The Economic Costs and Adaptations for Alternative Delta Regulations

Technical Appendix F

Stacy K. Tanaka
Christina R. Connell
Kaveh Madani
Jay R. Lund
Ellen Hanak
Josué Medellín-Azuara

with research support from Richard E. Howitt

July 2008

Description

This document is an appendix to the Public Policy Institute of California report, *Comparing Futures for the Sacramento-San Joaquin Delta*, prepared by a team of researchers from the Center for Watershed Sciences (University of California - Davis) and the Public Policy Institute of California.

Supported with funding from Stephen D. Bechtel Jr. and The David and Lucile Packard Foundation

PPIC PUBLIC POLICY INSTITUTE OF CALIFORNIA

The Public Policy Institute of California is dedicated to informing and improving public policy in California through independent, objective, nonpartisan research on major economic, social, and political issues. The institute's goal is to raise public awareness and to give elected representatives and other decisionmakers a more informed basis for developing policies and programs.

The institute's research focuses on the underlying forces shaping California's future, cutting across a wide range of public policy concerns, including economic development, education, environment and resources, governance, population, public finance, and social and health policy.

PPIC is a private, nonprofit organization. It does not take or support positions on any ballot measures or on any local, state, or federal legislation, nor does it endorse, support, or oppose any political parties or candidates for public office. PPIC was established in 1994 with an endowment from William R. Hewlett.

Contents

Summary

Water exports from the Sacramento-San Joaquin Delta are often a concern because they reduce net outflows of fresh water from the Delta and can entrain fish and disrupt flows within the Delta. Water users throughout California rely on the Delta watershed for uses within the Delta, exports via the pumps in the southern Delta, or diversions of water upstream. Water exports from the southern Delta supply urban users in the Bay Area and Southern California, as well as agricultural users in the San Joaquin and Tulare Basins.

These exports have become a central concern for the environmental health of the Delta, which has witnessed dramatic declines in numerous fish species in recent years. For several decades, exports have been regulated in various ways to protect fish, most notably with minimum flow requirements, maximum salinity standards at particular times of the year, and the export/import ratio (E/I ratio or carriage water requirement). Recent federal court actions and the Delta Vision Blue Ribbon Task Force's report (Isenberg et al., 2008) have highlighted the need to find alternative, multi-objective ways to manage the Delta.

Under the current system, where exports are drawn through Delta channels to the pumps, there are good reasons for directly targeting export reductions to avoid entrainment and other problems created by the altered flows within the Delta. If, instead, exports are diverted around the Delta through a peripheral canal, the role of the pumps in the southern Delta is reduced and the regulatory issue becomes one of maintaining appropriate flow levels into and out of the Delta. Regulatory flows are often measured as net outflows from the Delta to the ocean, or "net Delta outflows." In addition to potential environmental benefits, increased net Delta outflows could be sought to maintain salinity standards for agricultural and urban users within the Delta in the face of sea level rise, which will otherwise push salinity from the ocean and San Francisco Bay further into the Delta.

This appendix reports the results of two CALVIN modeling alternatives developed to represent a range of modified Delta operations. The first alternative represents changing (increasing and decreasing) export pumping capacity limits in the southern Delta. The second alternative represents increasing minimum net Delta outflow (MNDO) requirements. The CALVIN economic-engineering optimization model seeks the least-cost statewide water management scheme for water supply; it includes a wide range of resources and water management options. The CALVIN model represents an economically ideal water market (i.e., no transaction costs, risks, or uncertainty). Transfers are only limited by physical infrastructure capacities, environmental flow requirements, and the economic value of water.

Limited by downstream conveyance capacities, operations do not change greatly when southern Delta pumping plant capacities are increased. In contrast, when flexibility is reduced, either through reduced pumping capacity or increased minimum net Delta outflow requirements, annual average statewide water scarcity (shortages), scarcity costs (the costs of shortages to water users), and operating costs (from greater use of desalination, wastewater recycling, water treatment, and pumping) increase.

When exports are eliminated, average total statewide costs (water scarcity costs plus net operating costs) increase by $1.5 billion per year (2008 dollars) relative to the base case for the

year 2050. With reduced export capacity, the agricultural areas in San Joaquin and Tulare Basins bear most of the increased scarcity, not only as a result of the loss of access to exports, but also because they are able to transfer available water to Southern California urban users. The effects of ending exports are especially concentrated on agricultural communities in the southern Central Valley. Without these transfers, the costs to agricultural users are somewhat lower, but the costs to the economy (borne largely by urban users) increase by an additional $0.7 billion per year, for a total cost of $2.2 billion per year.

When average minimum net Delta outflows are increased to 2,218 thousand acre-feet (taf) per month (26,613 taf per year) – corresponding to roughly 94 percent of all modeled surface water flows in the Delta watershed - average total statewide costs increase by $2.7 billion per year over the base case. With increased outflow requirements, the increased water scarcity and associated costs are spread throughout California.

Regardless of the regulatory alternative adopted, the value of expanding surface water reservoir capacity remains low, due in part to reduced competition for the water and reduced availability of water supplies to fill the reservoirs. Outside of the Delta, key conveyance facilities, like the Hetch-Hetchy Aqueduct and Hayward intertie, provide the greatest benefits to the system if expanded. More generally, aqueducts, canals, and interties that facilitate the transfer of water, especially between agricultural and urban sectors, are the most valuable. New technology (wastewater reuse and desalination) becomes important for urban users with both types of regulatory changes.

Average Delta exports in the 2050 base case begin at about 6 million acre-feet (maf) per year, corresponding to 13.3 maf per year of average net Delta outflow. The volume of Delta exports associated with various levels of Delta outflow differs depending on the regulatory alternative (Figure F.S1). When exports are eliminated, there is about 18.7 maf per year of Delta outflow and approximately $1.5 billion per year increase in net costs. Increasing minimum Delta outflow requirements to 18.7 maf per year still allows for approximately 4.5 maf per year of exports, with a considerably lower net cost of $0.5 billion per year. When minimum net Delta outflow requirements are increased, more of the outflow is supplied by reduced upstream diversions. Thus the same level of Delta outflow can be achieved at lower cost by changing minimum net outflow requirements rather than directly restricting exports.

Reducing Delta exports increases net statewide costs under both types of regulatory alternatives (Figure F.S2). Likewise, increases in net Delta outflows raise statewide costs under both alternatives. However, for an equivalent amount of average outflows, statewide costs increase more rapidly when exports are reduced than when minimum outflow requirements are increased (Figure F.S3).

In practice, an explicit reduction in pumping would not necessarily increase Delta outflow, but it could reduce fish entrainment at the pumps. Likewise, a required increase in Delta outflows would provide more fresh water through the Delta, but would not necessarily reduce Delta exports, because many export users would be able to purchase water from lower-value upstream diverters. In devising new regulations for the Delta, policymakers and managers will need to evaluate the trade-offs among water users and the ecosystem. Estimates presented here should be useful in assessing the costs and adaptations available for various users of Delta waters throughout California.

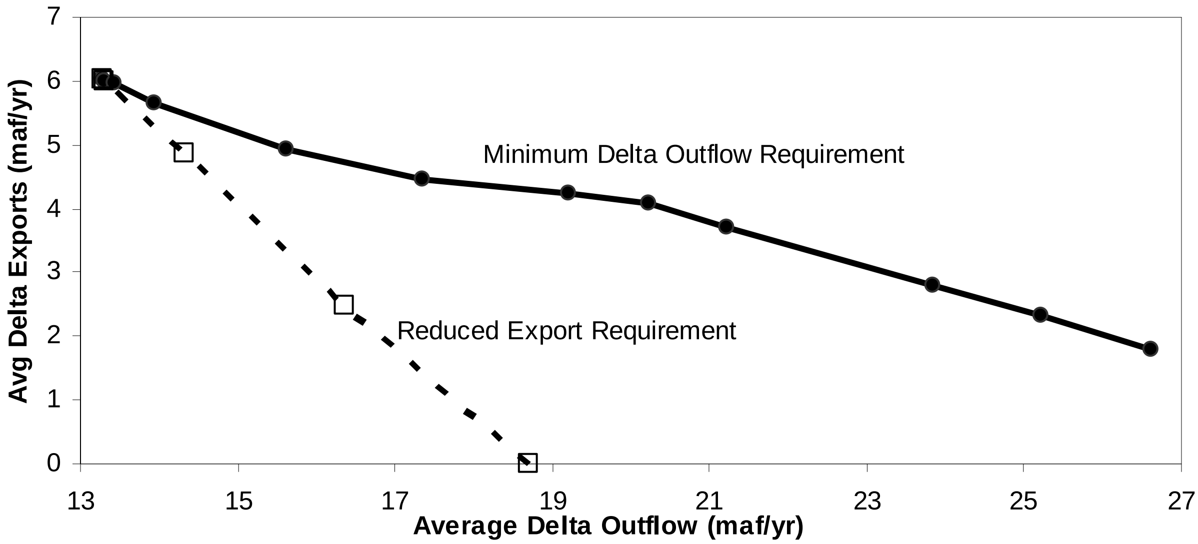


Figure F.S1 - Average Delta exports for a given level of Delta outflow for the two regulatory alternatives (reduced exports and increased minimum net Delta outflow)

Note: As the average Delta outflow increases (from a base of about 13 maf/year), annual average Delta export pumping decreases under both regulatory alternatives. However, exports decrease at a faster rate when export restrictions are applied, Applying a minimum net Delta outflow requirement is the alternative which increases average Delta outflows with the least effect on exports (as evidenced by the 'flatter' curve).

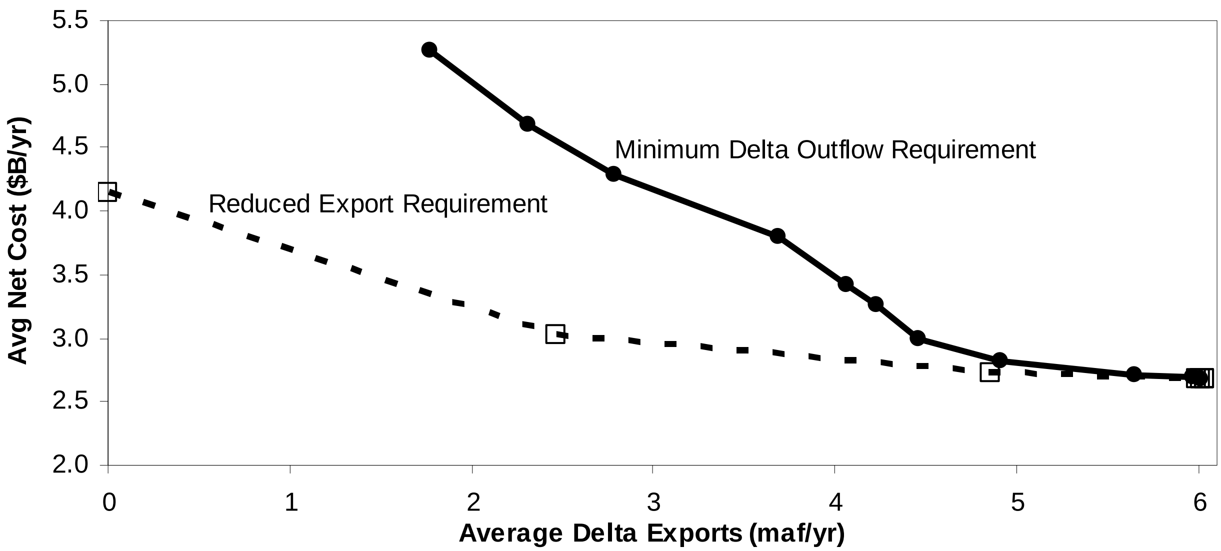


Figure F.S2 - Average Delta export pumping and associated statewide net costs

Note: As average Delta exports increase, average net costs decrease as more water becomes available. Changing the minimum net Delta outflow requirement is a more expensive means of controlling Delta exports than directly restricting export volumes (note that the 'Minimum Delta Outflow Requirement' line is above the 'Reduced Export Requirement' line).

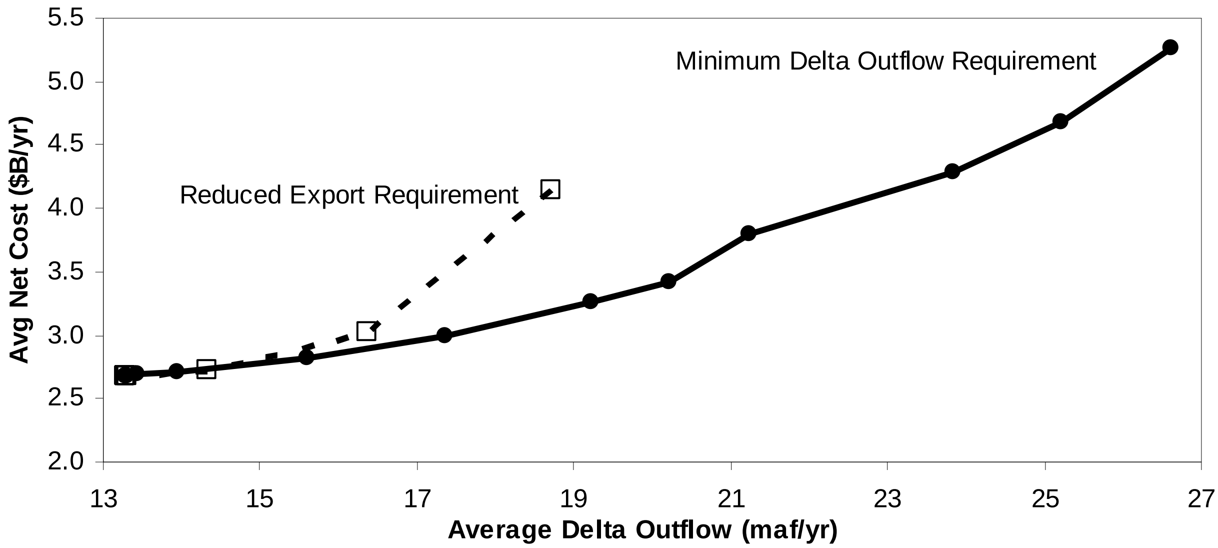


Figure F.S3 - Average Delta outflows and associated statewide net costs

Note: As average Delta outflows increase, the average net costs increase as water becomes scarcer and users switch to more costly supply alternatives. Generally, restricting exports is a more expensive means of increasing the average Delta outflow (note the 'Reduced Export Requirement' line tends to be above the 'Minimum Delta Outflow Requirement' line).

Acknowledgments

We thank David Fullerton, Ray Hoagland, Spreck Rosekrans, and Robert Wilkinson for helpful comments on an earlier draft. We alone are responsible for any remaining errors.

Acronyms

af	acre-foot
CALVIN	California Value Integrated Network
BC	Base Conditions Case
CCWD	Contra Costa Water District
CDE	Changing Delta Exports Modeling Alternative
CLWA	Castaic Lake Water Authority
CMWD	Central Metropolitan Water District
CVP	Central Valley Project
CVPM	Central Valley Production Model
EBMUD	East Bay Municipal Utilities District
EMWD	East Metropolitan Water District
ESA	Endangered Species Act
HC	Hydraulic Capacity at Banks Case
HEC	Hydrological Engineering Center
HEC-PRM	Hydrological Engineering Center – Prescriptive Reservoir Model
IC	Infrastructure Capacity at Banks Case
maf	million acre-feet
MNDO	Minimum Net Delta Outflow Modeling Alternative
MWD	Metropolitan Water District
NE	No Export Case
RT	Restricted Transfers Case
SB-SLO	Santa Barbara-San Luis Obispo
SBV	San Bernardino Valley
SCVWD	Santa Clara Valley Water District
SDMWD	San Diego – Metropolitan Water District
SFPUC	San Francisco Public Utilities Commission
SWAP	Statewide Agricultural Production Model
SWP	State Water Project
taf	thousand acre-feet
UC	Unlimited Capacity at Banks Case

Introduction

Water exports from the Sacramento-San Joaquin Delta are an important source of supplies to the Bay Area, the southern Central Valley, and Southern California, providing drinking water to roughly two-thirds of all Californians and irrigation water to millions of acres of farmland. These exports have become a central concern for the environmental health of the Delta, which has witnessed dramatic declines in numerous fish species in recent years. For several decades, various flow requirements and salinity standards at specific times of the year have regulated exports to protect fish.

In December 2007, a ruling by federal Judge Wanger further restricted flows from the export pumps at the southern edge of the Delta, to reduce the risk of entraining delta smelt, a species listed under both the federal and state endangered species acts.[1] At about the same time, the Delta Vision Blue Ribbon Task Force released its strategic vision for the Delta (Isenberg et al., 2008). That report echoed the views of many environmental advocates in arguing for the need to consider a future with reduced exports, in which export users rely more on local supplies and conservation. It also acknowledged an often overlooked facet of Delta water management, that upstream diversions from the Sacramento and San Joaquin River watersheds represent a more significant drain on Delta flows than exports (Lund et al., 2007). Upstream water users, the Task Force argued, should contribute to providing additional flows to the Delta.

Reducing exports and increasing flows to the Delta are two related, but distinct, regulatory tools. Under the current system, where exports are drawn through Delta channels to the pumps, there are good reasons for directly targeting export reductions to avoid entrainment and other problems created by altered flows within the Delta. If, instead, exports are diverted around the Delta through a peripheral canal, the role of the pumps in the southern Delta is reduced, and the regulatory issue becomes one of maintaining appropriate flows into the Delta. Regulatory flows are typically measured as net outflows from the Delta to the ocean, or "net Delta outflows." In addition to potential environmental benefits, increased net Delta outflows could be sought to maintain salinity standards for agricultural and urban users within the Delta in the face of sea level rise, which is likely to push salinity from the ocean and Bay further into the Delta.[2]

Although direct export restrictions can be used to increase net Delta outflows, this goal also can be attained more directly by requiring increased minimum net outflows. Even if exporters have the regulatory responsibility to ensure that such flow requirements are met (as is currently the case), this more general type of regulation allows upstream diverters to participate in the solution by leasing or selling some of their water to exporters.

In this appendix, we explore the implications of these two regulatory alternatives – export restrictions and increases in minimum net Delta outflows – for California's economy and

[1] Natural Resources Defense Council, et al. v. Kempthorne, Findings of Fact and Conclusions of Law Re Interim Remedies Re: Delta Smelt ESA Remand and Reconsultation, United States District Court, Eastern District of California, 1:05-cv-1207 OWW GSA (2007).
[2] This issue is discussed in Appendix C and Chapter 4 of the main report.

for water users in different parts of the state. We also examine how water users would respond to increased Delta regulations by adjusting their water supply portfolio with tools such as transfers, groundwater banking, recycling, desalination, and conservation. We assess how these regulations change the costs of providing water for environmental mitigation in different parts of the state, and how they affect the attractiveness of different infrastructure investments, including new conveyance and new surface and groundwater storage facilities.

The appendix is organized as follows. The next section provides an overview of the modeling approach used, including how the specific regulatory alternatives are modeled. The following two sections provide results for export restrictions and increased Delta outflow requirements. The two alternatives are then compared in terms of cost effectiveness in meeting different regulatory goals. The final section provides a brief conclusion. Regional details appear in Addendum J1.

