California's water futures: How water conservation and varying Delta exports affect water supply in the face of climate change

By

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Abstract

Changes in climate, population, water conservation, and the Sacramento-San Joaquin Delta will affect water management, the economy, and the environment in California. This thesis uses an integrated statewide hydro-economic model to examine the water supply and cost implications of changes in urban water conservation, Delta export capacity, and a dry form of climate warming for water management in California with population and infrastructure conditions projected for 2050. Adaptation options include coordinated use of system re-operation, remaining Delta pumping capacity, urban and agricultural water conservation, water markets, conjunctive use of ground and surface water, seawater desalination, and expanded water recycling. Results indicate that, depending on climate and Delta export conditions, conserving 30% of California's 2000 level urban demands (bringing urban use down to 154gpcd) could save California $10 million to $2.4 billion annually (after conservation implementation costs) or $2 – $623/acre foot conserved. Expanding surface water storage capacity becomes less valuable with urban conservation, because it is so rarely used. Recycled water and desalination are expanded primarily when no Delta exports are available and become much less economical with high levels of urban water conservation.

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Chapter 1 : Introduction

This thesis examines water supply management in California in the year 2050 with major increases in population; mandated increases in urban water conservation; a drier, warmer climate; and reduced exports from the Sacramento-San Joaquin Delta. While all of these changes might not occur together, long-term water policy and plans should probably consider such contingencies.

California's vast water supply system includes most of California's surface area and extends from the Klamath River's headwaters in southern Oregon to the vast watershed of the Colorado River. Within California, this system includes roughly 40 million acre-feet of surface storage capacity and 150 million acre-feet of groundwater storage capacity. This system serves much of the state's 37 million people and 9 million acres of irrigated agricultural land. The service area includes the Central Valley, southern California, the San Francisco Bay Area, and parts of the southern Central Coast. Most water available to this system converges on the Sacramento-San Joaquin Delta.

California's water system has been under continuous development since the late 1800s, with most large-scale facilities built between 1928 and 1980, a period of 50 years. Built with the goal of fostering widespread urban and agricultural growth, California's water supply system was an incredible feat of engineering and economic development for its time. However, the state's contemporary and future economy and society differ substantially from the agrarian economy imagined when today's system was planned. Decades after the vast infrastructure was laid, new issues and water management opportunities have arisen: including climate change; the sustainability of Delta water exports; improvements in water use efficiency; and the integrated management of this vast, complex, and decentralized-managed system.

From 1998 to 2005, annual gross human water use in California averaged 42 million-acre feet (maf) (DWR 2009). Urban gross use is about 8.5 million-acre feet and agricultural gross use is about 33.2 million acre-feet/yr. Since much of this water use returns downstream and is available for reuse, agricultural net (consumptive) use averages 25.8 million acre-feet today and urban net use averages 6.5 million acre-feet (maf). Average net agricultural and urban use is 32.3 maf/yr. The current reported surface supply available is 27.4 maf/yr. Net groundwater withdrawal areages 8.4 maf/yr. As California's population and cities continue to grow, gross urban water use could increase to as much as 15 maf/yr by 2050. This urban growth is also projected to reduce irrigated land by 0.9 million acres, thereby reducing agricultural water demand by about 2.5 million acre-feet. (DWR, 2009; Howitt et al. 2008)

Problems

This thesis examines two major potential water problems in California: 1) water scarcity due to a warmer and drier climate and 2) the fragility of the Sacramento San Joaquin Delta, due in part to sea level rise. The potential of integrated water management, employing an economical range of supply and demand management actions, particularly urban water conservation, is examined.

Climate Change

California's water system is characterized by a spatial and temporal mismatch in supply and demand. Water is available in northern areas during winter and most human water demands are in the central and southern parts of California during the summer. In addition, interregional water transfers, which would serve to move water from where it is more abundant in the north, to where it is demanded in the south and west, are limited by capacity and legal constraints.

Even though water may be available, cheap water will not be. Warm, dry forms of climate change may reduce historical surface water inflows (rim inflows) by roughly 26%, groundwater inflows by 10% and increase surface reservoir evaporation by 37% statewide (Connell-Buck et al. 2010).

Delta Woes

The Sacramento and San Joaquin rivers end in a large inland maze of channels called the Sacramento San Joaquin Delta. Pumps for the State Water Project (SWP) and federal Central Valley Project (CVP) in the southern Delta make the Delta the main hub in California's water system for moving water from north to south. Located approximately 40 miles east of San Francisco, much of the Delta is reclaimed marshland that has subsided below sea level. The Delta is an inland estuary managed as a water supply system. Among the main challenges for the Delta are: seismic activity, weak levees, and decline of native species (Lund et al. 2007, 2010; Suddeth et al. 2010).

There is roughly a 68% chance in the next 30 years that the Delta area will have an earthquake powerful enough to cause multiple island levee failures and flooding. As the levees fail, depending on the time of year, seawater may be pulled into the land area occupied by the islands, many of which lie below sea level. The DWR estimates that such an event would require the pumps to be turned off for at least a year while repairs are underway, and could cost the State of California roughly $32 billion. (URS, 2006)

Even without a major earthquake, rising sea levels and continued subsidence put pressure on Delta levees. Much of the soil in the Delta is peat, a substance that oxidizes and decomposes when exposed to air. The interiors of several islands are now more than 15 feet below sea level. Since this is an estuary, the water level outside of each island's levee is roughly sea level, having higher levels with combinations of high tides, storms, and low atmospheric pressure. Climate change studies suggest that sea levels may rise roughly 30 – 75 inches by 2100. These factors increase pressure on the levees. (Vermeer et al, 2009)

The ecology of the Delta also has been compromised. The delta smelt, a native to the Delta, is listed as a threatened species under the federal Endangered Species Act. The smelt may go extinct if a solution is not quickly found. The smelt is sometimes seen as an indicator if ecosystem health. Other species are also in sharp decline. (Lund et al., 2007, 2010)

In response to the delta smelt's population collapse, US District Court Judge Wanger imposed restrictions on water exports from the Delta in 2007, and ordered a new biological opinion for the continued operation of the export pumps by the State Water Project and the Central Valley Project. The new biological opinion developed by the US Fish and Wildlife Service, issued in 2008, incorporates higher restrictions on pumping. In 2009, National Marine Fisheries Service issued a new biological opinion intended to protect salmon, steelhead, and green sturgeon. This biological opinion would further reduce Delta water exports. Rising pumping restrictions due to endangered species listings have decreased the reliability of Delta water exports to the Bay Area, the southern Central Valley, and Southern California. (DWR, 2009)

Proposed solutions

Several major reports and studies have been done on these problems, each proposing similar solutions.

In 2007, Governor Schwarzenegger created the Delta Blue Ribbon Task Force and issued Executive Order S-17-06 to "develop a durable vision for sustainable management of the Delta." ((Calif.) 2008)) The Delta Task Force wrote the Delta Vision Strategic Plan, to "restore the Delta ecosystem and create a more reliable water supply for California." The plan cited, among other actions, water conservation, reduced or changed diversions from the Delta, new storage and conveyance facilities and better links between the two. With regards to water supply, the Task Force recommended California find additional storage, conserve water through both reuse and less use in both agricultural and urban sectors, incentivize local and regional efforts for brackish water cleanup and seawater desalination. (Delta Vision 2008).

The Bay Delta Conservation Plan – a habitat conservation plan intended to provide a broader ecosystem recovery approach for the Delta in compliance with the federal and state Endangered Species Acts - is expected to be released soon. The Final Interim Plan, released at the end of August, 2010 recommends that water conservation be employed statewide, the water conveyance system be improved, and water storage expanded statewide. Delta flow criteria are recommended, along with recommendations from the Delta Vision Strategic Plan. Water conservation, conveyance improvement and expanded storage appear here as well. (Delta Stewardship Council, 2010)

The state's California Climate Adaptation Strategy (California Natural Resources Agency, 2009) recommends California adapt to climate change, as it pertains to water, by reducing per capita water use 20% by the year 2020, expanding surface and groundwater storage, supporting agricultural water use efficiency, improving state-wide water quality, and 'fixing' the Delta water supply, quality, and ecosystem conditions, as developed in the Bay Delta Conservation Plan. Again, water conservation, expanded storage, and Delta changes are proposed.

Background research on proposed solutions

Several solutions have been proposed to help address water supply and Delta issues. Six commonly-proposed actions include water conservation, increased storage, desalination, water recycling, decreasing Delta exports, and water markets. Studies of these actions are summarized below.

Water conservation

Water conservation is frequently cited as a main strategy for the state to address climate change and other water management challenges.

Several major conservation studies of California include: 1) the Pacific Institute's "Waste Not Want Not" (Gleick et al. 2003), 2) CALFED's Water Use Efficiency Comprehensive Evaluation (2006), and 3) the State Water Resources Control Board's "20x2020" (2010). All three studies quantitatively analyzed the possible amounts of water conservation. Gleick et al. (2003) and CALFED (2006) evaluated current water use in California and gave estimates for what California could do cost effectively. "20x2020" (2010), on the other hand, stated a water conservation goal and devises how to get there. Table 1:1 summaries key elements of the three studies.

Gleick et al. (2003) estimated that the baseline level of water use in the urban sector in 2000 was 7 maf per year, and that California could conserve 2 maf per year cost effectively, and up to 2.3 maf with current technology. This is approximately 28.7 percent of the total average urban water demand. Conservation was considered "cost effective" if its cost is less expensive than the cheapest alternative new water supply source. The maximum cost-effective cost per acre-foot for residential water was $580 and $600 per acre-foot for industrial water, but many solutions cost less. Some actually had a negative cost, when the energy savings of implementing them was taken into consideration.

CALFED's "Water Use Efficiency Comprehensive Evaluation" (2006) estimated that the baseline water use for 2030 demands is 12.3 maf per year (maf/year) for urban water users. CALFED estimated that of this, 1.2 – 2.1 maf/year could be conserved cost effectively. Water conservation was considered cost effective if its cost is lower than the most expensive local water supply option currently used. The CALFED study calculated that this conservation scheme would cost between $223 – 522 per acre-foot. The total cost of urban water conservation would then be between $0.27 and $1.1 billion/year.

In 2008, Governor Schwarzenegger challenged California to conserve twenty percent of urban water use by the year 2020. In 2010 the State Water Resources Control Board (SWRCB) responded to this call by publishing a road map plan of how to achieve the so-called “20x2020.” This plan employed many findings from CALFED’s “Water Use Efficiency Comprehensive Evaluation” (2006) study to illustrate how to conserve this much water. After evaluating water use from 1995 to 2005, they used water use numbers from 2005 to establish a baseline for water use. In 2005, California’s urban sector used 7.9 maf. With a population of approximately 37 million, this equates to 192 gallons per capita daily (gpcd) use. A twenty percent reduction of that would be 154 gpcd (1.59 maf for 2005 level demands). They noted that in 2000, demands were 8.9 maf, or 1.78 maf more. This 1.59 – 1.78 maf is where their estimate of the amount of water conserved cost effectively in 2020 comes from. Since no year 2020 water use estimates were calculated in the document, the 154 gpcd estimate will be used by this thesis for reference. Like CALFED, they defined cost effective as any cost cheaper than the most expensive local option currently used. They did not estimate a cost for this conservation, noting only that the marginal costs listed in CALFED (2006) were now out of date and are likely higher now.

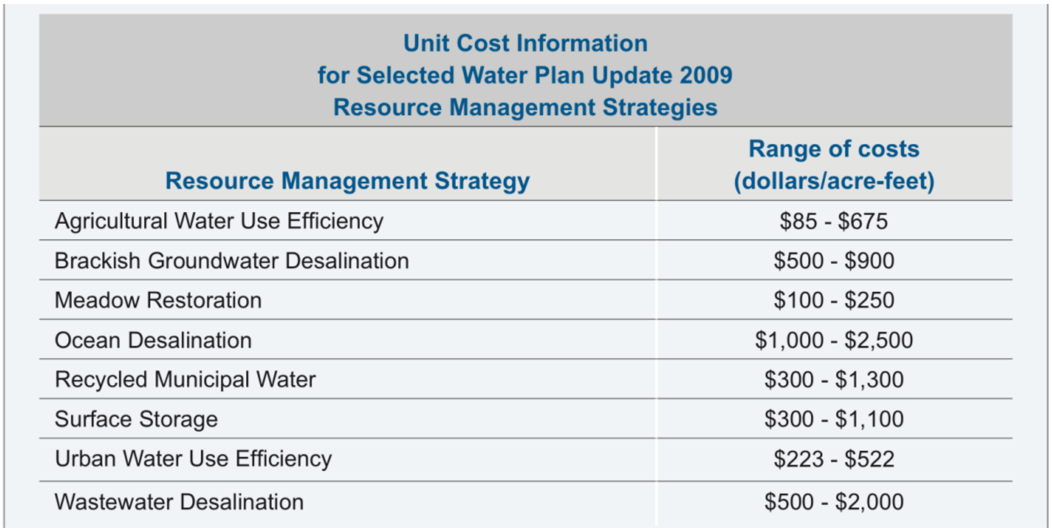
Table 1:1: Key parts of major water conservation studies in California

Water Conservation Studies for California			
Study	**Waste Not Want Not**	**Water Use Efficiency Evaluation**	**20x2020[3]**
Citation	Gleick et al., 2003	CALFED, 2006	SWRCB, 2010
Gross %Conserved	28.7 - 33.6%[1]	9 - 25%	20%
Definition of Cost Effective	Cost less than new supply	Costs less than the most expensive local option currently used	Costs less than most expensive local option currently used
Cost of Cost Effective Measures	Less than $580/af for Residential, $600/af for Industrial	Average cost: $223 - 522/af for Urban	Not Stated – Notes CALFED’s Comprehensive Evaluation costs may be too low
Gross Conservation	2 - 2.3 maf/yr[2]	1.2 - 2.1 maf/yr	1.59-1.78 maf/yr[3], 154 gpcd
Demand Level Study Base	Urban Water Use for year 2000	Projected demands for 2030 based on use levels from 2000	2005 use patterns in the Draft 2009 Water Plan
Considers Climate Change?	No	No	Only emissions reductions from using less water
Baseline	7 maf	12.3 maf	7.9 maf, 192 gpcd
Notes	[1] 28.7% is cost effective [2] 2 maf is cost effective		[3] Not an independent study, but a partial update of CALFED's Water Use Efficiency Comprehensive Evaluation [3] 1.59 = amount conserved if 2005 demands are reduced 20%, 1.78 maf = reduction in demand from 2000 to 2005

New Supplies: Desalination and Recycled Water

Urban water recycling and seawater desalination are commonly seen as a means of extending California's water supplies. Table 1:2 lists the estimated range of unit costs for water supplied from different resource management strategies in California from the most recent update of the California Water Plan (DWR, 2009).

Table 1:2: Unit costs of select water supplies. (DWR, 2009)



Unit Cost Information
for Selected Water Plan Update 2009
Resource Management Strategies

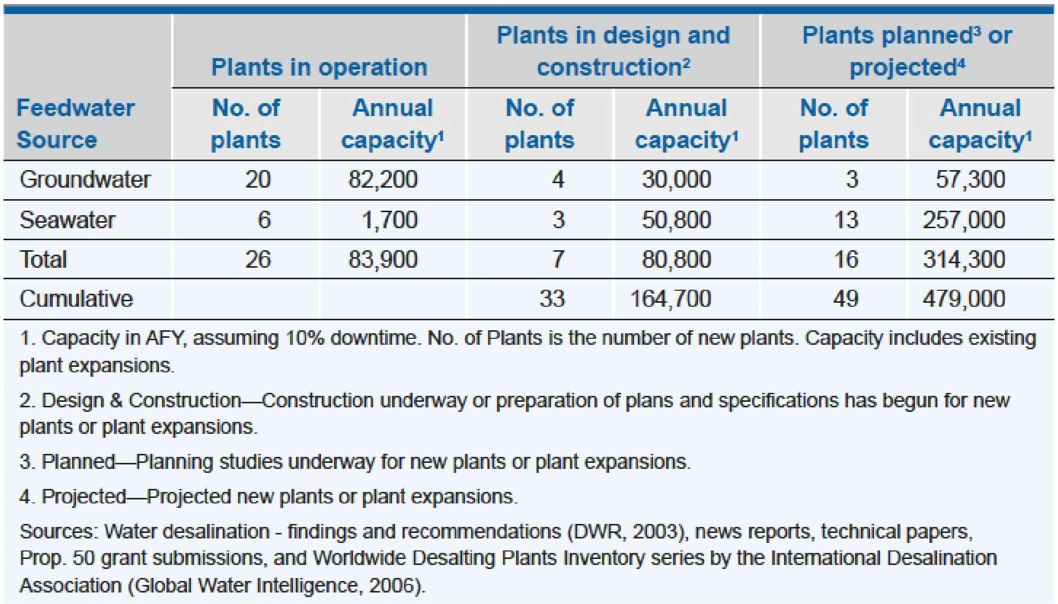
Resource Management Strategy	Range of costs (dollars/acre-feet)
Agricultural Water Use Efficiency	\$85 - \$675
Brackish Groundwater Desalination	\$500 - \$900
Meadow Restoration	\$100 - \$250
Ocean Desalination	\$1,000 - \$2,500
Recycled Municipal Water	\$300 - \$1,300
Surface Storage	\$300 - \$1,100
Urban Water Use Efficiency	\$223 - \$522
Wastewater Desalination	\$500 - \$2,000

Desalination

Ocean desalination removes salt from seawater. Brackish water is water that is too salty to meet acceptable standards for use, but much less salty than seawater. Brackish desalination is the process of making brackish water (usually groundwater) usable, and it is far less costly than ocean desalination (Table1.2).

Currently little of California's water supply is from desalination, but there are plans to increase its supply. Twenty-six desalination plants currently operate in California, seven are under construction and sixteen more are planned. These existing plants supply 84 thousand-acre feet of water/year (82 taf/yr is brackish desalination). Once the seven plants currently under construction are finished, desalination capacity could rise to 165 thousand-acre feet per year (112 taf/year is brackish desalination). If all planned desalination plants are built, California's total desalination capacity will rise to 479 thousand-acre feet per year (169.5 taf is brackish desalination). (2009 Water Plan) (Table 1:3)

Table 1:3: Desalination capacity and type (DWR, 2009)



Feedwater Source	Plants in operation		Plants in design and construction[2]		Plants planned[3] or projected[4]	
	No. of plants	Annual capacity[1]	No. of plants	Annual capacity[1]	No. of plants	Annual capacity[1]
Groundwater	20	82,200	4	30,000	3	57,300
Seawater	6	1,700	3	50,800	13	257,000
Total	26	83,900	7	80,800	16	314,300
Cumulative			33	164,700	49	479,000

1. Capacity in AFY, assuming 10% downtime. No. of Plants is the number of new plants. Capacity includes existing plant expansions.

2. Design & Construction—Construction underway or preparation of plans and specifications has begun for new plants or plant expansions.

3. Planned—Planning studies underway for new plants or plant expansions.

4. Projected—Projected new plants or plant expansions.

Sources: Water desalination - findings and recommendations (DWR, 2003), news reports, technical papers, Prop. 50 grant submissions, and Worldwide Desalting Plants Inventory series by the International Desalination Association (Global Water Intelligence, 2006).

The capital costs of these new plants are large. The cost of building a 300 taf/year of new seawater desalination plant capacity is between $1.5 and $2 billion. The life expectancy of the plants is twenty to thirty years. (DWR, 2009)

Operating these plants is also costly. Once the plants are built, there is a high energy cost to desalinating the water. Roughly 1,800 kilowatt hours of energy are required to desalinate one acre-foot of brackish water and 4,000 kilowatt hours are needed for one acre-foot of seawater. This energy is a large part of total desalination costs (which also include amortization of the plant investments). The 2009 Water Plan estimates seawater desalination to cost between $1,000 and $2,500 per acre-foot. Gleick et al. (2003) estimates the cost range from $997 - $3,260 per acre-foot. Fryer (2010) says desalination costs are $2,000 - $3,000 per acre-foot.

Brackish water desalination can be much less costly. Total brackish desalination costs between $500 and $900 per acre-foot (DWR, 2009).

Desalination's high cost makes it suitable only for uses with high economic values, such as residential, commercial, and industrial uses. Desalinated water is generally more expensive than the value it might produce in agriculture.

Recycled Water

Wastewater that has been sufficiently treated for direct or controlled use is referred to as recycled water. Wastewater from an upstream location often is diluted in a stream and reused downstream. For this analysis, only wastewater that would not be reused downstream had it not been treated will be considered recycled water.

Wastewater recycling currently generates 450 – 580 thousand acre-feet of water each year. Numerous new wastewater recycling plants and expansions of existing plants have been proposed that, if completed, will increase that capacity to 1.85 to 2.25 million acre-feet per year by 2030. Capital costs for these projects are estimated to range from $9 - $11 billion (DWR, 2009). Additional costs are often required for re-distribution of recycled water to water users.

Recycling wastewater often requires desalination techniques, but it is generally less energy-intensive than desalinating seawater, and so is less costly. Depending on the level of treatment, recycled water can cost as little as $300 per acre-foot to $1,300 for existing facilities (Table 1.2). Recycled water is sufficiently inexpensive that, depending on the level of treatment required, recycled water can be used for agriculture. In 2009, 46 percent of recycled water was used by agriculture for irrigation (DWR, 2009). When wastewater recycling requires more rigorous desalination, the cost is estimated to be $500 to 2,000 per acre foot. (DWR, 2009)

Despite the 2009 Dual Plumbing Code, which created codes for recycled water to facilitate a broader range of uses (e.g. non-potable residential and commercial uses), many problems persist. Recycled water is saltier than fresh water, so some drinking water treatment plants cannot tolerate it. Recycled water requires its own distribution system. On new projects, this generally does not add much cost, but retrofitting existing infrastructure to have dual piping can be very expensive. Finally, public acceptance for using recycled water is an issue. (DWR, 2009)

Water Markets

Water markets are a commonly-cited way to minimize the costs of water scarcity. While the thought of one party transferring (usually temporarily) water rights to someone willing to pay more is sometimes seen as controversial, markets can often reduce the overall cost of scarcity. They can also sometimes increase overall supply. (Howitt and Vaux, 1982; Hanak et al. 2011)

Conjunctive Groundwater Use

Conjunctive use is the planned and integrated use and storage of surface water and groundwater supplies. DWR estimates that groundwater currently supplies 35% of total urban and agricultural demands annually on average (15maf). Currently, active conjunctive use programs provide an average of 2.5 maf /year of water for Southern California. Estimates indicate that average deliveries could increase by 0.5 – 2 maf statewide with implementation of conjunctive use and large scale system re-operation and conveyance capacity modification. (DWR, 2009)

Expanded Surface Storage

California currently has more than 41 maf of surface water storage capacity. The US Bureau of Reclamation is examining enlargement of Shasta, Pine Flat and Friant dams and building Temperance Flat and Sites Reservoirs (USBR, 2003, 2004). However, there is a cost to expanding surface storage. Temperance Flat could cost

$350 per acre foot or water delivered and Sites reservoir would cost over $1,000 per acre foot of water produced (Hanak, et al., 2009, DWR 2007)

Delta Conveyance Solutions

Several studies have been done on Delta conveyance (Lund et al. 2010). Notable studies include the CALFED Record of Decision, Delta Vision Blue Ribbon Task Force's Strategic Plan and following Implementation Report, DWR's Delta Risk Management Strategy (DRMS), *Comparing Futures for the Sacramento San Joaquin Delta*, and the Bay Delta Conservation Plan. A summary of earlier studies appears in Table 1:4.

Absent from most of these studies is analysis of state-wide economic and supply implications of simultaneous changes in Delta exports, urban water conservation, and climate change, the subject of this thesis.

Solutions everywhere, but how to integrate them?

Water managers have an enormous variety of options from which solutions can be crafted, as summarized in Table 1.5. While many solutions are proposed, there is little research on how the many available options can be best combined operationally, particularly with the potential demise of Delta exports, dry forms of climate warming, and expanded urban water conservation.

Overview

This thesis continues with a review of modeling approaches available to examine how the combined and independent effects of climate change, loss of Delta export capacity, and water conservation could affect water management in California (Chapter 2). A CALVIN modeling approach is selected and its setup is explained (Chapter 3). The results are then explored (Chapter 4), and synthesized into several concluding thoughts (Chapter 5).

Table 1:4: Delta conveyance studies

Delta Conveyance Studies – Conveyance-Specific Results					
Study	**CALFED Record of Decision**	**Delta Vision Strategic Plan, Implementation Report**	**Comparing Futures**	**Bay Delta Conservation Plan**	**Delta Risk Management Strategy***
Citation	CALFED ROD, EIS/EIR (2000)	Delta Vision Blue Ribbon Task Force, (2008)	Lund et al. (2008, 2010)	BDCP Working Draft (2010)	DWR (2009)
Solutions Studied	No Action	No Action	Through-Delta Conveyance	No Action	
	Existing System Conveyance	Existing System Conveyance		Through-Delta Conveyance	Improved Levees
	Modified Through-Delta Conveyance	Modified Through-Delta Conveyance			Armored Pathway
	Dual Conveyance	Dual Conveyance	Dual Conveyance	Dual Conveyance	
	Peripheral Canal		Peripheral Canal	Tunnel or Canal	Isolated Conveyance
			No Exports		
Modeled?	Yes - CalSIM	Solutions not modeled	Yes – CALVIN	Yes, but not state-wide implications	Assessed Cost of Catastrophe
Climate Change?	Mentioned in discussion for adaptive management, otherwise no.	Yes	Yes, but not modeled	Yes	Yes
Preferred Solution	Modified Through-Delta Conveyance	Dual Conveyance	Peripheral Canal	Dual Conveyance	NA*
Notes:		Also evaluates the implementation costs of different export levels	Also evaluates how 50% and 25% export scenarios affect the state		*Phase 2 not completed

Table 1:5: Water supply portfolio options

Water supply system portfolio options

Demand and allocation options
Urban water use efficiency (water conservation)*
Urban water shortages (permanent or temporary water use below desired quantities)*
Agricultural water use efficiency*
Agricultural water shortages*
Ecosystem demand management (dedicated flow and non-flow options)
Ecosystem water use effectiveness (e.g., flows at specific times or with certain temperatures)
Environmental water shortages
Recreation water use efficiency
Recreation improvements
Recreation water shortages

Supply management options

Expanding supplies through operations (affecting water quantity or quality)
Surface water storage reoperation* (reduced losses and spills)
Conveyance facility reoperation*
Cooperative operation of surface facilities*
Conjunctive use of surface and groundwater*
Groundwater storage, recharge, and pumping facilities*
Blending of water qualities
Changes in treatment plant operations
Agricultural drainage management

Expanding supplies through expanding infrastructure (affecting water quantity or quality)
Expanded conveyance and storage facilities*
Urban water reuse (treated)*
New water treatment (surface water, groundwater, seawater, brackish water, contaminated water)*
Urban runoff/stormwater collection and reuse (in some areas)
Desalination (brackish and seawater)*
Source protection

General policy tools
Pricing*
Subsidies, taxes
Regulations (water management, water quality, contract authority, rationing, etc.)
Water markets, transfers, and exchanges (within or between regions/sectors)*
Insurance against drought
Public education

* Options represented in CALVIN
Source: Hanak et al. 2011

Chapter 2 : Modeling Approaches

This project seeks to better understand how urban water conservation, varying Delta exports and a warmer, drier climate would affect water management in California. For this question, a modeling approach is needed to avoid the insurmountable inconvenience, cost, delays, and permits that such a field experiment would require. Ideally, such a model should represent all of California's major water sources and demands, and examine economic and water supply implications. Harou et al. (2009) review regional hydro-economic modeling theory and applications generally.

Existing models

Several large scale models exist for large parts of California's water system. These models include the CalSIM, WEAP, LCP-Sim and CALVIN. Table 2:1summaries each model.

Table 2:1: Summary of large-scale water models of California

Model	**CalSIM II**	**LCP-Sim***	**WEAP**	**CALVIN**
Citation	Draper et al, (2004) Sunding (2009), Dracup (2005)	DWR (2010)	Groves (2010), Yates (2009)	Medellín-Azuara (2008), Tanaka et al. (2011)
Type	Simulation	Optimization	Simulation	Optimization
Geographic Coverage	Central Valley, SWP and CVP contractors in SF Bay, Tulare Basin and So. Cal.	Urban So. Cal. and urban Bay Area	Sacramento and San Joaquin basins	Trinity, Central Valley, Bay Area, So. Cal., Colorado R. and Santa Barbara/SLO
Adaptive Operations	No	Yes	No	Yes
Economic Performance	No	Yes	No	Yes
1. Conservation	Yes	Yes	Yes	Yes
2. Delta Exports	Yes	Yes	Yes	Yes
3. Climate Change	Yes	Yes	Yes	Yes
1 - 3 Combined	No	No	Yes	Yes

Notes

* Designed to be iterated with CalSIM II and optimize costs in a yearly timestep

** Area that includes hydrologic flows, demand, water use and return flow, groundwater use and storage, etc.

CalSIM II

The Department of Water Resources and the Bureau of Reclamation created CALSIM II to model the Central Valley Project (CVP) and State Water Project (SWP) operations (Draper et al. 2004). CalSIM covers the Sacramento Valley and the Eastern San Joaquin Basin, with SWP and CVP deliveries to the Tulare Basin, as well as to the Bay Area and Southern California. Most climate change studies have focused on the Sacramento Valley. (Dracup et al., 2005)

As a simulation model, CalSIM runs specific scenarios based on specific operating priorities. The system requires users to set up a series of weighted priorities. The simulation model uses these rules to allocate water based on the weighted priorities. The model then runs, attempting to fulfill the highest priorities first. CalSIM does not make decisions based on economics directly, but reflects defined priorities for water deliveries and operations.

