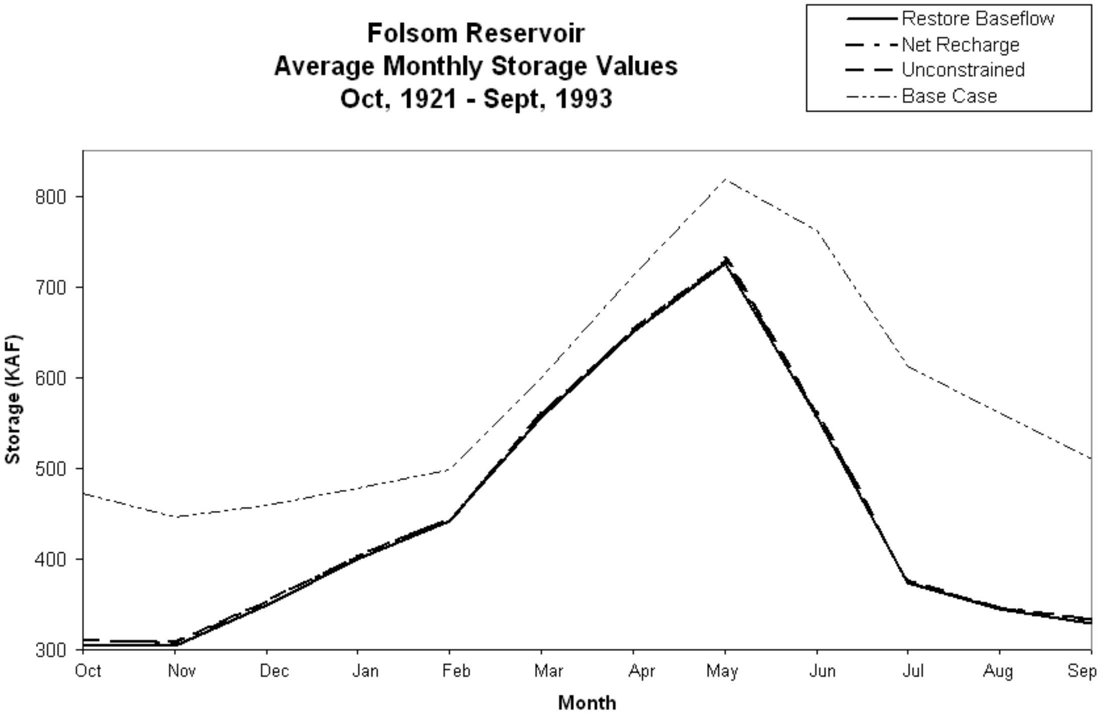


Figure E.11 Folsom Reservoir Average Monthly Storage Values

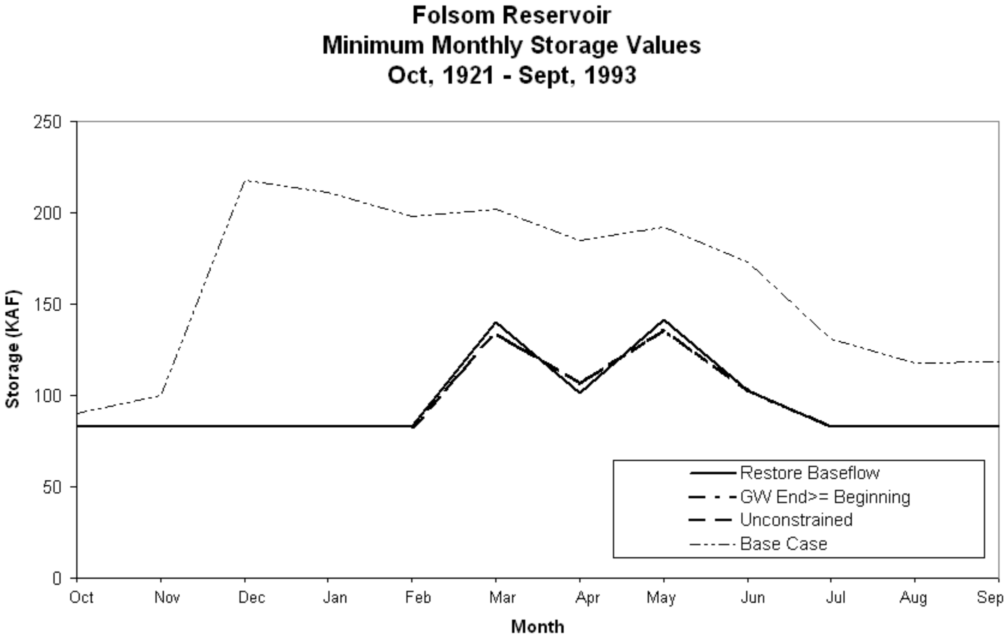


Figure E.12 Folsom Reservoirs Minimum Monthly Storage Values

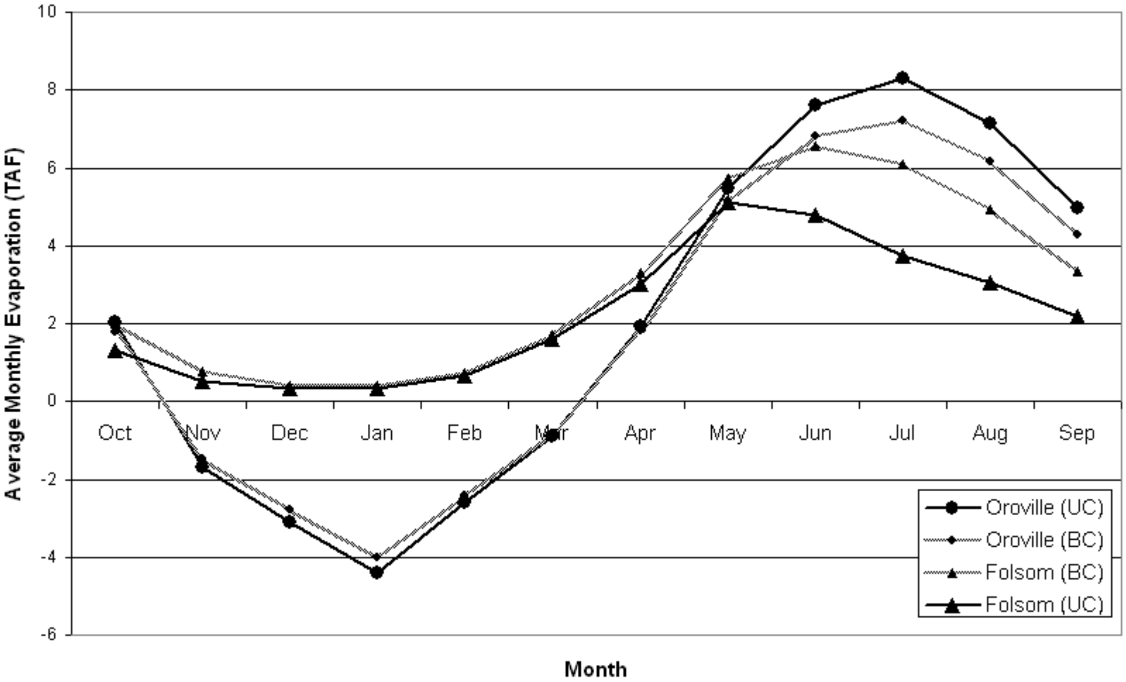


Figure E.13 Folsom and Oroville Reservoirs Average Monthly Evaporation (TAF)