1. Modeling Approach

To provide an integrated understanding of the statewide economic costs and adaptations available for these regulatory alternatives, we employ a large-scale economic-engineering optimization model, CALVIN. The CALVIN model has been presented elsewhere (Jenkins et al. 2001) and as such, only a brief discussion is provided herein.

The CALVIN Model

CALVIN (California Value Integrated Network) is a generalized network flow-based economic-engineering optimization model of California's intertied water supply system. CALVIN has been used previously to examine various water management problems in California (Jenkins et al., 2001; Newlin et al., 2002; Draper et al., 2003; Tanaka et al., 2003; Jenkins et al., 2004; Pulido-Velázquez et al., 2004; Null and Lund, 2006; Tanaka et al., 2006; Lund et al., 2007; Medellín-Azuara et al., 2008).

Optimization models are well suited to explore alternatives and identify those with more promising performance. CALVIN seeks to minimize operating costs and economic losses for urban and agricultural users throughout California's water system over the range of water conditions seen in the historical hydrology (water years 1921 – 1993).[3] CALVIN uses a generalized network flow optimization solver for water resources systems, HEC-PRM (Hydrological Engineering Center – Prescriptive Reservoir Model), to find the least cost solution with specified constraints (HEC, 1991). The specified constraints in CALVIN represent the physical and institutional limits imposed on the water system, e.g. physical limits on infrastructure capacity or regulatory limits on the use of these facilities.

The CALVIN model represents most of the state's water system, including 92 percent of California's population and 88 percent of the state's irrigated lands (Figure F.1). It includes the major facilities of the State Water Project (SWP) and the Central Valley Project (CVP), along with many regional and local facilities. In all, the model includes 53 surface water reservoirs and 31 groundwater basins. CALVIN's economic calculations cover 24 agricultural areas and 30 urban areas (Figure F.2). [4]

CALVIN requires many physical and economic input parameters to characterize California's water system. Physical parameters include infrastructure capacity (such as canals and pumping plants), environmental requirements (such as minimum instream flows and wildlife refuge requirements), operating requirements (such as flood storage in reservoirs), and inflows into ground and surface reservoirs. Economic parameters include urban and

---

[3] CALVIN also has been used to explore outcomes under a hydrology influenced by different forms of climate change (Tanaka et al., 2006; Medellín-Azuara et al., 2008). Although climate change is not analyzed for these CALVIN results, we provide some indications of how the results might be affected by climate change in a discussion of the results.

[4] For the statewide CALVIN schematic and detailed documentation see http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/.

agricultural water demand functions and operating costs for water treatment, conveyance, and hydropower facilities.[5]

The results presented here simulate the level of development in the year 2050, with a projected population of 65 million (up from 39 million in 2008) (Medellín-Azuara et al., 2008; Department of Finance, 2008). Urban water demands were developed based on the year 2020 per capita demands by county and population estimated by the California Department of Water Resources Bulletin 160-98 and by estimates from Metropolitan Water District of Southern California data for Southern California urban areas (Jenkins, 2000; Jenkins et al., 2003), scaled to the estimated 2050 population. The 2050 agricultural water demands and values were developed from results from the Statewide Agricultural Production Model (SWAP) (Howitt et al., 1999). CALVIN's economic data are in 1995 dollars, but for this report all costs have been updated to 2008 dollars using the Engineering News-Record multiplier of 1.48.

In addition to current facilities, the model runs presented here include some additional facilities expected to be completed by 2050, including several new interties which are planned or underway (e.g., Freeport Project and the Hayward intertie). Likewise, urban coastal areas were assumed to have access to desalted seawater at a cost of $1,400 per acre-foot (in 1995 dollars, or $2,072 per acre-foot in 2008 dollars) and all urban areas were assumed to have access to up to 50 percent of their wastewater flows as recycled water, at a cost of $1,000 per acre-foot (in 1995 dollars, or $1,480 per acre-foot in 2008 dollars). As new technology is developed, the cost for desalination and recycled wastewater may decrease and make them more economically competitive with traditional supplies. If desalination were to be similar to or less than wastewater recycling, an increase in desalination (when possible) is expected, along with a reduction in wastewater recycling because users will prefer the more economically efficient (i.e., lower cost) supply source. For wastewater recycling, the major costs come from adding capacity at the wastewater treatment plant and expanding the current water redistribution system. Household and industrial water conservation is available at a variable cost represented by a constant-elasticity of demand curve for residential users and survey-based cost functions for industrial users (Jenkins et al., 2003). Traditional water supplies from surface and ground waters incur operating costs for pumping, recharge, water treatment, and some relatively saline urban supplies also incur additional user costs from poor water quality (Jenkins et al., 2001).

The CALVIN model generates a rich set of results for each simulation, including time series of deliveries to agricultural and urban users, stream, channel, and aqueduct flows, annual average scarcity costs for each demand area, the marginal economic values of additional water at every node in the network, the economic shadow values on the binding constraints, and storage volumes in reservoirs and groundwater basins.

Although it is quite comprehensive, CALVIN – like all models - has limitations. In this case, data are problematic for some areas. CALVIN has fixed monthly urban and agricultural economic water demands (based on "normal" water year demands), water use efficiencies, and environmental requirements.[6] CALVIN does not include minimum instream flow requirements for temperature or water quality control purposes. Hydropower representation is

---

[5] More detailed information on the required CALVIN inputs appear in Jenkins et al. (2001).

[6] Urban and agricultural demands, water use efficiencies, and environmental requirements can vary by month, but do not vary by year or year type.

limited to a few major facilities. Reservoir and river recreation values are not included in CALVIN. Groundwater basins are highly simplified; stream-aquifer interactions and deep percolation due to rainfall are not modeled in CALVIN, but rather controlled by fixed inflows based on CVGSM NAA (Central Valley Groundwater Simulation Model No Action Alternative) data (Jenkins et al., 2001). And significant uncertainties exist regarding inflows and return flows in some parts of the system.

In addition, the model's assumption that water managers have perfect foresight about hydrological conditions somewhat reduces scarcity and its associated costs during droughts (Draper, 2001). The CALVIN model represents an ideal water market (i.e., no transaction costs, risks, or uncertainty), where transfers are only limited by physical infrastructure capacities, environmental flow requirements, and the economic value of water. Water rights, as defined today, have been replaced by a market-driven allocation system, where water is supplied to users to maximize the economic benefit of the state as a whole. Perfect foresight and a lack of institutional barriers allow water users to make optimal plans for water transfers, whereas in practice, some of these transfers may not occur. These assumptions lead to idealized results, which can be interpreted to represent the minimum (or lower bound) costs that can be obtained from more flexible operations. Nevertheless, despite these and other documented limitations (Jenkins et al., 2001), CALVIN is the most comprehensive tool available to assess management possibilities for California's water supply system and has successfully indicated many sought-after water management actions.

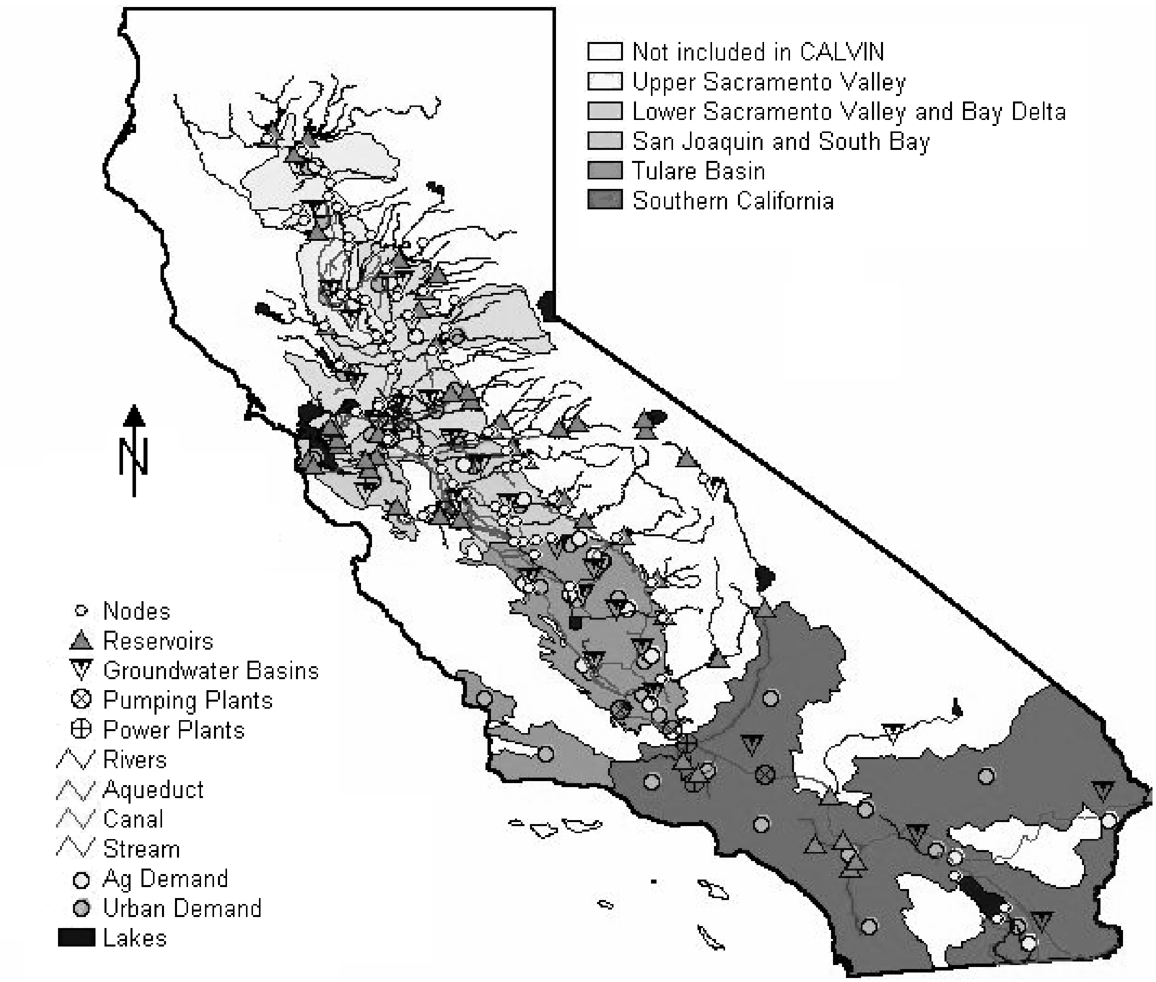


Figure F.1 - Demand areas and major inflows and facilities represented in CALVIN.

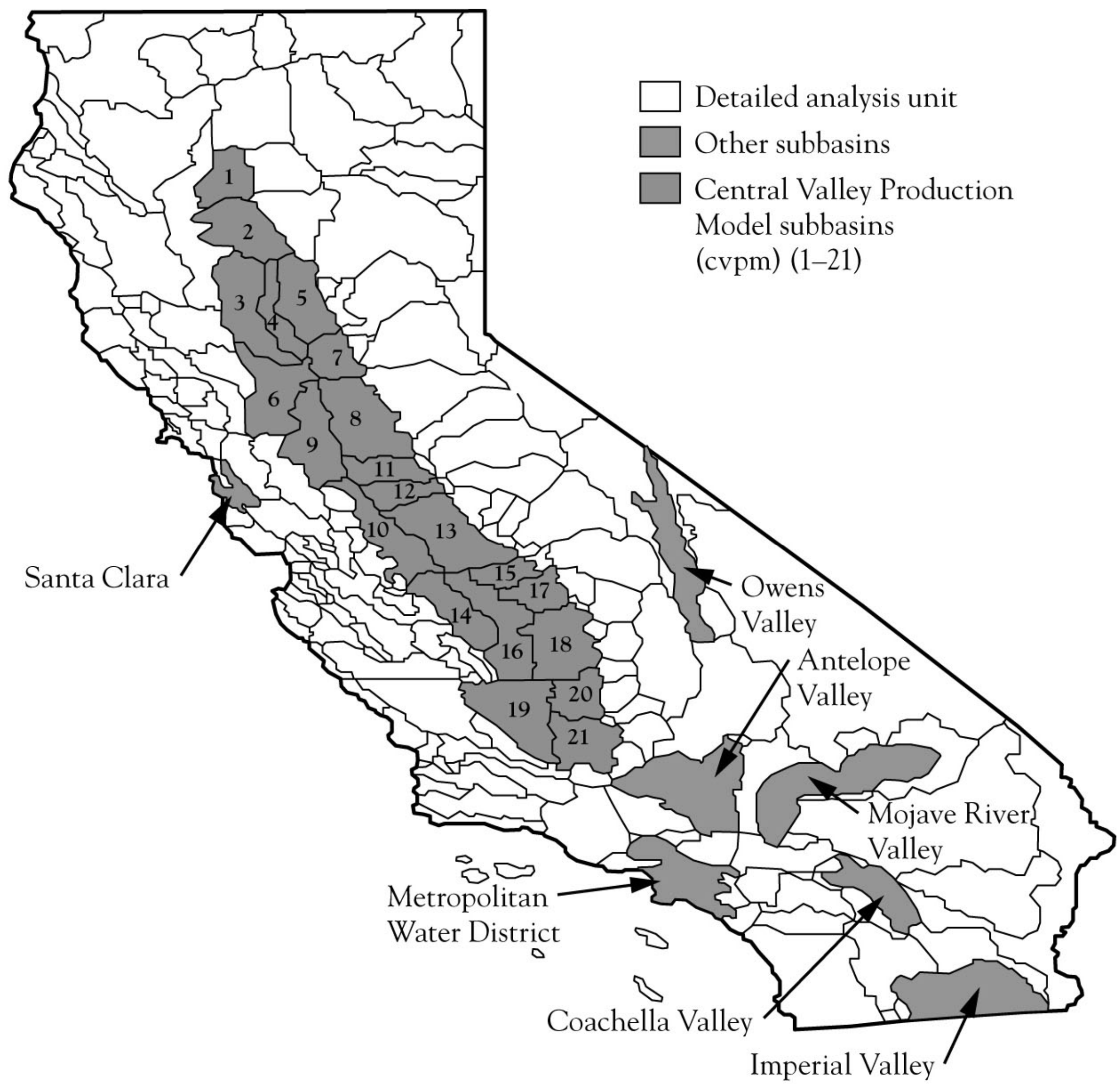


Figure F.2 - Agricultural regions represented in CALVIN.

Modeling Regulatory Alternatives

The two alternatives modeled in this study have the same infrastructure, water demands, and non-Delta environmental water demands. They differ in terms of the amount of water that may be exported through Delta pumps and the volume of water that must flow to the ocean (Delta outflow) (Table F.1).

Restricting Delta Exports

In this alternative, exports are restricted by modifying the pumping plant capacities for the State Water Project (Banks), Central Valley Project (Jones), and the Contra Costa Water

District (Rock Slough, Old River, and Contra Costa). Relative to the base case – which corresponds to Delta regulatory conditions preceding the 2007 federal court decision to protect delta smelt, but with projected 2050 water demands – the model is run for successive levels of export restrictions: decreasing all pumping plant capacities by 50 percent and 75 percent, and setting all pump capacities to zero (i.e., no exports).[7] Diversions for in-Delta agriculture and the North Bay Aqueduct are allowed to continue because the purpose of this modeling alternative was to assess the impacts of reduced capacity at the southern Delta pumps. The reduction or abandonment of exports examined here is not the sudden unavailability of water exports due to levee collapse (Illingworth et al., 2005) or other catastrophic events, but a planned and prepared cutback, where water users have time to add other cost-effective supply sources.

Because, until recently, many exporters hoped to increase export levels from the Delta, this analysis also explores increasing export capacity. For these scenarios, the model augments pumping capacity at the Banks plant from its current regulatory level of 6,600 cfs to a proposed limit (8,500 cfs), its infrastructure limit (10,300 cfs), and, finally, unlimited capacity.[8] For the increased export scenarios, pumping capacities at the other facilities are held constant, as is aqueduct conveyance capacity south of the pumps.

For all restricted Delta export scenarios, Delta outflow requirements are kept at current (pre-Wanger) levels, corresponding approximately to the regulations in D-1641, the water rights decision accompanying the most recent water quality control plan for the Delta.[9] The minimum net Delta outflows (MNDO) range from 179 taf per month in September to 374 taf per month in March. The annual average MNDO is 5.6 maf per year.

Increasing Delta Outflow Requirements

In this alternative, required Delta outflows are systematically increased from current levels by raising the minimum net Delta outflow (MNDO) values.[10] For example, if the new monthly MNDO is 250 taf per month, all months with required flows below this value are raised to 250 taf, and months with higher required outflows are unchanged. For the three levels above 1,600 taf month, the minimum outflow requirement is an average over all months, because there is not always enough water in the system to meet the minimum monthly standard. In these dry months, the minimum flow is at least 1,600 taf. For example, in the scenario with 2,220 taf per month requirements, the flow in some months might be as low as 1,600 taf, but the overall monthly average is 2,220 taf. At this level of required outflow, there is, on average, very little room for diversions from the Delta: 94 percent of all modeled inflows in the Delta watershed must be sent to the ocean.

---

[7] For Banks, the 50 percent and 75 percent reductions are relative to the plant's hydraulic capacity.

[8] Banks pumping plant has a maximum installed capacity of 10,300 cfs, but regulatory requirements limit pumping to 6,600 cfs in April through November, 8,500 cfs in January and February, and 7,590 cfs in March and December. As part of the South Delta Improvement Project (SDIP), the maximum allowable pumping limit would increase to 8,500 cfs.

[9] In CALVIN, these outflow requirements are derived from DWRSIM_2020D09B-Calfed-514-output (DWR, 1998 ; Jenkins et al., 2001),

[10] For the increasing Delta outflow requirement pumping plant capacity at all southern Delta facilities were set to their regulatory limit, except Banks pumping plant. Capacity at Banks was set to the proposed SDIP capacity of 8,500 cfs.

Table F.1 - Modeled Alternatives

Modeled Alternative	Banks/Total Delta Pumping Capacity		Required Delta Outflow	
	(cfs)	(taf/month)[a]	Minimum (taf/month)[b]	Annual Average (taf/year)
Restricting Delta Exports				
No Export (NE)	0/0	0/0	179	5,593
Restricted Transfers (RT)	0/0	0/0	179	5,593
75% Capacity Reduction (75%R)	2,125/3,425	129/207	179	5,593
50% Capacity Reduction (50%R)	4,250/6,850	257/414	179	5,593
Base Conditions (BC)[c]	6,600/11,800	398/712	179	5,593
Proposed SDIP Capacity (PC)	8,500/13,700	513/827	179	5,593
Infrastructure Capacity (IC)	10,300/16,500	682/996	179	5,593
Unlimited Capacity (UC)	Unlimited	Unlimited	179	5,593
Increasing Minimum Net Delta Outflow (MNDO)				
Base Conditions[d]	8,500/13,700	513/827	179	5,593
250 MNDO	8,500/13,700	513/827	250	5,699
500 MNDO	8,500/13,700	513/827	500	7,285
700 MNDO	8,500/13,700	513/827	700	9,130
1000 MNDO	8,500/13,700	513/827	1,000	12,271
1200 MNDO	8,500/13,700	513/827	1,200	14,500
1400 MNDO	8,500/13,700	513/827	1,400	16,828
1500 MNDO	8,500/13,700	513/827	1,500	18,013
1600 MNDO	8,500/13,700	513/827	1,600	19,205
1909 MNDO	8,500/13,700	513/827	1,600	22,911
2064 MNDO	8,500/13,700	513/827	1,600	24,764
2218 MNDO	8,500/13,700	513/827	1,600	26,613

[a] Monthly average pumping equivalents of the cubic-feet per second.