The use of linear programming to optimize adherence to water management priorities within each monthly time step adds some flexibility beyond traditional simulation methods. However, operational decisions are likely to seek greater changes in response to major changes in future economic, environmental, and technological conditions.

Studies have been done in CalSIM on conservation, Delta export reductions, a warmer climate and drought independently, but not combined. (Draper et al, 2004; Sunding et al. 2009; Dracup et al. 2005; DWR, 2006[a] and 2009[a])

LCPSIM

LCPSIM (Least Cost Planning Simulation) is a priority-based, mass balance model designed to be used with CalSIM II to minimize the expected costs and losses from shortages to urban areas. LCPSIM helps CalSIM calculate water transfer and carryover storage operations and adjust modeled State Water Project delivery targets based on undeliverable State Water Project quantities. LCPSIM was originally designed as a systems-analysis based economics model. It has been used in DWR Environmental Impacts Studies and Environmental Impacts Reports since 1990 and used in CALFED. (DWR, 2010)

Studies have utilized LCPSIM to analyze conservation, Delta export reductions, a warmer climate and drought, but not combinations. (DWR, 2010)

WEAP

Water Evaluation And Planning, or WEAP, is a simulation model. WEAP was used for the 2009 California Water Plan Update. Two WEAP models are used in the Water Plan: the Hydrologic Region (HR) model and Planning Area (PA) model. The HR WEAP model covers all ten hydrologic regions in California, but only at a low-resolution level. The PA model is higher resolution, representing monthly hydrologic flows, water use and return flow, demand and groundwater use and storage, but it only covers the Sacramento River and San Joaquin Hydrologic Regions. (Groves, 2010)

It has incorporated the effects of conservation, Delta export reductions, a warmer climate and drought together, but as it is a simulation model only, does not currently have the capacity to make decisions based on economics directly. (Groves 2010; Yates 2009)

CALVIN

CALifornia Value Integrated Network, or CALVIN, is a network flow-based economic-engineering optimization model of California's water systems (Draper et al. 2003). CALVIN is a prescriptive model that manages surface and groundwater resources to minimize the costs of water storage (scarcity) and use in California. Representing 90% of the state's urban and agricultural water demands and about two-thirds of all state runoff, CALVIN has the largest detailed study area of the models assessed. Figure 2:1 illustrates CALVIN's coverage.

CALVIN has been used to study Delta export reductions, a warmer climate and drought, but not combined. CALVIN has also not been used to study water conservation beyond that represented in the normal price-elasticity of demand. Tanaka et al. (2011) used CALVIN to study the economic and supply effects of different Delta water export levels and Harou et al. (2010), Connell (2009), Medellin et al. (2008), and Tanaka et al. (2006) have used CALVIN to study the effects of climate change in California.

CALVIN has some well-documented drawbacks, with perfect foresight being the most prominent (Draper et al. 2003). CALVIN attempts to deliver water to the highest economically valued uses at the lowest cost. Since, at the onset of the study, CALVIN foresees what will happen in all 72 years of weather, it can prepare for droughts years before they happen. This creates a somewhat unrealistically positive outcome (Draper 2001). Nevertheless, the results of this analysis are useful, because it indicates that any scarcity or delivery cost that still occurs, even with perfect planning, would be very difficult to avoid.

Model selected

CALVIN was employed for this project because it has the largest detailed study area of the models assessed, is economically driven, and thus allows the most economically promising and adaptive water management alternatives to emerge for a wide range of conditions.

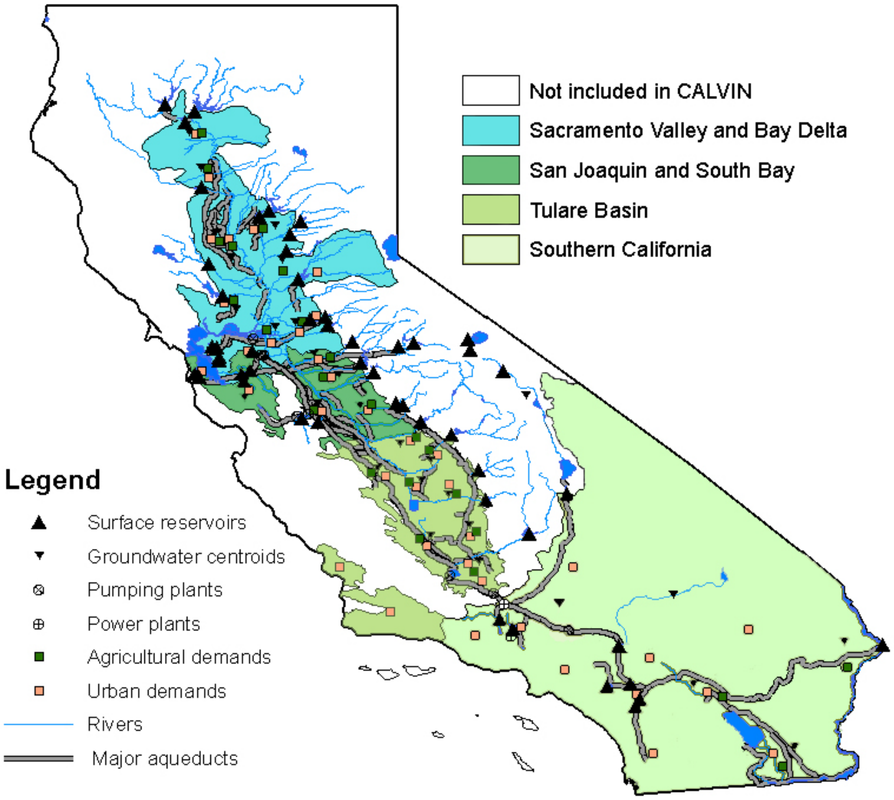


Figure 2:1: Modeled coverage area of CALVIN

Chapter 3 : Model Setup

This study employs the results and methods from Connell-Buck et al. (2011) and Tanaka et al. (2008, 2011), with reduced urban water demands to assess the effects of urban water conservation and reduced Delta water exports in California under a dry form of climate change. (Agricultural water conservation is represented using price responses to scarcity of water available through the market.) Earlier studies have looked at Delta and climate changes separately. This study looks at Delta and adverse climate changes together, along with externally-imposed reductions in urban water use.

Major changes in CALVIN model assumptions used for this study are discussed below.

CALVIN Inputs

Climate scenarios

Climate change has been examined in past CALVIN studies including Harou et al. (2010), Connell-Buck et al. (2011). Medellín-Azuara et al. (2008) and Tanaka et al. (2006). This study applies the climate changes that Connell-Buck et al. (2011). incorporated into CALVIN, a downscaled version of the GFDL A2 CM2.1, a warm-dry climate scenario by Maurer and Hidalgo (2008) used in the California Energy Commission's Climate Change Assessment 2008 study. This warmer, drier climate has 26% less average annual runoff, 10% less groundwater inflow and increased surface reservoir evaporation by 37% statewide Connell-Buck et al. (2011). The overall effects of dryness are much greater than for warming alone (Connell-Buck et al. 2011).

Delta water export reductions

Delta export capacities were modeled using the proposed South Delta Improvement Project (SDIP) as full exports, 50% and 25% export pumping capacity used in the South Delta Improvement Plan (SDIP), and no exports (as simply no water exported from the Delta South). This is the same method used by Tanaka et al. (2008, 2011).

In Tanaka et al. (2008, 2011), pumping plant capacities for the State Water Project (Banks), Central Valley Project (Jones), and the Contra Costa Water District (Contra Costa, Old River and Rock Slough) were modified. While the combined infrastructure capacity of these plants is large (16,500 cfs or 11.95 maf/year), they are regulated to operate at the D-1641 levels (pre-Wanger decision levels), of 11,800 cfs (maximum physical capacity of 8.54 maf/year) (Tanaka, 2008, 2011). Banks pumping capacity may increase as a result of the South Delta Improvement Project (SDIP) (USBR, 2006). The SDIP proposes increasing the State Water Project's Banks pumping capacity from its current monthly varying level to be allowed to pump an average of 8,500 cfs (maximum 6.16 maf/year).

The modeled full exports cases in this thesis use D-1641 pumping levels on all pumps except Banks; the SDIP pumping capacity expansion was applied to Banks pumping plant.

As noted in Tanaka et al. 2008, this increases the modeled full export capacity to 9.92 maf/year. However, other Delta restrictions, such as required Delta outflow and the economics of water use may keep actual pumping levels below capacity.

Reduced export capacities are derived from the modeled base case. As a result, 50% exports allows half the exports of the base case, (maximum pumping capacity of 4.97 maf/year) and 25% exports limits maximum exports to 2.48 maf/year. The "no export" case reduces the capacity of all Delta pumping plants discussed to zero. The reductions in pumping capacity were treated as a planned cutback, rather than a drastic and catastrophic change, allowing water users to prepare and adapt to these changes with other supply sources and conservation activities (Tanaka, 2008). Modeled and actual capacities appear in Figure 3:1 and Table 3:1.

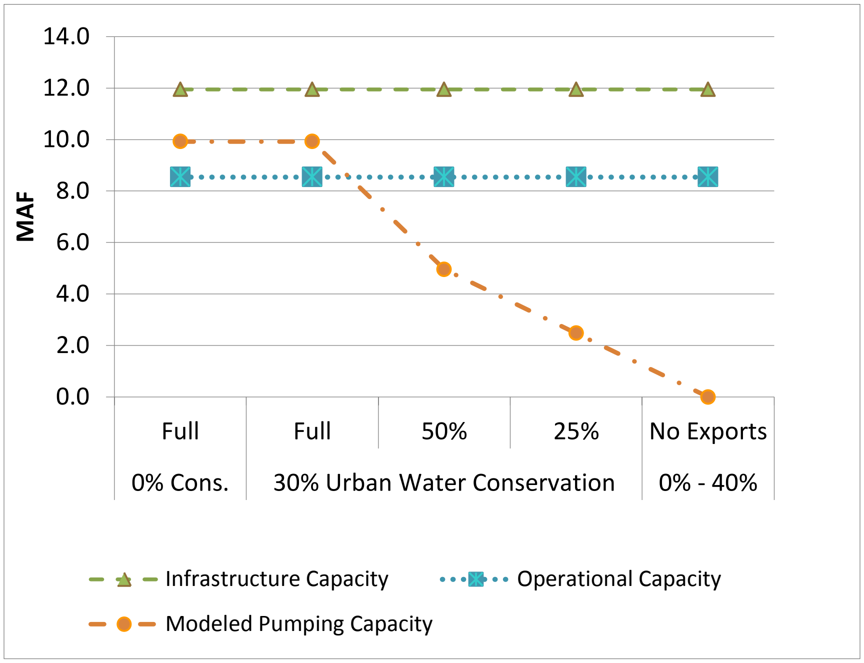


Figure 3:1: Modeled annual Delta export pumping capacities

Table 3:1: Modeled Delta export pumping capacity, current operational capacity, and infrastructure capacity (maf/yr)

Urban Conserv.	Delta Export Capacity Level	Modeled Pumping Capacity	Current Operational Capacity	Infrastructure Capacity
0%	Full	9.7	8.5	12.0
30%	Full	9.7	-	-
	50%	5.0	-	-
	25%	2.5	-	-
0%, 40%	No Exports	0.0	-	-

This table of Delta water export capabilities reflects a range of potential reductions in Delta water exports due to regulatory, water quality, or infrastructure causes.

Changed Costs for New Water Supply Technologies

All monetary calculations in this thesis will be in $2008. In this thesis, seawater desalination costs are reduced to $1,628 per acre feet ($2008) from previous CALVIN studies ($2,368/af). This reduced level of average costs is somewhat optimistic because estimates of seawater desalination costs for California range from $1,000/af to $3,200/af (DWR, 2009; Gleick et al. 2003; Fryer 2010).

As noted above, California water agencies currently recycle less than 580 taf of water annually, but by 2030, statewide capacity could rise to 1.85 – 2.25 maf (Water Plan, 2009). As used in Connell (2009) and previous CALVIN studies, urban municipal recycling capacity has the technical potential to use up to 50% of an urban area's wastewater flows (Tanaka, 2008). In CALVIN, up to 40% of an urban area's total supply can be from wastewater flow (Jenkins, 2000). For this thesis, in each of the runs, the combined total capacity of existing and expanded recycled water is approximately 2.1 maf/year. The cost of any expanded recycled water supply is set at $1480/af. Existing recycled water is modeled with costs of $518 – $1,480 ($2008) per acre-foot, to reflect different levels of treatment from non-potable direct use to potable indirect use. These numbers reflect the need to cover only operating costs, not the costs of new construction. (Newlin, 2001)

For both seawater desalination and water recycling, CALVIN requires a simplifying assumption that capital costs of capacity be represented within the variable operating costs of these facilities. This simplification allows water recycling and seawater desalination to be used far more flexibly than they would be in reality. Thus, desalinated and recycled water tend to be used more in infrequent drier periods, when it would actually not be possible or economical to quickly make such major capital expansions.

Urban water conservation

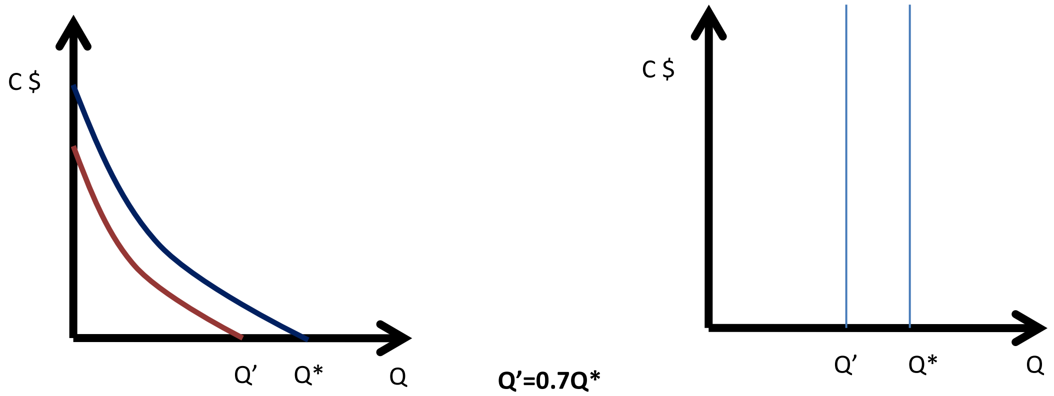
Urban residential water demand in CALVIN averages 221 gallons per capita per day (gpcd) for 2050 demand levels (Jenkins et al. 2004, Medellin-Azuara et al. 2008). This level of demand corresponds approximately to the estimated per capita urban water use in 2000, 220 gpcd (Department of Water Resources, 2005). Three levels of urban water conservation are modeled; no further conservation and 30 and 40 percent reductions from estimated 2050 residential water demands (Table 3.2 and 3.3).

Urban water conservation was estimated by multiplying the existing 2050 urban residential water demand penalty sets by 0.7 and 0.6, respectively. Both the demands, and the shortage cost for the demands were multiplied. This allows penalty functions for demand areas to retain their original slope, and the marginal willingness to pay (the price those who did have a shortage would be willing to pay for one unit more of water) to be comparable to runs without additional conservation; there is no demand hardening. Since CALVIN's idealized water markets trade water to those with the combined lowest delivery cost and highest scarcity cost, this effectively reduces urban demands while helping to prevent CALVIN from unduly favoring urban areas. The cost of implementing this conservation is added back in during post processing. Additional conservation incurs a water shortage or scarcity cost defined by the demand curve.

CALVIN has two kinds of water demands: economic and fixed. Fixed demands are constrained to receive a defined (fixed) quantity of water in each time step. These are typically smaller urban demands as well as high-valued commercial water uses. To conserve water for fixed demands, Q', the defined delivery, Q* is multiplied by 0.7 for thirty-percent water conservation, and 0.6 for forty-percent water conservation, as illustrated in Figure 3.2. Fixed demands are represented as constraints, with essentially infinite costs for shortage. Fixed demands are on the right-side chart in Figure 3.2.

Economic demands have a set amount of target water deliveries, Q*. Water scarcity costs are incurred when deliveries are less than the delivery target. Figure 2:1 also shows an example relationship between shortage and shortage cost. Shortage costs have a convex shape, meaning that larger shortages incur shortage costs at an increasing rate.

Industrial water demands were not changed for these runs. Industrial water demands are about 6% of urban water use today.



Elastic Demands

Fixed Demands

Note: Residential and Commercial use only - Industrial demand is not changed

Figure 3:2: Method used to model 30% urban water conservation

Table 3:2: Average per capita water use vs. percent conservation

	Per Capita Use (gpcd)			Total Urban Demand (maf)
	Coast*	**Inland****	**State**	**Statewide**
Base Case	185	296	221	12.8
30% Urban Water Conservation	129	207	154	9.2
40% Urban Water Conservation	111	177	132	7.9

*Coast includes San Francisco, Central Coast and South Coast Hydrologic Regions

**Inland includes Sacramento River, South Lahontan, San Joaquin River, Tulare Lake and Colorado River Hydrologic Regions

A 30% reduction in urban demands in CALVIN results in the same statewide per-capita use called for in the state's new 20x2020 program - 154 gpcd statewide. (This is so because the 20X2020 program takes the year 2005 as a baseline, and urban water use fell from 220 to 201 gpcd between 2000 and 2005 [Department of Water Resources, 2009]). CALVIN's 40% conservation is 132 gpcd. Table 3:2 illustrates this. While 30% conservation in CALVIN is not identical to 20x2020 implementation at a finer level, they are similar and will be compared.

Agricultural Demands

Agricultural demands were determined as outlined in Connell (2009), using the Statewide Agricultural Production model (Howitt et al. 2012). SWAP is a separate optimization model designed to maximize farm profit for agricultural production regions. Economic demands for agricultural water use and their associated penalty functions were derived from SWAP results and brought into CALVIN. One factor determining the penalty functions is the value per acre of different crops. Figure 3.3 illustrates these. For more specific agricultural water demand information, see Howitt et al. (2001, 2012).

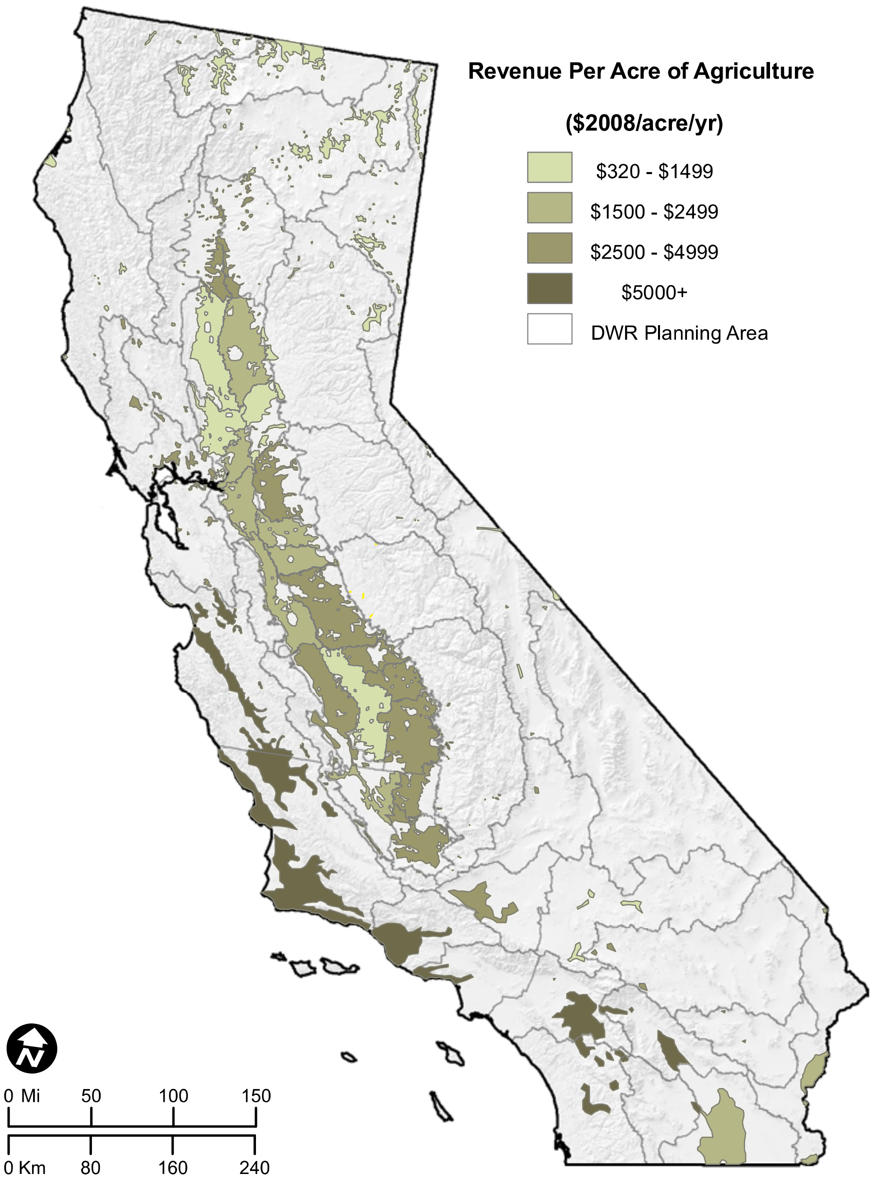


Figure 3:3: Revenue per acre of agriculture in CALVIN (Courtesy of Josue Medellín-Azuara, UC Davis)

Agricultural water conservation was not implemented prescriptively by regulatory processes as was done for urban conservation because the market-based agricultural conservation represented in the CALVIN model better represents the varied and flexible opportunities for agriculture throughout California. Agricultural conservation is indirectly implemented in CALVIN by using economic representation of demands and water transfers. Effectively the scarcity for agriculture can be interpreted as agricultural conservation, achieved largely by fallowing (Perry et al. 2009).

Expanded Storage

If a facility is ever used to capacity, CALVIN automatically calculates the economic value (willingness-to-pay) of the demand sectors to expand the facility's capacity by one unit –

equivalent to assessing the value of having an additional acre foot of storage capacity. This is referred to as the marginal benefit of expansion. Since the Bureau of Reclamation has proposed expanding Shasta, Pine Flat, and Friant Dams, the marginal benefits of these facilities are analyzed. The Bureau of Reclamation also is proposing building two new facilities, Temperance Flat and Sites reservoirs. Temperance Flat would be built upstream of Friant Dam (on Millerton Lake), so the marginal benefit of Millerton Lake will be assessed as well. Sites Reservoir would take water from the Sacramento River and store it off stream, so assessing its marginal benefit directly would require additional work outside of the confines of this thesis. The marginal benefits of other reservoirs on the Sacramento River upstream of where Sites Reservoir is proposed can provide some insight to its marginal benefit, however, and will be assessed. A more thorough analysis, such as that done by Null (2003) would be required for an in-depth assessment, but the method used here will provide a rough understanding of the benefits of this solution.

Modeled policies and conditions

This study explores the effects of additional urban water conservation under different levels of Delta exports, and climate conditions. CALVIN was used to model these different conditions. Delta exports range from no exports to full export levels (6 MAF/yr) following Tanaka et al. (2008, 2011). Two climate scenarios were analyzed; historical and a warm-dry form of climate change (GFDL A2 CM2.1) used in Connell-Buck et al. (2011) and Medellin-Azuara et al. (2008). Water conservation was included at levels of 30% and 40% of projected 2050 urban demands as detailed in Table 3:1.

Table 3:3 summarizes the combinations of climate, Delta export, and water conservation scenarios explored. Conservation runs for this thesis will be compared to previous runs by Connell- Buck et al. (2011) and Sicke (2011) without additional urban water conservation.

Table 3:3: Modeled policies and conditions

		Policy Options		Results
		Urban Conserv.	**Delta Exports**	**Model Source**
Model Runs	***Historical Climate***	***0%***	Full Exports	Connell-Buck et al. (2011), Sicke (2011)
			No Exports	
		30%	Full Exports	Current Study
			50%	
			25%	
			No Exports	
	Warmer, Drier Climate	***0%***	Full Exports	Connell-Buck et al. (2011), Sicke (2011)
			No Exports	
		30%	Full Exports	Current Study
			50%	
			25%	
			No Exports	
		40%	No Exports	

Chapter 4 : Modeling Results

This chapter examines model results indicating how California might economically adapt and integrate management to respond to changes in the Delta and climate using a diverse portfolio of actions, including substantial additional urban water conservation. For each case, deliveries and shortages, operations and scarcity costs, operational changes (including Delta exports), management portfolios, conservation, expanding facilities, and the cost of environmental flows are presented and discussed.

As with all long-term planning models, it is important interpret the results carefully. All models have limitations and this is particularly the case when applied for conditions in the distant future. Nevertheless, such computer models are useful for illustrating more likely and feasible outcomes for complex systems under a range of conditions. The insights and testing of ideas and pre-conceptions with models are among the most valuable contributions of modeling.

Water deliveries and shortages

Average water deliveries and scarcity to urban and agricultural areas are summarized and discussed below for broad areas of California. These are examined for the different urban water conservation, Delta export, and climate conditions presented in Chapter 3.

Recall that CALVIN represents about 90% of urban and agricultural water demands and about two-thirds of all state runoff. Urban and agricultural demands are divided by region. (Howitt, 2009, Medellín-Azuara, 2008).

Table 4:1: 2050 urban and agricultural demands by region (maf/yr)

	Urban Demands			Ag Demands
	Conservation Level			0 - 40% Cons.
	0%	30%	40%	
Sacramento Valley	2.01	1.42	1.23	7.86
San Joaquin Valley	1.70	1.22	1.06	4.05
Tulare Basin	1.54	1.07	0.89	8.87
Southern California	8.11	5.83	5.07	3.34
Total	13.35	9.54	8.24	24.12

Statewide and regional water deliveries for urban and agricultural uses are affected by levels of urban water conservation, water export capacity from the Delta, and climate, as seen in Table 4:1 and Table 4:2 and 4.3. Water scarcities (the target water demands minus water deliveries) appear in Table 4:4. Two patterns emerge: a warmer, drier climate or a reduction in Delta exports both result in agriculture receiving less water, and urban water conservation reduces scarcity more in a warmer, drier climate than under historical conditions.

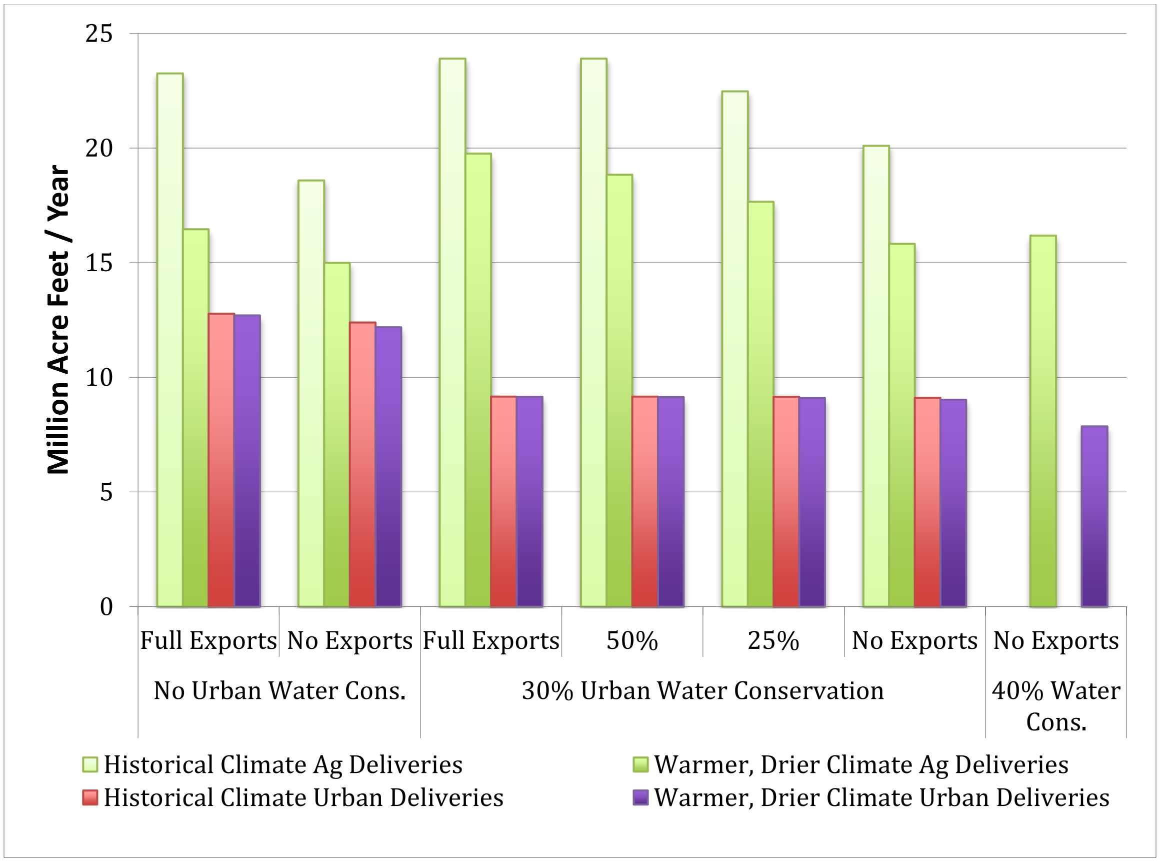


Figure 4:1: Statewide urban and agricultural water deliveries with different scenarios

Table 4:2: Statewide urban and agricultural deliveries (maf/year)

	Policy Options		Results		
	Urban Conserv.	Delta Export Level	Agriculture	Urban	Total
Historical Climate	0%	Full Exports	22.8	13.2	36.0
		No Exports	18.8	13.2	32.0
	30%	Full Exports	23.8	9.6	33.4
		50%	23.8	9.6	33.4
		25%	22.8	9.6	32.4
		No Exports	19.8	9.5	29.3
Warmer, Drier Climate	0%	Full Exports	16.3	13.0	29.3
		No Exports	15.0	13.2	28.2
	30%	Full Exports	19.3	9.6	28.9
		50%	19.1	9.6	28.7
		25%	17.2	9.5	26.7
		No Exports	15.8	9.4	25.2
	40%	No Exports	16.3	8.1	24.4

Both a warmer, drier climate or Delta export reductions affect water availability for much of California. With well-functioning water markets, available water often can be sold to urban users or higher-valued agricultural users. As a result, urban water users see little change in deliveries from full exports to no exports, as seen in Table 4:4. The drop in deliveries between no conservation and conservation cases is primarily from the 3.8 maf of additional urban water conservation.