[b] Monthly minimums vary by month and water year type in the current regulatory framework; 179 taf is the lowest monthly level.

[c] Base conditions with 2050 water demands and Banks pumping plant at regulatory capacity (varies by month).

[d] Base conditions with 2050 water demands and Banks pumping plant at hydraulic capacity (8,500 cfs).

2. Restricting Delta Exports

Delta Exports and Outflows

Restricting Delta exports results in some predictable outcomes and some surprises. Predictably, when pumping is set below base conditions, average exports decline. They also become less variable: for the 50 percent and 75 percent reductions in capacity, pumping was at or near the remaining capacity in all months and years (Figure F.3). Because pumping capacity is not always fully utilized under base conditions, the decline in exports is somewhat less than proportional: relative to base case average levels of about 5.9 maf per year, 50 percent and 75 percent reductions in pumping capacity lead to 4.9 maf and 2.5 maf of annual export volumes (or declines of 18% and 58%), respectively. Base case exports are slightly higher than recent (pre-Wanger decision) exports because of higher overall water demands for the 2050 projected population and land use.[11] Thus, although the details of the restrictions are somewhat different, these two scenarios provide a broad indication of the potential long-term impacts of the Wanger decision, which is estimated to reduce State Water Project exports by 22 to 30 percent on average (Department of Water Resources, 2007).

Somewhat surprisingly, relaxing pumping restrictions relative to the base conditions adds little to average export levels. Even with completely unconstrained pumping, average exports are 6.0 maf per year, an increase of only 41 taf per year over base case 2050 conditions. The reason: exporters run into capacity constraints on their conveyance facilities. Without expanding the California Aqueduct and the Delta Mendota Canal, or perhaps improving the modeled representation of them, there is little to be gained by increasing pumping capacity. Most additional deliveries come from improvements in operations and reductions in surplus Delta outflows, rather than reductions in Sacramento Valley deliveries.

Although these scenarios maintain current required outflows, export restrictions increase water flowing to the ocean by increasing the "surplus" outflows (flows exceeding the requirement) (Figure **F.4**). There is approximately 7.7 maf per year of surplus Delta outflow under the baseline condition. This surplus increased by 5.4 maf per year (to a total outflow of 18.7 maf per year) when exports were prohibited. In contrast, the increase in export capacity has almost no effect on surplus Delta outflows, given its limited effect on export volumes. When Banks capacity is unlimited, surplus outflows decrease by only 44 taf per year.

---

[11] See Lund et al. (2007), Table 6.1 for exports in the 1995-2005 period by region and sector. Total Delta exports (excluding in-Delta diversions) averaged 5.6 maf over this period.

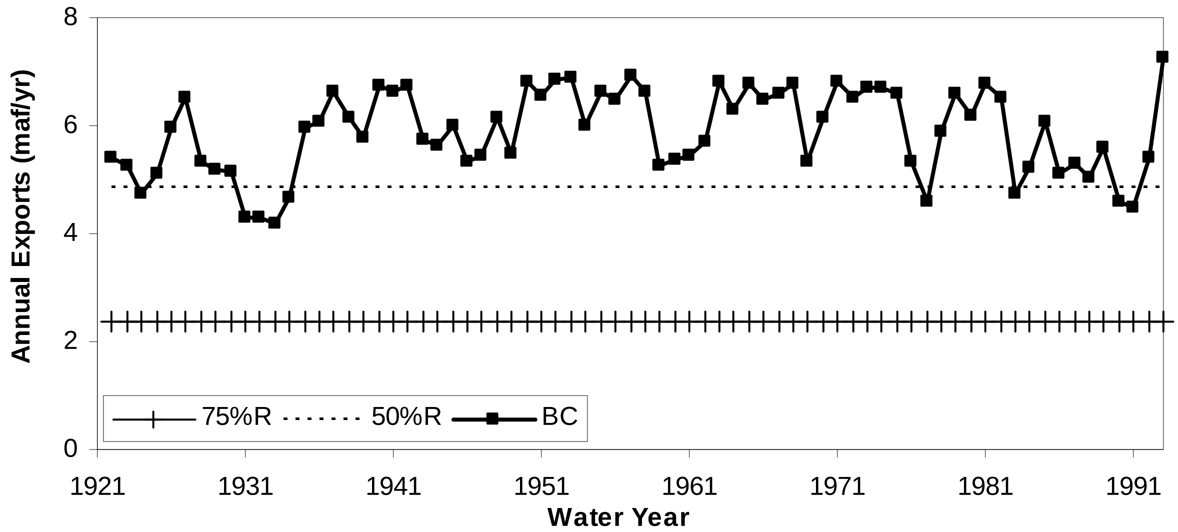


Figure F.3 - Annual Delta exports with changing export restrictions

Note: Under base conditions annual exports are variable, ranging from 4.2 maf/year to 7.2 maf/year, with an average of 5.9 maf/year. As export capacity decreases, the variability also decreases because pumping is at or near capacity in all years.

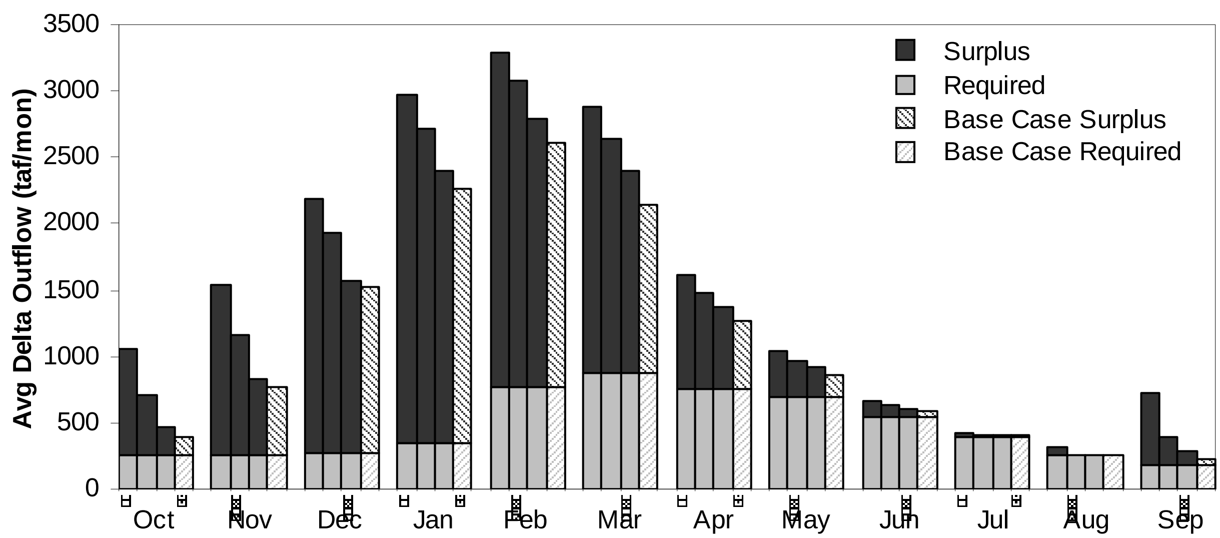


Figure F.4 - Monthly average Delta outflows with changing export restrictions

Notes: Stacked column data is presented in the following order: no export, 75% reduction in export capacity, 50% reduction in export capacity, and base operating capacity (base case denoted with dashed areas)

Shortages and Costs

When exports are restricted, water shortage or "scarcity" rises, as do scarcity and operating costs. "Scarcity costs" are the economic costs to local water users of these shortages; this includes lost agricultural profits and the costs to households and businesses of water conservation measures and other reductions in water use. Operating costs – the annual cost of delivering usable water - also can increase if more costly water sources are needed.

Even under base conditions, there is some scarcity - just below three maf per year – because availability, conveyance and infrastructure capacity, and cost of additional supplies prohibit some users from obtaining all the water they could economically put to use (Table F.2 and Figure F.5). [12] Agricultural users bear the brunt of additional export restrictions, while urban scarcity and scarcity costs remain relatively constant until exports are severely limited (Figure F.6). The higher willingness to pay for water in the urban sector accounts for this disparity: as exports are restricted, agricultural users who are in a position to transfer water to the urban sector do so. With restrictions at the pumps, the sales come from farmers in the San Joaquin and Tulare Basins. The combination of reduced exports and transfers means that agriculture in this part of the state faces significant scarcity. When exports are ended altogether, 1.2 million acres go out of production.[13] Meanwhile, Sacramento Valley farmers are essentially cut off from the market, and so see a small increase in water availability. Southern California farmers, who depend on Colorado River flows, are also unaffected, because there is no additional room in the Colorado River Aqueduct to transfer water to urban users.

Without Delta exports, the greatest urban impacts are in Southern California, which experiences additional shortages on the order of 260 taf per year. In the Bay Area, the hardest hit agencies are those that contract with the SWP and CVP in Santa Clara and Alameda Counties (29 taf per year).

Operating costs (including desalination, water treatment, recycling, and pumping) rise considerably with export restrictions, moving from \$2.4 billion per year under base conditions to \$2.6 billion per year without exports (

Table F.3). These increases are driven by the use of more costly supply alternatives, such as desalination and wastewater reuse, and reduced hydropower production.

Overall, the lion's share of cost increases come from increased scarcity costs. Annual statewide net costs of the water system (operating costs plus scarcity costs minus hydropower benefits) rise from \$2.7 billion to \$4.1 billion per year when moving from base conditions to a situation without exports, a net increase of \$1.5 billion per year (Figure F.7).

---

[12] For more detailed depictions of agricultural and urban costs within regions, see Appendix F1.

[13] Some agricultural users also benefit financially from transferring water. These revenues are not included in the scarcity cost estimates for the agricultural sector because evaluation of the change in agricultural production is done outside of CALVIN. Acreage losses are estimated using the SWAP model. For more detailed discussion of San Joaquin and Tulare Basin irrigated crop acreage changes and the associated impacts, see Addendum F.2.

As mentioned previously, when exports are eliminated, the San Joaquin and Tulare Basin agricultural users bear the brunt of the reduction in water availability because they sell much remaining water to urban users in Southern California. If agricultural users in the San Joaquin and Tulare Basins do not transfer water to Southern California (and other users on the west-side of the San Joaquin and Tulare Basins), annual average agricultural scarcity decreases by 1.0 maf per year to 919 taf per year. Urban scarcity increases by 111 taf per year to 459 taf per year. Average annual scarcity costs to agricultural users decrease by $146 million per year, and urban scarcity costs increase by $180 million per year. Most of the increased urban scarcity costs occur in Southern California ($142 million per year) and Bakersfield and Delano in the Tulare Basin ($34 million per year). Overall total statewide costs increase from $4.1 billion per year to $4.8 billion per year because of increased operating costs. The large increases in operating costs results from increases in desalination and reduced hydropower generation. Overall, there is an additional $700 million per year of scarcity and operating costs when agricultural water transfers from the San Joaquin and Tulare Basins are prohibited. The total cost of ending exports without transfers to urban areas becomes $2.2 billion/year.

Table F.2 - Agricultural and urban scarcity and scarcity costs with export restrictions

Region	Average Scarcity (taf/year)					Average Scarcity Cost ($M/year)				
	RT	NE	75%R	50%R	BC	RT	NE	75%R	50%R	BC
Agricultural Economic Water Users										
Sacramento Valley	137	137	150	294	317	2	2	2	4	4
San Joaquin Valley	1944	1866	1864	1138	604	164	153	153	50	15
Tulare Basin	3579	4669	3637	1654	1004	563	719	435	93	37
Southern California	941	941	941	941	941	191	191	191	191	191
Statewide[a]	6601	7614	6592	4028	2867	919	1065	781	338	247
Urban Economic Water Users										
Sacramento Valley	0	0	0	0	0	0	0	0	0	0
San Joaquin Valley	29	29	0	0	0	51	51	0	0	0
Tulare Basin	34	0	0	0	0	37	0	0	0	0
Southern California	396	318	93	76	60	566	424	97	78	66
Statewide[a]	459	347	93	76	60	654	475	97	78	66
Total of All Economic Water Users[a]										
Sacramento Valley	137	137	150	294	317	2	2	2	4	4
San Joaquin Valley	1973	1896	1864	1138	604	215	204	153	50	15
Tulare Basin	3613	4669	3637	1654	1004	600	719	435	93	37
Southern California	1337	1260	1035	1017	1001	757	615	288	270	257
Statewide[a]	7060	7961	6685	4104	2926	1573	1540	877	416	312

[a] Totals may not sum due to rounding, RT is no exports with restricted transfers, NE is no exports, 75%R is 75% reduction in export pumping capacity, 25%R is 25% reduction in export pumping capacity, and BC is base case (2050 demands).

Table F.3 - Annual average statewide net operating costs with export restrictions

	Statewide Annual Average Costs ($M/year)				
	RT	NE	75%R	50%R	BC
Groundwater	771	736	773	806	818
Surface Water Treatment	1143	1492	2044	2060	2061
Desalination	1933	541	55	55	55
Recycled Water	1446	1452	354	348	347
Surface Water Pumping	449	981	1669	1784	1832
Hydropower Benefits	2476	2605	2746	2745	2749
Total Net Operating Costs[a]	3266	2596	2151	2308	2365
Statewide Scarcity Cost	1573	1540	877	416	312
Total Statewide Net Costs[a]	4839	4136	3028	2724	2677

[a] Totals may not sum due to rounding, RT is no exports with restricted transfers, NE is no exports, 75%R is 75% reduction in export pumping capacity, 25%R is 25% reduction in export pumping capacity, and BC is base case (2050 demands).

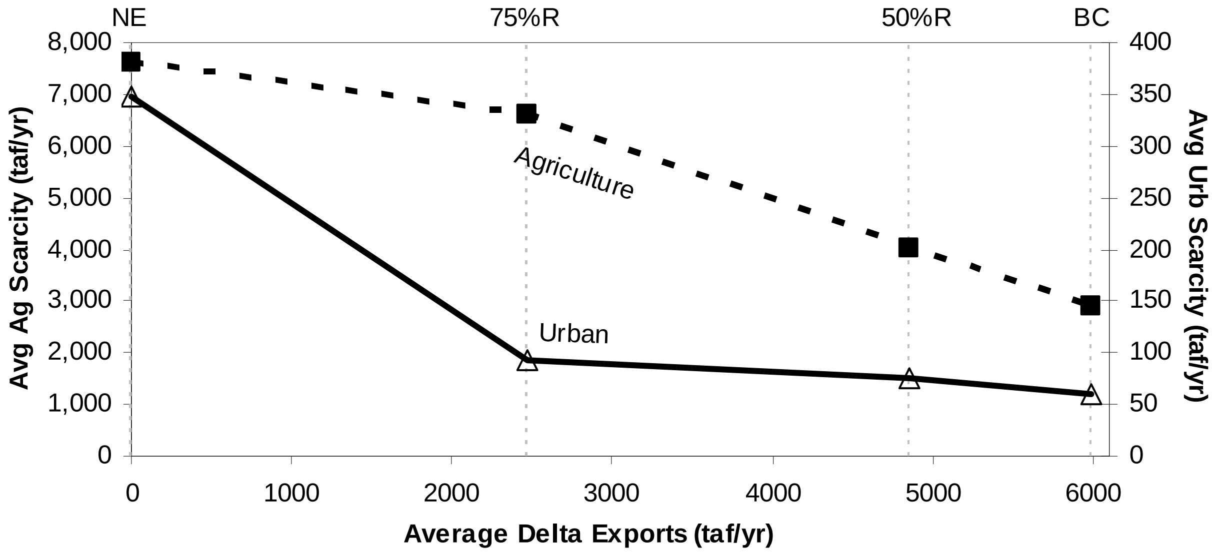


Figure F.5 - Annual average statewide scarcity with changing export restrictions

Note: Urban and agricultural scarcity declines as export capacity is increased. Initial increases in export capacity (from 0% to 25% of current capacity) primarily benefit urban users. Further increases primarily benefit agricultural users.

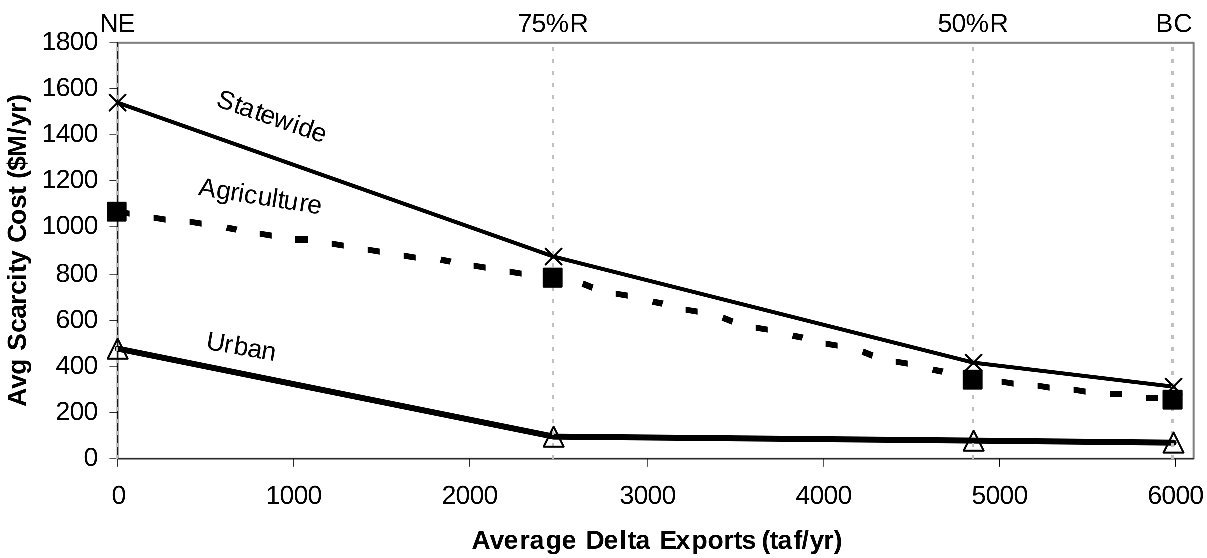


Figure F.6 - Annual average statewide scarcity costs with changing export restrictions

Note: As export capacity is increased, scarcity for urban and agricultural users is reduced, resulting in a decrease in scarcity costs. If export capacity is raised from 0% to 25% of current capacity, urban users see a substantial reduction in scarcity costs. Agricultural users do not see substantial decreases until export capacity is at least 50% of base capacity.

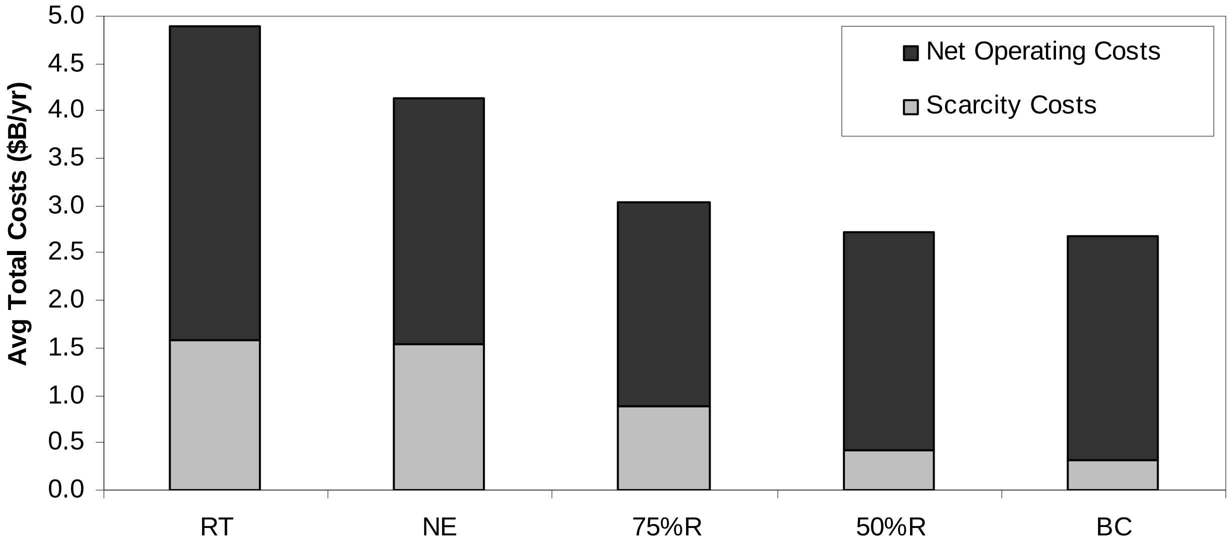


Figure F.7 - Annual average total costs with changing export restrictions

Notes: 'RT' is no exports with restricted transfers, 'NE' is the no export case, '75%R' is the 75% reduction in capacity case, '50%R' is the 50% reduction in capacity case, and 'BC' is the base conditions case. As export capacity is reduced, scarcity costs increase. Operating costs also increase because users turn to more expensive supplies, such as desalination and recycling. For the restricted transfers case, operating costs increase substantially more than scarcity costs relative to the no export alternative.

Shifting Supply Portfolios

Export restrictions lead to some significant adjustments in the state's water supply portfolio. As noted above, scarcity, or simply doing without, is a big part of the adjustment for agricultural users, who will also have incentives to make more efficient use of remaining supplies. For the urban sector, water transfers (mainly from agriculture) become a more important part of the supply portfolio. For both agricultural and urban areas, groundwater storage becomes more important. Finally, as traditional supplies of fresh water become increasingly costly or unavailable, urban water users turn toward recycled wastewater and desalination to stretch existing supplies.

Recycled Wastewater

Recycled water is assumed to be available at a cost of $1,000 per acre foot (in 1995 dollars, equivalent to $1,480 in 2008 dollars). Overall, eight of the thirty urban users in CALVIN rely on wastewater reuse under base case regulatory conditions in 2050; four more join this group when Delta exports are eliminated. The Bay Area and South Central Valley are the heaviest users under base conditions. When Delta exports are reduced, all regions increase wastewater reuse, with the largest increases in Southern California (due in part to having the most wastewater recycling capacity). Without Delta exports Southern California communities rely on wastewater recycling for 10.1 percent of their demand (approximately 840 taf per year), versus 3.5 percent of demand (104 taf per year) in the South Bay and South Central Valley and 1.8 percent of demand (28 taf per year) north of the Delta (Table F.4).

Desalination

Desalination, which at $1,400 (in 1995 dollars, equivalent to $2,072 in 2008 dollars) per acre foot is still considerably more expensive than recycled water, expands in a more limited way. In the model, only eight urban areas have access to unlimited ocean desalination, and only three urban areas use this source under base case regulatory conditions (Santa Barbara-San Luis Obispo, San Diego, and the eastern zone of the Metropolitan Water District of Southern California). When Delta exports are eliminated, two more urban areas join this group (San Francisco and Santa Clara Valley). Urban areas will only use desalination when all less expensive supplies have been exhausted. Desalination is used when wastewater treatment capacity prevents an urban user from fulfilling demand with recycled water. In general, desalination is used less than wastewater recycling (Table F.4). For all urban areas, except Santa Barbara-San Luis Obispo (included in the Tulare region) and the Santa Clara Valley, desalination use is sporadic (used less than 15 percent of the time). These results may overstate the extent to which desalination is actually used, because CALVIN makes desalination more attractive than it may be in practice.[14] On the other hand, some agencies may choose to invest in desalination as a hedge against drought risk, and CALVIN underestimates this type of risk-averse investment strategy.

Table F.4 - Annual average wastewater reuse and desalination with changing export restrictions

Region	Annual Average Use (taf/year)			
	NE	75%R	50%R	BC
Wastewater Reuse				
Sacramento Valley	28	20	9	8
San Joaquin, Bay Area & Tulare	104	65	65	65
Southern California	841	145	145	145
Statewide[a]	972	230	219	218
Desalination				
Sacramento Valley	0	0	0	0
San Joaquin, Bay Area & Tulare	255	21	21	21
Southern California	6	6	6	6
Statewide[a]	261	27	27	27

[a] Totals may not sum due to rounding.

[14] In CALVIN, coastal urban areas have unlimited access to desalination plants without having to invest in construction (capital) costs or pay maintenance costs for existing facilities. They can call upon desalination for infrequent, but large volumes of water at the same cost as if they used it frequently for small volumes. For example, San Francisco only uses desalination for three months out of the 72-years, but uses about 14 taf per month each time. In practice, it would not be economically feasible to build a 14 taf per month (235 cfs) desalination plant to be used only three times in 72-years.

The Overall Supply Portfolio

Figure F.8 provides an overview of the shifting water supply portfolio for the state. Under base conditions, both north and south of Delta users rely on surface water to meet over half of their demands. After surface water, groundwater is the most commonly used supply source. When exports are eliminated, north of Delta users increase usage of all supply sources by a small amount (one to two percentage points) to reduce use of more expensive treatment options (i.e., wastewater recycling and desalination) and to reduce their annual average scarcity. South of Delta users are forced to cut surface water use by nearly a quarter (14 percentage points) and groundwater pumping by roughly one-sixth (5 percentage points). To reduce scarcity, they more than quadruple the volume of wastewater recycling and desalination. (Re-use here is within-region agricultural reuse of agricultural drainage.) Overall water use declines by 18 percent in this region.[15]

Environmental Water Costs

Restricting exports also has consequences for the costs of furnishing water for environmental uses. CALVIN includes two types of environmental water uses: minimum instream flows and fixed deliveries to wildlife refuges. Both are treated as fixed regulatory requirements. In the base case, an additional acre-foot of water for the environment costs other water users anywhere from under a dollar to more than $1,400 (Table F.5). These "marginal" costs are highest when the environmental flows are "consumptively used" (i.e., when the water cannot be reused downstream), such as Mono and Owens Lake inflows, and flows for wildlife refuges.

Restricting Delta exports slightly decreases the marginal costs of environmental flows north of the Delta, while greatly increasing these costs south of the Delta (Table F.5). The greatest increases in the marginal costs are for the required flows into Mono and Owens Lakes and the Kern and San Joaquin Wildlife Refuges.

[15] Measured as the result of increased scarcity, which moves from 8.6 to 24.8 percent of the portfolio (91.4%/75.2% = 82.2%).

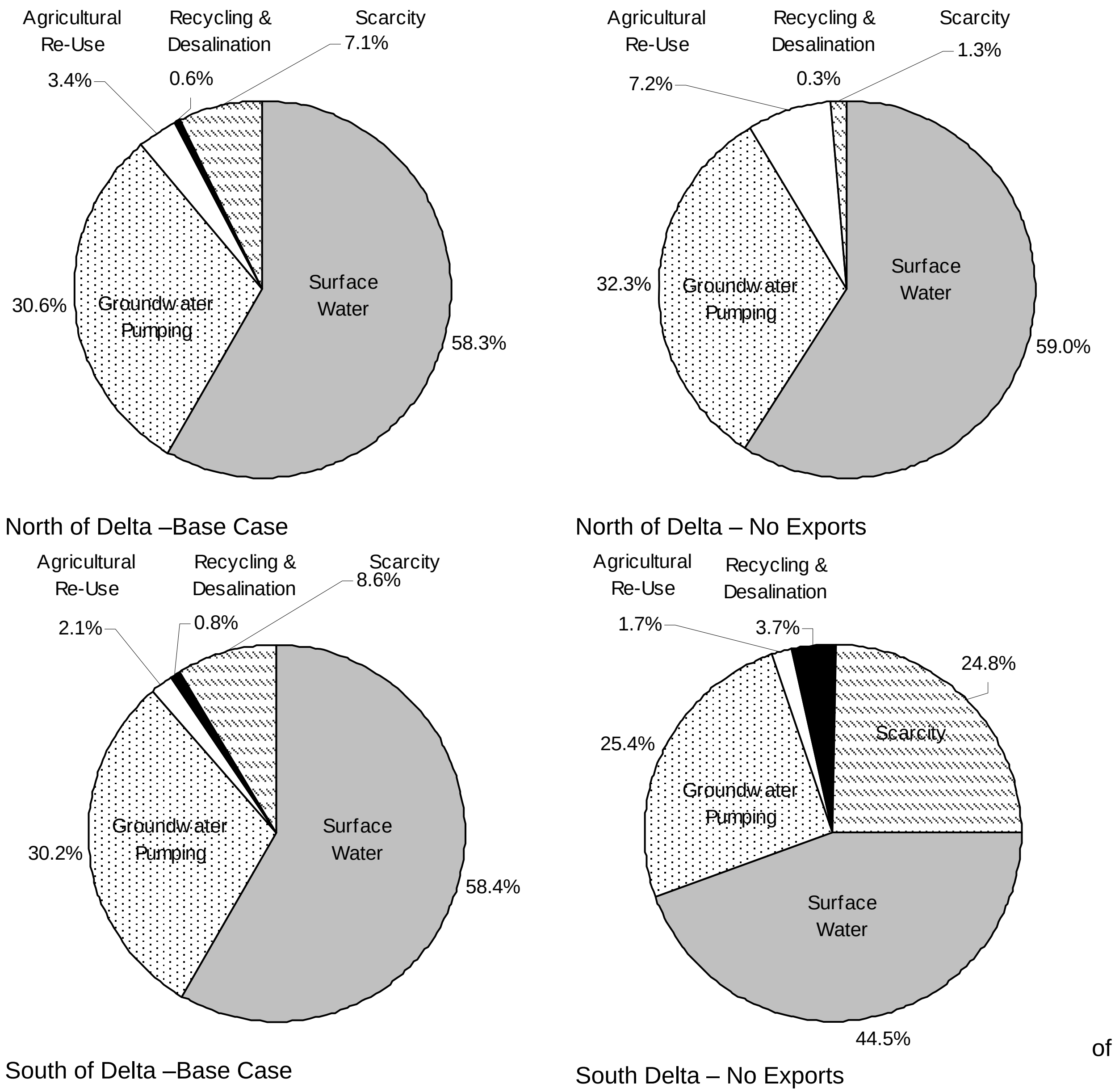


Figure F.8 - Water portfolio north and south of the Delta, with and without exports (2050)

Note: For this base case, Banks pumping plant capacity was set to the regulatory limit (6,600 cfs in April through November, 7,950 cfs in March and December, and 6,600 cfs in January and February). All other pumping plants were at their current regulatory capacity.

Table F.5 - Marginal cost of environmental water requirements with changing export restrictions

North or South of Delta	Location	Average Marginal Economic Cost ($/af) NE	75%R	50%R	BC
	Minimum Instream Flow				
North	Trinity River[a,b]	47.0	48.2	50.7	51.5
North	Sacramento River	2.4	2.3	3.0	3.1
North	Clear Creek	24.1	24.1	24.6	24.6
North	Feather River	0.8	0.6	0.4	0.5
North	Yuba River	0.5	0.5	0.5	0.6
North	American River	1.2	0.9	0.8	0.9
North	Mokelumne River	8.2	5.6	5.5	5.7
North	Calaveras River	0	0	0	0
South	San Joaquin River	277.5	209.5	108.3	54.2
South	Stanislaus River	4.0	3.9	3.3	3.3
South	Tuolumne River	3.9	3.9	3.3	3.5
South	Merced River	60.5	60.3	54.1	29.7
	Refuges				
North	Sacramento East Refuges[a]	1.3	2.2	3.9	4.3
North	Sacramento West Refuges[a]	0.6	1.6	3.3	4.0
South	Pixley National Wildlife Refuge[a]	168.8	168.6	97.4	50.6
South	Kern National Wildlife Refuge[a]	756.5	254.4	113.7	56.7
South	San Joaquin Wildlife Refuge[a]	601.3	231.4	90.7	35.6
	Other				
North	Required Net Delta Outflow	0.4	1.5	3.2	3.8
South	Delta Mendota Pool	131.2	131.1	82.3	31.7
South	Owens Lake[b]	1741.4	1302.0	1153.0	1101.7
South	Mono Lake[b]	2104.7	1636.7	1478.0	1423.7

Notes: Zero is 0; almost zero is 0.0.

[a] Consumptive environmental flows.

[b] Marginal values of environmental flows immediately downstream of hydropower generating reservoirs may also reflect lost benefits of hydropower generations.

The Value of New Facilities

The statewide economic value of new conveyance or storage capacity can be measured as the value of an additional acre-foot of capacity, or the "marginal value." With tighter export restrictions, it is typically more valuable to expand key conveyance facilities than to expand surface reservoirs (Table F.6).

Conveyance Facilities

With restricted Delta exports, facilities including the Hayward intertie, the Hetch-Hetchy Aqueduct, Mokelumne Aqueduct, Colorado River Aqueduct, and the proposed New Don Pedro intertie could provide additional benefits if expanded. These facilities would allow urban areas in the Bay Area and Southern California to access more water, which becomes increasingly scarce without Delta exports. Facilities that provide water to the Bay Area are especially valuable. Although the Bay Area and Southern California have similar levels of reliance on supplies from the Delta (around a third), historically Southern California has benefited from earlier investments in interties, probably thanks to the presence of a large regional wholesaler (the Metropolitan Water Agency of Southern California). In contrast, the Coastal Aqueduct becomes less valuable as Delta exports are restricted, because it depends entirely on the availability of water in the California Aqueduct and does not have an alternative water source available. Unsurprisingly, as Delta export capacity is reduced, the value of restoring the reduced capacity at the Banks and Jones pumping plants increases.

Expanding Surface and Underground Storage

Statewide, the volume of water stored in existing surface reservoirs is higher without exports (Figure F.9). North of the Delta storage is significantly higher because the reservoirs can no longer serve locations south of the Delta.[16] South of the Delta, overall storage levels tend to be higher without exports, but individual reservoirs may be emptier or fuller.

Consequently, the value of additional reservoir capacity at many locations decreases as export restrictions are tightened. Northern California reservoirs all lose value because they are less useful for meeting statewide water demands. Some storage south of the Delta loses value because less water is available to store (Table F.6). Reservoirs that would benefit from expansion tend to be in the Tulare Basin, where water can be exported to urban areas of Southern California. These reservoirs are generally already at capacity in the winter. If expanded, they could store more winter flows for use in summer.

Statewide, active groundwater storage is generally higher without exports, for similar reasons (Figure F.10). Some artificial recharge facilities in areas dependent on Delta exports become more attractive when exports are restricted (Table F.6). The Santa Clara Valley benefits from recharging more treated wastewater, as would agencies in the Antelope Valley and the Mojave Basin. Urban areas could also benefit somewhat from diverting more fresh water into their aquifers for storage, when it is available.

[16] Higher reservoir storage levels also generate more hydropower, which is modeled as a benefit to the system.

Table F.6 - Marginal values of expanding capacity at key facilities with changing export restrictions

North or South of Delta	Name	NE	75%R	50%R	BC
		Average Marginal Value of Expansion ($/af/year)			
Conveyance Facilities ($/af/year)					
North	Freeport Project	7	0	0	0
North	Mokelumne River Aqueduct	274	0	0	0
South	New Don Pedro Intertie	863	462	428	252
South	Hetch Hetchy Aqueduct	1365	686	534	480
South	EBMUD-CCWD Intertie	21	0	0	0
South	Hayward Intertie	766	370	215	161
South	Jones Pumping Plant	1880	198	55	0
South	Banks Pumping Plant	1885	203	61	3
South	Cross Valley Canal	224	3	1	1
South	Friant-Kern Canal	7	5	1	0
South	Coastal Aqueduct	0	1173	1313	1371
South	Colorado River Aqueduct	1011	565	414	362
Surface Reservoirs ($/af/year)					
North	Shasta Lake	8	8	8	8
North	Clair Engle Lake	3	3	3	3
North	Black Butte Lake	5	6	7	8
North	Lake Oroville	12	13	14	15
North	Thermalito Afterbay	4	6	8	9
North	New Bullards Bar Res	17	17	17	18
North	Englebright Lake	44	44	44	44
North	Clear Lake & Indian Valley Reservoir	0	1	2	2
North	Camp Far West Reservoir	3	4	5	6
North	Folsom Lake	10	11	12	13
South	New Melones Reservoir	9	9	9	9
South	San Luis Reservoir	0	0	0	0
South	New Don Pedro Reservoir	17	17	17	18
South	Hetch-Hetchy Reservoir	5	5	5	5
South	Millerton Lake	29	17	9	6
South	Lake Kaweah	166	165	95	51
South	Lake Success	148	148	85	46
South	Lake Skinner	27	321	470	522
Artificial Recharge Facilities ($/af/year)					
South	Santa Clara Valley	1873	238	85	31
South	Mojave	357	382	394	392
South	Antelope Valley	1715	1244	1109	1051

Note: Marginal values shown are monthly averages.

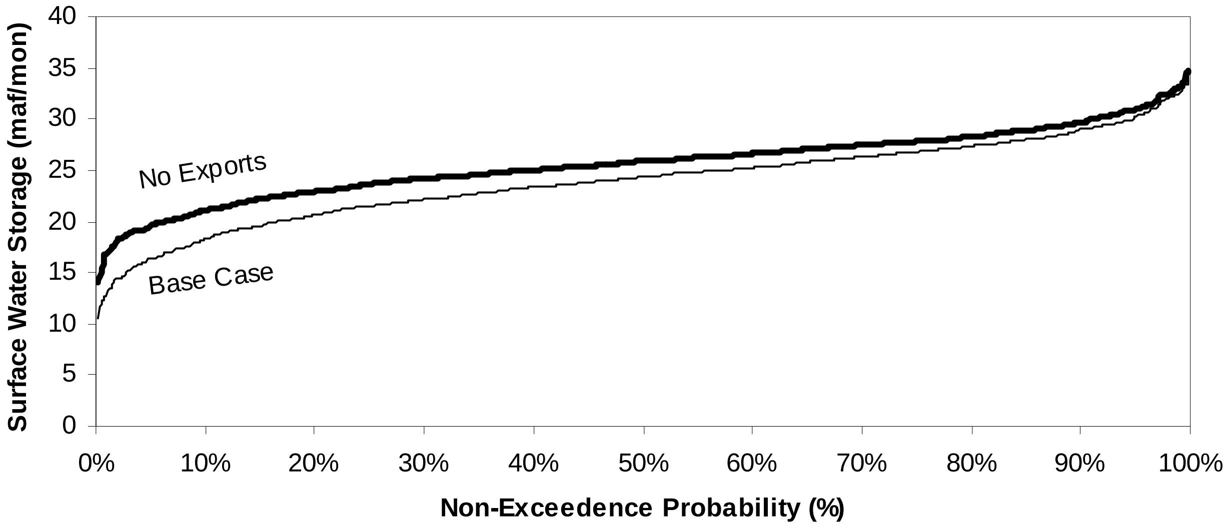


Figure F.9 - Statewide surface storage with changing export restrictions

Note: Non-exceedence probability is the probability of having storage volumes below (not exceeding) the given storage volume. For example, in the No Exports case, there is a 20 percent chance that monthly storage will be less than approximately 23 million acre-feet.