After achieving these levels of water conservation, there is no longer sufficient urban demand to lead to significant urban water purchases from agriculture, so agriculture receives more water. Reductions in urban water demand increase water availability and use for agriculture, especially south of the Delta. However, reductions in urban use do not translate to a one-for-one increase in agricultural use. When statewide urban water demand is reduced by 3.8 maf/year, agricultural water use increases by about 1 maf/year (mostly south of the Delta) under a historical climate scenario. With a warmer, drier climate, which reduces overall water availability and deliveries statewide, the reduction in urban use leads to a larger shift toward agriculture (about 3 MAF/year). However, the increase in agricultural deliveries from urban conservation is much less (~1 maf/year) if Delta exports are ended.

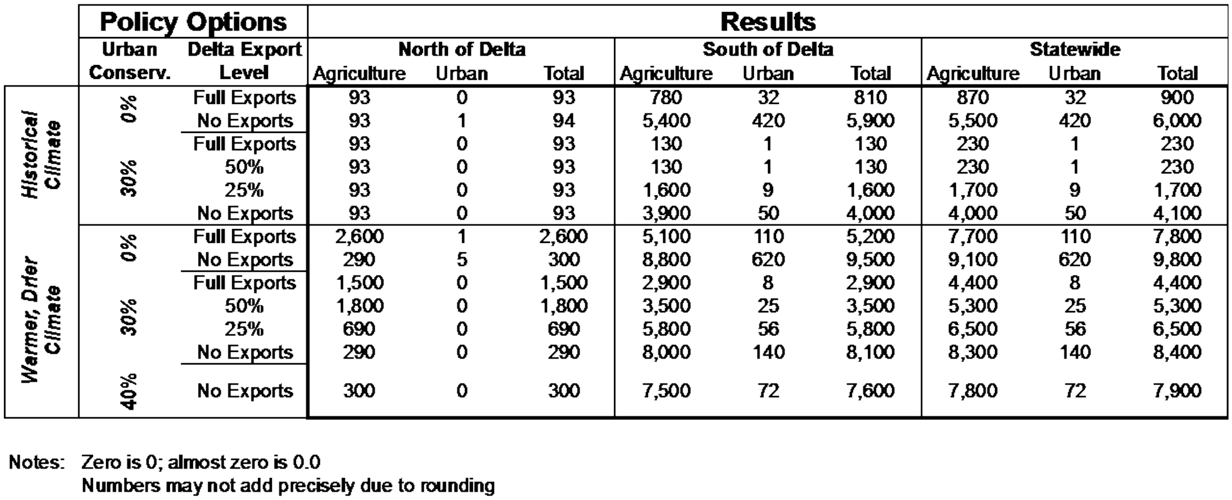
Table 4:4 illustrates that urban water conservation reduces agricultural water scarcity significantly and nearly eliminates urban water scarcity in California, regardless of climate scenario.

Ending Delta export capacity in a warmer, drier climate increases scarcity south of the Delta by approximately 4.1 maf/yr.

Table 4:3: Annual average water delivery in California (maf)

	Policy Options		**Results**								
	Urban Conserv.	**Delta Export Level**	**North of Delta**			**South of Delta**			**Statewide**		
			Agriculture	Urban	Total	Agriculture	Urban	Total	Agriculture	Urban	Total
Historical Climate	***0%***	Full Exports	7.8	2.0	9.8	15.0	11.2	26.2	22.8	13.2	36.0
		No Exports	7.8	2.0	9.8	11.0	11.2	22.2	18.8	13.2	32.0
	30%	Full Exports	7.8	1.4	9.2	16.0	8.1	24.1	23.8	9.6	33.4
		50%	7.8	1.4	9.2	16.0	8.1	24.1	23.8	9.6	33.4
		25%	7.8	1.4	9.2	15.0	8.1	23.1	22.8	9.6	32.4
		No Exports	7.8	1.4	9.2	12.0	8.0	20.0	19.8	9.5	29.3
Warmer, Drier Climate	***0%***	Full Exports	5.3	2.0	7.3	11.0	11.0	22.0	16.3	13.0	29.3
		No Exports	7.6	2.0	9.6	7.4	11.2	18.6	15.0	13.2	28.2
	30%	Full Exports	6.3	1.4	7.7	13.0	8.1	21.1	19.3	9.6	28.9
		50%	6.1	1.4	7.5	13.0	8.1	21.1	19.1	9.6	28.7
		25%	7.2	1.4	8.6	10.0	8.0	18.0	17.2	9.5	26.7
		No Exports	7.6	1.4	9.0	8.2	7.9	16.1	15.8	9.4	25.2
	40%	No Exports	7.6	1.2	8.8	8.7	6.9	15.6	16.3	8.1	24.4

Table 4:4: Average annual scarcity in California (taf)



	Policy Options		Results								
	Urban Conserv.	Delta Export Level	North of Delta			South of Delta			Statewide		
			Agriculture	Urban	Total	Agriculture	Urban	Total	Agriculture	Urban	Total
Historical Climate	0%	Full Exports	93	0	93	780	32	810	870	32	900
		No Exports	93	1	94	5,400	420	5,900	5,500	420	6,000
	30%	Full Exports	93	0	93	130	1	130	230	1	230
		50%	93	0	93	130	1	130	230	1	230
		25%	93	0	93	1,600	9	1,600	1,700	9	1,700
		No Exports	93	0	93	3,900	50	4,000	4,000	50	4,100
Warmer, Drier Climate	0%	Full Exports	2,600	1	2,600	5,100	110	5,200	7,700	110	7,800
		No Exports	290	5	300	8,800	620	9,500	9,100	620	9,800
	30%	Full Exports	1,500	0	1,500	2,900	8	2,900	4,400	8	4,400
		50%	1,800	0	1,800	3,500	25	3,500	5,300	25	5,300
		25%	690	0	690	5,800	56	5,800	6,500	56	6,500
		No Exports	290	0	290	8,000	140	8,100	8,300	140	8,400
	40%	No Exports	300	0	300	7,500	72	7,600	7,800	72	7,900

Notes: Zero is 0; almost zero is 0.0
Numbers may not add precisely due to rounding

As urban water conservation does not directly translate into more agricultural water deliveries, only some of the reduced urban use is translated into reduced water scarcity. Table 4:5 illustrates how much scarcity is reduced in each urban conservation scenario. When there is little scarcity to begin with, conserving water does not substantially increase supply. Under historical climate conditions, California averages 900 taf/yr of water scarcity. Conserving 3.8 maf/yr of urban water (30%) reduces overall average scarcity by only 650 taf/yr. With full export capacity, there was little scarcity to begin with and reduced urban use in wet years is largely unavailable for agricultural and urban uses, so only 17% of conserved water is used to reduce average scarcity.

With a warmer, drier climate, urban water conservation plays a greater role in diminishing water scarcity. With a warmer, drier climate, scarcity decreases 3.3 maf when 3.8 maf of urban water is conserved. Approximately 89% of the conserved water is used to reduce scarcity in California under full exports and a drier, warmer climate. However, when Delta exports are not allowed, it is more difficult to make conserved urban water available for other agricultural and urban users. (Such urban conservation effectiveness is likely to vary locally however, being higher in coastal areas dependent on the Delta.)

Table 4:5: Conserved urban water utilization

	Urban Conservation Level	Delta Export Level	Conserved urban water (maf/year)	Scarcity reduction (maf/year)	% Conserved water utilized
Historical	**30%**	**Full Exports**	3.81	0.65	17%
	30%	**No Exports**	3.81	1.9	50%
Warmer, Drier Climate	**30%**	**Full Exports**	3.81	3.4	89%
	30%	**No Exports**	3.81	1.4	37%
	40%	**No Exports**	5.11	1.9	37%

Export restrictions negate the positive effects of urban water conservation. In both climate scenarios, reducing Delta exports increases statewide scarcity. With historical climate conditions, scarcity North of the Delta is already low. Restricting exports increases scarcity South of the Delta up to four times more than the base case. In a warmer, drier climate, scarcity occurs statewide. If urban demands are reduced 30% due to conservation, restricting exports increases scarcity less South of the Delta. Northern California's scarcity decreases as exports are restricted, but with much greater water scarcity South of the Delta.

Figure 4:2 illustrates agricultural water deliveries across the state, as a percent of target water use, for selected Delta pumping capacity and urban water conservation levels given historical climate conditions. Table 4:7 illustrates that with full Delta exports, approximately 96% of demands are met statewide. With no Delta exports, only 86% of demands are met statewide, and 77% of agricultural demands are met. Ceasing Delta exports concentrates agricultural water scarcity south of the Delta, decreasing deliveries there to 67% of demands. Urban conservation allows all agriculture areas to receive at least 83% of the water demanded statewide and 76% south of the Delta.

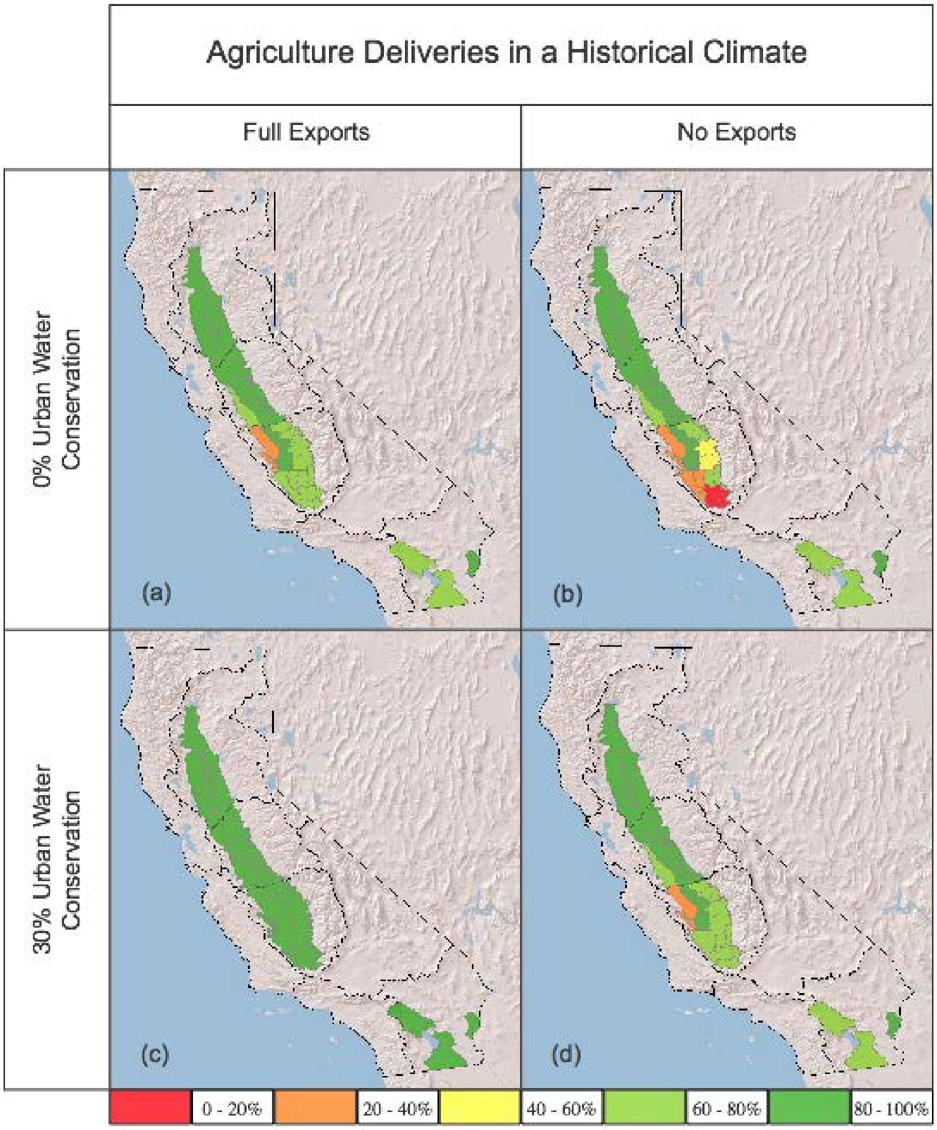


Figure 4:2: Percent of agricultural water demands met in a historical climate

A warmer, drier climate generates more widespread scarcity, or shortage, than a historical climate, and Delta export reductions aggravate this scarcity. Figure 4:3 depicts the percentage of agricultural demands supplied for several conditions with a drier, warmer climate.

Without urban conservation, scarcity is widespread, even with optimal management. As was found in Connell-Buck et al. (2011), in a warmer, drier climate with full exports, statewide deliveries are approximately 78% of demands overall and only 68% of agricultural demands are met. With 30% urban water conservation, deliveries rise to 86% of demand statewide and 82% for agriculture. Delta export capacity at 25% of full capacity, combined with 30% urban water conservation, allows 73% of agricultural demands to be met statewide and 64% south of the Delta.

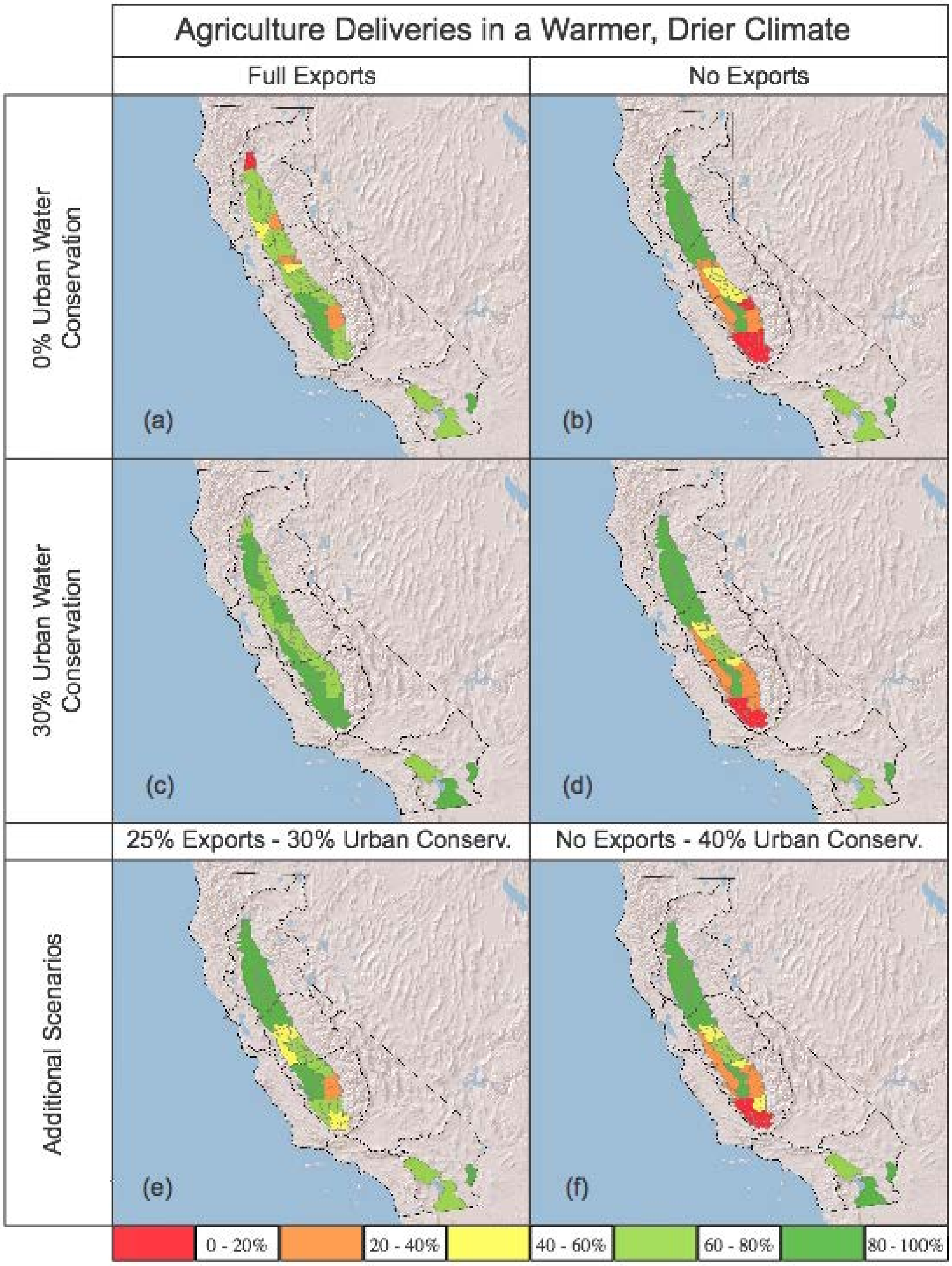


Figure 4:3: Percent of agricultural demands met in a warmer, drier climate

Eliminating Delta exports exacerbates agricultural scarcity and focuses it on the southern Central Valley. This increases with a drier, warmer climate. With no Delta exports and no urban conservation, 62% of agricultural demands are supplied statewide, but only 46% south of the Delta (Tables 4:6 and 4:7). Severing Delta exports concentrates agricultural water scarcity in the southern Central Valley. Urban conservation allows all agricultural areas to receive at least 66% of the water demanded statewide and 51% south of the Delta. With an increase in urban water conservation to 40%, only 1% more agricultural demand is supplied than with 30% urban conservation statewide. South of the Delta, however, 3% more demands are supplied than in the 30% case.

Table 4:6: Average agricultural demands supplied annually (maf)

	Policy Options		Results				
	Urban Conserv.	Delta Export Level	Sacramento Valley	San Joaquin Valley	Tulare Basin	Southern California	Total
Historical Climate	0%	Full Exports	7.8	4.0	8.9	2.6	23.3
		No Exports	7.8	3.6	4.7	2.5	18.6
	30%	Full Exports	7.8	4.0	8.9	3.2	23.9
		50%	7.8	4.0	8.9	3.2	23.9
		25%	7.8	3.9	8.1	2.7	22.5
		No Exports	7.8	3.8	5.8	2.7	20.1
Warmer, Drier Climate	0%	Full Exports	5.3	2.3	6.4	2.5	16.5
		No Exports	7.6	2.0	3.0	2.5	15.0
	30%	Full Exports	6.3	3.1	7.5	2.7	19.8
		50%	6.1	2.8	7.2	2.7	18.8
		25%	7.2	2.2	5.6	2.7	17.7
		No Exports	7.6	2.1	3.4	2.7	15.8
	40%	No Exports	7.6	2.2	3.7	2.9	16.3

Table 4:7: Percent of agricultural demands supplied annually (%)

	Policy Options		Results				
	Urban Conserv.	Delta Export Level	Sacramento Valley	San Joaquin Valley	Tulare Basin	Southern California	Total
Historical Climate	0%	Full Exports	99	100	100	77	96
		No Exports	99	90	53	74	77
	30%	Full Exports	99	100	100	96	99
		50%	99	100	100	96	99
		25%	99	95	91	82	93
		No Exports	99	94	65	82	83
Warmer, Drier Climate	0%	Full Exports	67	57	72	74	68
		No Exports	96	49	34	74	62
	30%	Full Exports	81	78	85	82	82
		50%	78	70	81	82	78
		25%	91	53	63	82	73
		No Exports	96	52	39	82	66
	40%	No Exports	96	53	41	88	68

Urban water conservation decreases scarcity for agriculture statewide. In all but no-export cases, conservation is able to reduce scarcity below that of the base case statewide. Increasing urban conservation from 30 to 40% does not significantly change this.

Since urban areas are willing to pay more for water, with effective water markets, urban demands are largely supplied, albeit even with higher costs to urban water users.

Table 4:8 shows average regional water demands for different conservation scenarios. (Recall that urban conservation was applied to residential use, and not industrial use. This explains why 30% urban conservation numbers are slightly lower.) Table 4.8 shows water deliveries to major regions in California. Table 4:9 simply divides each region delivery by its respective target demand.

Table 4:8: Average annual urban demands supplied by region (taf)

	Policy Options		**Results**				
	Urban Conserv.	**Delta Export Level**	**Sacramento Valley**	**San Joaquin Valley**	**Tulare Basin**	**Southern California**	Total
Historical Climate	***0%***	Full Exports	1662	1634	1406	8075	12777
		No Exports	1660	1605	1396	7731	12392
	30%	Full Exports	1179	1171	985	5825	9160
		50%	1179	1171	985	5825	9160
		25%	1179	1171	984	5817	9152
		No Exports	1179	1171	984	5776	9111
Warmer, Drier Climate	***0%***	Full Exports	1660	1626	1406	8007	12700
		No Exports	1657	1586	1302	7639	12184
	30%	Full Exports	1179	1171	984	5818	9153
		50%	1179	1170	984	5802	9136
		25%	1179	1166	984	5776	9106
		No Exports	1179	1165	982	5698	9025
	40%	No Exports	1019	1013	812	5018	7861

Urban water conservation counters the effects of Delta export reductions up to the 25% export capacity level for both the historical climate and a warmer, drier climate, but cannot fully counter the increased scarcity from completely halting Delta exports. Even with no Delta exports, Table 4:9 shows that about 99% of California's urban demands are supplied in a historical climate, no export case and 98% in a warmer, drier climate. Conserving 40% of urban demands allows 98.5% of urban demands to be supplied. Scarcity without Delta exports remains concentrated in Southern California.

Table 4:9: Average percent of urban demands supplied in each scenario.

	Policy Options		Results				
	Urban Conserv.	Delta Export Level	Sacramento Valley	San Joaquin Valley	Tulare Basin	Southern California	Total
Historical Climate	0%	Full Exports	100%	100%	100%	100%	100%
		No Exports	100%	98%	99%	95%	97%
	30%	Full Exports	100%	100%	100%	100%	100%
		50%	100%	100%	100%	100%	100%
		25%	100%	100%	100%	100%	100%
		No Exports	100%	100%	100%	99%	99%
Warmer, Drier Climate	0%	Full Exports	100%	100%	100%	99%	99%
		No Exports	100%	97%	93%	94%	95%
	30%	Full Exports	100%	100%	100%	100%	100%
		50%	100%	100%	100%	100%	100%
		25%	100%	100%	100%	99%	99%
		No Exports	100%	99%	100%	98%	99%
	40%	No Exports	100%	100%	100%	99%	99%

Water scarcity and operating costs

The costs of water shortages and water operations are described in this section for the range of urban water conservation, Delta export, and climate conditions examined. In examining these results, note that the cost estimates do not include the costs of implementing the urban conservation scenarios. In reality, such conservation would incur significant up-front costs, at least in a transition period where existing water users change plumbing, appliances, and landscaping to lower water-using technologies and plants. However, by allowing energy as well as water savings, many indoor conservation measures can actually save costs over the longer run (See Cooley et al. 2010 for some examples, including low-flow showerhead replacements, cost-efficient front-loading clothes washers, faucet aerators, and a variety of commercial appliances). Following a transition period, the assumption of no additional costs would be consistent with a shift in behaviors and tastes such that the new norms do not constitute a great overall hardship. Other advanced economies with semiarid climates, such as Spain, Australia, and Israel, where per capita urban water use is much lower, provide some models for California in this regard (Hanak et al. 2011).

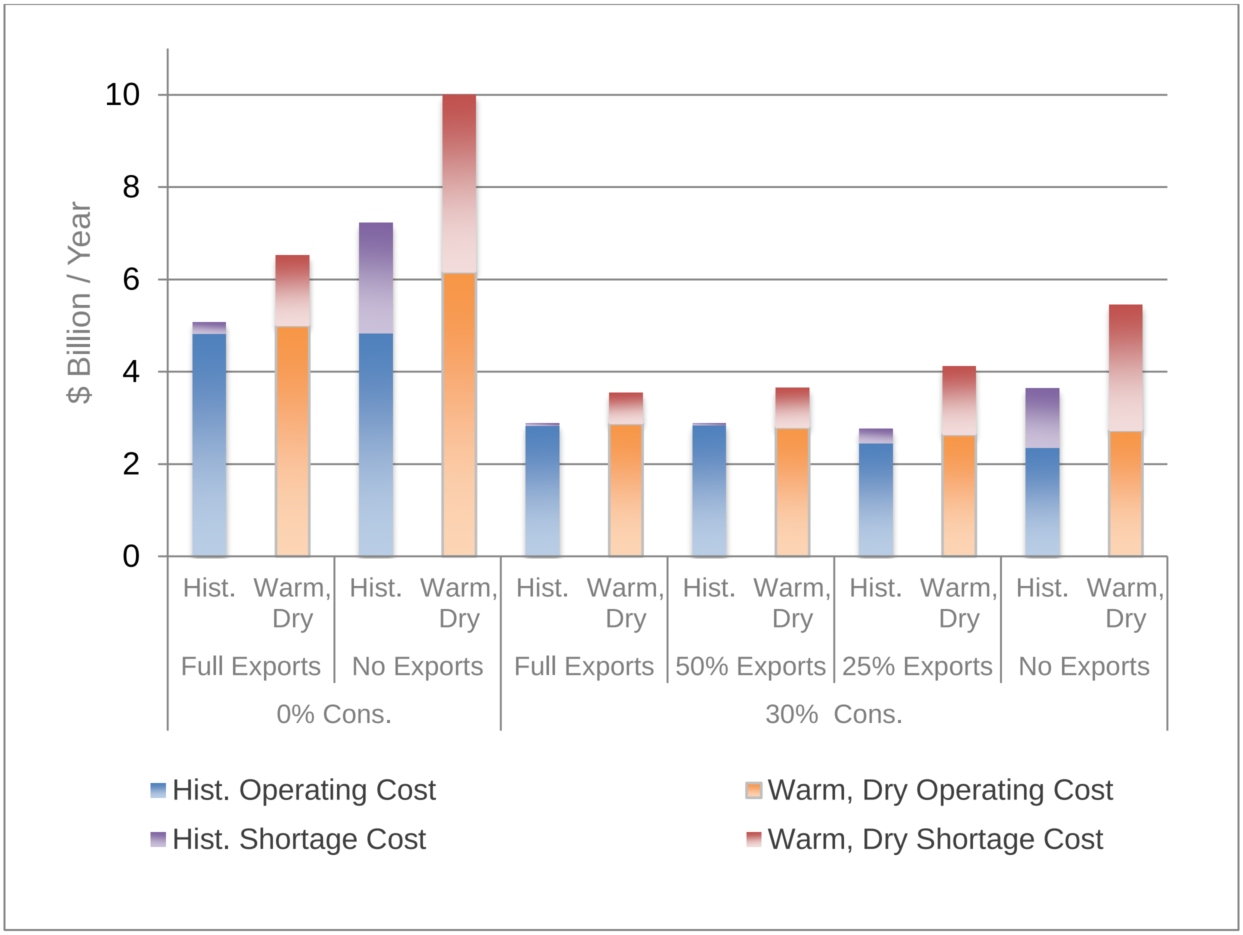


Figure 4:4: Average annual statewide operating and scarcity costs for each scenario, excluding conservation implementation costs.

Table 4:10: Average statewide operating and scarcity costs for each case, excluding conservation implementation costs ($ billions/yr).

	Policy Options		**Results**		
	Urban Conserv.	**Delta Pumping Capacity**	**Operating Cost**	**Scarcity Cost**	**Total Cost**
Historical Climate	***0%***	Full Exports	$4.8	$0.2	$5.1
		No Exports	$4.8	$2.4	$7.2
	30%	Full Exports	$2.8	$0.0	$2.9
		50%	$2.8	$0.0	$2.9
		25%	$2.5	$0.3	$2.8
		No Exports	$2.4	$1.3	$3.6
Warmer, Drier Climate	***0%***	Full Exports	$5.0	$1.5	$6.5
		No Exports	$6.2	$3.9	$10.0
	30%	Full Exports	$2.9	$0.7	$3.5
		50%	$2.8	$0.9	$3.6
		25%	$2.6	$1.5	$4.1
		No Exports	$2.7	$2.7	$5.4
	40 %	No Exports	$1.9	$2.4	$4.4

Notes: Zero is 0. Almost zero is 0.0.

Figure 4:4 and Table 4:10 illustrate that 30% urban water conservation saves California between \$2.2 and \$4.6 billion annually, not counting the implementation costs of urban conservation. Under both climate conditions, the operational cost savings of conservation and reduced pumping more than compensate for the increased scarcity cost of decreased Delta exports (again neglecting conservation implementation costs).

Total statewide costs are more strongly affected by conservation than climate change. Figure 4:4 illustrates that 30% urban water conservation annually saves California an average of \$2.2 to \$3.0 billion in full-exports cases and \$3.6 to \$4.6 billion for no export cases.