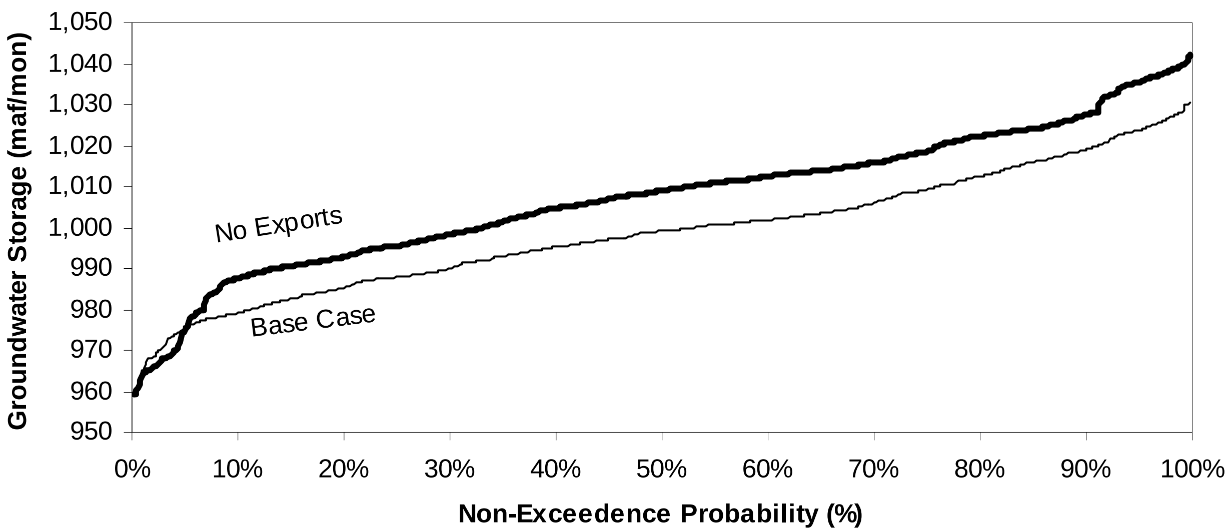


Figure F.10 - Statewide active groundwater storage with changing export restrictions

Note: Non-exceedence probability is the probability of having storage volumes below (not exceeding) the given storage volume. For example, in the No Exports case, there is a 40 percent monthly chance that groundwater storage will be less than approximately 1 billion acre-feet.

Summary

From our base case, under the regulatory regime in place before the Wanger decision, water exports would likely increase a little from recent pre-Wanger decision levels under 2050 water demand conditions. Whereas relaxing restrictions on pumping would lead to only small changes in deliveries, increasing these restrictions has significant consequences for deliveries and costs to the economy. The effects are felt most quickly in the agricultural sector in the San Joaquin Valley and Tulare Basin, where even an 18 percent cut in total export volumes entails significant scarcity costs (approximately $90 million per year). As exports are further restricted, the costs increase dramatically for all users. Urban agencies in the Bay Area and Southern California, which are also highly dependent on the Delta, are able to make up much of the initial loss through water transfers and other adjustments. New facilities, such as the Freeport Project and interties to the California Aqueduct, allow urban users to replace Delta water with other sources. Consumptive environmental requirements have high costs, especially for refuge and wildlife areas located south of the Delta. Overall, eliminating Delta exports would be costly for all sectors and, unless caused by a catastrophe, would probably be an unacceptable means of managing the Delta from an economic perspective.

3. Increasing Delta Outflow Requirements

Delta Outflows and Exports

Table F.7 shows how the required and total volume of water flowing to the ocean increases as minimum net Delta outflow requirements are increased. Not surprisingly, surplus outflows decrease with this change. Under base conditions surplus outflows occur in all months except July and August (Figure F.11). When the MNDO is raised to 1,600 taf per month, there is still surplus from November through June, but at much lower volumes. When the MNDO is raised to an average of 2,220 taf per month, surplus outflows are eliminated altogether. The highest total outflows always occur in winter (December through March) and the lowest outflows in summer (June through September).

Table F.7 - Annual average required, surplus, and total Delta outflows

	Annual Average Delta Outflows (taf/year)		
Minimum net outflow/month	**Required**	**Surplus**	**Total**
Base (179)	5,593	7,700	13,293
250	5,699	7,600	13,299
500	7,285	6,157	13,442
700[b]	9,130	4,817	13,947
1,000	12,271	3,341	15,612
1,200	14,500	2,848	17,349
1,400[b]	16,828	2,392	19,220
1,500[b]	18,013	2,213	20,226
1,600	19,205	2,027	21,232
1,909[a]	22,911	937	23,849
2,064[a]	24,764	457	25,221
2,218[a]	26,613	0	26,613

[a] This represents the monthly average net Delta outflow for these scenarios. The individual monthly MNDO value may not be lower than 1,600 taf per month.

[b] A modeling set for this level of MNDO was formulated and run, but the results are not included in this discussion.

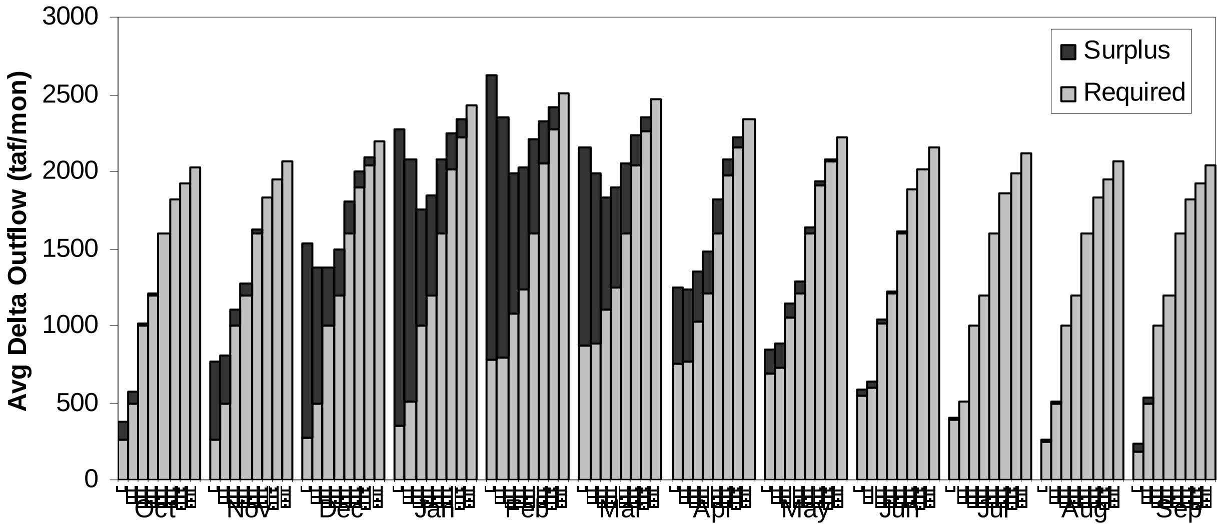


Figure F.11 - Average monthly required and surplus Delta outflows with increasing minimum net Delta outflow

Note: The eight MNDO levels are presented, in order from left to right: base conditions, 500 taf per month, 1,000 taf per month, 1,200 taf per month, 1,600 taf per month, 1,909 taf per month, 2,064 taf per month, and 2,218 taf per month.

As outflow requirements increase, Delta exports decrease (Figure F.12), but because exports are still allowed, this is not a one-to-one relationship. Flows to meet the outflow requirement can come from reduced upstream diversions, reduced exports, and surplus Delta outflows. South of Delta water users can negotiate with north of the Delta users for available water, which then supplies the highest value uses.

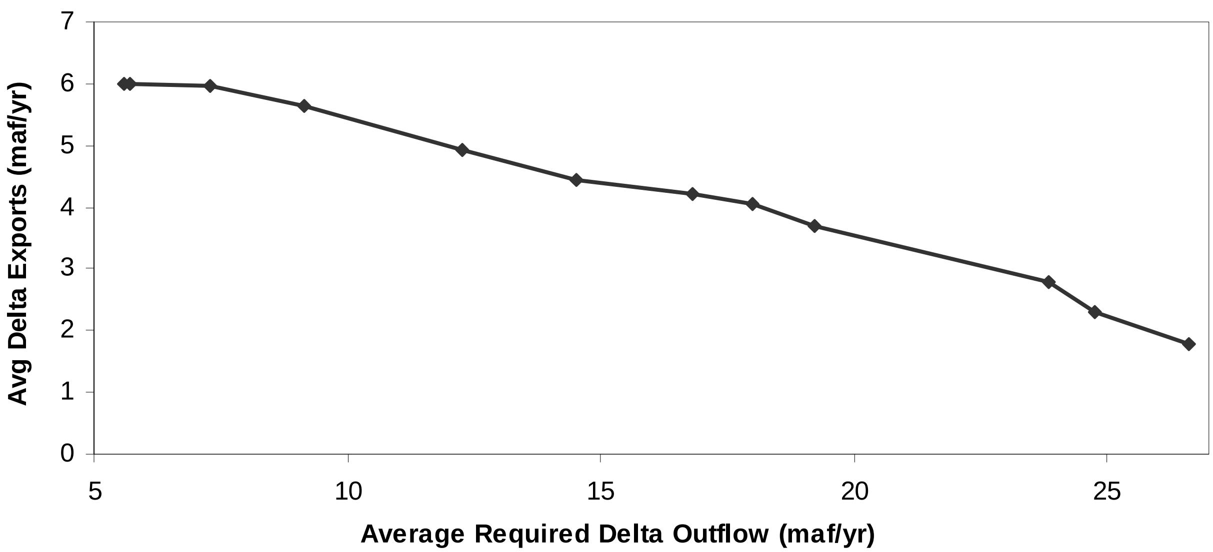


Figure F.12 - Annual average Delta exports with increasing minimum net Delta outflows

Scarcity and Costs

As the MNDO increases, flows over the Tehachapi Mountains to Southern California are relatively unaffected unless the minimum outflows are raised above 1,600 taf per month. Flows into Southern California drop from 2.2 maf per year to less than 1.5 maf per year when MNDO is increased to 2,218 taf per month. As with the reduced capacity alternative, the reduction in available supplies from the Delta is largely made up with transfers from the San Joaquin and Tulare Basins. The ability to purchase lower value water from agricultural users means south of Delta urban water users do not face supply reductions until outflows are restricted at the highest levels.

In contrast, agricultural regions face additional shortages almost as soon as the MNDO is raised over base conditions (Table F.8 and Figure F.13). However, these increases are usually modest until the MNDO reaches about 1,000 taf per month (or 12.3 maf per year – more than double current annual levels), and they rise steadily after that. By the time the average MNDO reaches 2,218 taf per month, scarcity and scarcity costs are higher in all agricultural regions, except those in Southern California, which rely on Colorado River water.

Agricultural water users who compete directly with urban users or required environmental flows experience the largest increases in scarcity. Unlike the export restriction scenarios, the Sacramento Valley and San Joaquin River and eastside stream agricultural users are not isolated from the effects of changing Delta outflow requirements. As the MNDO is raised, consumptive use in both the Sacramento and San Joaquin River systems decreases, allowing more water to reach the Delta. At the highest level of required outflow, there is an additional 3.1 maf per year in the Sacramento River below Rio Vista and an additional 4.5 maf per year in the San Joaquin River at Vernalis.

As scarcity increases, so do scarcity costs (Table F.8 and Figure F.14). Operating costs also rise, driven by the use of more costly supply alternatives and reduced hydropower production.[17] Overall net costs to the state increase from \$2.6 billion per year to \$4.9 billion per year when outflow requirements are increased to 2,218 taf per month (Table F.9 and Figure F.15).

---

[17] Overall, net operating costs increase when restrictions move from base conditions to 2,218 MNDO, but not continuously. There are periods when operating costs decrease between MNDO alternatives. As the MNDO increases, operating costs also rise, until there are insufficient supplies available of a given source. At that point the costs for those sources (such as groundwater pumping and surface water pumping) begin to decrease, while costs for alternatives (such as desalination and wastewater recycling) increase. Hydropower generation decreases as the MNDO increases. Depending on the relative values of the increasing and decreasing costs (and hydropower generation), the net operating costs may decrease or increase.

Table F.8 - Scarcity, scarcity costs, and net operating costs with increasing minimum net Delta outflows

	Annual Average Scarcity (taf/year)					Annual Average Scarcity Cost ($M/year)				
Economic User	**BC**	**1000**	**1600**	**1909**	**2218**	**BC**	**1000**	**1600**	**1909**	**2218**
Agricultural Economic Water Users										
Sacramento Valley	317	1723	5105	6277	6783	4	53	380	530	599
San Joaquin Valley	604	1274	3467	4276	4415	14	48	316	434	454
Tulare Basin	1004	1788	3193	4527	6242	36	110	332	608	1057
Southern California	941	941	941	941	941	191	191	191	191	191
Statewide[a]	2867	5727	12706	16021	18382	245	402	1219	1764	2301
Urban Economic Water Users										
Sacramento Valley	0	0	3	4	5	0	0	0	0	0
San Joaquin Valley	0	0	9	9	14	0	0	4	5	6
Tulare Basin	0	0	0	0	0	0	0	16	16	20
Southern California	60	76	88	93	219	0	0	0	0	0
Statewide[a]	60	76	101	106	238	0	0	20	21	26
Total of All Economic Water Users [a]										
Sacramento Valley	317	1723	5108	6282	6788	4	53	380	530	599
San Joaquin Valley	604	1274	3476	4285	4430	14	48	319	439	460
Tulare Basin	1004	1788	3193	4527	6242	36	110	348	624	1076
Southern California	1001	1017	1030	1034	1160	191	191	191	191	191
Statewide[a]	2926	5803	12807	16128	18621	245	402	1239	1785	2327

[a] Totals may not sum due to rounding

Table F.9 - Annual average statewide net operating costs with increasing minimum net Delta outflows

	Annual Average Cost ($M/year)[a]				
Economic User	**BC**	**1000**	**1600**	**1909**	**2218**
Groundwater	818	792	755	727	698
Surface Water Treatment	2060	2066	2059	2057	1669
Desalination	55	55	213	226	315
Recycled Water	348	352	374	374	1344
Surface Water Pumping	1834	1804	1743	1698	1159
Hydropower Benefits	2751	2720	2675	2650	2637
Total Net Operating Costs[b]	2364	2349	2470	2433	2548
Statewide Scarcity Cost	245	402	1239	1785	2327
Total Statewide Net Costs[b]	2609	2751	3709	4217	4875

[a] See footnote 17.
[b] Totals may not sum due to rounding.

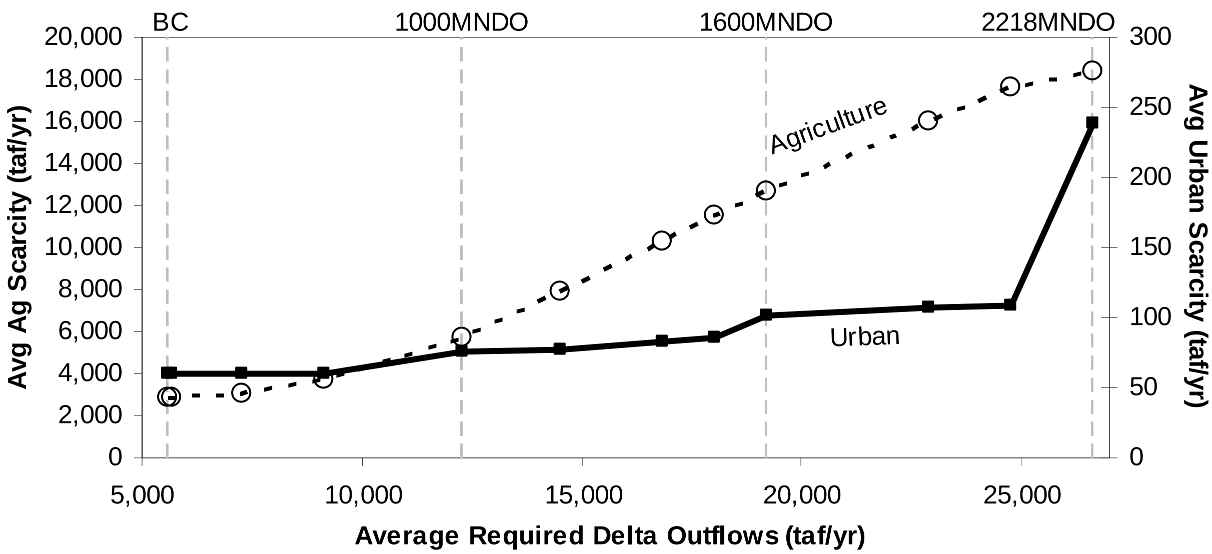


Figure F.13 - Annual average statewide scarcity with increasing minimum net Delta outflows

Note: Base case (BC) average required Delta outflows: 5,593 taf per year. Scarcity increases with required Delta outflow. For small increases in required Delta outflow, only agricultural users experience an increase in scarcity. Substantial increases in urban scarcity do not occur until required Delta outflows reach nearly 25,000 taf per year. Overall, as required Delta outflows increase, agricultural users bear the brunt of the reduced water use.

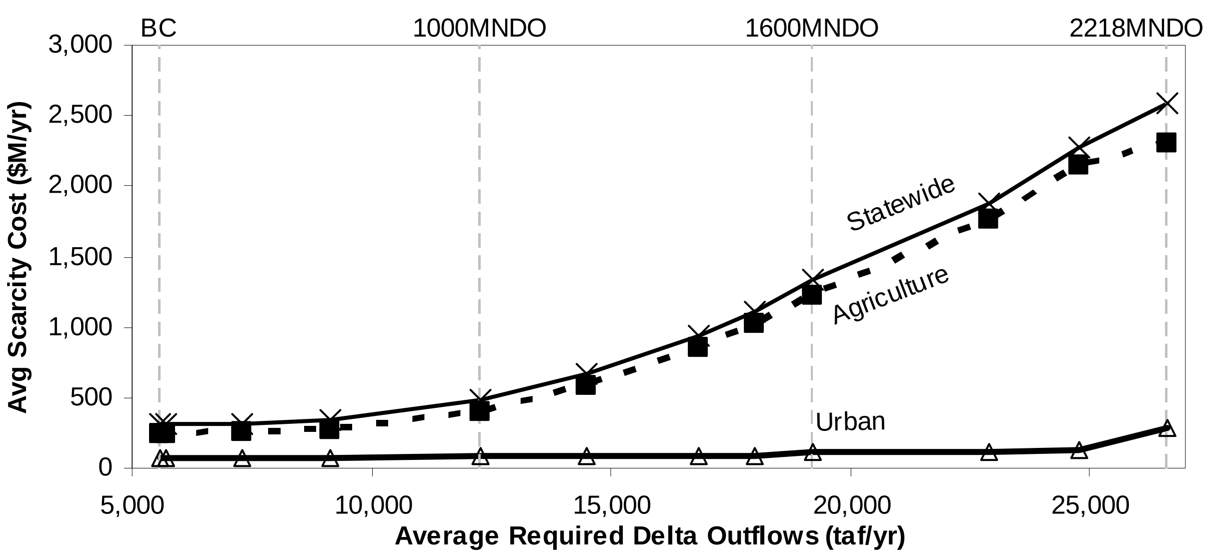


Figure F.14 - Annual average statewide scarcity costs with increasing minimum net Delta outflows

Note: Base case (BC) average required Delta outflows: 5,593 taf per year. Agricultural users experience the largest increases in scarcity costs as required Delta outflows increased. Urban scarcity costs increase, but at a much lower rate.

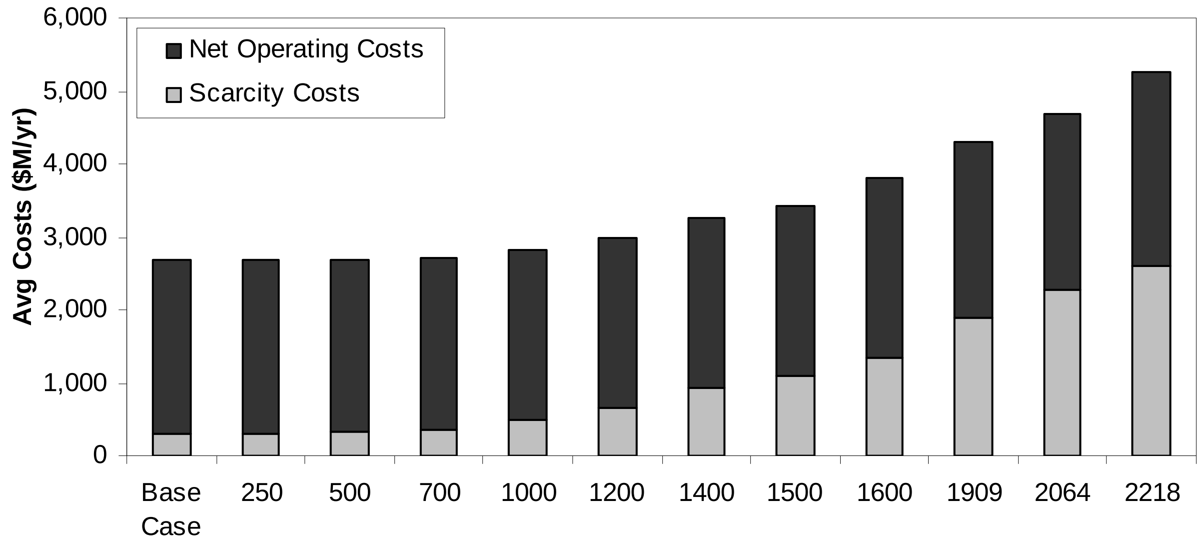


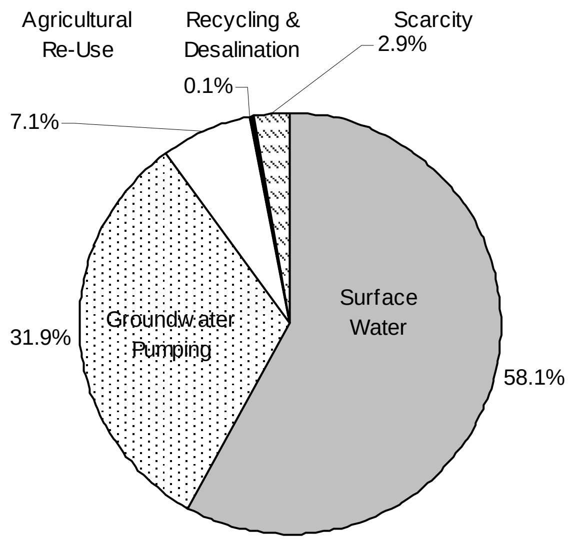
Figure F.15 - Annual average costs with increased minimum net Delta outflow

Note: Both scarcity and net operating costs increase as the required Delta outflow increases. The largest cost increases result from agricultural scarcity.

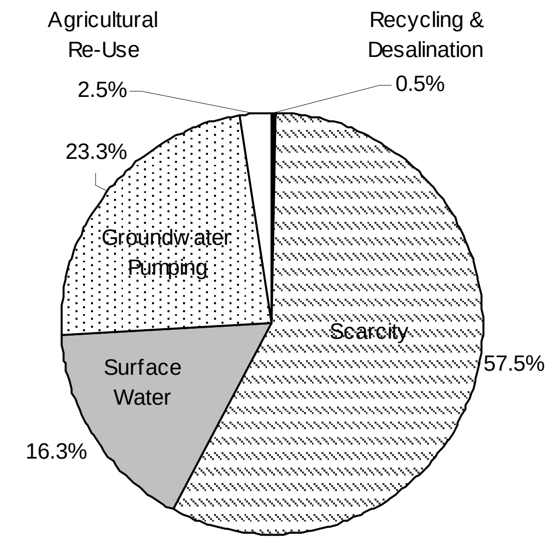
Shifting Supply Portfolios

As in the case of export restrictions, water users are forced to make adjustments to their overall supply portfolios. However, in this case users both north and south of the Delta are affected. The shifting composition of supply for these two regions is shown in Figure F.16, which compares the base case for 2050 with a level of Delta outflow requirements comparable to the No Export alternative (1,909 taf per month). In this scenario - corresponding to 81 percent of modeled flows in the Delta watershed - users both north and south of the Delta have substantial reductions in both surface water and groundwater deliveries and higher scarcity. The declines are most dramatic for north of Delta users, whose surface supplies are cut by 72 percent (43 percentage points), and whose overall water use declines by more than 55 percent.[18] South of Delta users lose 30 percent of their surface supplies (18 percentage points) and lose one-quarter of water deliveries overall.[19] Recycled urban wastewater and desalinated water use increases in both regions, as urban agencies make up for the loss of other lower cost supplies. (For details, see Table F.10.)

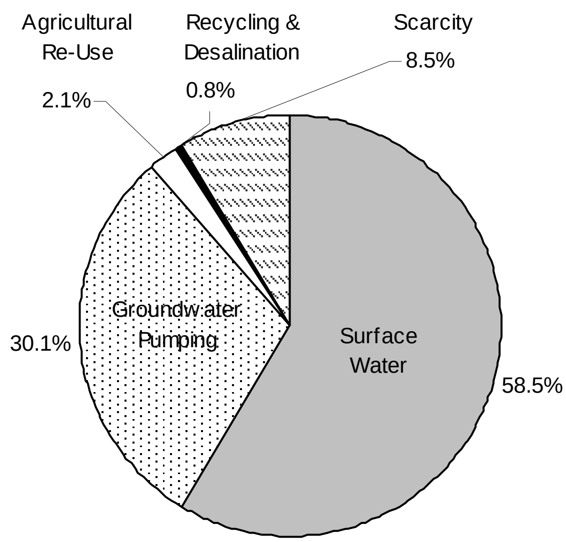
[18] Measured as the result of increased scarcity, which moves from 2.9 to 57.5 percent of the portfolio (97.1%/42.5% = 43.8%).
[19] Measured as the result of increased scarcity, which moves from 8.5 to 31.7 percent of the portfolio (91.5%/68.3% = 74.7%).



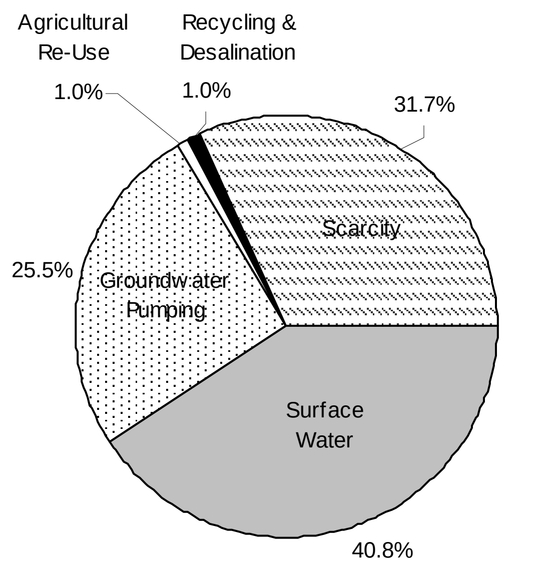
North of Delta – Base Case



North of Delta – 1909 taf per month MNDO



South of Delta – Base Case



South of Delta – 1909 taf per month MNDO

Figure F.16 - Water portfolio north and south of the Delta with current and significantly increased net Delta outflows (2050)

Table F.10 - Annual average wastewater reuse and desalination for increasing minimum required net Delta outflow

Region	Annual Average Use (taf/year)							
	BC	**500**	**1000**	**1200**	**1600**	**1909**	**2064**	**2218**
Wastewater Reuse								
Sacramento Valley	8	8	17	18	24	25	40	43
San Joaquin, Bay Area & Tulare	65	65	65	65	78	78	78	78
Southern California	145	145	145	145	145	145	164	802
Statewide[a]	218	218	227	228	247	247	281	923
Desalination								
Sacramento Valley	0	0	0	0	23	25	28	41
San Joaquin, Bay Area & Tulare	21	21	21	21	74	78	80	105
Southern California	6	6	6	6	6	6	6	6
Statewide[a]	27	27	27	27	103	109	114	152

[a] Totals may not sum due to rounding.

Environmental Marginal Costs

As deliveries are reduced to meet increasing Delta outflow requirements, the marginal cost of environmental flows increases (Table F.11). In contrast to the case of export restrictions, these added costs are shared more evenly across the state. As before, the marginal costs are highest for the consumptively used environmental flows. In addition to the required Delta outflows themselves, the greatest increases in marginal costs are for the Trinity River minimum instream flows, Mono and Owens Lake inflows, and the wildlife refuges.

Table F.11 - Marginal opportunity cost of environmental water with increasing minimum net Delta outflows

		Average Marginal Economic Cost ($/af)						
North or South of Delta	**Location**	**Base (179)**	**1000**	**1200**	**1600**	**1909**	**2064**	**2218**
	Minimum Instream Flow							
North	Trinity River[a,b]	51.2	111.4	145.2	611.1	695.2	765.3	1056.1
North	Sacramento River	3.0	6.8	8.9	50.2	50.4	49.2	55.9
North	Clear Creek	24.5	29.2	31.2	81.9	86.2	86.3	90.7
North	Feather River	0.6	3.4	4.3	8.0	9.0	9.1	14.4
North	Yuba River	0.6	0.8	0.8	1.1	0.9	0.9	1.1
North	American River	0.9	3.9	4.4	15.7	15.0	15.1	15.6
North	Mokelumne River	5.8	11.9	14.2	39.6	39.6	40.0	49.4
North	Calaveras River	0	0	0	0	0	0	0
South	San Joaquin River	52.8	54.6	48.7	38.7	24.2	17.8	20.8
South	Stanisalus River	3.3	11.1	15.4	26.9	27.9	29.5	58.4
South	Tuolumne River	3.4	10.6	13.6	19.2	20.4	22.1	40.1
South	Merced River	29.5	21.4	17.4	15.1	12.7	13.5	21.0
	Refuges							
North	Sacramento East Refuges[a]	4.3	52.0	79.2	434.2	503.8	565.2	804.5
North	Sacramento West Refuges[a]	3.8	53.2	81.6	194.0	276.6	372.4	660.2
South	Pixley National Wildlife Refuge[a]	49.1	100.1	121.6	167.2	170.5	171.0	171.3
South	Kern National Wildlife Refuge[a]	55.3	114.4	145.6	224.6	290.0	362.0	628.7
South	San Joaquin Wildlife Refuge[a]	34.3	92.4	123.1	535.3	612.3	679.5	955.0
	Other							
North	Required Net Delta Outflow	3.6	57.7	88.6	502.1	581.0	649.6	928.4
South	Delta Mendota Pool	30.4	75.0	96.6	410.0	466.2	518.4	737.5
South	Owens Lake[b]	1101.3	1158.9	1192.6	1268.9	1337.6	1413.4	1638.3
South	Mono Lake[b]	1423.2	1482.2	1517.6	1598.3	1671.0	1750.8	1987.6

[a] Consumptive environmental flows.

[b] Marginal values of environmental flows immediately downstream of hydropower-generating reservoirs may also reflect lost benefits of hydropower generation, in addition to downstream scarcity and operating costs.

The Value of New Facilities

Conveyance Facilities

As with restricted Delta exports, expansion of facilities that allow urban areas, primarily in the Bay Area and Southern California, to access more water have the highest economic benefit (Table F.12). These conveyance facilities include the Hayward intertie, the Freeport Project, the proposed New Don Pedro intertie, the Friant-Kern Canal, and the Colorado River Aqueduct. Because exports are allowed, there would be modest benefit to expanding the pumping plant capacity at Banks and Jones to allow more transfers of water south during the wet periods (when "surplus" flows remain) for use in the drier periods. As with the reduced export capacity alternative, expanding some of the artificial recharge facilities associated with urban areas would also create benefits (Table F.12).

Expanded Surface and Underground Storage

Similarly to the restricted Delta export alternative, the value of additional surface water storage is less than the value of expanding key conveyance facilities. Overall, as the MNDO increases, the value of additional surface storage increases, until the regulatory limits reach a point where there is insufficient water available to store and still meet the outflow requirements (Table F.12). The largest increases in average value are for reservoirs north of the Delta, followed by the San Joaquin and Tulare Basins and the Southern Bay Area. Southern California has the reservoir with the greatest benefit if expanded (Lake Skinner), but its value decreases as the MNDO increases because of reduced water supply availability.

As the MNDO is increased, the system must manage its ground and surface waters more aggressively. Surface water reservoirs are drawn down further and the range of storages are greater (Figure F.17). When MNDOs are high, reservoirs are filled higher when water is available, but drawn down further to supply demands. Groundwater storage also has a larger drawdown-refill cycle as MNDOs increase (Figure F.18), indicating much more aggressive conjunctive use.

Summary

Regulations that increase minimum Delta outflows raise water scarcity and economic costs statewide. But water transfers, changed operations, increased use of recycling and desalination, and water conservation allow users to adapt, albeit at some cost. Agricultural areas experience the greatest scarcity, especially north of the Delta. Initially they sell water south and ultimately they forgo supplies to meet Delta outflow requirements. Urban areas are relatively protected from changes in Delta outflows until the highest levels of restrictions. New facilities, such as the Freeport Project and interties to the California Aqueduct, allow urban users to replace Delta water with other sources. Overall, statewide, there are few major changes in scarcity until minimum Delta outflows exceed 1,000 taf per month. This indicates that the state might be able to adapt to changes in the outflow requirements in most periods without major impacts if flexibility in operations and transfers are already in place and some key conveyance facilities are constructed or expanded.

Table F.12 - Average marginal values of expanded conveyance and storage facilities with increasing monthly minimum net Delta outflow

North or South of Delta	Name	Average Marginal Value of Expansion ($/af/year)					
		Base (179)	1000	1600	1909	2064	2218
Conveyance Facilities ($/af/year)[a]							
North	Freeport Project	0	4	31	31	31	39
North	Mokelumne River Aqueduct	0	1	2	3	2	2
South	New Don Pedro Intertie	333	262	256	253	204	232
South	Hetch Hetchy Aqueduct	480	478	427	424	418	380
South	CCWD/EBMUD Intertie	0	0	0	0	0	0
South	Hayward Intertie	161	157	175	172	171	150
South	Jones Pumping Plant	0	0	0	0	0	0
South	Banks Pumping Plant	2	157	175	172	171	150
South	Cross Valley Canal	0	1	2	3	6	8
South	Friant-Kern Canal	0	1	1	1	1	1
South	Coastal Aqueduct	1372	1312	1213	959	901	644
South	Colorado River Aqueduct	362	421	534	604	681	913
Reservoirs ($/af/year)							
North	Shasta Lake	8	9	17	20	93	107
North	Clair Engle Lake	3	3	8	9	81	92
North	Black Butte Lake	8	10	38	52	140	160
North	Lake Oroville	15	15	28	34	111	123
North	Thermalito Afterbay	9	12	24	31	120	135
North	New Bullards Bar Reservoir	18	19	36	45	133	155
North	Englebright Lake	44	45	75	87	168	186
North	Clear Lake & Indian Valley Reservoir	2	3	14	20	118	133
North	Camp Far West Reservoir	6	8	31	43	137	161
North	Folsom Lake	13	14	31	40	127	153
South	New Melones Reservoir	9	9	10	9	76	86
South	San Luis Reservoir	0	0	3	5	67	78
South	New Don Pedro Reservoir	8	8	9	9	75	85
South	Hetch-Hetchy Reservoir	5	5	6	7	75	85
South	Millerton Lake	5	6	12	13	79	91
South	Lake Kaweah	49	53	98	114	158	158
South	Lake Success	45	48	85	102	141	143
South	Lake Skinner	523	521	465	431	354	284
Artificial Recharge Facilities ($/af/year)							
South	Santa Clara Valley	31	670	561	614	670	936
South	Mojave	391	369	373	372	369	393
South	Antelope Valley	1049	1386	1253	1322	1386	1651

[a] Some marginal values of conveyance expansion will initially increase in value because additional capacity would allow more water to be transferred, but as MNDO increases, the available supplies decrease and additional capacity may no longer be needed because there is insufficient water to fill the conveyance facility.

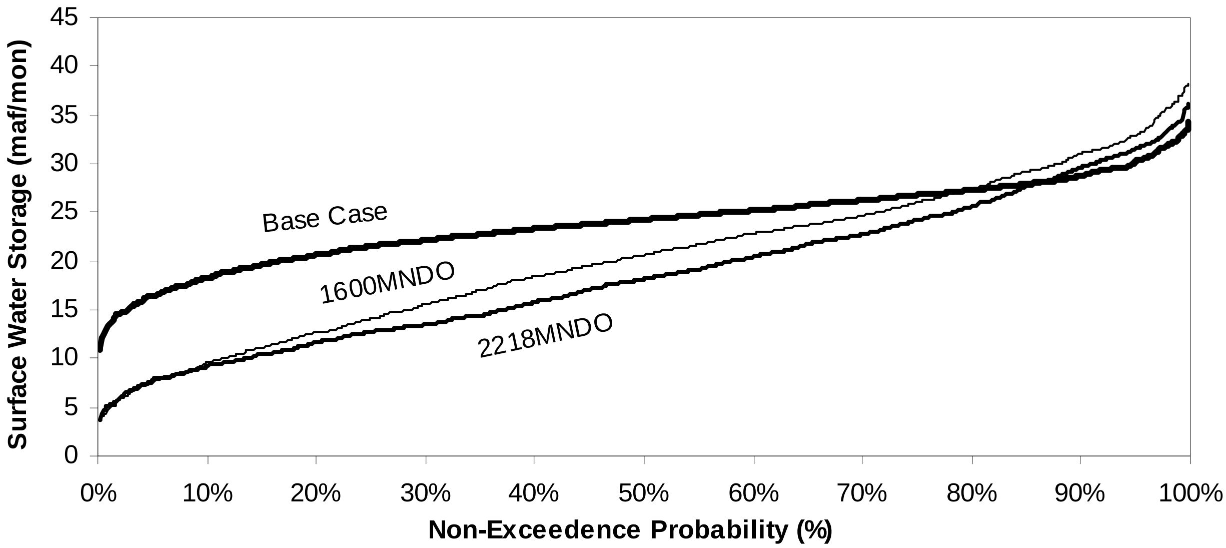


Figure F.17 - Statewide surface water storage with increasing minimum net Delta outflow

Note: Non-exceedence probability is the probability of having a storage volume that is below (not exceeding) the given storage volume. For example, in the base case, there is a 20 percent chance that storage will be less than approximately 23 maf per month.