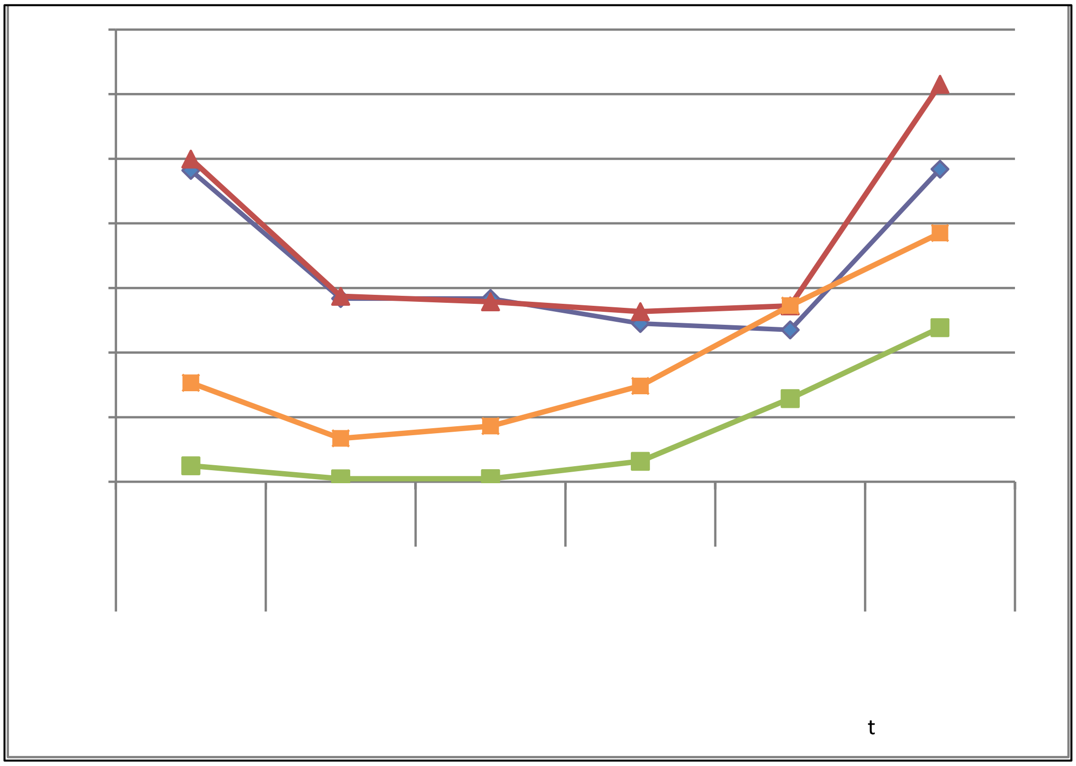


Figure 4:5: How scarcity and operating costs change with Delta export and conservation conditions

In Figure 4:5, scarcity follows the same shape between historical and a warmer, drier climates, but the costs are least \$1 billion/yr greater for a warmer, drier climate. Scarcity costs are, on average \$2.2 billion less than operating costs for all scenarios.

Much of the conservation savings comes from lower operations costs (Wilkinson 2000). Figure 4:5 illustrates that the operations costs between the drier, warmer climate and the historical climate are nearly identical, as are the savings. Operations costs drop at least \$2 billion annually with 30% urban water conservation.
Table 4:11 details operation costs to show the sources of this cost savings. In cases with Delta exports, much of the savings comes from decreased pumping and treatment costs. In no-exports cases, however, the savings comes largely from less recycled water and seawater desalinization use. For example, in a warmer, drier climate, CALVIN estimates

that $2.3 billion/yr would be spent on seawater desalination without Delta exports. However, with 30% additional urban conservation, this number drops to $35 million. In Table 4:11, hydropower provides revenue, so it appears as a negative cost.

Table 4:11: Annual average statewide net operation costs ($ million)

	Policy Options		Results						
	Urban Conserv.	Delta Export Level	Groundwater Pumping	Surface Water Pumping	Surface Water Treatment	Recycled Water	Seawater Desalination	Hydropower Benefits	Total Net Operating Costs
Historical Climate	*0%*	Full Exports	805	1,958	2,087	341	78	-449	4,820
		No Exports	712	959	1,515	1,617	314	-280	4,836
	30%	Full Exports	772	1,064	1,235	68	0	-306	2,833
		50%	772	1,058	1,236	68	0	-301	2,833
		25%	760	662	1,158	72	0	-207	2,445
		No Exports	699	505	1,123	184	30	-197	2,344
Warmer, Drier Climate	*0%*	Full Exports	735	2,020	2,187	391	78	-424	4,986
		No Exports	637	458	1,162	1,696	2,301	-111	6,142
	30%	Full Exports	754	976	1,279	66	0	-215	2,859
		50%	733	885	1,252	91	4	-192	2,774
		25%	666	754	1,239	131	4	-176	2,619
		No Exports	622	349	1,010	801	35	-110	2,706
	40%	No Exports	620	292	867	233	17	-110	1,918

Table 4:12 shows operating costs north and south of the Delta. The biggest differences in operations costs are major decreases with reductions in water exports and increases with a drier, warmer climate.

Table 4:12: California's annual operating costs by region ($ billion)

	Policy Options		Results		
	Urban Conserv.	Delta Export Level	North of Delta	South of Delta	Statewide
Historical Climate	*0%*	Full Exports	0.29	4.53	4.82
		No Exports	0.32	4.52	4.84
	30%	Full Exports	0.23	2.60	2.83
		50%	0.23	2.60	2.83
		25%	0.24	2.21	2.44
		No Exports	0.25	2.09	2.34
Warmer, Drier Climate	*0%*	Full Exports	0.29	4.69	4.99
		No Exports	0.46	5.69	6.14
	30%	Full Exports	0.23	2.63	2.86
		50%	0.24	2.53	2.77
		25%	0.25	2.37	2.62
		No Exports	0.27	2.44	2.71
	40%	No Exports	0.23	1.69	1.92

Notes: Numbers may not add precisely due to rounding

Scarcity costs are distributed fairly evenly across the state, but export reductions increase and focus scarcity costs on the southern Central Valley. Table 4:13 illustrates scarcity cost by region in California. Urban areas can maintain low scarcity costs through water markets, recycling and seawater desalination (all of which come at some costs to urban areas), along with higher agricultural scarcity and scarcity costs. When urban water conservation is implemented, at 25% Delta export capacity, agricultural scarcity is approximately equal to full exports, pre-conservation case levels.

Table 4:13: Average annual scarcity costs by region and demand ($ million)

	Policy Options		Results								
	Urban Conserv.	Delta Export Level	North of Delta			South of Delta			Statewide		
			Agriculture	Urban	Total	Agriculture	Urban	Total	Agriculture	Urban	Total
Historical Climate	0%	Full Exports	13	0	13	190	47	240	200	47	250
		No Exports	13	2	15	1,800	590	2,400	1,800	590	2,400
	30%	Full Exports	13	0	13	33	0.8	34	46	0.8	47
		50%	13	0	13	34	1.3	35	46	1.3	48
		25%	13	0	13	300	7.6	300	310	7.6	320
		No Exports	13	0	13	1,200	43	1,300	1,200	43	1,300
Warmer, Drier Climate	0%	Full Exports	340	1.9	340	1,100	110	1,200	1,400	110	1,500
		No Exports	40	7.7	48	2,900	900	3,800	2,900	900	3,900
	30%	Full Exports	150	0.0	150	510	6.5	520	670	6.5	670
		50%	190	0.0	190	650	18	670	840	18	860
		25%	70	0.0	70	1,400	44	1,400	1,400	44	1,500
		No Exports	40	0.5	40	2,500	150	2,700	2,600	150	2,700
	40%	No Exports	41	0.0	41	2,300	63	2,400	2,400	63	2,400

Notes: Zero is 0; almost zero is 0.0
Numbers may not add precisely due to rounding

Delta water exports

Delta water exports change with additional urban water conservation, reductions in export pumping capacity, and a drier, warmer climate, as shown in Figure 4:6 and Table 4:14. The 3.8 maf/year reduction in urban water demand for 2050 by itself reduces water exports from the Sacramento-San Joaquin Delta by 1.8 maf/year with historical climate conditions. This implies a lack of large latent agricultural demands by 2050 to absorb any remaining water use reductions by cities. Reductions in water export capacity from the Delta more directly reduce water export volumes, with increasing effect at greater reductions in export capacity. When Delta export pumping capacity is reduced, the remaining capacity is more fully utilized.

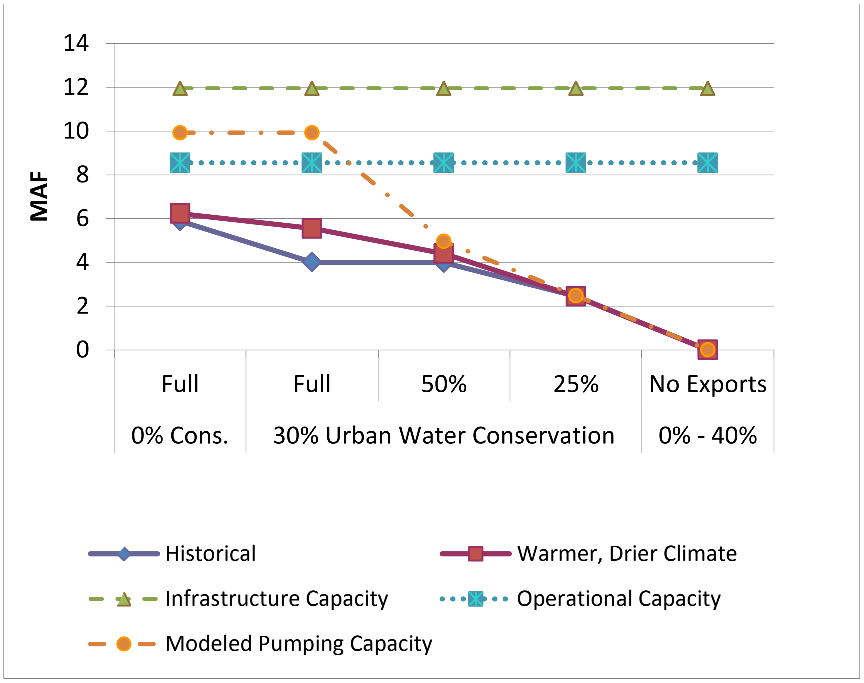


Figure 4:6: Average annual Delta pumping volume for each pumping capacity and climate scenario.

Table 4:14: Average annual Delta pumping for each case (maf)

Urban Conserv.	Delta Export Level	Historical Climate	Warmer, Drier Climate	Modeled Capacity
0%	Full Exports	5.89	6.23	9.92
30%	Full Exports	4.01	5.55	9.92
	50%	3.99	4.40	4.96
	25%	2.45	2.44	2.48
0% - 40%	No Exports	0	0	0

Notes: Zero is 0; almost zero is 0.0

Adding a drier, warmer climate largely negates the effects of 30% urban water conservation on Delta exports, with water exports largely returning to pre-conservation conditions (unless restricted by export capacity constraints). In Table 4:14, with a drier, warmer climate, only 6.23 maf/yr is pumped from the Delta, despite scarcity downstream, about 0.3 maf/yr more than with a historical climate and without urban conservation.

Despite having a larger pumping capacity and scarcity downstream, Delta exports remain close to typical levels seen in the recent past, at only 6.23 maf. Tanaka et al. (2008, 2011) note that despite the 9.92 maf/year theoretical export capacity, a combination of current size of the California Aqueduct and the Delta Mendota Canal, limits on San Luis reservoir (or the model representing them) and Delta outflow requirements may not allow much more water through. However, when substantial urban water conservation is implemented, export pumping drops below 6.0 maf/year even with a warmer-drier climate, which prompts agricultural users South of the Delta to increase Delta export demand. When export capacities are reduced, annual Delta pumping capacity is more fully utilized. At 50% of the expanded export capacity (4.96 maf/year), between 80% and 89% of the capacity is used. When only 25% of the expanded export capacity is allowed (2.48 maf/year), 98% - 99% of the capacity is used.

Shifting management and supply portfolios

The economical mix of water management actions employed varies significantly for the different water conservation, Delta export, and climate cases examined.

Figure 4:7 provides an overview of how California's urban and agricultural users' water portfolios shift under different scenarios. Consistent with Tanaka et al. (2008, 2011), surface water is the largest water source for both urban and agricultural users, and groundwater is the second most used. Without Delta exports, scarcity increases for agricultural users. Urban users see some increase in scarcity, but use additional recycling and seawater desalination. Urban water conservation decreases scarcity for agriculture and urban users, and also reduces the amount of water recycling and desalination.

Figure 4:8 shows water portfolios south of the Delta. Agriculture south of the Delta bears much of the scarcity from reduced exports. With historical climate conditions and full Delta export capacity, there is little scarcity south of the Delta. If Delta exports are ended, roughly one third of agricultural demands are not supplied south of the Delta. With 30% urban conservation, agricultural scarcity drops to about 21%. A warmer, drier climate increases scarcity statewide. At full Delta export capacity, scarcity is roughly evenly distributed statewide with about one-fourth of the state's agriculture demands not supplied. With export reductions, however, water scarcity is focused south of the Delta. With no Delta exports, north of Delta demands are largely supplied, but roughly half of agricultural demands south of the Delta are not. Urban water conservation helps reduce this scarcity.

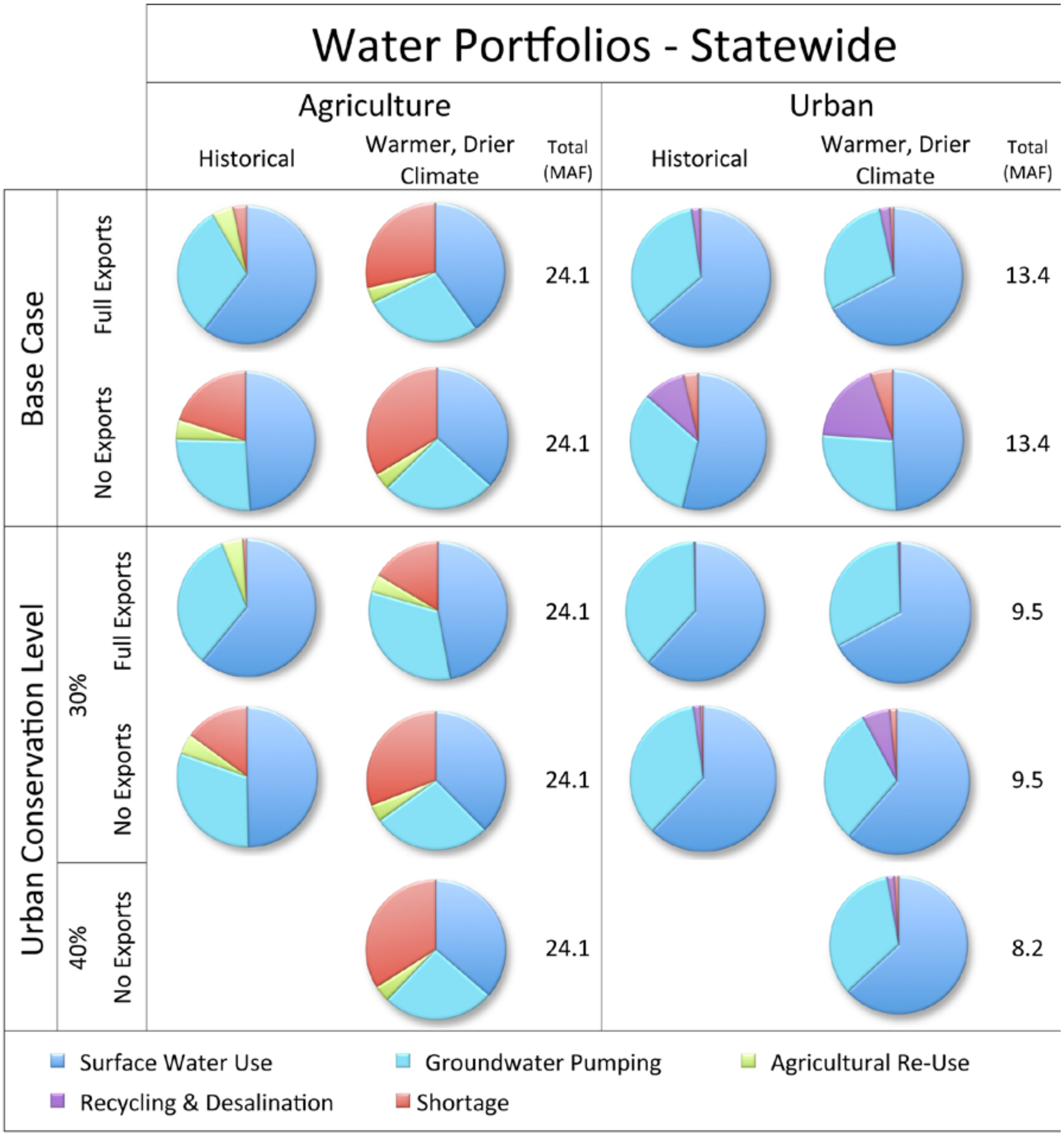


Figure 4:7: Statewide water supply portfolios of agriculture and urban water users

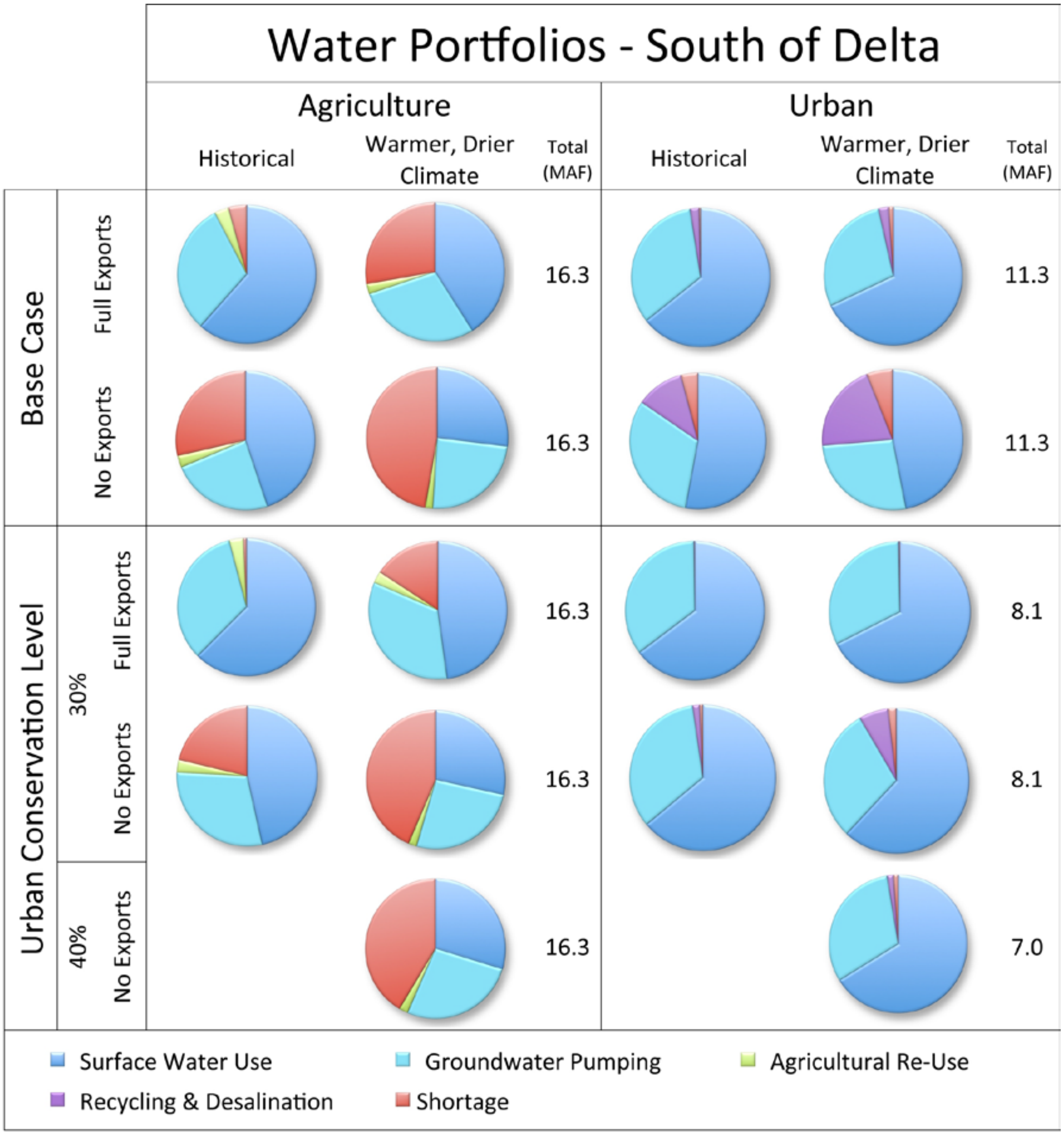


Figure 4:8: Water supply portfolios in Southern California

Recycled Water and Seawater Desalination

Recycling and desalination are primarily used when Delta exports are not available and when urban conservation is not implemented. Table 4:15 and Table 4:17 and Figure 4:9 - Figure 4:13 illustrate that in all cases with some Delta exports, less than 40 taf/year of water is generated (on average) through seawater desalination and 270 taf/year (on average) through wastewater recycling (often with considerable variability within years). Note that representation of desalination and reuse in CALVIN is represented imperfectly in having capital costs represented as variable costs, making availability of these sources optimistic. Recycling and desalination use is similar between climate scenarios at full exports (less than 300 taf/year for recycled water and less than 40 taf/year for seawater desalination). When Delta exports are stopped, recycled water use jumps to over 1000 taf/yr in each case. Seawater desalination use is more sensitive to the climate conditions. With a historical climate, when Delta exports are stopped, desalination use rises by only 110 taf/year. In a warmer, drier climate, ending Delta exports increases seawater desalination use to over 1.1 maf/year.

Urban water conservation substantially reduces both recycled water and desalination use. It reduces recycled water use by at least half, and reduces seawater desalination use to less than 25 taf/year. This drop reflects CALVIN's goal to minimize costs. To use more seawater desalination or recycled water would not be cost effective. As Figure 4:11 – 4.12 illustrate, Los Angeles' and San Diego's use of recycled water and seawater desalination drops considerably with greater urban water conservation. Conservation allows these areas to reduce use of more expensive water supply options.

Table 4:15: Average annual urban water recycling and seawater desalination (taf)

	Policy Options		Results	
	Urban Conserv.	**Delta Export Level**	**Seawater Desalination**	**Recycled water**
Historical Climate	***0%***	Full Exports	37	198
		No Exports	152	1,099
	30%	Full Exports	0	26
		50%	0	27
		25%	0	33
		No Exports	19	125
Warmer, Drier Climate	***0%***	Full Exports	38	270
		No Exports	1,110	1,179
	30%	Full Exports	0	38
		50%	2.8	60
		25%	2.8	85
		No Exports	22	562
	40%	No Exports	10	163

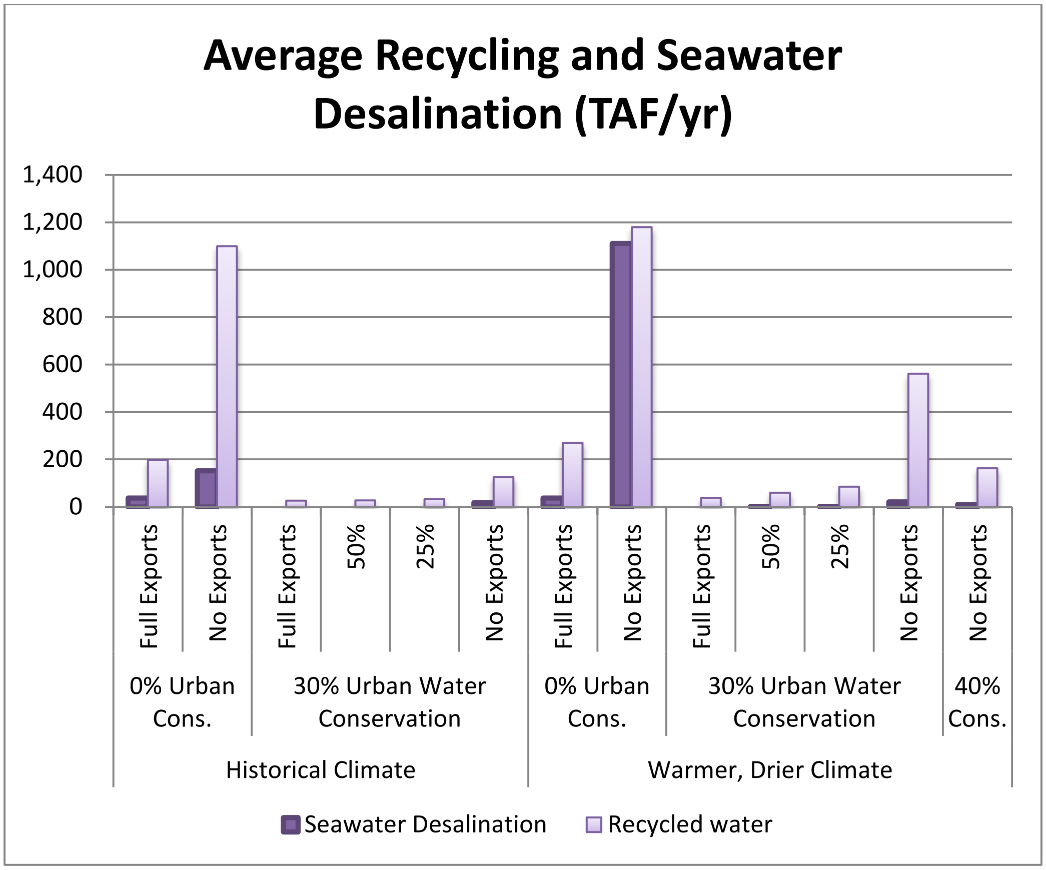


Figure 4:9: Average annual recycling and seawater desalination in California (taf)

Table 4:16 shows how much recycled water comes from existing and expanded recycled water capacity. Even with urban water conservation in a historical climate, while 13 taf/year of recycled water comes from the existing capacity, another 13 taf/year also comes from expanded capacity. Only 3% of existing capacity is utilized, yet CALVIN found it optimal to also use some expanded recycled water capacity. For that run, there was plenty of existing statewide capacity, but it was not all located where the water was demanded. This trend continues for other scenarios. When Delta exports stop, the location(s) recycled water is demanded shift sufficiently that expanded recycled water capacity used exceeds existing capacity. For that scenario, only two recycling plants were being used, an existing capacity in Santa Barbara, San Louis Obispo area, and expanded capacity in Contra Costa. Figure 4:11 and Figure 4:12 indicate where recycling is taking place in the model, in per capita use, for a selection of scenarios.

The timing of recycled water and seawater desalination use is volitile. The figure below shows how much recycled water is generated from expanded vs. existing recycling. As a note, existing recycled water has a monthly capacity of approximately 36 taf and expanded recycling has a monthly capacity of approximately 137 taf. This suggests that neither existing or expanded recycling is used near capacity statewide, but may be used to capacity for specific locations. Existing recycling is used continously throughout the year, with small increases in the dry season. Expanded recycling, however, appears to be largely used in the summer. This pattern is because CALVIN has a flat per acre foot cost for recycling water, so it generates water only when needed. To dampen the peaks of expanded use, some storage , either surface or underground, could be utilized. Seawater desalination is still more volital, as discussed in the seawater desalination study appendix to this thesis.

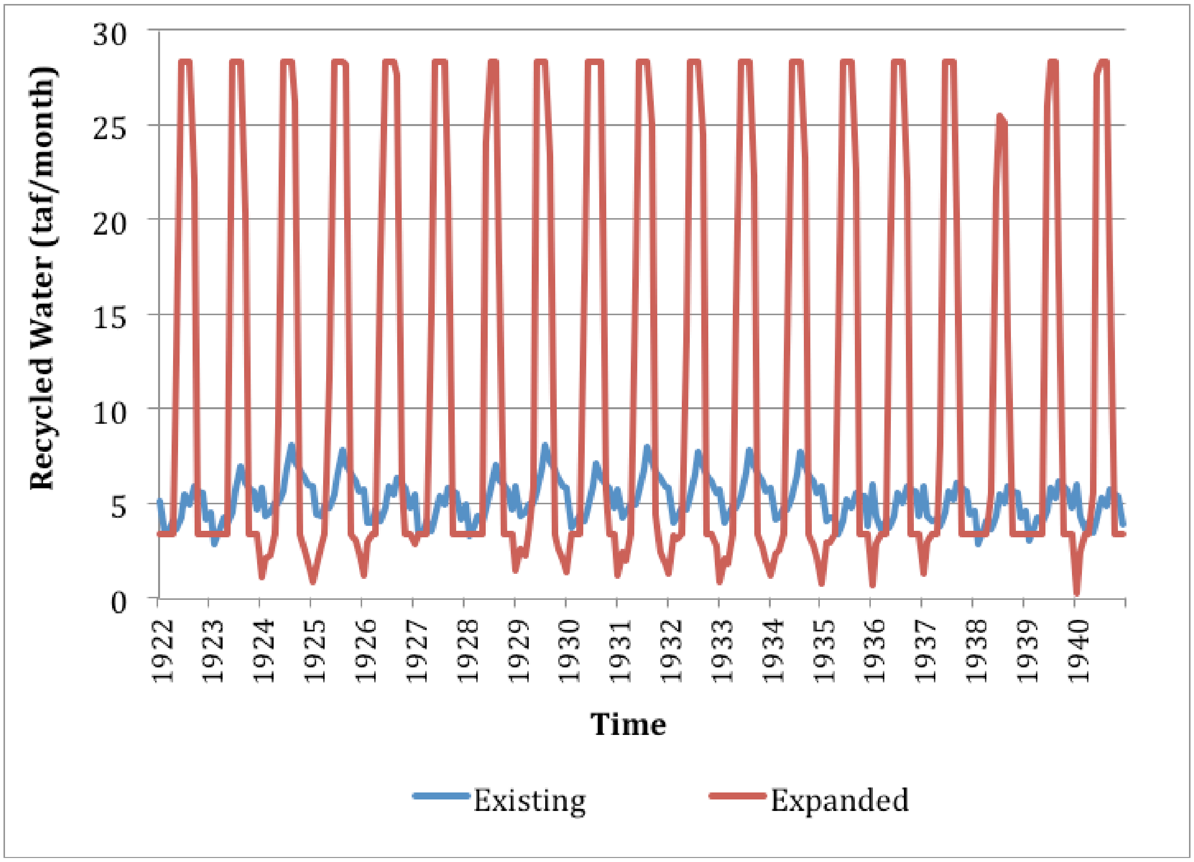


Figure 4:10: Monthly recycled water generated in a historical climate with full exports and no urban water conservation

The amount of recycling capacity itself, however, appears to be more than sufficient to meet California's needs under optimal conditions. Unless Delta exports stop, more than 85% of the approximately 2.1 maf/year of modled recycled water capacity would go unused under optimal conditions. If exports were to stop, approximately 40% of the capacity remains unused. Only 1.2 maf/yr of expanded municipal recycling was used, even in the worst cases, without Delta exports. In every other case, no more than 260 taf/yr were used on average. While CALVIN's foresight sometimes is overly optimistic about the selection of the most cost-effective solutions, if actual recycled water use levels are similar to those suggested by CALVIN, the decision to expand recycling to a 1.85 to 2.25 maf capacity (currently under consideration in California) could result in at least 650 taf of unused capacity in the future.