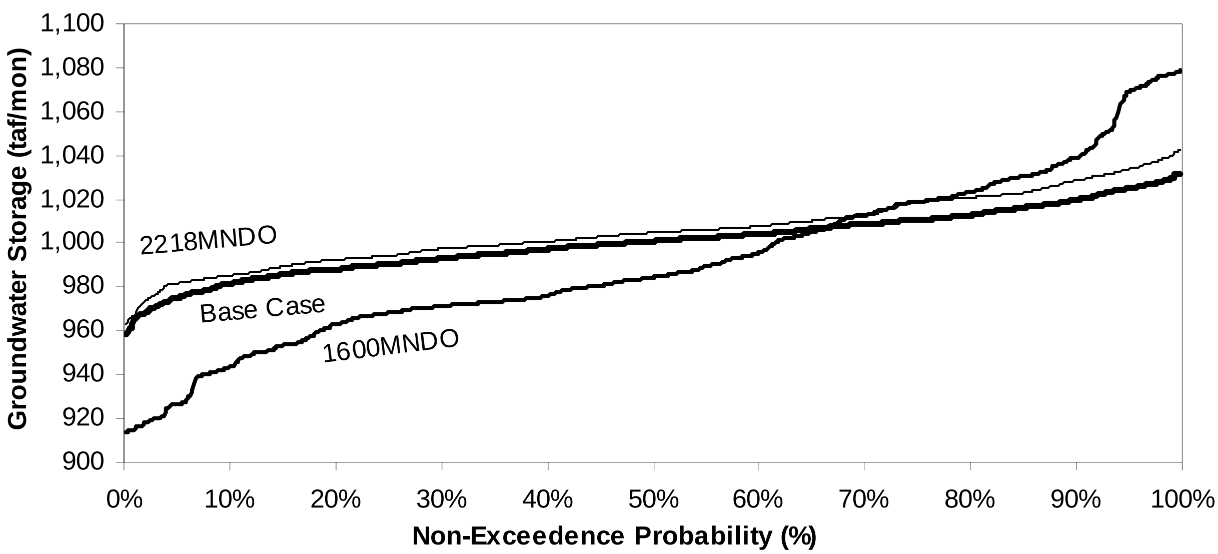


Figure F.18 - Statewide groundwater storage non-exceedence for increasing minimum net Delta outflow

Note: Non-exceedence probability is the probability of having a storage volume below (not exceeding) the given storage volume. For example, in the base case, there is a 20% chance that storage will be less than approximately 990 taf per month.

4. Comparing the Regulatory Alternatives

The two alternatives assessed here represent very different means of changing Delta operations. One alternative restricts exports through the pumping plants in the southern Delta, ultimately eliminating exports. The second alternative increases minimum net Delta outflow requirements, culminating in an outflow requirement of 26.6 maf per year, or 94 percent of unimpaired Delta outflows. The analysis assesses the most cost-effective way for water users to adjust to these sometimes radical changes in water availability.

Which alternative makes the most sense from a regulatory perspective depends on the goal at hand. Both alternatives reduce exports, and both increase Delta outflows; however, as shown in Figure F.19, they do this in quite different ways. When exports are set to zero, there is about 18.7 maf per year of net Delta outflow and an annual average cost of $4.1 billion per year - $1.5 billion higher than the costs of scarcity and operations in the base case. With the increased MNDO requirement, for the same level of Delta outflow, export pumping is at about 4.5 maf per year and the annual average cost falls to $3.2 billion per year. Thus, the same level of Delta outflow can be achieved, while still allowing exports, and the cost is reduced by $1.0 billion per year.

If the regulatory goal is to limit environmental problems caused by the pumps, as in the recent Wanger decision, it is most cost effective to directly target southern Delta export activity (Figure F.20). In this case, a policy to increase Delta outflows will result in considerably higher cost to water users, because it leads to greater overall reductions in water availability. In contrast, if the regulatory goal is to increase flows into and out of the Delta, the most cost effective strategy is to increase minimum Delta outflow requirements (Figure F.21). Even if export users bear the regulatory responsibility for this requirement, they will be able to purchase some water from agricultural areas upstream of the Delta in the Sacramento Valley and along the eastern side of the San Joaquin Valley. This market increases water scarcity in the selling areas, but generates overall economic benefits statewide, because it allows the lowest value uses of water to contribute to the solution.

At present, there may be no alternative to direct export restrictions, given the environmental threats to delta smelt and other declining fish species from pumping activity. But if exports were instead routed through a peripheral canal, the direct issue of the pumps would be removed, and the regulatory problem would become one of determining appropriate levels of flows into the Delta for environmental purposes and to meet water quality standards for in-Delta users. Whenever the objective is to increase Delta flows, the state will use its water more efficiently, with greater gains to the overall economy, if it regulates these flows directly. Market incentives will engage the participation of upstream users, even if they are not required by regulation to contribute to the higher flow requirements.

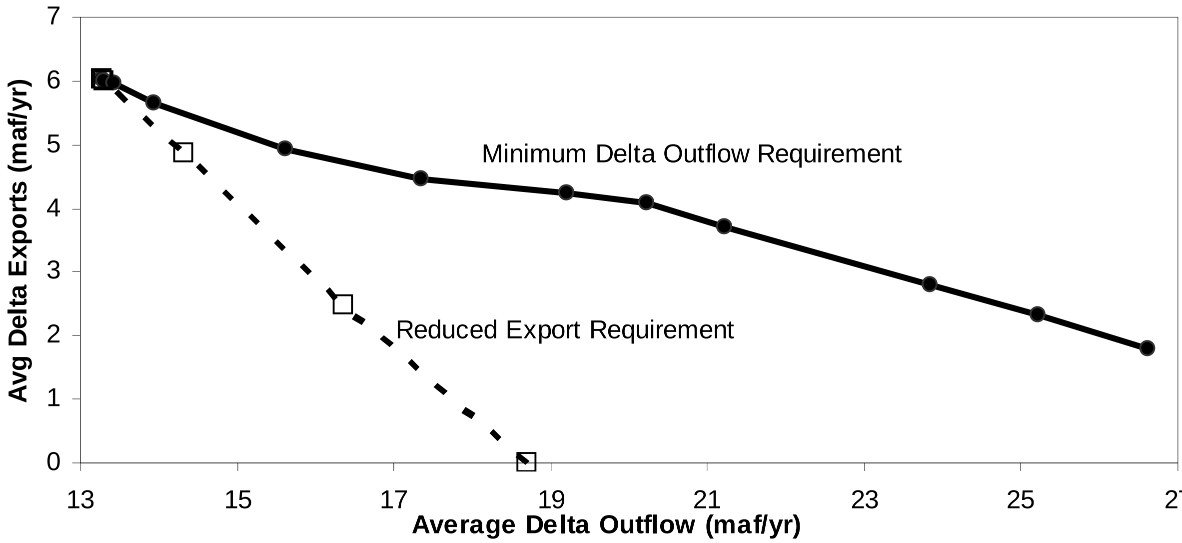


Figure F.19 - Average Delta exports for a given level for Delta outflow for the two alternatives (reduced export capacity and increased minimum net Delta outflow)

Note: As the average Delta outflow increases (from a base of about 13 maf/year), annual average Delta export pumping decreases under both regulatory alternatives. However, exports decrease at a faster rate when export restrictions are applied, Applying a minimum net Delta outflow requirement is the alternative which increases average Delta outflows with the least effect on exports (as evidenced by the 'flatter' curve).

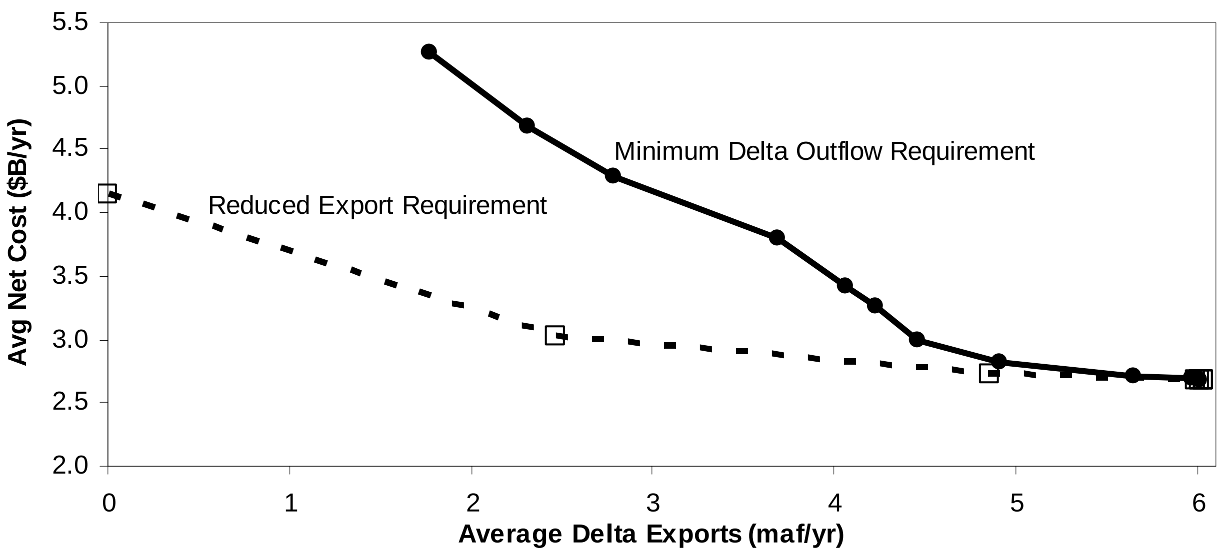


Figure F.20 - Average Delta export pumping and associated statewide net costs

Note: As average Delta exports increase, average net costs decrease as more water becomes available. Changing the minimum net Delta outflow requirement is a more expensive means of controlling Delta exports than directly restricting export volumes (note that the 'Minimum Delta Outflow Requirement' line is above the 'Reduced Export Requirement' line).

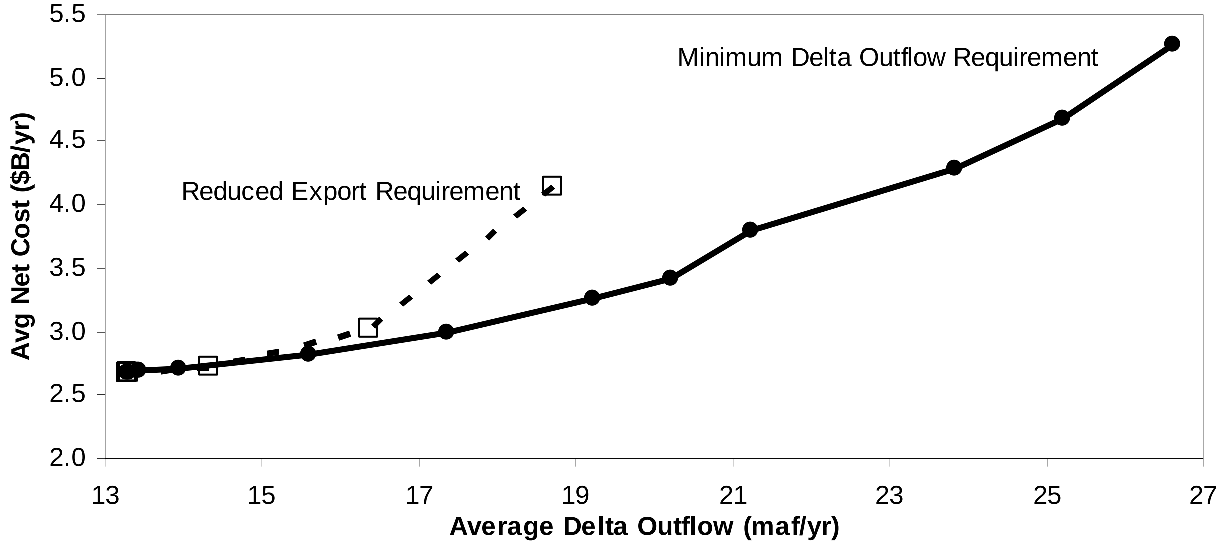


Figure F.21 - Average Delta outflows and associated statewide net costs

Note: As average Delta outflows increase, the average net costs increase as water becomes scarcer and users switch to more costly supply alternatives. Generally, restricting exports is a more expensive means of increasing the average Delta outflow (note the 'Reduced Export Requirement' line tends to be above the 'Minimum Delta Outflow Requirement' line)

Conclusions

As Delta exports are restricted, scarcity increases for agricultural users south of the Delta. Some of these costs would be offset by revenues from sales of water by senior right-holders to urban areas and higher-valued agriculture. As long as they have time to plan for these changes, urban areas are not significantly affected until exports are severely reduced (below 2.5 maf per year). At this point no additional water is available for purchase from lower value users (due to lack of water south of the Delta and inability to transfer water through the Delta from Sacramento Valley and eastside San Joaquin Valley farmers). The significant increase in Central Valley and Southern California scarcity and scarcity costs when exports are curtailed highlights the dependence of these regions on the Delta. If south-of Delta transfers are restricted, the costs to agriculture decrease somewhat, but the costs to urban areas increase significantly, and overall costs to the economy are higher.

As export capacities are reduced, agricultural and urban users south of the Delta increase wastewater recycling and desalination to offset the reduction in surface and groundwater supplies. When minimum net Delta outflows are increased, urban users north and south of the Delta increase wastewater recycling and desalination to offset reductions in surface and groundwater supplies.

The effects of climate change were not explicitly evaluated in this study. However, previous CALVIN studies (Tanaka et al., 2006; Medellin-Azuara et al., 2008) demonstrate that changes in hydrology lead to increased scarcity and costs as users adapt to reduced supplies and a seasonal shift in water availability. It seems likely that if climate warming effects were added to either of the Delta regulatory alternatives examined here, scarcity and scarcity costs would increase and the economic results (marginal costs of environmental flows and infrastructure expansion) would be similar, though larger in absolute value.

Direct economic valuation of environmental services is controversial (Shabman and Stephenson, 2000). Instead of attempting this, we calculate the shadow values on required environmental flows to estimate the opportunity cost to water users of environmental requirements. As exports decrease, the opportunity cost of the environmental flows increases, especially in the Central Valley. The highest opportunity costs are when the flows are used on site and not returned to the water system, as is the case with wildlife refuges.

Additional surface water storage, while having some economic benefit, is not as valuable as expanding key conveyance and recharge facilities. Aqueducts, canals, and interties that allow users to buy and sell water, especially between the agricultural and urban sectors, are the most valuable.

As exports are decreased, Delta outflow increases. The increases are larger in some months, especially in summer and fall. Depending on the management goals, having more (or alternating more and less) water flow through the Delta may be desirable. If a fresh water Delta is the desired outcome, it is more cost-effective to increase Delta outflow requirements directly and still allow exports. If the desired goal is a reduction in fish entrainment, then a direct reduction in pumping capacity is more efficient. Some of the increased scarcity to export users could be reduced if a peripheral canal were constructed to allow the CVP, SWP, and CCWD to export water without using the Delta for conveyance. A combination of Delta alternatives and management options will be needed to reduce entrainment, reduce salt water intrusion as sea level rises, and provide water supplies for agricultural and urban uses.

Overall, management of the Delta requires a balancing of the interests that rely on it; this includes in-Delta users, water export users, upstream diverters, and environmental concerns. Results from large system models, like CALVIN, allow decision makers to better understand consequences of changes in management throughout the system. While imperfect, such results produce reasoned (and reasonable) insights. Overall, California's water supply system has considerable capacity to adapt to changes in Delta water policies. While such adaptation incurs cost, it need not incur catastrophe if well managed.

References

Black and Veatch (1995), California Water Charge Survey, Black and Vetch Management Consulting Division, Irvine, CA.

CALFED (2000), CALFED Bay-Delta Program Annual Report 2000, CALFED, Sacramento, CA.

CALFED (2001), CALFED Briefing Book, CALFED, Sacramento, CA.

CDFG (2008), Bay Delta Region Delta Smelt, Sacramento, CA.

Department of Finance, E-2. California County Population Estimates and Components of Change by Year — July 1, 2000–2007, http://www.dof.ca.gov/html/DEMOGRAP/ReportsPapers/Estimates/E2/E-2_2000-07.php

Department of Water Resources, "DWR Releases Water Delivery Impact Estimates Following Wanger Decision," Advisory, Sacramento, California, December 24, 2007.

Department of Water Resources (1998), DWRSIM Model – 2020D09B-Calfed-514, California Department of Water Resources, Sacramento, CA. Data files: DWRSIM_2020D09B-Calfed-514-main.dat.

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

FWF (2007), Agreement to Reduce Pumping to a Minimum To Protect Delta Smelt, Sacramento Fish and Wildlife Office, Fish and Wildlife Service, Sacramento, CA.

HEC (1991), Columbia River System Analysis Model – Phase I, Report PR-16, US Army Corps of Engineers Hydrologic Engineering Center, Davis, CA, October.

Howitt, R. E., K.B. Ward, and S.M. Msangi (1999), "Appendix A: Statewide Water and Agricultural Production Model," Center for Environmental and Water Resources Engineering, University of California, Davis, CA.

Illingworth, W., R. Mann, and S. Hatchet (2005), "Economic Consequences of Water Supply Export Disruption Due to Seismically Initiated Levee Failures in the Delta," Appendix B of Jack R. Benjamin & Associates, Preliminary Seismic Risk Analysis Associated with Levee Failures in the Sacramento – San Joaquin Delta, Jack R. Benjamin & Associates, Menlo Park, CA.

Isenberg, P., M. Florian, R.M. Frank, T. McKernan, S. Wright McPeak, W.K. Reilly, and R. Seed, "Blue Ribbon Task Force Delta Vision: Our Vision for the California Delta," State of California Resources Agency, Sacramento, California, December 2007.

Jenkins, M.W. (2000), "Appendix B1: Representation of Urban Water Demands and Local Supplies", Center for Environmental and Water Resources Engineering, University of California, Davis, CA.

Jenkins, M.W., A.J. Draper, J.R. Lund, R.E. Howitt, S. Tanaka, R. Ritzema, G. Marques, S.M. Msangi, B.D. Newlin, B.J. Van Lienden, M.D. Davis, and K.B. Ward (2001), "Improving California Water Management: Optimizing Value and Flexibility," Center for Environmental and Water Resources Engineering Report No. 01-1, Dept. of Civil and Environmental Engineering, University of California, Davis, CA.