Table 4:16: Average annual use of existing and expanded recycled water capacity

	Policy Options		Results						
	Urban Conserv.	Delta Export Level	Water Recycled (taf/yr)	Total Cap. Utilized		Existing Cap. Utilized		Expanded Cap. Utilized	
				% /year	(taf/ year)	% /year	(taf/ year)	% /year	(taf/ year)
Historical Climate	0%	Full Exports	198	10%	198	14%	60	8%	138
		No Exports	1,099	53%	1,099	29%	124	59%	976
	30%	Full Exports	26	1%	26	3%	13	1%	13
		50%	27	1%	27	3%	14	1%	13
		25%	33	2%	33	5%	19	1%	13
		No Exports	125	6%	125	10%	42	5%	83
Warmer, Drier Climate	0%	Full Exports	270	13%	270	24%	104	10%	167
		No Exports	1,179	57%	1,179	41%	175	61%	1,004
	30%	Full Exports	38	2%	38	6%	25	1%	13
		50%	60	3%	60	11%	46	1%	13
		25%	85	4%	85	10%	44	3%	41
		No Exports	562	27%	562	13%	58	31%	504
	40%	No Exports	163	8%	163	11%	49	7%	114

Total recycling capacity = 2,074 taf/year

Recycled water and seawater desalination are used in no-export conditions to help make up for less available surface water. A few locations in CALVIN are primarily supplied from the State Water Project. These urban areas use recycling and desalination to help compensate for the loss of Delta exports. As shown on the recycled water maps (Figure 4:11 and 4.11), Santa Barbara – San Luis Obispo and Contra Costa demand areas consistently use recycled water, regardless of scenario. (In the case of Santa Barbara and San Luis Obispo, this might be due to under-representation of alternative water sources in these areas.) Areas in the Los Angeles area appear to be sensitive to export reductions, and recycled water use increases as exports decrease.

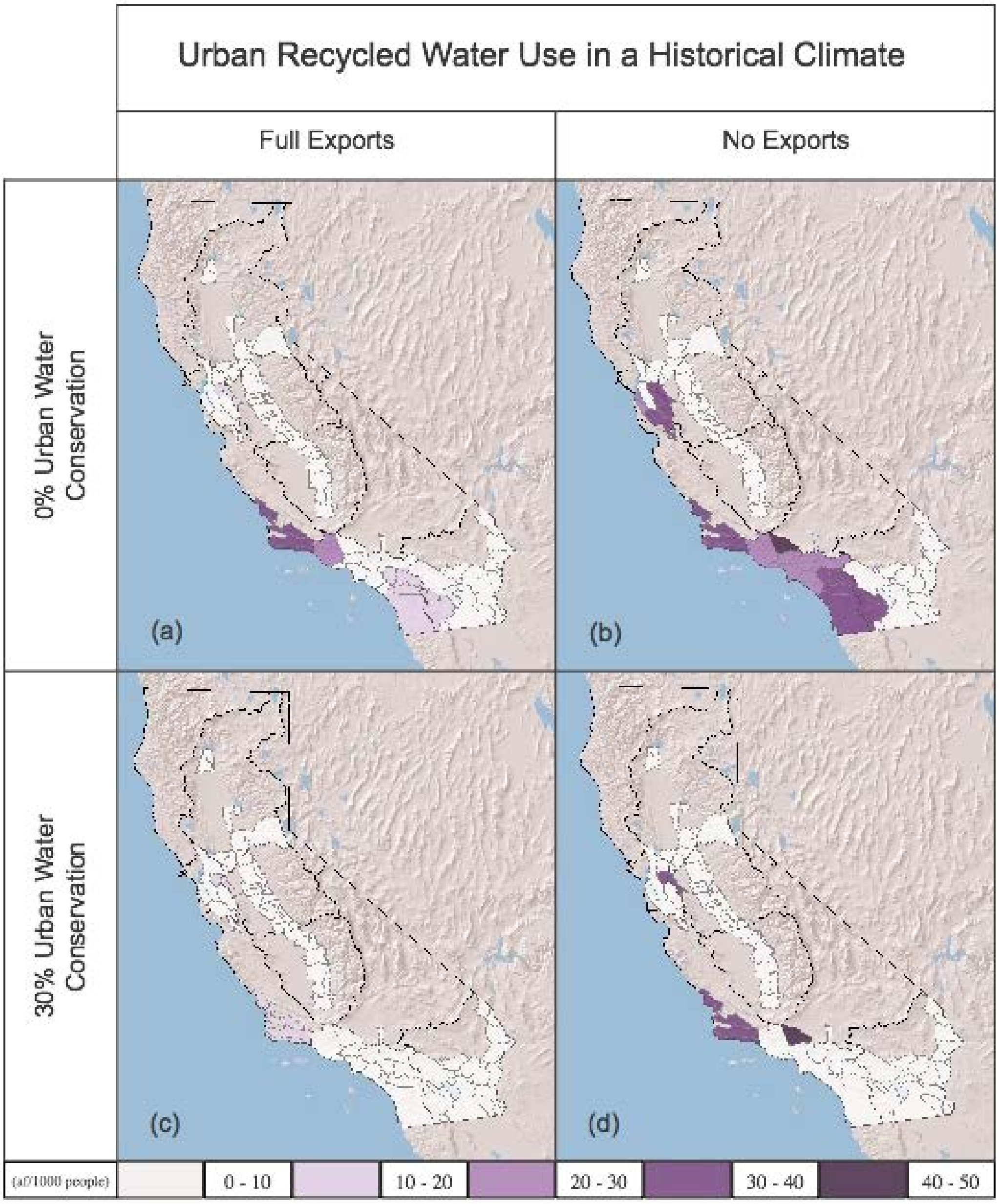


Figure 4:11: Average annual acre-feet of urban wastewater recycling use per 1000 people with historical climate conditions

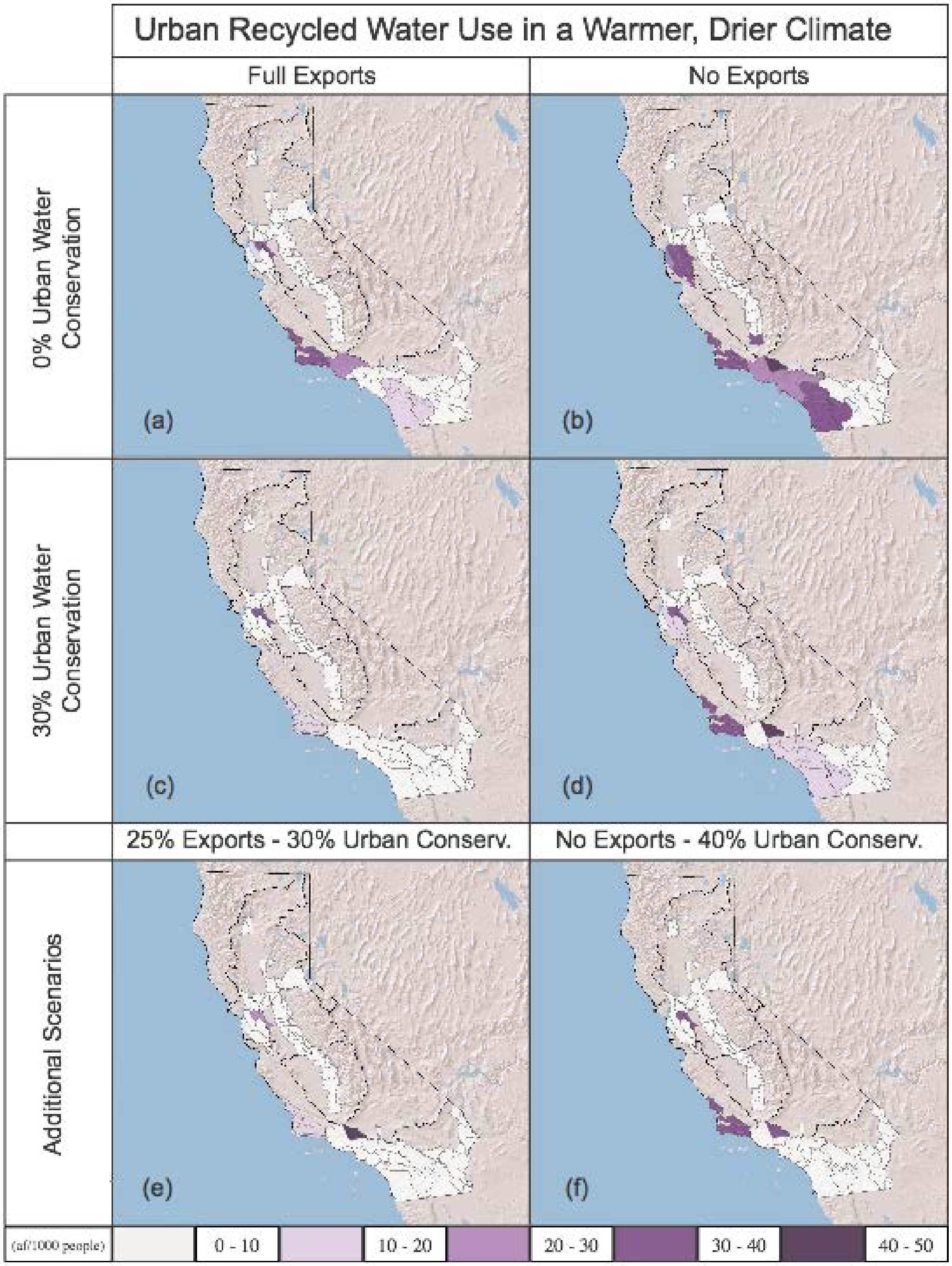


Figure 4:12: Average annual acre-feet of urban wastewater recycling use per 1000 people with a warmer, drier climate.

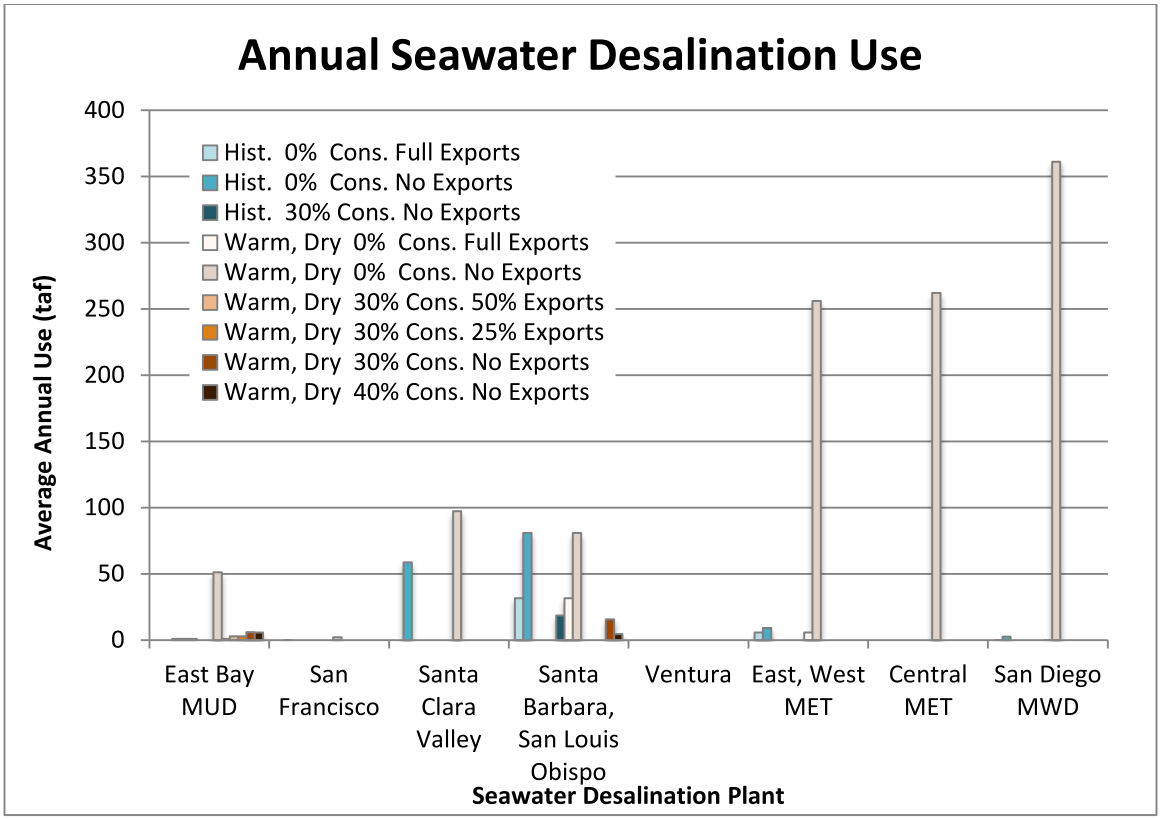


Figure 4:13: Average annual seawater desalination in different urban areas in California

Table 4:17: Average annual seawater desalination by urban area (taf)

	Historical Climate						Warmer, Drier Climate						
	0% Urban Conserv.		30% Urban Conservation				0% Urban Conserv.		30% Urban Conservation				40% Urb. Cons.
	Full Exports	No Exports	Full Exports	50%	25%	No Exports	Full Exports	No Exports	Full Exports	50%	25%	No Exports	No Exports
East Bay MUD	0	0	0	0	0	0	0	51.2	0	2.8	2.8	5.9	5.7
San Francisco	0	0.5	0	0	0	0	0	2.0	0	0	0	0	0
Santa Clara Valley	0	58.7	0	0	0	0	0	97.3	0	0	0	0	0
Santa Barbara, San Luis Obispo	31.5	80.8	0	0	0	18.5	31.5	80.8	0	0	0	15.6	4.4
Ventura	0	0	0	0	0	0	0	0	0	0	0	0	0
East, West MET	5.8	9.2	0	0	0	0	5.8	256.0	0	0	0	0	0
Central MET	0	0	0	0	0	0	0	262.0	0	0	0	0	0
San Diego MWD	0.2	2.5	0	0	0	0	0.2	361.0	0	0	0	0	0
Total	37.5	151.7	0	0	0	18.5	37.5	1110.3	0	2.8	2.8	21.5	10.1

Note: Zero is 0; almost zero is 0.0

Water markets and movement

CALVIN seeks to minimize water scarcity and operating costs, within water availability, capacity, and environmental constraints. In theory, two types of institutions enable such cost minimization; an idealized water market and an economically focused central administration that reallocates water through administrative fiat. An idealized market assumes, given California's water infrastructure and its internal costs and limitations, that water will always be traded to those who are willing to pay more. Although in practice California's water market does not function as smoothly as this idealized market, state policy aims to support market development as a way of reallocating water from lower to higher valued uses.

Generally, urban areas are willing to pay more for water than farmers, so the model often has them buy water to reduce scarcity. For this reason, some of the scarcity experienced in the agricultural sector results from farmers selling water, compounding the scarcity of water arising from hydrologic and infrastructure constraints. Indirect costs and benefits of transfers to the wider economy are conventionally left to external post-processing and commonly have symmetrical multipliers of similar magnitudes (Harou et al. 2009).

The effect of water markets is also traceable by where water is transferred. Table 4:18 illustrates how water transfers change for different scenarios. Pumping over the Tehachapi mountains to southern California urban users drops to half its normal level with 30% conservation, and to a quarter or less if Delta exports end. Much of this water normally comes from the Delta, so this would be expected. Diversions to the Friant Kern Canal, which supplies the Tulare Basin with San Joaquin River water, diminish with a drier, warmer climate. At times, water conservation allows the Colorado River Aqueduct to not be full to its capacity of 1,300 taf/yr.

Table 4:18: Average annual major inter-regional flows (taf)

						ado River to South Coast
Historical Climate	Full Exports	640	5900	1600	2400	1300

Conjunctive groundwater use

Conjunctive use is the planned and integrated use of surface and ground water supplies. It is expected that in a wet year, less of the total supply of water will come from groundwater because surface water is abundant. In a dry year, however, more groundwater will be pumped because less surface water is available. Figure 4:14 and Figure 4.14 show how much groundwater contributes to total annual water deliveries, shown from wet to dry years If each point is connected, a line showing how this ratio changes as years become wetter emerges. The steeper the slope of this line, the more inter-annual conjunctive use is taking place in that case. The slopes of the lines in Figure 4:14 and Figure 4.14, as well as the maximum and minimum use (for the wettest and driest years). This information is shown in Table 4:19.

Results indicate conjunctive use increases slightly when urban water is conserved. Conjunctive use also increases in a warmer, drier climate. These results are consistent with previous conjunctive use studies in CALVIN (Jenkins et. al., 2004). Conjunctive use in Jenkins et al. (2004) reported a range from 22% to 56% of deliveries from groundwater. In a warmer, drier climate with full exports and no conservation, this range widens to 14% to 62% of deliveries. This suggests that conservation alleviates some pressure on groundwater supplies and allows more groundwater banking to happen. Export reductions slightly decrease conjunctive use statewide.

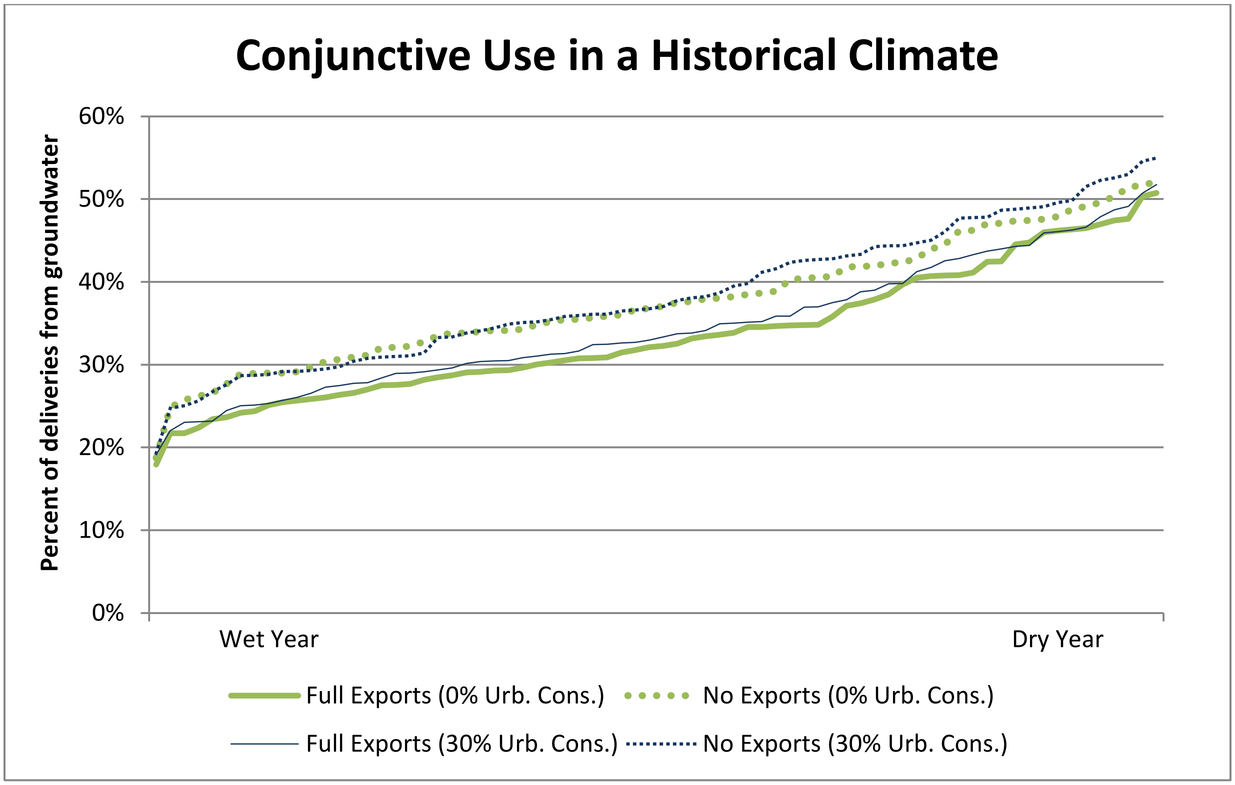


Figure 4:14: Percent of statewide deliveries from groundwater in dry vs. wet years in a historical climate.

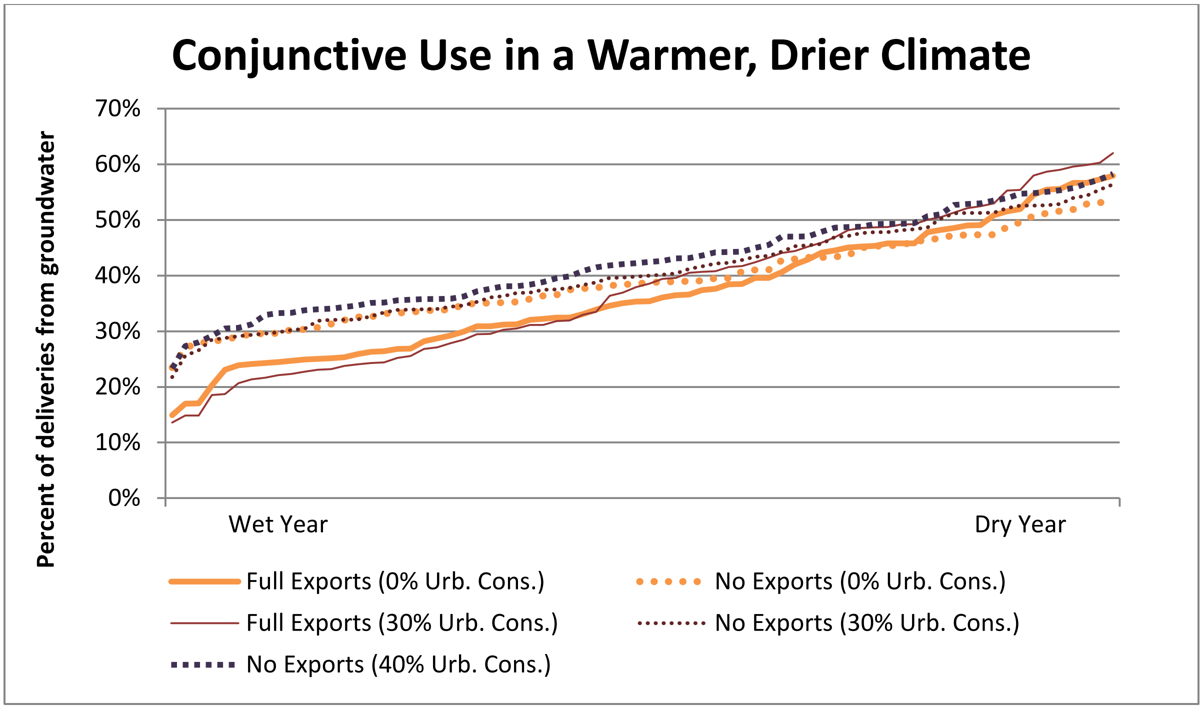


Figure 4:15: Percent of statewide deliveries from groundwater in dry vs. wet years in a warmer, drier climate.

Table 4:19: Slope, max and min of percent deliveries from groundwater listed above

	Policy Options		Results		
	Urban Conserv.	Delta Export Level	Slope	Min	Max
Historical Climate	0%	Full Exports	33	18	51
		No Exports	34	19	52
	30%	Full Exports	33	19	52
		50%	29	19	48
		25%	34	18	52
		No Exports	36	19	55
Warmer, Drier Climate	0%	Full Exports	44	15	58
		No Exports	31	23	54
	30%	Full Exports	49	14	62
		50%	40	17	56
		25%	33	18	51
		No Exports	35	22	56
	40%	No Exports	35	23	58

Figure 4:16 and Figure 4.17 show the amount of groundwater in storage for each of the modeled runs. Decreases are caused by pumping and increases are from refill due to controlled and natural inflows into the basins. These figures both show that as exports are reduced, so is variation in groundwater storage levels, this indicating less groundwater banking.

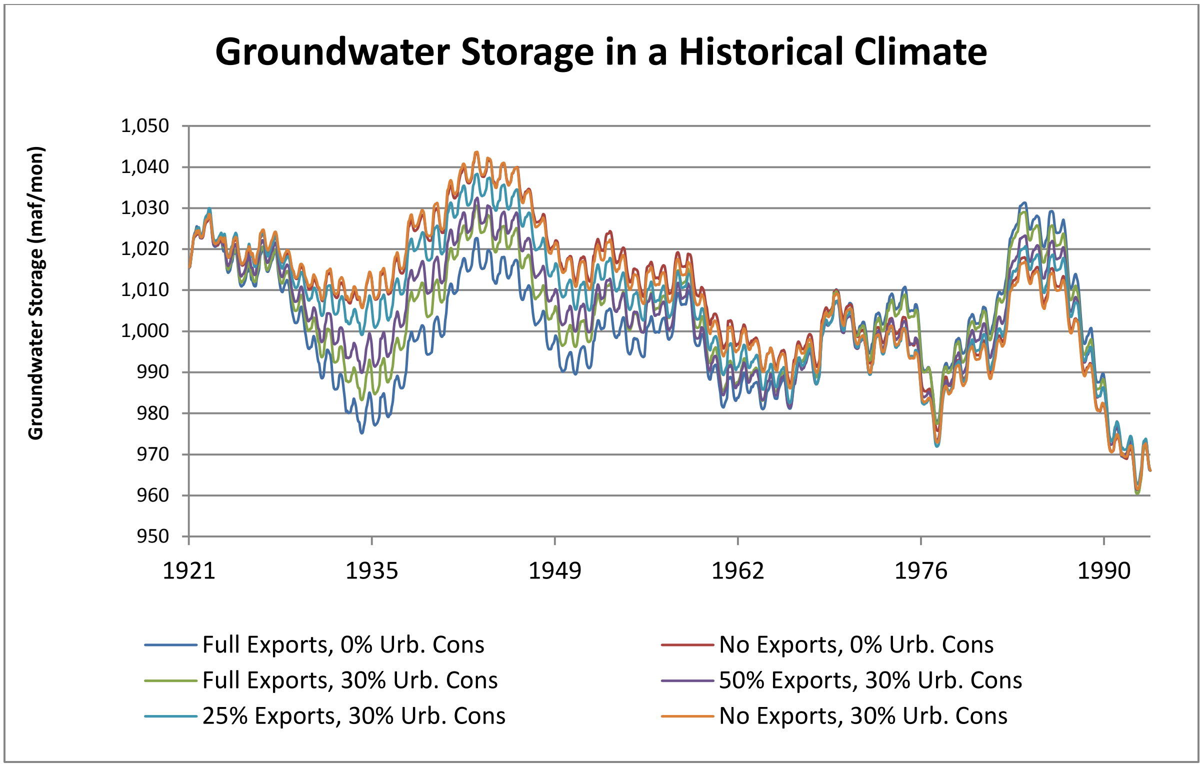


Figure 4:16: Modeled groundwater storage levels in a historical climate

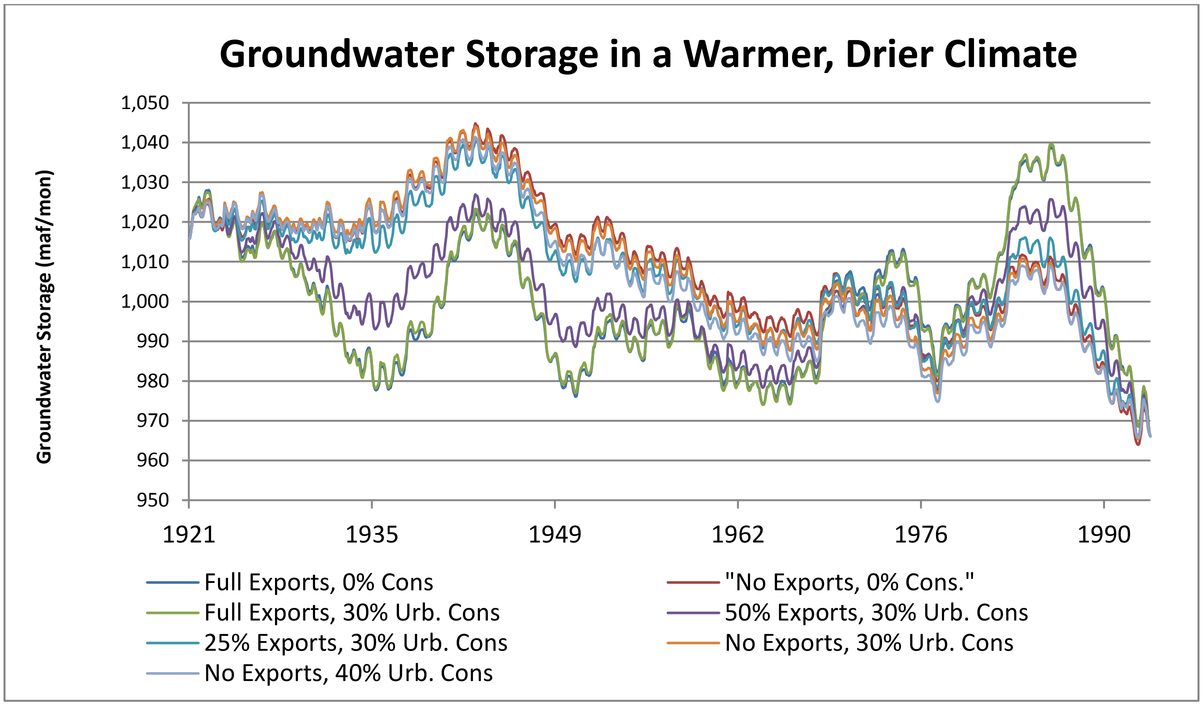


Figure 4:17: Modeled groundwater storage levels in a warmer, drier climate

Infrastructure use and value of expansion

California’s water supply system relies on a variety of types of infrastructure operating over an extensive network under conditions which vary greatly by location and from wet to dry years and seasons.   Given its constraints, CALVIN results can help determine the value of expanding these facilities, by location and time.

Surface Storage

Surface storage was analyzed three ways: average monthly storage, the average October storage and how often the reservoirs fill to capacity, and the marginal benefit of each reservoir.   The average monthly storage level is useful for seeing overall trends. October marks the start of the wet season for California, when reservoirs are generally near their lowest, so the average October storage levels and seeing how often in a 72 year period of time (percent) reservoirs are full are useful for understanding detailed storages by reservoir. Finally, the marginal benefit, or value of expanding a piece of infrastructure, in this case a researvoir, is calculated each time that infrastructure is used to capacity. The average marginal benefit per year shows how valuable expanding the reservoir would be.

California’s average monthly storage is shown in Figure 4:18. While there is some variation within each climate scenario, the difference between each policy is small compared to the difference between the historical and warmer, drier climates. This suggests that climate is a larger driver for average monthly storage levels in California than any of the policy solutions examined.

What differences there are in storage levels for each of the export and conservation policy model runs are most notable in October. Two patterns are notable in average October storage levels shown in Table 4:20 and Table 4.20: a warmer, drier climate reduces water stored in reservoirs state-wide, and storage levels north of the Delta consistently rise as Delta export capacity is reduced, while south of Delta storage levels remain nearly the same. A table of storage levels for individual reservoirs is in the appendix.

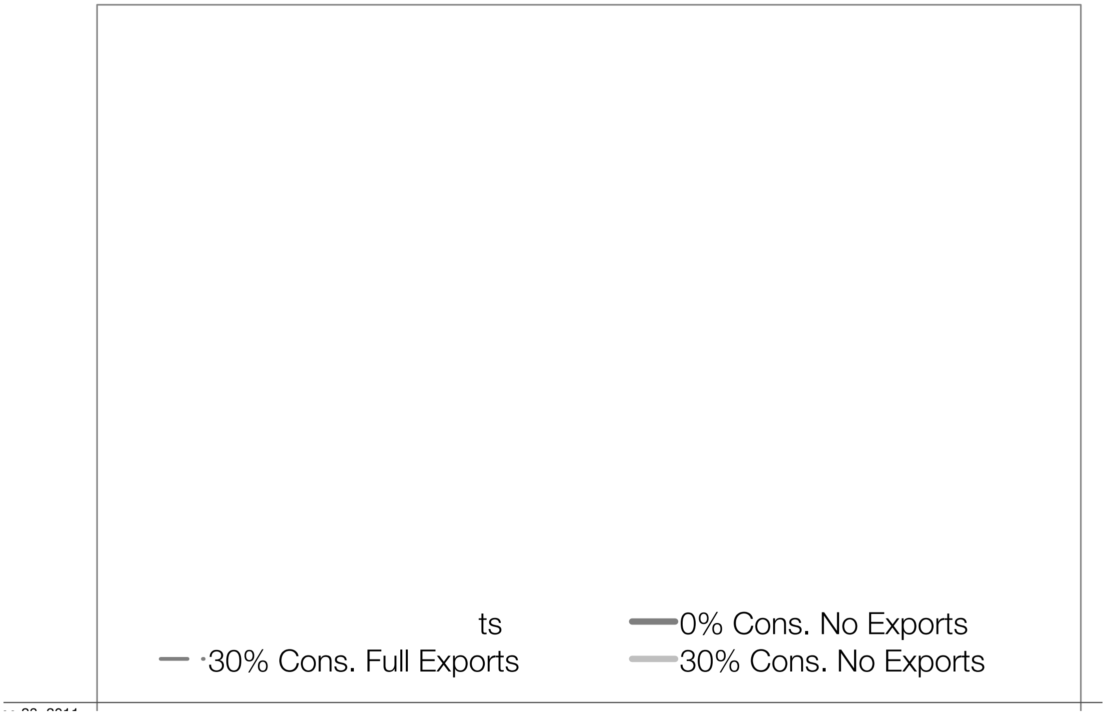


Figure 4:18 California's average monthly storage

Table 4:20: Average reservoir storage in October, percent of full conditions (of 72 years modeled)

	Policy Options		Results			
	Urban Conserv.	Delta Export Level	North of Delta	South Bay & San Joaquin	Tulare	Southern California
Historical Climate	0%	Full Exports	65%	63%	39%	51%
		No Exports	80%	80%	16%	51%
	30%	Full Exports	76%	77%	43%	51%
		50%	73%	73%	43%	51%
		25%	78%	77%	15%	51%
		No Exports	82%	84%	16%	51%
Warmer, Drier Climate	0%	Full Exports	42%	40%	25%	50%
		No Exports	52%	52%	32%	50%
	30%	Full Exports	43%	40%	23%	50%
		50%	44%	42%	23%	50%
		25%	48%	47%	22%	50%
		No Exports	54%	56%	30%	50%
	40%	No Exports	54%	55%	26%	50%
Total Storage Capacity (maf)			13.9	8.1	1.3	2.1

Table 4:21: Average October Storage (% Full)

		Historical Climate						Warmer, Drier Climate							
		0% Urban Conserv.		30% Urban Conservation				0% Urban Conserv.		30% Urban Conservation				40% Urb. Cons.	
		Full Exports	No Exports	Full Exports	50%	25%	No Exports	Full Exports	No Exports	Full Exports	50%	25%	No Exports	No Exports	Storage Capacity (taf)
North of Delta	Clair Engle Lake	52	59	56	55	57	59	33	35	32	32	32	36	35	2270
	Whiskeytown Lake	75	76	75	75	76	76	44	58	48	49	52	60	60	240
	Shasta Lake	79	95	91	89	95	95	55	63	57	58	61	64	64	3400
	Black Butte Lake	22	46	28	29	34	60	19	25	22	20	23	25	25	99
	Lake Oroville	**89**	**99**	**99**	**98**	**99**	**99**	**57**	**75**	**57**	**59**	**63**	**79**	**79**	**3149**
	Folsom Lake	**55**	**81**	**76**	**70**	**82**	**84**	**31**	**43**	**36**	**33**	**38**	**50**	**50**	**720**
	Camp Far West Reservoir	**15**	**24**	**16**	**17**	**21**	**24**	**9**	**9**	**9**	**7**	**12**	**9**	**9**	**103**
	Clear Lake & Indian Valley Res.	**13**	**30**	**13**	**15**	**20**	**40**	**3**	**9**	**2**	**5**	**8**	**7**	**7**	**606**
	Englebright Lake	99	99	99	99	99	99	89	99	95	95	96	100	100	66
	Lake Berryessa	41	74	67	55	63	81	19	32	16	21	28	31	29	1602
	New Bullards Bar Res	69	92	91	89	92	92	52	61	55	54	53	63	63	660
	New Hogan Lake	20	27	24	23	29	33	19	21	19	19	20	21	21	274
South of Delta	**EBMUD aggregate**	**72**	**67**	**71**	**71**	**71**	**68**	**76**	**73**	**71**	**71**	**70**	**74**	**68**	**132**
	Los Vaqueros Reservoir	**97**	**69**	**78**	**79**	**72**	**69**	**80**	**70**	**82**	**76**	**77**	**71**	**70**	**105**
	Pardee Reservoir	**65**	**81**	**79**	**70**	**76**	**95**	**22**	**21**	**22**	**21**	**28**	**36**	**46**	**198**
	Camanche Res	**41**	**55**	**52**	**50**	**54**	**72**	**55**	**57**	**52**	**63**	**70**	**71**	**68**	**304**
	New Melones Reservoir	89	87	94	93	88	88	40	40	62	53	43	40	43	1975
	San Luis Reservoir	4	23	4	4	4	22	7	21	6	69	88	22	25	2038
	Lake Del Valle	27	69	28	28	25	70	29	70	30	68	66	70	70	40
	Millerton Lake	34	47	36	34	35	41	32	32	29	29	28	31	30	436
	Lake McClure	**72**	**71**	**74**	**73**	**71**	**71**	**29**	**30**	**31**	**29**	**29**	**30**	**30**	**676**
	Hensley Lake	**16**	**16**	**16**	**16**	**16**	**16**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**46**
	Eastman Lake	**12**	**9**	**13**	**10**	**9**	**9**	**9**	**10**	**10**	**9**	**10**	**11**	**11**	**120**
	New Don Pedro Reservoir	**81**	**78**	**88**	**87**	**80**	**80**	**26**	**25**	**38**	**28**	**25**	**24**	**25**	**1690**
	SF aggregate	15	15	25	25	22	22	17	15	16	15	15	16	17	225
	Hetch Hetchy Reservoir	60	56	63	63	57	56	39	39	38	33	35	38	30	360
	Lake Lloyd/Lake Eleanor	32	36	34	34	36	37	12	12	11	11	13	13	13	301
	Santa Clara Aggregate	22	22	25	25	22	22	23	22	24	22	22	22	23	170
	Turlock Reservoir	**23**	**36**	**28**	**31**	**40**	**42**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**67**
	Lake Isabella	**15**	**13**	**19**	**14**	**8**	**7**	**4**	**2**	**1**	**1**	**0**	**1**	**1**	**241**
	Lake Kaweah	**3**	**3**	**4**	**4**	**2**	**2**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**44**
	Lake Success	**5**	**5**	**5**	**5**	**5**	**5**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**31**
	Pine Flat Reservoir	48	18	52	54	18	20	31	41	29	29	28	38	34	945
	Silverwood Lake	60	60	61	61	61	61	60	64	63	60	60	61	62	73
	Lake Perris	26	25	25	25	25	25	25	26	26	25	25	25	29	127
	Pyramid Lake	56	57	56	56	56	57	57	57	58	56	56	57	57	170
	Castaic Lake	**91**	**91**	**91**	**91**	**91**	**91**	**92**	**92**	**93**	**91**	**91**	**92**	**92**	**324**
	Domenigoni/Diamond Valley	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**51**	**50**	**50**	**50**	**50**	**800**
	Grant Lake	**42**	**41**	**41**	**41**	**42**	**41**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**48**
	LAA Storage	**12**	**11**	**23**	**23**	**11**	**11**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**103**
	Long Valley Reservoir	19	18	13	13	19	19	11	11	11	11	11	11	10	184
	Lake Mathews of MWDSC	43	43	43	43	43	43	43	43	43	43	43	43	43	182
	Lake Skinner	76	76	76	76	76	76	76	76	76	76	76	76	76	44

Table 4:22 illustrates how many years (percent), out of 72, that reservoirs ever reach capacity. In a warmer, drier climate, reservoirs south of Hensley Lake seldom fill.

Shadow values (or marginal benefits) indicate the economic benefit if one additional unit of capacity were added to an already fully utilized resource. For storage, the marginal benefit would be the economic benefit of adding one additional acre-foot of storage to the reservoir. Table 4:23 illustrates the average annual marginal value of expanding a large selection of reservoirs in CALVIN. In both historical and warmer, drier climate conditions, Lake Kaweah and Lake Success consistantly have the highest values for increasing storage capacity. In a warmer-drier climate, the marginal values of expanding storage in northern California become higher than than reservoirs located further south.

Table 4:22: Percent of years reservoirs reach capacity (out of 72)

		Historical Climate						Warmer, Drier Climate						
		0% Urban Conserv.		30% Urban Conservation				0% Urban Conserv.		30% Urban Conservation				40% Urb. Cons.
		Full Exports	No Exports	Full Exports	50%	25%	No Exports	Full Exports	No Exports	Full Exports	50%	25%	No Exports	No Exports
North of Delta	Clair Engle Lake	53	63	67	63	64	63	22	32	24	24	25	32	32
	Whiskeytown Lake	100	100	100	100	100	100	53	69	65	61	68	69	69
	Shasta Lake	97	97	97	97	97	97	49	63	57	49	54	64	64
	Black Butte Lake	99	99	99	99	99	99	67	86	75	68	79	83	85
	Lake Oroville	100	100	100	100	100	100	88	99	97	89	90	99	99
	Folsom Lake	100	100	100	100	100	100	50	64	61	54	65	81	85
	Camp Far West Reservoir	94	94	97	96	96	97	79	68	74	65	76	69	69
	Clear Lake & Indian Valley Reservoir	42	50	39	43	42	60	17	18	17	17	18	17	17
	Englebright Lake	100	100	100	100	100	100	100	100	100	100	100	100	100
	Lake Berryessa	14	42	43	31	36	74	4	3	3	3	7	4	6
	New Bullards Bar Res	100	100	100	100	100	100	76	99	85	76	76	99	99
	New Hogan Lake	44	57	54	51	51	60	22	19	17	22	18	18	19
South of Delta	Pardee Reservoir	92	89	99	99	99	97	35	28	33	32	40	42	60
	Los Vaqueros Reservoir	99	0	0	0	0	0	13	3	32	35	14	7	3
	Camanche Res	53	51	76	68	75	79	47	36	47	49	53	51	42
	EBMUD aggregate	15	3	13	17	14	3	24	22	11	15	11	19	7
	New Melones Reservoir	86	75	88	85	75	75	3	3	7	4	6	6	7
	San Luis Reservoir	0	0	0	0	0	0	17	0	19	78	60	0	0
	Lake Del Valle	0	0	0	0	0	0	13	0	3	0	0	0	0
	Millerton Lake	49	43	43	44	31	33	29	18	28	28	17	15	15
	Lake McClure	76	56	79	76	57	57	7	7	7	6	7	7	7
	Hensley Lake	39	36	39	36	36	36	17	15	15	15	17	17	17
	Eastman Lake	19	18	21	19	18	18	1	1	1	1	1	3	1
	New Don Pedro Reservoir	76	64	82	79	67	67	6	7	7	6	8	7	8
	SF aggregate	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hetch Hetchy Reservoir	51	43	54	54	42	42	8	10	10	6	8	10	8
	Lake Lloyd/Lake Eleanor	40	42	40	40	40	40	1	1	3	1	3	3	3
	Santa Clara Aggregate	1	0	3	3	0	0	1	0	3	0	0	0	1
	Turlock Reservoir	75	60	76	75	61	63	3	3	3	3	3	3	4
	Lake Isabella	29	21	32	19	13	11	15	8	13	13	8	8	6
	Lake Kaweah	100	92	100	100	94	92	54	54	61	61	54	54	54
	Lake Success	89	88	89	89	88	88	74	74	74	74	74	74	74
	Pine Flat Reservoir	99	24	99	99	25	24	13	21	14	14	13	18	15
	Silverwood Lake	6	3	99	99	100	15	22	3	99	100	100	6	3
	Lake Perris	1	0	3	3	4	3	0	0	46	0	13	0	0
	Pyramid Lake	17	0	0	0	1	0	24	1	17	0	0	1	0
	Castaic Lake	100	4	1	47	96	1	94	26	85	94	1	11	11
	Eastside Reservoir (Diamond Valley)	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grant Lake	24	22	14	14	22	22	0	0	0	0	0	0	0
	LAA Storage	4	1	21	21	3	1	0	0	0	0	0	0	0
	Long Valley Reservoir (Lake Crowley)	4	7	1	1	7	7	0	0	0	0	0	0	0
	Lake Mathews of MWDSC	1	0	93	96	1	0	0	0	28	0	0	0	0
	Lake Skinner	100	97	100	100	96	96	83	0	19	0	0	0	0

The Bureau of Reclamation has proposed expanding Shasta, Pine Flat and Friant Dam and building Temperance Flat and Sites Reservoirs. The maximum marginal benefit for expanding Shasta is $67/af/year, Friant (Millerton) is $120/af/year, and Pine Flat Reservoir is $103/af/year. These maximums all happen in a warmer, drier climate without urban water conservation.

Temperance Flat costs are likely to exceed water users' willingness to pay. Temperance Flat proposed location is upstream of Friant Dam. Preliminary estimates indicate that Temperance Flat will cost $350/af/year (DWR, 2007). If it is assumed that the marginal benefit of expanding Millerton Lake (Friant Dam) could also translate to the marginal benefit of Temperance Flat, then the marginal benefit, or average amount that water users would be willing to pay, is only $120/af/year.

Sites Reservoir would be located off stream of the Sacramento River and store the River's water, but estimating its marginal benefit is not as easy, nor applicable. Sites Reservoir is estimated to cost $1000/af/year (Hanak et al., 2009), but the largest marginal benefit of expanding of any reservoir north of the Delta is $325/af/year. There are other reasons this dam has been proposed, however, such as flood protection and water quality improvement. The value of these features is not assessed in this study, only the supply benefits. As a result, the actual benefit from this reservoir could be higher.

It is also important that CALVIN's assumptions of perfect foresight and idealized water markets provide optimistic (and thus possibly low) marginal benefits for new storage. Draper (2001) explored this.

Table 4:23: Marginal benefit of expanding storage capacity ($/af/year)

		Historical Climate						*Warmer, Drier Climate*						
		0% Urban Conserv.		*30% Urban Conservation*				*0% Urban Conserv.*		*30% Urban Conservation*				40% Urb. Cons.
		Full Exports	No Exports	Full Exports	50%	25%	No Exports	Full Exports	No Exports	Full Exports	50%	25%	No Exports	No Exports
North of Delta	Clair Engle Lake	3	3	3	3	3	3	39	30	32	40	33	32	32
	Whiskeytown Lake	8	6	6	7	6	6	65	34	49	62	46	34	34
	Shasta Lake	8	8	8	8	8	8	67	34	51	66	49	34	34
	Black Butte Lake	9	4	6	6	5	4	250	63	146	163	100	62	62
	Lake Oroville	15	11	13	13	12	10	78	18	56	66	43	17	17
	Folsom Lake	13	10	11	11	10	9	153	20	85	94	49	15	14
	Camp Far West Reservoir	6	2	3	3	2	1	171	19	93	115	66	14	12
	Clear Lake & Indian Valley Reservoir	2	0	1	1	1	0	48	2	25	29	14	2	1
	Englebright Lake	44	44	44	44	44	44	326	44	184	209	116	44	44
	Lake Berryessa	0	0	0	0	0	0	2	0	0	2	2	0	0
	New Bullards Bar Res	18	17	17	17	17	17	156	19	90	104	55	19	18
South of Delta	New Hogan Lake	2	2	1	1	1	0	49	38	26	39	30	20	4
	Pardee Reservoir	2	5	1	1	1	1	14	32	20	23	25	41	24
	Los Vaqueros Reservoir	16	0	0	0	0	0	13	10	34	37	2	34	19
	Camanche Res	2	1	1	1	1	0	14	33	20	24	25	42	25
	EBMUD aggregate	0	1	0	0	0	0	12	17	19	21	21	39	21
	New Melones Reservoir	9	10	9	10	10	10	3	3	3	2	3	5	4
	San Luis Reservoir	0	0	0	0	0	0	11	0	13	0	0	0	0
	Lake Del Valle	0	0	0	0	0	0	5	0	3	0	0	0	0
	Millerton Lake	6	95	5	5	20	62	37	120	56	34	22	33	33
	Lake McClure	9	18	8	9	18	18	20	22	12	15	20	24	20
	Hensley Lake	13	53	10	13	53	53	64	75	39	52	68	79	69
	Eastman Lake	6	26	5	6	26	26	7	7	4	5	7	8	6
	New Don Pedro Reservoir	8	9	8	8	9	8	4	3	4	2	3	5	4
	SF aggregate	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hetch Hetchy Reservoir	6	7	5	5	7	7	7	6	5	3	5	7	5
	Lake Lloyd/Lake Eleanor	15	17	15	15	17	17	2	2	3	1	2	4	3
	Santa Clara Aggregate	0	0	0	0	0	0	3	0	0	0	0	0	3
	Turlock Reservoir	7	7	6	6	7	7	3	3	3	2	3	5	4
	Lake Isabella	4	46	1	1	6	15	32	76	32	12	1	5	2
	Lake Kaweah	56	457	47	52	261	379	269	263	225	235	254	254	254
	Lake Success	49	403	42	47	241	340	361	361	308	333	357	357	357
	Pine Flat Reservoir	5	47	4	4	20	31	20	103	51	47	62	95	44
	Silverwood Lake	0	0	0	0	16	1	1	8	24	9	8	2	1
	Lake Perris	0	0	0	0	0	0	0	0	9	0	0	0	0
	Pyramid Lake	0	0	0	0	0	0	2	14	8	0	0	0	0
	Castaic Lake	3	0	0	1	1	0	8	18	12	1	0	2	1
	Eastside Reservoir (Diamond Valley)	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grant Lake	52	116	44	44	57	76	0	0	0	0	0	0	0
	LAA Storage	10	26	8	8	11	16	0	0	0	0	0	0	0
	Long Valley Reservoir (Lake Crowley)	10	26	7	8	11	16	0	0	0	0	0	0	0
	Lake Mathews of MWDSC	0	0	0	0	0	0	0	0	3	0	0	0	0
	Lake Skinner	816	1	0	0	0	0	148	0	2	0	0	0	0

Note: These are the maximum average benefits. Marginal benefits driven by agricultural prices are actually up to 1.48 times less valuable than those listed here.

Expanding Conveyance Facilities

When Delta exports are restricted, the Bay Area and Southern California resort to more expensive aupplies, such as recycled water and seawater desalination (See Figure 4:11 – 4.12). However, if conveyance facilities were expanded, these areas could receive access to more of the water elsewhere in the system instead.

Expansions to the Hayward Intertie, the Hetch Hetchy Aqueduct, the Mokelumne Aqueduct, the Colorado River Aqueduct and a New Don Pedro intertie to the Hetch Hetchy Aqueduct, could improve such access. The marginal benefits of expanding selected conveyance facilities are shown in Table 4:24. Not surprisingly, as Delta exports decrease, the marginal benefit of expanding Delta exports rises. The marginal values of Tracy and Banks Pumping plants indicate that when Delta exports are cut off, without conservation the last acre foot of exports is worth more than expanded recycled water ($1,480/af), but with urban water conservation, it is worth just slightly less.

Table 4:24: Marginal benefits of expanding conveyance facilities ($/af/year)

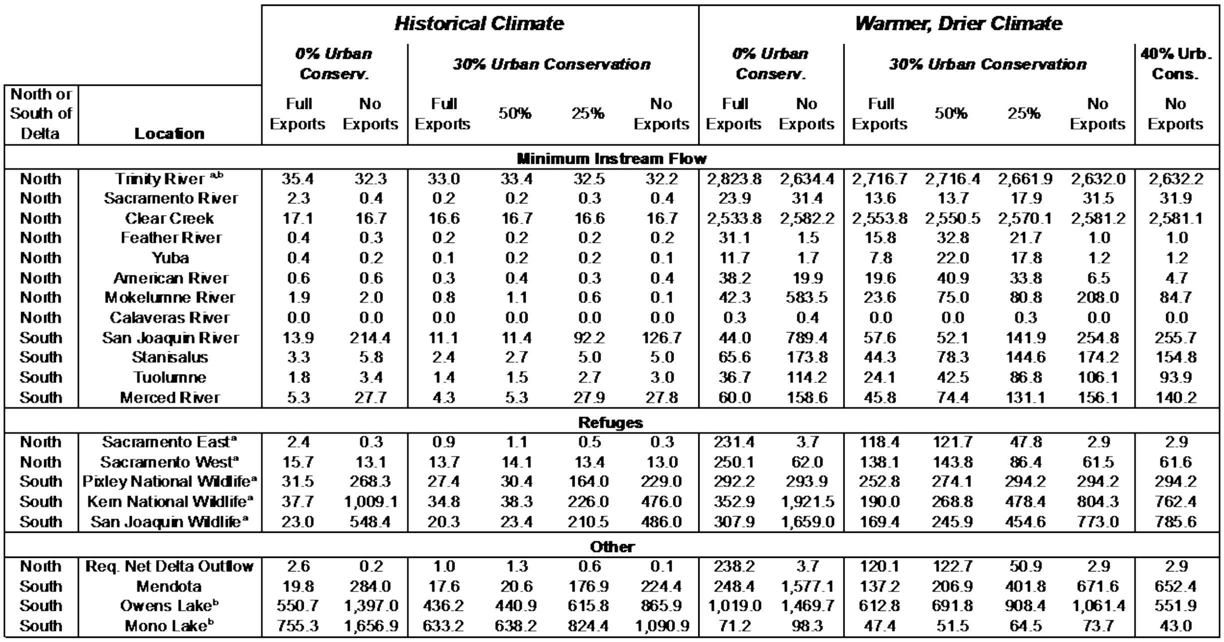
e	*Warmer, Drier Climate*	
		40% Urb. Cons.

Note: These are the maximum average benefits. Marginal benefits driven by agricultural prices are actually up to 1.48 times less valuable than those listed here. All prices exceeding$500/af/year are driven by urban demands.

Export restrictions and a warmer, drier climate also affect the marginal cost of water supplied for environmental purposes. Environmental water uses are treated as fixed regulatory requirements. The marginal cost reflects the opportunity cost to agricultural and urban water operations of supplying the environmental flow with one additional acre foot of water. This is shown in Table 4:25.

Table 4:25 shows three notable patterns: (i) a warmer, drier climate greatly increases the marginal cost for most environmental uses; (ii) urban conservation decreases these marginal costs, often by half; and (iii) as Delta exports are reduced, marginal costs of environmental flows decrease slightly north of the Delta (aside from the Mokelumne River), but grow significantly south of the Delta.

Table 4:25: Monthly average marginal benefits of environmental flows ($/af)



		Historical Climate						Warmer, Drier Climate						
		0% Urban Conserv.		30% Urban Conservation				0% Urban Conserv.		30% Urban Conservation				40% Urb. Cons.
North or South of Delta	Location	Full Exports	No Exports	Full Exports	50%	25%	No Exports	Full Exports	No Exports	Full Exports	50%	25%	No Exports	No Exports
Minimum Instream Flow														
North	Trinity River [a,b]	35.4	32.3	33.0	33.4	32.5	32.2	2,823.8	2,634.4	2,716.7	2,716.4	2,661.9	2,632.0	2,632.2
North	Sacramento River	2.3	0.4	0.2	0.2	0.3	0.4	23.9	31.4	13.6	13.7	17.9	31.5	31.9
North	Clear Creek	17.1	16.7	16.6	16.7	16.6	16.7	2,533.8	2,582.2	2,553.8	2,550.5	2,570.1	2,581.2	2,581.1
North	Feather River	0.4	0.3	0.2	0.2	0.2	0.2	31.1	1.5	15.8	32.8	21.7	1.0	1.0
North	Yuba	0.4	0.2	0.1	0.2	0.2	0.1	11.7	1.7	7.8	22.0	17.8	1.2	1.2
North	American River	0.6	0.6	0.3	0.4	0.3	0.4	38.2	19.9	19.6	40.9	33.8	6.5	4.7
North	Mokelumne River	1.9	2.0	0.8	1.1	0.6	0.1	42.3	583.5	23.6	75.0	80.8	208.0	84.7
North	Calaveras River	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.3	0.0	0.0
South	San Joaquin River	13.9	214.4	11.1	11.4	92.2	126.7	44.0	789.4	57.6	52.1	141.9	254.8	255.7
South	Stanisalus	3.3	5.8	2.4	2.7	5.0	5.0	65.6	173.8	44.3	78.3	144.6	174.2	154.8
South	Tuolumne	1.8	3.4	1.4	1.5	2.7	3.0	36.7	114.2	24.1	42.5	86.8	106.1	93.9
South	Merced River	5.3	27.7	4.3	5.3	27.9	27.8	60.0	158.6	45.8	74.4	131.1	156.1	140.2
Refuges														
North	Sacramento East[a]	2.4	0.3	0.9	1.1	0.5	0.3	231.4	3.7	118.4	121.7	47.8	2.9	2.9
North	Sacramento West[a]	15.7	13.1	13.7	14.1	13.4	13.0	250.1	62.0	138.1	143.8	86.4	61.5	61.6
South	Pixley National Wildlife[a]	31.5	268.3	27.4	30.4	164.0	229.0	292.2	293.9	252.8	274.1	294.2	294.2	294.2
South	Kern National Wildlife[a]	37.7	1,009.1	34.8	38.3	226.0	476.0	352.9	1,921.5	190.0	268.8	478.4	804.3	762.4
South	San Joaquin Wildlife[a]	23.0	548.4	20.3	23.4	210.5	486.0	307.9	1,659.0	169.4	245.9	454.6	773.0	785.6
Other														
North	Req. Net Delta Outflow	2.6	0.2	1.0	1.3	0.6	0.1	238.2	3.7	120.1	122.7	50.9	2.9	2.9
South	Mendota	19.8	284.0	17.6	20.6	176.9	224.4	248.4	1,577.1	137.2	206.9	401.8	671.6	652.4
South	Owens Lake[b]	550.7	1,397.0	436.2	440.9	615.8	865.9	1,019.0	1,469.7	612.8	691.8	908.4	1,061.4	551.9
South	Mono Lake[b]	755.3	1,656.9	633.2	638.2	824.4	1,090.9	71.2	98.3	47.4	51.5	64.5	73.7	43.0

Note: These are the maximum average benefits. Marginal benefits driven by agricultural prices are actually up to 1.48 times less valuable than those listed here.

Cost-effectiveness of urban water conservation

Thirty percent urban water conservation is estimated to save California at least $2.2 billion in scarcity and operating costs annually at 2050 demand levels (Table 4:10), neglecting implementation costs. This section examines how different costs for conservation affect the overall cost – or net savings– of conservation, defined as the benefit of conservation minus its implementation cost.

A simple way to understand the benefit of conservation is to consider scarcity and operations costs before and after conservation. As discussed previously, 30% urban water conservation averages California between $2.2 and $3.0 billion/yr in benefits in full-exports scenarios and and $3.6 – $4.6 billion/yr for no export cases (Figure 4:19). [1]

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[1] A small share of this cost difference is not from conservation, but rather from the assumption of a lower cost for seawater desalination in the lower cost scenarios ($1,628/af versus $2,072/af in standard CALVIN runs). At most, with 30% urban water conservation in a warmer, drier climate without Delta exports, only 22 taf/yr of seawater was desalinated at the lower cost. This amount would cost $35.8 million/yr at the lower price ($1,628), or $45.6 million at the normal CALVIN seawater desalination cost ($2,072/af). Thus the savings from less expensive seawater desalination is only $9.8 million/year, or 0.2% of total savings.

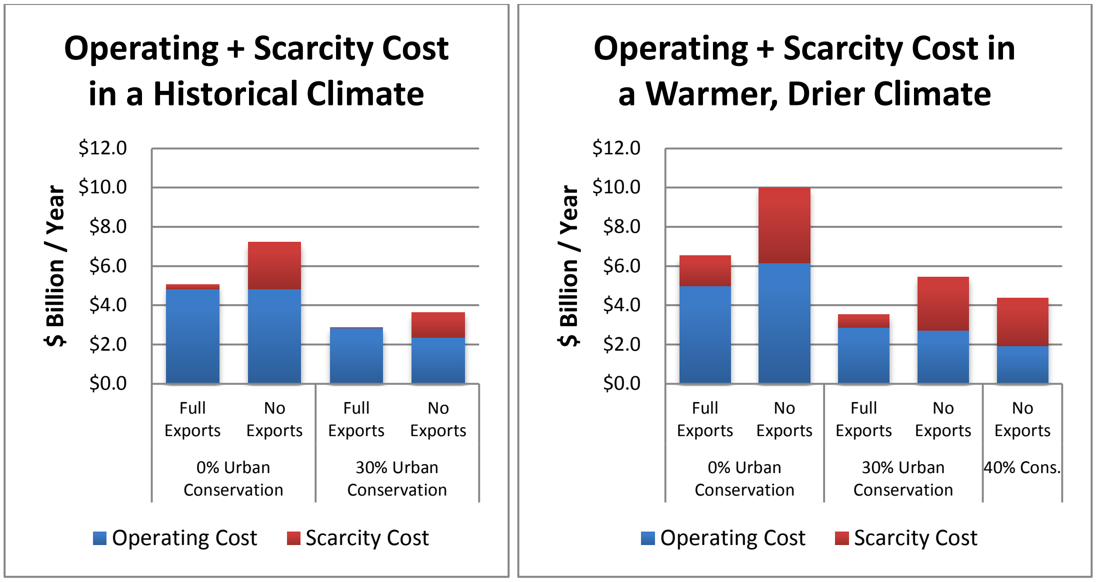

Figure 4:19: Operating and scarcity cost comparison of conservation vs. no conservation

The average benefit of conservation is calculated as the total scarcity and operations cost savings divided by the amount of water conserved. [Benefit / af = (Scarcity and Operations Cost without conservation) – (Scarcity and operations cost with it)/annual volume conserved] Table 4:26 summarizes the average benefit per acre-ft of conservation.

Table 4:26: Average annual economic benefit of water conserved.

	Policy Options			Results	
	Urban Conserv.	Delta Export Level	Amount Conserved (TAF)	Scarcity + Operations Cost ($B)	Benefit/af
Historical Climate	*0%*	Full Exports	0	$5.1	-
		No Exports	0	$7.2	-
	30%	Full Exports	3,810	$2.9	$573
		No Exports	3,810	$3.6	$941
Warmer, Drier Climate	*0%*	Full Exports	0	$6.5	-
		No Exports	0	$10.0	-
	30%	Full Exports	3,810	$3.5	$783
		No Exports	3,810	$5.4	$1,195
	40%	No Exports	5,111	$4.4	$1,100

This benefit per acre foot also can be seen as the maximum economical cost of implementing conservation under different scenarios. For example, with full exports, 30% conservation (which saves 3,810 taf) can be cost-effective up to a cost of $573/af under historical climate conditions and up to $783/af under a warm-dry form of climate change. Without Delta exports, the benefit of 30% urban conservation jumps to $941/af under a historical climate and $1,195 with a warmer, drier climate. With 40% urban water conservation, the average benefit/af declines slightly to $1,100/af.

Overall, these average benefits per acre-foot of urban conservation significantly outweigh the estimated costs of implementing conservation in all scenarios except the full export, historical climate case. The cost of implementing urban water conservation has been analyzed in CALFED (2006) and Gleick et al. (2003). Their estimates of annual implementation cost for 'cost effective' conservation vary somewhat. CALFED (2006) estimates the average annual implementation cost of conservation is up to $522 per acre foot of water conserved for 2.1 maf (baseline = 12.3 maf) for 17% urban water conservation ($572 per acre foot in $2008). Gleick et al. (2003) estimated that the cutoff for 'cost effective' conservation of up to 2 maf (baseline = 7 maf) for approximately 29% urban water conservation is $580 per acre foot in $2003, or $739 per acre foot in $2008, but that many conservation options would be significantly less expensive. (CALFED (2006) and Gleick et al. (2003) cost estimates are adjusted for inflation using Engineering News Record Building Index in San Francisco). Since CALFED lists an average, it will be used here as an estimate for implementation costs.[2]

The net savings of conservation is the benefit of conservation minus the cost of implementation. Using CALFED's annual conservation implementation cost estimate, conservation saves $21 to $670 per acre foot for 2050 conditions, depending on export and climate conditions. Table 4.27 illustrates that with full exports, the net savings of conservation is $2 – $212/af, depending on climate, and for no exports scenarios, the net savings rises to $411 to $623 per acre foot. Thus suggests that conservation is approximately cost neutral only in a historical climate with full exports, and otherwise is worth nearly 1.5 – 2 times the cost of implementation.

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[2] Cost conversions come from Engineering News Record Building Index in San Francisco, the same source that Calvin uses to convert $1995 to $2008), (Tanaka, et al, 2008)

Table 4:27: Net annual savings from water conservation

	Policy Options			Results					
	Urban Conserv.	Delta Export Level	Amount Conserved (AF)	Scarcity + Operations Cost ($B)	Benefit /af	Cost of Conservation * /af	Net Savings from Conservation /af	Total Savings ($B/year)
Historical Climate	0%	Full Exports	0	$5.1	-	-	-	-
		No Exports	0	$7.2	-	-	-	-
	30%	Full Exports	3,810	$2.9	$573	$572	$2	0.01
		No Exports	3,810	$3.6	$982	$572	$411	1.57
Warmer, Drier Climate	0%	Full Exports	0	$6.5	-	-	-	-
		No Exports	0	$10.0	-	-	-	-
	30%	Full Exports	3,810	$3.5	$783	$572	$212	0.81
		No Exports	3,810	$5.4	$1,195	$572	$623	2.38
	40%	No Exports	5,111	$4.4	$1,100	$572	$528	2.70

* Cost from CALFED (2006) of $522 converted to $2008

Using CALFED's (2006) estimates for the cost of implementing conservation, converted to 2008 dollars an across-the-board 30% urban water conservation would cost roughly $2.2 billion to implement and result in an average net savings of $10 million to $2.38 billion annually for California for 2050 (Table 4.27). Assuming the same unit costs, total implementation cost would rise to $2.9 billion annually for 40% conservation, generating net benefits to the economy of $2.7 billion in a warmer, drier climate. (However, unit implementation costs are likely to rise with this higher levels of conservation effort.[3] Figure 4:20 shows these total costs across the various cases. Thus, significant additional urban water conservation efforts seem economically justified for a wide range of 2050 conditions. Under conditions of much greater water scarcity due to reduced Delta exports and/or a warm, dry form of climate change, very large amounts of urban water conservation are economically justified, contributing far more to the state's water management portfolio at far lower cost than many other proposed actions.

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[3] According to Gleick et al. (2003), costs rise if conservation exceeds 20% (roughly CALVIN's 30%).

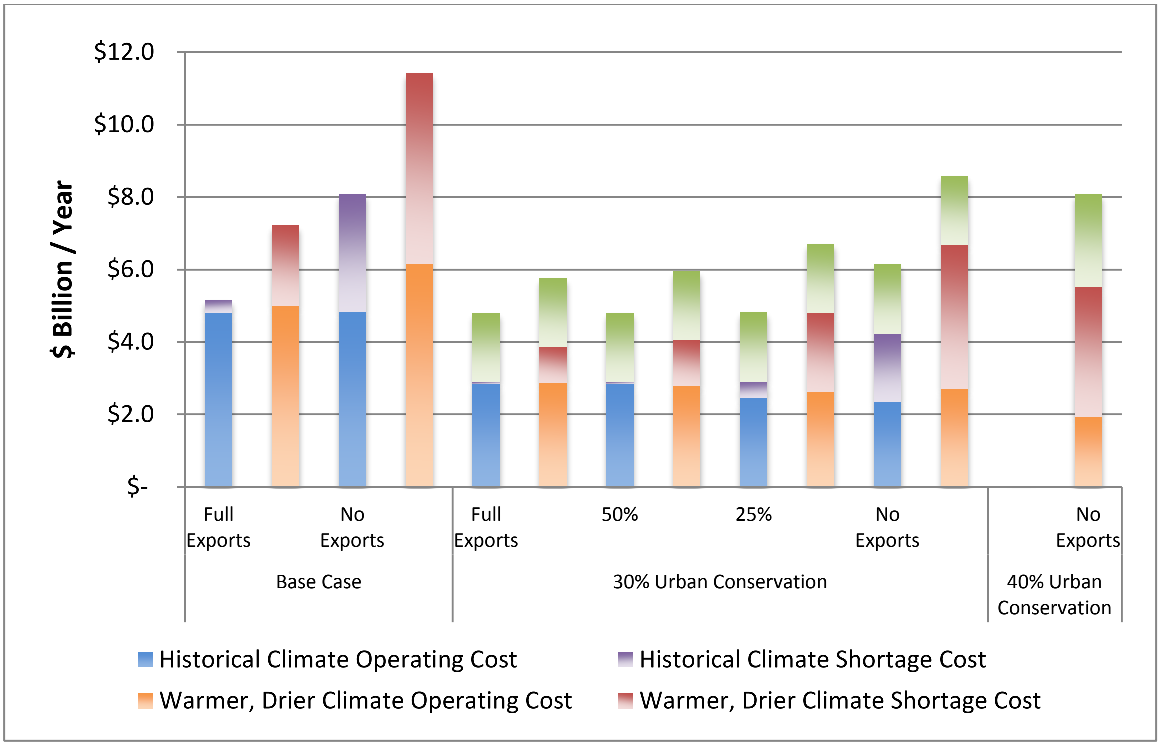

Figure 4:20: Statewide water supply costs with additional urban conservation (Scarcity, operating and conservation implementation)

Real cost savings would likely be higher than those found here. CALVIN is an optimization model. Its goal is already to minimize cost. These calculations show the benefit of conservation in an already ideally optimized system. Therefore, this may represent the minimum cost savings possible. Actual savings may be notably larger. Actual savings also is likely to be larger if the urban conservation were targeted to particularly promising areas (coastal cities and consumptive uses), rather than the across-the-board reductions in gross use modeled here. (Rosenberg et al., 2008)

Now, recall that CALFED actually gave a range for the cost of conservation implementation: $244 – 572 ($2008), depending on how much water was conserved. Thus far, $572 has been used here because as the amount of conservation increases, so does the average cost. To allow flexibility for the actual cost of urban water conservation, a range of unit conservation costs were analyzed, from $200 to $1,200/af The total costs (scarcity cost plus operations plus implementation) are listed in Figure 4:21 and Figure 4:22. As a point of reference, CALFED's 2006 study estimated an average cost of $572/af ($2008) for 17 % conservation. The dashed line indicates the total cost for the no conservation case with full Delta exports.

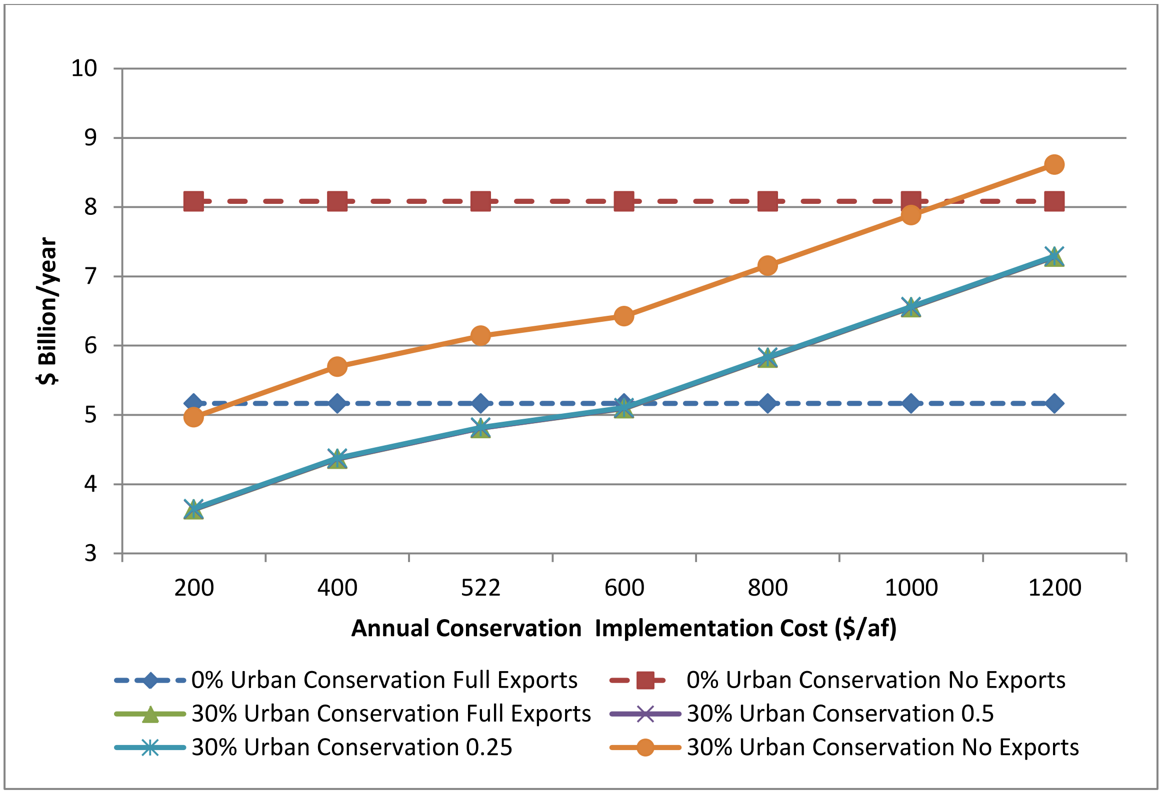

Figure 4:21: Effect of 30% urban conservation implementation cost on overall system costs for various Delta export levels under historical climate conditions

For these 2050 conditions, average urban conservation costs up to roughly $600/af appear justified under a wide range of Delta export conditions. However, if Delta exports are ended entirely, urban water conservation of $1000/af or more often will be justified.

Because the modeling assumed universal urban water use reductions, it seems likely that there will be some locations and occasions within California where urban water conservation will generate more benefits than others. Urban conservation of indoor water use in inland California will be less valuable because much of the savings result in reduced return flow that can be used by others downstream Outdoor and coastal conservation is likely to generate greater net benefits because it is more likely to reduce consumptive net water use. These details can be explored in later studies.

With a drier, warmer climate, Figure 4:22 indicates that still higher costs for urban water conservation become justifiable.

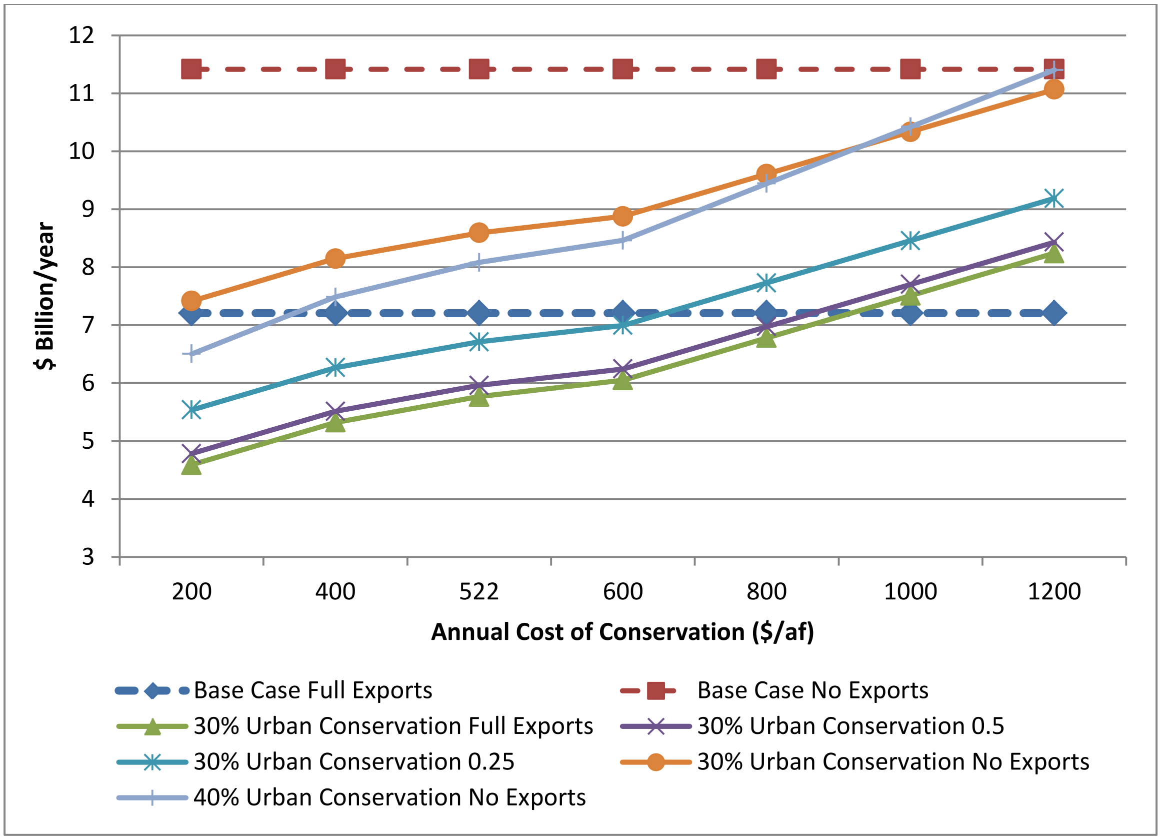

Figure 4:22: Effect of 30% urban conservation implementation cost on overall system cost for various Delta export levels under warm, dry climate conditions.

Chapter 5 Conclusion

Chapter 5 discusses the results in Chapter 4 in four areas: urban water conservation, new infrastructure, Delta exports, and a warmer, drier climate.

Urban Water Conservation: Pays for itself and then some.

On average, urban water conservation decreases operating and scarcity costs between $2.2 and $5.6 billion statewide, which, at an implementation cost of $572 (CALFED's average cost estimate of $522 in $2008) per acre-foot, saves California nearly $10 million to $2.4 billion annually, as illustrated in Table 5:1. This savings comes primarily from decreased operations costs, but approximately 1/3 of the savings comes from decreased scarcity as well. Conservation reduces costs most in no exports cases with a drier, warmer climate.

Table 5:1: Statewide savings from 30% urban water conservation ($ billion/year)

		Operations Cost Savings	Scarcity Cost Savings	Implement. Cost	Net Savings
Historical Climate	Full Exports	1.98	0.20	2.18	0.01
	No Exports	2.49	1.10	2.18	1.41
Warmer, Drier Climate	Full Exports	2.12	0.86	2.18	0.81
	No Exports	3.43	1.12	2.18	2.38
	No Exports 40% Cons.	4.22	1.40	2.92	2.70

Note: Numbers may not add due to rounding

Table 5:2 further divides the operation cost savings by source. The origins of cost savings depend on Delta export and climate conditions. In full export cases, cost savings come largely from less surface water pumping and treatment. In no exports cases, much of the cost savings comes from less use of recycled water. In a warmer, drier climate, additional cost savings comes from less seawater desalination and water recycling. Recall Table 4:11 and Table 4:15 showed that in a warmer, drier climate with no Delta exports and no conservation, California would use a little over 1.1 maf of seawater desalination at the cost of $2.3 billion. Reducing the demand for seawater desalination, rather than the cost, results in an average cost savings between $2.27 and $2.28 billion/yr. Since CALVIN has perfect foresight and idealized water markets, actual savings from urban water conservation could be larger.

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Table 5:2: Annual operations cost savings from conservation ($ million/year)

	Policy Options		Results						
	Urban Conserv.	Delta Export Level	Groundwater Pumping	Surface Water Pumping	Surface Water Treatment	Recycled Water	Seawater Desalination	Hydropower Benefits	Net Operating Costs Savings
Historical Climate	30%	Full Exports	33	894	852	273	78	-143	1,987
		No Exports	13	455	392	1,432	284	-84	2,493
Warmer, Drier Climate	30%	Full Exports	-19	1,044	909	325	78	-209	2,127
		No Exports	16	108	152	895	2,266	-1	3,436
	40%	No Exports	17	166	295	1,463	2,284	-1	4,224

Note: Negative numbers count against cost savings either through increased use or because they normally are a source of revenue

In an idealized water market where reducing scarcity cost is the goal (as in CALVIN), if it costs more for one sector, like urban areas, to experience scarcity than another, like agriculture, urban areas would purchase enough water to balance the cost between the two sectors more evenly. Urban water conservation reduces scarcity in both the agricultural and urban sectors because it reduces urban demand, and the pressure placed on agriculture to sell water.

Table 5:3 shows how much scarcity savings results from urban water conservation for both agriculture and urban areas. Even though urban areas receive most of the water demanded, there is a noticeable cost for the small amount that is not delivered. In a warmer, drier climate without Delta exports, urban water conservation actually saves urban users more in reduced scarcity costs than agriculture. Recall that in Table 4:4 and Table 4:13, in a warmer, drier climate with no Delta exports and no conservation, approximately 95% of urban demands were met. The scarcity cost of the remaining 5% was $900 million per year. With 30% urban water conservation, 99% of urban water demands are fulfilled and the remaining 1% has a scarcity cost of approximately $150 million annually. Thus, conservation results in a cost savings of approximately $756 million annually. While most of the water conserved in urban water conservation increases agricultural water deliveries (between 1 and 3 million acre feet per year, depending on the climate and pumping scenario), urban areas can see a larger cost benefit. Of course, urban areas are also likely to bear most, if not all, of the costs of implementing conservation as well.

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[4] Even when seawater desalination costs are reduced, conservation allows California to use only demand 22 taf of seawater desalination, saving only $9.8 million/year, or 0.2% of total savings.

Table 5:3: Annual scarcity cost savings from urban conservation ($ million)

	Policy Options		Results		
	Urban Conserv.	**Delta Export Level**	**Statewide**		
			Agriculture	Urban	Total
Historical Climate	***30%***	Full Exports	155	46	201
		No Exports	549	549	1,097
Warmer, Drier Climate	***30%***	Full Exports	758	102	860
		No Exports	367	756	1,123
	40%	No Exports	561	841	1,402

Given the cost savings both from operations and reduced scarcity costs, implementing urban water conservation can cost anywhere from $573 – $1,195 per acre foot and still be cost effective. Urban water conservation generally results in a net benefit, rather than cost.

New Infrastructure: Not a Panacea

New infrastructure includes expanded water recycling, seawater desalination, more surface water storage and expanded conveyance infrastructure.

Desalination and water recycling are potential ways to increase water supply, but results indicate that these technologies are often not as economical as other options. Water recycling was only used consistently in a few areas in all climate and export conditions, namely Santa Barbara, San Louis Obispo, by East Bay Municipal Utilities District and Santa Clarita. It was used more broadly without water conservation. Seawater desalination was used primarily in a warmer, drier climate with no Delta exports and no urban water conservation. As shown in Table 5:4, in that case, 1.1 maf/yr of water supply was generated by seawater desalination. Once water conservation was implemented, seawater desalination use averaged only 22 taf/yr, or 50 times less.

Table 5:4: Use or value of various options

		Policy Options		Results - State Average			
		Urban Conserv.	Delta Export Level	Water Conservation (benefit / af)	Storage Use (% of Capacity)	Expanded Recycling (maf)	Desal Use (maf)
Model Runs	Historical Climate	0%	Full Exports	NA	63%	0.19	0.04
			No Exports	NA	80%	1.05	0.02
		30%	Full Exports	$573	77%	0.03	0.00
			50%	*	73%	0.03	0.00
			25%	*	77%	0.03	0.00
			No Exports	$982	84%	0.12	0.02
	Warmer, Drier Climate	0%	Full Exports	NA	40%	0.25	0.04
			No Exports	NA	52%	1.13	1.11
		30%	Full Exports	$783	40%	0.03	0.00
			50%	*	42%	0.06	0.00
			25%	*	47%	0.08	0.00
			No Exports	$1,195	56%	0.89	0.02
		40%	No Exports	$1,100	55%	0.12	0.01

* Benefit generated by comparison to Tanaka et al, 2008 would be $714/af for 50% exports and $794 / af for 25% exports

** Not Available

In cases without Delta exports, much of the savings from conservation comes from less recycling and seawater desalination. Under historical conditions, $1.7 of the $3.6 billion/yr in operations and scarcity cost saving, or 47%, comes from less water recycling and seawater desalination. In a warmer, drier climate that number is even higher; $3.1 of the $4.6 in operations and scarcity cost savings, or 68%, comes from less water recycling and seawater desalination. [5]

Increased storage and conveyance capacities across the board are not clearly beneficial, but expanding at individual locations may be. In a warmer, drier climate, the marginal value of expanding storage increases north of the Delta, but increases less consistently south of the Delta. Export reductions decrease the value of expanding storage north of the Delta, and do little south of the Delta. Of the 43 surface reservoirs in CALVIN, only four had a marginal value of expansion higher

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[5] CALVIN results imperfectly reflect actual seawater desalination and water recycling usage. CALVIN could underestimate actual use of these options because it has perfect foresight and ideal water markets, or greatly overestimate the use of these options because capital costs for expanded recycling and desalination is averaged into variable costs for these supplies.

than $100/af in a historical climate and nine in a warmer, drier climate. Of these only two have marginal values of expansion that were consistently over $100/af each of the 13 scenarios studied; Lake Kaweah and Lake Success. (Table 4:23)

The value of expanding conveyance varies inconsistently across the two climate scenarios, but is generally higher than that of storage capacity expansion. As shown in Table 4:24, the marginal value of conveyance increases with reduced Delta exports from $0 to $1,430/af with conservation, and up to $2,800 without conservation, depending on the scenario. Considering that expanded recycled water costs approximately $1,480/af, this suggests that some Delta exports are rather valuable. In a warmer, drier climate specifically, expanding other conveyance, such as the Freeport project and Colorado River Aqueduct may also be valuable, as the marginal costs on them range from $152 to $510 and $72 to $720, respectively, with conservation, and up to $1,660 and $1,280, respectively, without conservation.

By lowering urban demand, conservation decreases the marginal value of expanding storage, conveyance, water recycling, and desalination statewide.

Delta Export Reductions: Raise costs

Delta export reductions can affect costs more than a warmer, drier climate. On average, ending Delta exports costs $300 million/yr more than the total cost difference between historical and warmer, drier climate conditions, under equivalent assumptions about urban conservation.

Thirty percent urban water conservation counters most scarcity effects of ending Delta exports and all of the cost effects at the statewide level. Thirty percent urban water conservation can reduce total scarcity to a level lower than that with full exports and no conservation in all but the no Delta exports case. Conservation can completely counter cost increases from Delta export reductions to below that of the full exports, no conservation case in each respective climate scenario. The no exports, 30% conservation cases cost $500 million to $1.0 billion/yr less than their respective full exports, no conservation cases.

The effects of allowing only 50% of total export capacity are notably less than those of ending exports entirely. The scarcity and cost differences between full capacity and 50% capacity are negligible under a historical climate (900 taf/year and $200 million/year greater) despite pumping approximately 30% less water. As pumping is reduced further, the unit costs to the economy of each acre-foot lost increase.

Warmer, Drier Climate: Reduces deliveries

As expected, a warmer, drier climate decreases water availability and deliveries. Scarcity throughout the state rises more in a warmer, drier climate than when Delta exports are ended under historical climate conditions: 3.8 – 6.9 maf/year vs. 2 – 5.1 maf/year.

In the absence of conservation, a warmer, drier climate costs $2.0 to $3.3 billion/yr more (on average) than the historical climate, with much of that cost from scarcity. (Scarcity costs $1.9 - $2.1 billion more between historical and a warmer, drier climate, while operations costs differ by $200 million to $1.4 billion, respectively.) Approximately 65 - 80% of the scarcity cost is experienced by the agricultural sector. Much of the operations cost comes from increased seawater desalination in the no conservation, no exports case.

In a warm, dry climate, urban water conservation decreases scarcity, with notable decreases in operations costs. Conservation decreases operations costs between $2.1 and $3.5 billion in a warmer, drier climate (vs. $2.0 to $2.4 billion in a historical climate). As mentioned previously, much of this difference is from decreased seawater desalination. Conservation is also worth $250 – 300/af more in a warmer, drier climate than in a historical climate.

Additional research

This thesis serves primarily as an overview of how many different water management solutions interact with each other. Further research could be conducted on economically modeling urban water conservation to determine where it is most beneficial to conserve. Agricultural conservation, while less valuable from a willingness to pay standpoint, could also be modeled directly, instead of as a shortage.

In addition to understanding the cost savings of water conservation, it may be useful to explore its net energy savings. Given that currently 20% of California's energy is used to heat, move, and treat water, this could be a compelling study. (CEC, 2005)

It would potentially also be useful to explore water conservation benefits in a climate change scenario that is contains warming, but not drying.

USGS recently came out with a new groundwater model covering California. CALVIN's groundwater data could be updated incorporate this new information. This may give further insight into groundwater levels and conjunctive use opportunities and limitations.

Capacity constraints within CALVIN could be further explored. Even though Banks pumping plant capacity was expanded in this thesis, the plant is not used much more than it currently is, despite scarcity downstream. Further investigation into the source of this capacity constraint, as well as others, could help reveal bottlenecks within California's water system.

While the marginal benefit of Millerton Lake (Friant Dam, located downstream of the proposed Temperance Flat project) indicates there is a low willingness to pay for the dam, further runs could individually add this and other storage reservoirs to further assess their value.

Concluding thoughts

Water management in California is a complex problem. There are no necessarily 'right' or 'wrong' answers, just potentially more and less beneficial ones. Integrated hydro-economic models, such as CALVIN, show both promising solutions and economic performance for complex solutions.

In this case, of the solutions analyzed, some overall conclusions are:

- Water conservation appears to be valuable and result in a net benefit.
- Seawater desalination is generally only used in no conservation, no Delta export cases, so if conservation is implemented, seawater desalination may not be used much.
- Recycled water is consistently used in only a few areas. Expanding recycled water in those areas may be beneficial, but expanding elsewhere may not be.
- Expanded surface storage appears to not be very valuable, compared to other solutions explored.
- Having some Delta conveyance is valuable.
- Expanding other conveyance may also be somewhat valuable.

It is important to keep in mind, however, that CALVIN is somewhat optimistic. Real world water managers have additional concerns to address that this model cannot, such as politics, non-ideal water markets and imperfect foresight. Having a robust and diversified portfolio can help prepare for the future. Models such as CALVIN help reveal promising areas to focus on for diversification and exploration, and also help put solutions into perspective.

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Appendix

Seawater Desalination in California: a Hydro-Economic Analysis Under Climate Change

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July 30, 2011

Summary

The CALVIN model was used to explore the effects of changing seawater desalination costs in all desalination plants included in the model. The Climate Change Assessment 2008 served as a basis to evaluate these effects under historical and warm dry hydrological scenarios. Results indicate seawater desalination is used the most in Southern California when its cost falls below $1480/AF, especially under warm-dry forms of climate change. With additional seawater desalination, water scarcity and its cost is reduced marginally overall.

Introduction

CALifornia Value Integrated Network, or CALVIN, is a network flow-based economic-engineering optimization model of California's water systems (Draper et al. 2003). CALVIN is a prescriptive model that manages surface and groundwater resources to minimize the costs of water shortage (scarcity) and use in California. CALVIN covers 90% of the state's urban and agricultural water demands and about two-thirds of all state runoff.

CALVIN models seawater desalination in eight major metropolitan regions: East Bay Municipal Utility District (EBMUD), San Francisco Public Utilities Commission (SFPUC), Santa Barbra – San Luis Obispo (SB-SLO), Santa Clara Valley (SCV), San Diego Municipal Water District (SDMWD), East and West Metropolitan Water District (EWMWD), Central Metropolitan Water District (CMWD), and Ventura. Proposed desalination plants in this list include SFPUC and SCV.

CALVIN is a generalized network flow model that calculates water generation and treatment costs by attaching them to flows through links. Seawater desalination typically costs $ 2072/af in CALVIN. This cost includes not only the actual cost to generate water from seawater desalination, but all costs associated with the plant and the generation of that water. Such costs include the energy and operational costs to maintain the facility and workforce, costs to manage and mitigate effluent from the plants, the costs to generate the power to perform the desalination, etc. This cost is applied to the amount of water actually generated from that facility. This approach has limitations, but since CALVIN is already a very large model, it allows the model to remain simple enough to run.

This study explores two things: the effects of varying costs of seawater desalination and the application of capacities to the desalination plants. Seawater desalination costs were set at $888, $1184, $1480, $1776 and $2072 per acre-foot ($2008). Since seawater desalination is expensive in CALVIN, a typical CALVIN run does not set capacity constraints on seawater desalination plants. As the price is lowered substantially, two sets of runs were done: with and without capacities. Seawater desalination capacity was set at 10% of the target 2050 demand at the nearby urban demand location for costs below $1776/AF. This setting prevents unrealistic desalination facility sizes under optimized conditions.

Methods and Results

Results from CALVIN model runs at these costs are summarized in Figure 1. The letter in front of the price per acre-foot indicates if the model was based on Historical (H) or a Warm Dry (WD) climate scenario.

Figure 1 shows that lowering seawater desalination cost increases its use when the price drops to $1184/af and below. This may be because the most expensive form of recycled water costs $1480/af as well. Contrary to expectations, under the Warm Dry scenario, an increase in desalinated water use mostly occurs only in Southern California.

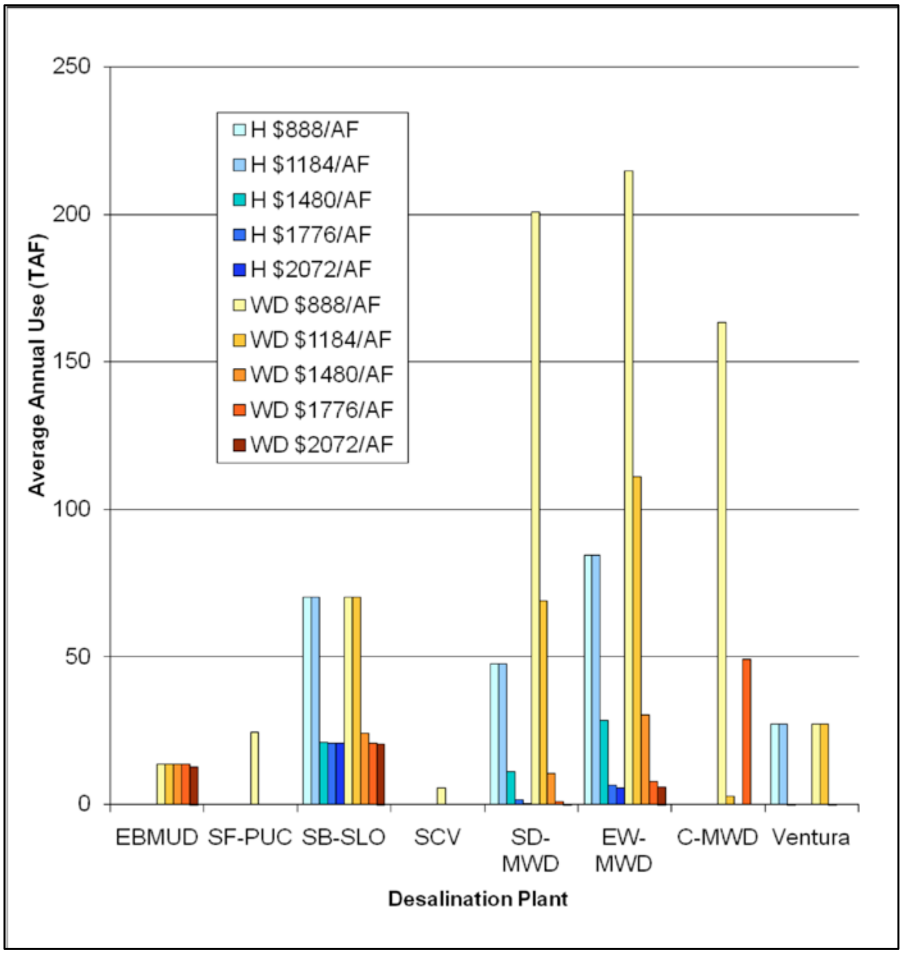

Figure 1. Average Annual Usage of Desalinated Water (TAF) by Desalination Plant

Figure 2 compares desalinated water use between Northern California and Southern California. For this study, Northern California includes the Bay Area and the Delta. Figure 2 also indicates greater ocean desalination potential in a warm dry climate. There is a major price break at $1480/af. This could be because expanded recycled water is priced at $1480 for all model runs, making expanding recycled water use more expensive at lower seawater desalination prices.

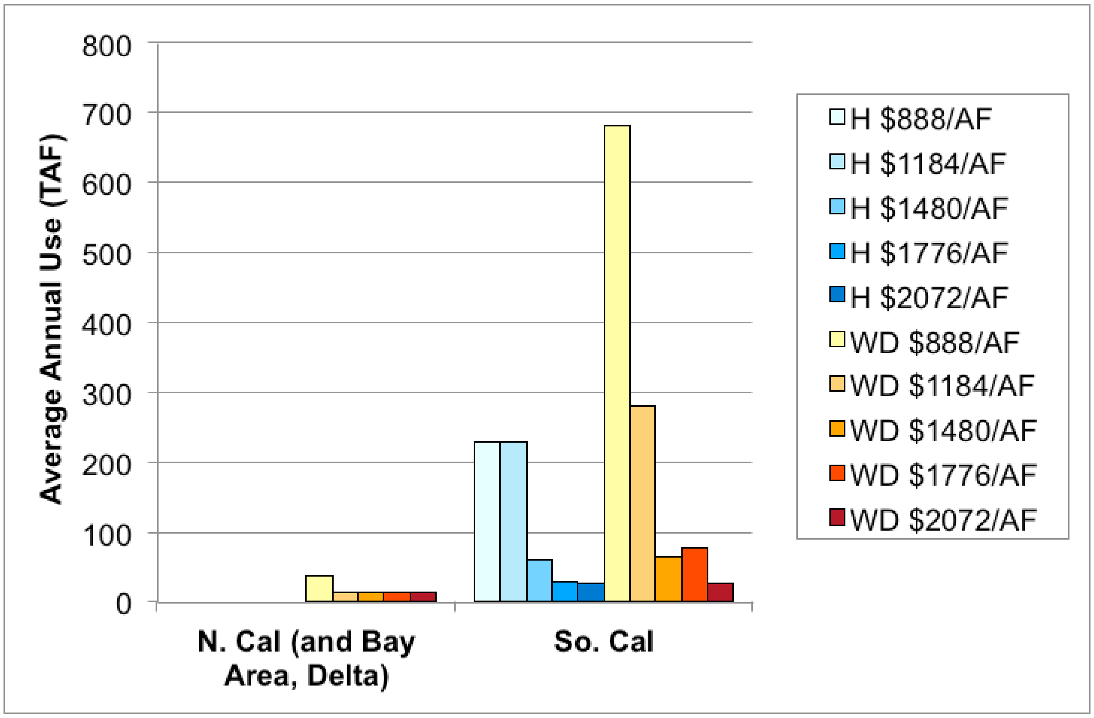

Figure 2. Average Annual Usage of Desalinated Water (TAF) in Northern and Southern California

Table 1 shows slightly lower agricultural annual water scarcity and its scarcity cost with lower seawater desalination costs. The historical hydrology case model runs show almost no change in the pattern of scarcity and scarcity costs in both Northern and Southern California. Even though the cost of desalinized water is lower, lower cost water from other sources in the system is used first and small shortages in agriculture may be economically optimal.

Reducing the cost of seawater desalinization in the Warm Dry scenario modestly decreases water scarcity and its costs, and also lowers the willingness to pay for additional water. There is a major jump in scarcity cost, scarcity and willingness to pay between $888/af and $1184/af in the warmer, drier climate. The differences between these two runs are consistently larger than the scarcity, scarcity costs and willingness to pay changes in all of the other runs combined. Despite all the changes between the $888 per acre foot and the higher costs, the percent of full water demand delivered stays approximately the same indicating some substitution among water sources if seawater desalination costs are sufficiently low.

Table 1: Water Scarcity and Scarcity Costs per year for Agricultural in California.

		WTP ($/AF)	Scarcity Cost ($K/yr)	Target (KAF)	Scarcity (KAF)	Delivery (% of Target)
Historical						
$888/AF	N. Cal	19	19441	11916	97	99
	So. Cal	343	277883	12207	772	94
$1184/AF	N. Cal	19	19441	11916	97	99
	So. Cal	343	277882	12207	772	94
$1480/AF	N. Cal	19	19441	11916	97	99
	So. Cal	343	277883	12207	772	94
$1776/AF	N. Cal	19	19441	11916	97	99
	So. Cal	343	277883	12207	772	94
$2072/AF	N. Cal	19	19441	10410	97	99
	So. Cal	343	277883	12207	772	94
Warm Dry						
$888/AF	N. Cal	156	394529	11916	2444	79
	So. Cal	372	663232	12207	2116	83
$1184/AF	N. Cal	158	463461	11916	2756	77
	So. Cal	372	718050	12207	2262	81
$1480/AF	N. Cal	159	471311	11916	2792	77
	So. Cal	372	724697	12207	2282	81
$1776/AF	N. Cal	158	463461	11916	2756	77
	So. Cal	372	718050	12207	2262	81
$2072/AF	N. Cal	159	471319	11916	2792	77
	So. Cal	372	724697	12207	2282	81

Table 2 shows that annual water scarcity and scarcity cost change only slightly at lower seawater desalination costs for urban areas in California. The scarcity and scarcity cost for the Historical climate scenario spike when the price exceeds $1776/AF. Changing the cost of seawater desalinization in a warmer drier climate modestly decreases water scarcity and its costs, lowering also the willingness to pay for additional water. There seem to be two jumps in the warmer drier climate case, one at $1184 and a second at $2072. Similar to Agriculture, in a warmer, drier climate, despite the changes between the price jumps, the percent of water delivered to the target stays approximately the same, indicating some substitution among water sources if seawater desalination costs are sufficiently low.

Table 2. Water Scarcity and Scarcity Costs per year for Urban areas in California.

		WTP ($/AF)	Scarcity Cost ($K/yr)	Target (KAF)	Scarcity (KAF)	Delivery (% of Target)
Historical						
$888/AF	N. Cal	0	0	3296	0	100
	So. Cal	563	2815	9513	4	100
$1184/AF	N. Cal	0	0	3296	0	100
	So. Cal	563	2815	9513	4	100
$1480/AF	N. Cal	0	0	3296	0	100
	So. Cal	563	2815	9513	4	100
$1776/AF	N. Cal	0	0	3296	0	100
	So. Cal	563	42231	9513	29	100
$2072/AF	N. Cal	0	0	3296	0	100
	So. Cal	563	46015	9513	31	100
Warm Dry						
$888/AF	N. Cal	10	23	3296	0	100
	So. Cal	902	10422	9513	13	100
$1184/AF	N. Cal	53	123	3296	1	100
	So. Cal	969	43945	9513	58	99
$1480/AF	N. Cal	54	124	3296	1	100
	So. Cal	974	45756	9513	60	99
$1776/AF	N. Cal	53	123	3296	1	100
	So. Cal	969	84513	9513	84	99
$2072/AF	N. Cal	186	1852	3296	2	100
	So. Cal	974	91124	9513	88	99

There are a few quirks with how seawater desalination is modeled in CALVIN that may cause odd behavior when prices are reduced significantly, but these quirks can be informative. Seawater desalination is often the most expensive water source in CALVIN, and thus is used minimally. CALVIN models seawater desalination as a set cost per acre foot used, nothing more. All overhead, capital, maintenance, energy environmental costs are factored into the per acre foot cost, so $2,072/af in CALVIN is not the equivalent unit price of seawater desalination from sources that only calculate the cost of generating one acre-foot of water itself. Additionally, since the cost is calculated in CALVIN per acre foot, there is basically no cost associated with capacity under-utilization. This means that a seawater desalination plant could theoretically sit idle for years, then, suddenly be used to generate a large volume of water for a month, and return to being idle for years at only the cost per acre foot for the water actually generated in that month. Another quirk about seawater desalination in CALVIN is that there is currently not a capacity set on the plants. Both quirks are unrealistic, but reveal potential volumes that would be demanded, were there no capacity-related limitations. These imperfections in how CALVIN represents desalination costs tend to over-employ desalination use.

The location that seems to utilize these quirks in the most unrealistic way is CMWD. Figure 3 shows use in a warmer, drier climate with $888/acre foot desalinated seawater. In several years, no seawater desalination occurs. In other years, as much as 800 thousand acre-feet of water is generated through seawater desalination.

Other desalination plants are used more continuously. This particular scenario generates the most obvious unrealistic patterns. In more high cost situations, some of these quirks disappear. In the standard seawater desalination price of $2072 in a warmer, drier climate, for example, the most any single plant uses is 24 taf/month. Intermittent use of the plant continues however.

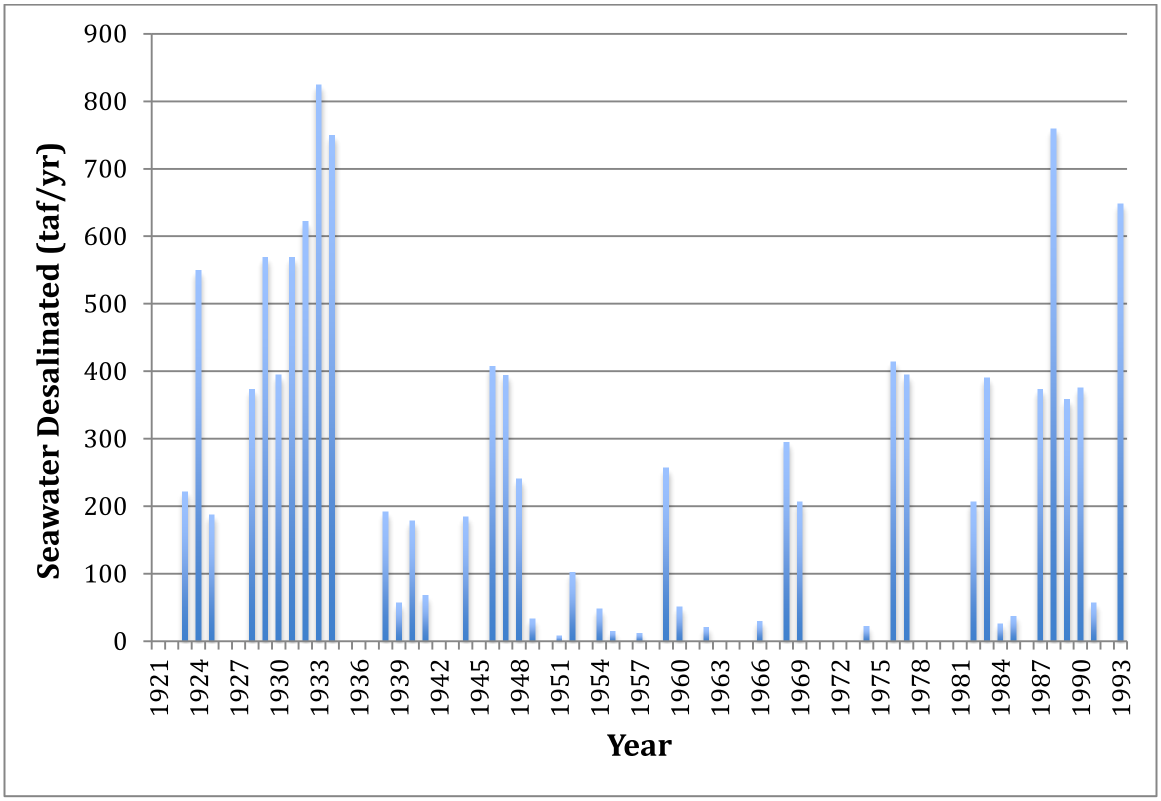

Figure 3: Seawater Desalination use at Central Metropolitan Water District

Typical Calvin runs do not have capacity constraints on seawater desalination, but adding capacity constraints alters use patterns especially for lower cost desalination, but use remains similar for higher costs. If each seawater desalination plant were allowed to only generate up to 10% of all water demanded by it's adjoining urban area, use shifts, as shown in Figure 4. Since C-MWD has the largest capacity, at $888/af in a warmer-drier climate, it is used more fully. All of the other desalination plants, however, are used less on average. Most notable among these are SD-MWD and EW-MWD.

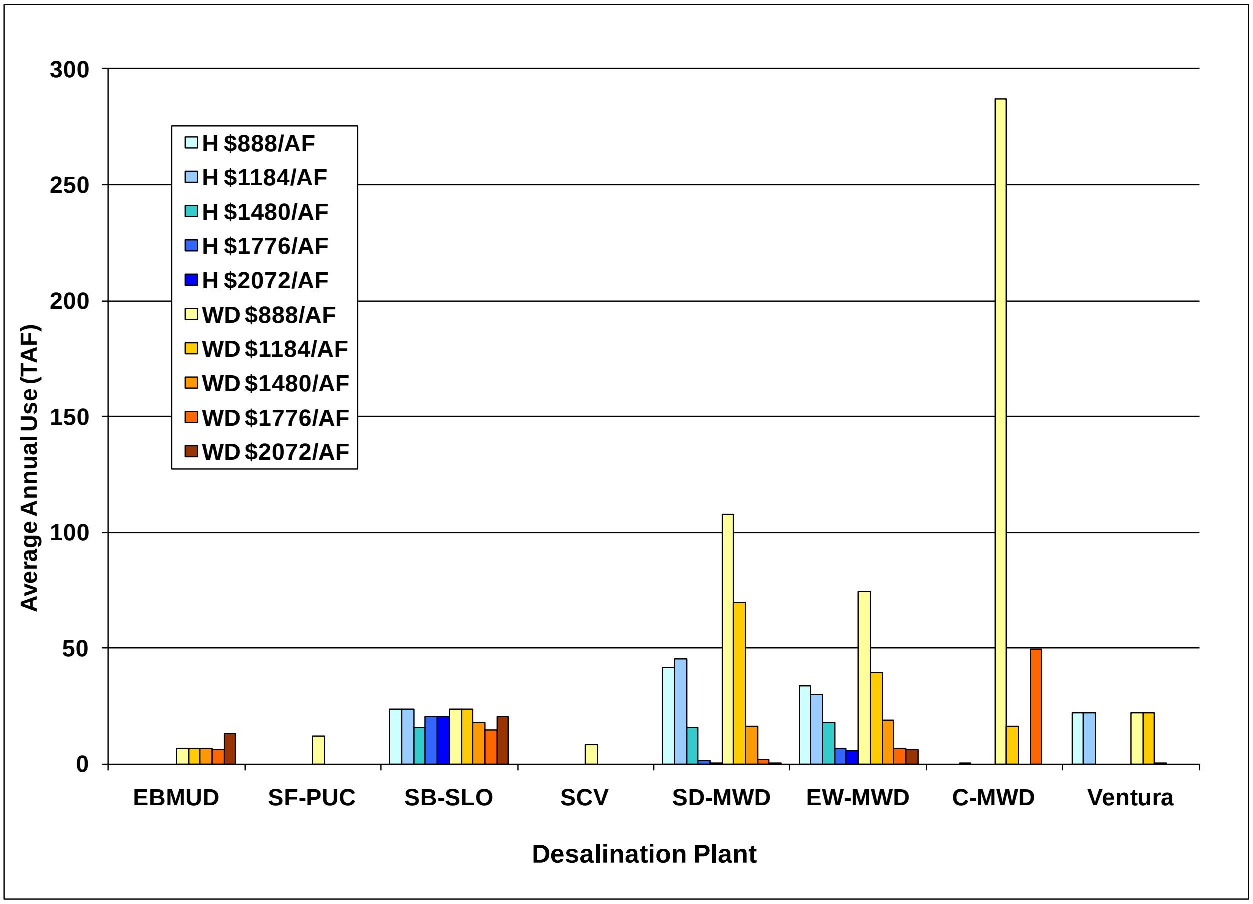

Figure 4: Seawater Desalination use by plant (taf/month) with capacity limited to 10% of all water demand

Use patterns change also at the regional level. Figure 5 shows the average seawater desalination use in all desalination plants, along with the range of use. Capacity constraints notably affect how much seawater is desalinated for costs les than $1480/af. At costs above this, little change is seen.

Conclusions

Unless seawater desalination becomes notably less expensive (less than $1480/af), it remains uneconomical source of water in California. With economically optimal water allocations, seawater desalination is used mostly in Southern California under warmer, drier climates. When the cost of seawater desalination drops from $2,072/af to $1,480/af, some increase in desalination is observed. When desalination cost drops below $1,480, however, its use increases more noticeably, especially at $888. This is because it is used in place of the then-more-expensive recycled water available. However, desalination does not significantly decrease scarcity or scarcity cost as other water sources in the system can outcompete seawater desalination including water traded from agriculture, regardless of price.

Currently CALVIN does not have imposed capacity constraints on seawater desalination plants in California due to their low and intermittent use. Should the cost of seawater desalination drop to or below $1480/af, however, capacity constraints should be implemented to help ensure less quirky results.

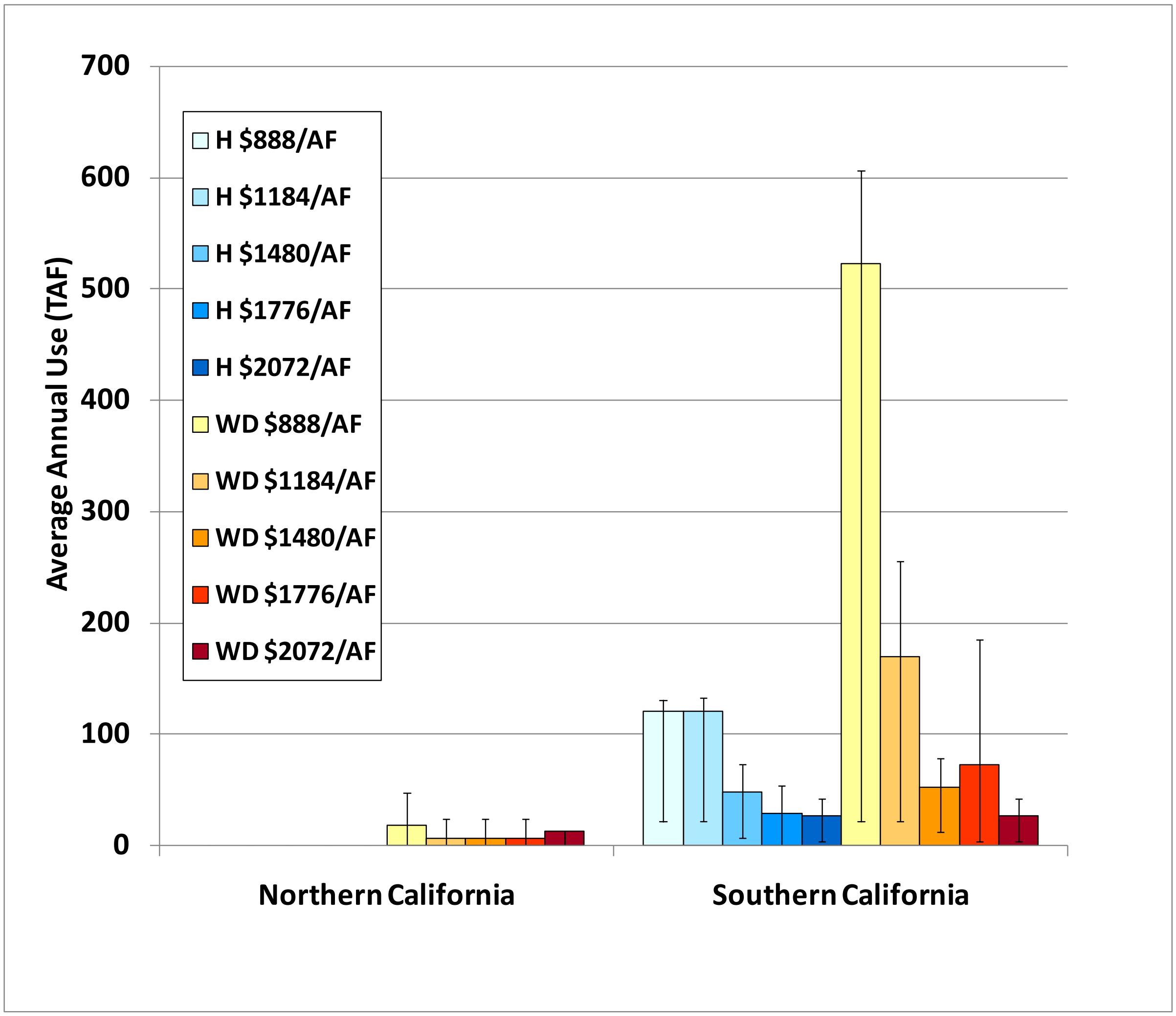

Figure 5: Seawater Desalination use in California and its range.

References

Draper, A.J., M.W. Jenkins, K.W. Kirby, J.R. Lund, and R.E. Howitt " Economic-Engineering Optimization for California Water Management ," *Journal of Water Resources Planning and Management,* ASCE, Vol. 129, No. 3, May/June 2003.