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

Lund, J.R., E. Hanak, W. Fleenor, R. Howitt, J. Mount, and P. Moyle (2007), *Envisioning Futures for the Sacramento-San Joaquin Delta*, Public Policy Institute of California, San Francisco, CA.

Medellín-Azuara, J. Harou, J.J., Olivares, M.A., Madani, K., Lund, J.R., Howitt, R.E., Tanaka, S., Jenkins, M.W., and Zhu, T. (2008), "Adaptability and Adaptations of California's Water Supply System to Dry Climate Warming.," *Climatic Change*, 87(Suppl 1): S75–S90.

Newlin, B.D., M.W. Jenkins, J.R. Lund, and R.E. Howitt (2002), "Southern California Water Markets: Potential and Limitations," *Journal of Water Resources Planning and Management*, 128(1), 21-32.

Null, S. and J.R. Lund (2006), "Re-Assembling Hetch Hetchy: Water Supply Implications of Removing O'Shaughnessy Dam," *Journal of the American Water Resources Association*, 42(2): 395-408.

Pulido-Velázquez, M., M.W. Jenkins, and J.R. Lund (2004), "Economic Values for Conjunctive Use and Water Banking in Southern California," *Water Resources Research*, 40(3).

Shabman, L. and L. Stephenson, (2000), "Environmental Valuation and Its Economic Critics," *Journal of Water Resources Planning and Management*, 126(6), 382-388.

Tanaka, S.K., J.R. Lund, and M.W. Jenkins (2003), "Effects of Increased Delta Exports on Sacramento Valley's Economy and Water Management," *Journal of the American Water Resources Association*, 39(6), 1509-1519.

Tanaka, S.K., T. Zhu, J.R. Lund, R.E. Howitt, M.W. Jenkins, M.A. Pulido, M. Tauber, R.S. Ritzema and I.C. Ferreira (2006), "Climate Warming and Water Management Adaptation for California," *Climatic Change*, 76(3-4): 361-387.

USBR (1997), Central Valley Project Improvement Act, Draft Programmatic Environmental Impact Statement, United States Bureau of Reclamation, Mid-Pacific Region, Sacramento, CA.

USDA (1999), 1997 Census of Agriculture: Ranking of States and Counties, U.S. Department of Agriculture, Washington, DC.

Addendum F1. Regional Results

Introduction

Most water problems are felt locally, and water management in California mostly occurs on local and regional levels. The purpose of this addendum is to provide a more regional and local presentation of economic impacts and water supply implications of decreasing Delta exports or increasing net Delta outflow requirements. CALVIN results are divided into major regions with regional and local results presented. The four regions are: Sacramento Valley and Delta, San Joaquin Valley and San Francisco Bay Area, Tulare Basin, and Southern California (Figure F.1). These are subsequently presented for agricultural demand areas (CVPMs) and urban demands. Table F1.1 translates the CVPM regions used in CALVIN into water districts and users present in those demand areas (Figure F.2). Table F1.2 outlines the urban areas evaluated in each region.

Table F1.1 - Users within CVPMs

CALVIN Region	CVPM/ SWAP Region	Description
Sacramento Valley and Delta	1	CVP Users: Anderson Cottonwood, Clear Creek, Bella Vista, Sacramento River miscellaneous users
	2	CVP Users: Corning Canal, Kirkwood, Tehama, Sacramento River miscellaneous users
	3	CVP Users: Glenn Colusa ID, Provident, Princeton-Cordora, Maxwell, Colusa Basin Drain MWC, Orland-Artois WD, Colusa County, Davis, Dunnigan, Glide, Kanawha, La Grande, Westside WD, and Tehama-Colusa Canal Service Area
	4	CVP Users: Princeton-Cordora-Glen, Colusa Irrigation Co., Meridian Farm WC, Pelger Mutual WC, Reclamation Districts 1004 and 108, Roberts Ditch, Sartain M.D., Sutter MWC, Swinford Tract IC, Tisdale Irrigation, Sacramento River miscellaneous users
	5	Most Feather River riparian and appropriative users
	6	Yolo and Solano Counties, CVP Users: Conaway Ranch, and Sacramento River miscellaneous users
	7	Sacramento Company north of the American River, CVP Users: Natomas Central MWC, Pleasant Grove-Verona, San Juan Suburban, Sacramento River miscellaneous users
	8	Sacramento County south of the American River, San Joaquin Company
	9	Delta Regions. CVP Users: Banta Carbona, West Side, Plainview

San Joaquin Valley and Bay Area	10	Delta Mendota Canal, CVP Users: Central California ID, Panoche, WD, Pacheco WD, Del Puerto, Hospital, Sunflower, West, Stanislaus ID, Mustang, Orestimba, Patterson WD, Foothill, San Luis WD, Broadview, Eagle Field, Mercy Springs, Pool Exchange Contractors, Schedule II water rights, Grasslands WD, SWP Users: Oak Flat WD
	11	Stanislaus River water rights: Modesto ID, Oakdale ID, and South San Joaquin ID
	12	Turlock ID
	13	Merced ID, CVP Users: Madera Chowchilla, Gravely Ford
Tulare Basin	14	CVP Users: Westlands
	15	Tulare Lake Bed, CVP Users: Fresno Slough, Fames, Tranquility, Traction Ranch, Laguna, Reclamation District 1606
	16	Eastern Fresno Company, CVP Users: Friant-Kern Canal, Fresno ID, Garfield, International
	17	CVP Users: Friant-Kern Canal, Hills Valley, Tri-Valley Orange Grove
	18	CVP Users: Friant-Kern Canal, County of Fresno, Lower Tule River ID, Pixley ID
	19	Kern Co. SWP service area
	20	CVP Users: Friant-Kern Canal, Shafter-Wasco, South San Joaquin
	21	CVP Users: Cross Valley Canal, Friant-Kern Canal, Arvin Edison
Southern California	22	Imperial ID
	23	Coachella Valley WD
	24	Palo Verde ID

Table F1.2 - Cities constituting urban demands in CALVIN regions

Region	Urban Demands
Sacramento Valley and Delta	Redding (fixed deliveries)
	Yuba City, Sacramento, Stockton, Napa-Solano County, Contra County Water District, East Bay Municipal Utilities District (EBMUD)
San Joaquin Valley and Bay Area	Modesto, Turlock, Merced, Manteca, and Madera (deliveries fixed). San Francisco Public Utilities Commission, Santa Clara Valley Water District (SCVWD), Alameda County Water District, Alameda Zone 7 (includes San Jose, Santa Clara, Palo Alto, Hayward, Fremont, Dublin, and Livermore)
Tulare Basin	Fresno, Bakersfield, Sanger, Visalia, Delano, San Luis Obispo- Santa Barbara (Central Coast Water Authority)
Southern California	San Bernardino Valley Water District, San Diego Metropolitan Water District (MWD) (all of San Diego County), Coachella Valley (Dessert Water Agency and Coachella Valley Water Agency), Eastern and Western MWD (Mainly Riverside County portion of MWD), Central MWD (Mainly Los Angeles and Orange County portions of MWD of Southern California, Mojave (Mojave Water Agency and Hi Desert Water Agency), Oxnard (Camarillo, Ventura), El Centro, Calexico, Brawley, Blythe, AVEKWA, Palmdale, Littlerock Creek, Castaic Lake Water Agency

Effects of Export Restrictions

Changing Delta export capacity affects different parts of the state differently regarding water scarcity, marginal willingness to pay, and their water supply portfolio. Marginal willingness to pay provides some quantitative indication of users' interest in water transfers/markets, conservation, and alternative water sources. Table F1.3, Table F1.4, and Table F1.5 indicate changes in scarcity, scarcity cost, and marginal willingness to pay under each modeling scenario for each region.

In the Sacramento Valley and Delta region, decreasing export capacity makes additional water available for some users such that scarcity in many northern CVPMs decreases (Table F1.3). Users with less scarcity tend to obtain most of their supplies from the Sacramento River and its tributaries on the northeastern side of the Central Valley (the Feather, Bear, and American Rivers) and from groundwater pumping. Conversely, when export capacity is increased, water scarcity likewise increases in most agricultural areas in the Sacramento Valley and Delta region. Urban demands in the Sacramento Valley do not experience water scarcity regardless of changes in export capacity. In some cases, (as indicated in

Table F1.2, above) urban water demands are met by fixed deliveries from pumping local groundwater basins.

Water scarcity for all agricultural users in the San Joaquin Valley and Bay Area increases dramatically with reduced exports (Table F1.4). Overall, San Joaquin Valley and Tulare Basin agricultural scarcity increases by 4.9 maf per year and scarcity costs increase by $821 million per year when exports are eliminated. Of that scarcity, 3.7 maf per year occurs in the Tulare Basin. Conversely, increases in export capacities have little effect on agricultural or urban users in the San Joaquin Valley, Bay Area, and Tulare Basin (Table F1.4).

The San Francisco Public Utilities Commission (San Francisco) and the Santa Clara Valley Water District (Santa Clara Valley, which includes Alameda County Water District and Alameda Zone 7) are the only urban areas north of the Tehachapi Mountains with increased scarcity when exports are reduced. Because urban water scarcity is usually more costly than equal volumes of agricultural scarcity, agricultural demands are expected to be shorted before urban demands (with transfers from the agricultural to the urban sector).

Deliveries to Southern California agricultural users (who use Colorado River water) are insensitive to Delta operations (Table F1.5). Regardless of the Delta export conditions, the three agricultural users in Southern California have approximately 0.9 maf per year of scarcity. All three agricultural areas receive water from the Colorado River Aqueduct, which also delivers water to urban users. However, the Colorado River Aqueduct is assumed to be at capacity in the base case, so Southern California agriculture (Palo Verde, Coachella, and Imperial) cannot transfer more water to the urban users. As a result, when exports are eliminated, all increases in Southern California scarcity are borne by the urban users. Scarcity increases by 259 taf per year and scarcity costs increase by $358 million per year.

As exports are reduced, urban Southern California purchases additional water from San Joaquin and Tulare Basin farmers, while increasing urban wastewater recycling and desalinization. Urban areas heavily dependent on the East and West branch of the SWP are the hardest hit by reductions in exports, as they have fewer alternative sources.

Table F1.3 - Sacramento Valley and Delta region average scarcity, scarcity cost, and marginal willingness to pay for changing export restrictions

	Average Scarcity (taf/year)[b]			Average Scarcity Cost ($M/year)[b]			MWTP[a] ($/af)[b]		
Economic User	**NE**	**BC**	**UC**	**NE**	**BC**	**UC**	**NE**	**BC**	**UC**
CVPM 1	7.3	7.0	7.0	0.1	0.1	0.1	6.8	6.3	6.2
CVPM 2	19.4	57.9	57.7	0.3	1.0	1.0	2.7	9.5	9.4
CVPM 3	0	0	0	0	0	0	0	0	0
CVPM 4	0.5	13.3	13.6	0.0	0.1	0.1	0.1	3.6	3.5
CVPM 5	8.8	96.6	97.2	0.1	1.3	1.2	0.4	4.5	4.4
CVPM 6	0	0	0	0	0	0	0	0	0
CVPM 7	20.9	26.7	27.3	0.3	0.4	0.4	5.5	7.4	7.7
CVPM 8	21.1	12.8	13.4	0.5	0.4	0.3	13.4	8.8	6.3
CVPM 9	59.1	102.9	93.9	0.4	0.7	0.7	1.9	4.6	4.2
Napa	0	0	0	0	0	0	0	0	0
CCWD[c]	0	0	0	0	0	0	0	0	0
EBMUD[c]	0	0	0	0	0	0	0	0	0
Stockton	0	0	0	0	0	0	0	0	0
Redding	0	0	0	0	0	0	0	0	0
Galt	0	0	0	0	0	0	0	0	0
Sacramento	0	0	0	0	0	0	0	0	0
Yuba	0	0	0	0	0	0	0	0	0
Regional Agricultural	137.0	317.2	310.1	1.8	4.0	3.9	-	-	-
Regional Urban	0	0	0	0	0	0	-	-	-
Regional Total	137.0	317.2	310.1	1.8	4.0	3.9	-	-	-

[a] Marginal willingness to pay.
[b] '0' denotes a value of zero, whereas '0.0' denotes less than 0.1.
[c] 'CCWD' refers to Contra Costa Water District and 'EBMUD' refers to East Bay Municipal Utilities District.

Table F1.4 - San Joaquin, Bay Area, and Tulare Basin average scarcity, scarcity cost, and marginal willingness to pay for changing export restrictions

	Average Scarcity (taf/year)			Average Scarcity Cost ($M/year)			MWTP[a] ($/af)		
Economic User	**NE**	**BC**	**UC**	**NE**	**BC**	**UC**	**NE**	**BC**	**UC**
CVPM 10	1133	168	168	118	3	3	145	20	20
CVPM 11	25	19	20	0	0	0	3	2	2
CVPM 12	145	139	139	3	3	3	22	21	21
CVPM 13	562	277	259	32	9	8	106	41	36
CVPM 14	645	106	106	137	4	4	214	35	35
CVPM 15	607	212	212	54	9	9	186	49	46
CVPM 16	57	19	19	3	0	0	138	26	26
CVPM 17	243	159	157	11	4	4	118	52	51
CVPM 18	1309	236	236	169	6	6	102	18	18
CVPM 19	551	95	95	90	4	4	162	34	34
CVPM 20	260	67	67	37	2	2	338	50	50
CVPM 21	997	110	110	217	6	6	208	44	44
SFPUC[c]	3	0	0	5	0	0	581	0	0
Modesto	0	0	0	0	0	0	0	0	0
Merced	0	0	0	0	0	0	0	0	0
Turlock	0	0	0	0	0	0	0	0	0
SCVWD[c]	26	0	0	46	0	0	1111	0	0
Fresno	0	0	0	0	0	0	0	0	0
Bakersfield	0	0	0	0	0	0	0	0	0
Sanger	0	0	0	0	0	0	0	0	0
Visalia	0	0	0	0	0	0	0	0	0
Delano	0	0	0	0	0	0	0	0	0
SB-SLO[c]	0	0	0	0	0	0	0	0	0
Regional Agricultural	6535	1608	1589	872	51	49	-	-	-
Regional Urban	29	0	0	51	0	0	-	-	-
Regional Total[b]	6565	1608	1589	923	51	49	-	-	-

[a] Marginal willingness to pay.
[b] Totals may not add due to rounding.
[c] ‘SCVWD’ refers to Santa Clara Valley Water District, ‘SFPUC’ refers to San Francisco Public Utilities Commission, and ‘SB-SLO’ refers to Santa Barbara-San Luis Obispo.

Table F1.5 - Southern California average scarcity, scarcity cost, and marginal willingness to pay for changing export restrictions

	Average Scarcity (taf/year)			Average Scarcity Cost ($M/year)			MWTP[a] ($/af)		
Economic User	**NE**	**BC**	**UC**	**NE**	**BC**	**UC**	**NE**	**BC**	**UC**
Palo Verde	185	185	185	24	24	24	179	179	179
Coachella Ag	44	44	44	7	7	7	449	449	449
Imperial	712	712	712	160	160	160	290	291	290
SBV[c]	9	0	0	10	0	0	660	0	0
SDMWD[c]	21	7	7	35	12	12	685	227	227
Coachella Urban	0	0	0	0	0	0	0	0	0
EMWD[c]	37	19	19	60	31	31	1002	508	508
Mojave	98	28	28	86	19	19	1049	698	698
Ventura	0	0	0	0	0	0	4	4	4
El Centro	0	0	0	0	0	0	0	0	0
CLWA[c]	12	2	2	16	2	2	1502	421	421
CMWD[c]	124	0	0	195	0	0	974	0	0
Blythe	2	2	2	1	1	1	501	501	501
Antelope Valley	14	0	0	21	0	0	1640	0	0
Regional Agricultural	941	941	941	191	191	191	-	-	-
Regional Urban	318	60	60	424	66	66	-	-	-
Regional Total[b]	1260	1001	1001	615	257	257	-	-	-

[a] Marginal willingness to pay.
[b] Totals may not add due to rounding.
[c] 'SBV' refers to San Bernardino Valley, 'SDMWD' refers to San Diego, 'EMWD' refers to Eastern Metropolitan Water District, 'CLWA' refers to Castaic Lake Water Authority, and 'CMWD' refers to Central Metropolitan Water District.

Ending Delta exports influences the source of water (surface water, canals, groundwater) supplying agricultural demands. Generally, users with access to the Sacramento River increase diversions when export capacity is reduced. Water not diverted by upstream users would either flow out of the Delta (as either required or surplus flows) or remain stored in surface reservoirs to increase hydropower generation. Agricultural areas that depend directly on streams flowing from the Sierra Nevada Mountains (primarily on the east side of the San Joaquin Valley, (e.g., CVPM regions 11, 12, 16, and 17) are much less affected by ending Delta exports, as their water supplies do not depend on the Delta and they cannot readily transfer water to other agricultural regions further south and west without going through the Delta. Water districts which depend more on Delta pumping (e.g., CVPM regions 10, 14, 19, and 21) are more severely affected. Additionally, agricultural demands whose regular supplies could be transferred to urban areas in the San Joaquin, Tulare, and Southern California reduce their water use and incur greater scarcity.

Effects of Increasing Net Delta Outflow Requirements

Increasing minimum net Delta outflows reduces Delta exports and upstream diversions. As with reduced export capacity, the economic effects of increased MNDO vary regionally.

For the Sacramento Valley and Delta region, scarcity and scarcity costs generally increase when MNDO requirements are increased due to transfers to water users south of the Delta (Table F1.6). All agricultural regions have increasing water scarcity with increased minimum outflow requirements. Water supply from the Sacramento, Feather, and Yuba Rivers and from Stony Creek decrease for northern agricultural users. The amount of groundwater pumped also decreases regionally and statewide. Scarcity for urban areas increases when MNDO is raised above 1,600 taf per month. At this point, EBMUD, Stockton, and Yuba see small increases in scarcity (0.8 taf, 1.0 taf, and 1.6 taf per year, respectively). As Delta outflow requirements increase further, CCWD and Sacramento also experience scarcity.

Water scarcity for all agricultural demands in the San Joaquin Valley and the Bay Area increase as the required MNDO increases (Table F1.7). Unlike the reduced export capacity alternative, agricultural areas in competition with urban users in Southern California and the Bay Area for supplies via the SWP and CVP see increased scarcity as MNDO increased. Agricultural demands in this region draw less water from the San Joaquin, Tuolumne, Merced, and Stanislaus Rivers. Groundwater pumping also decreases for agricultural demands in this region; however, under base case conditions, 25 percent of water supplies come from groundwater whereas with an MNDO of 1600 taf per month, 44 percent of water supplies come from groundwater. In this region, water is pumped and exported from the Delta but the higher economic value of water in urban areas diverts supplies away from agriculture.

As the MNDO is increased, additional urban areas experience scarcity. Under base case conditions, no San Joaquin Valley and Bay Area urban area experience scarcity. When the MNDO is increased to 1,600 taf per month, SFPUC and SCVWD are the only urban areas in this region with increased scarcity. Increases in urban scarcity are more costly than equal scarcity volumes in agriculture, so agricultural areas experience higher scarcity volumes.

Deliveries to Southern California agricultural users are insensitive to increased Delta outflow requirements (Table F1.8). These users are served by the Colorado River and the Colorado River Aqueduct capacity limit prevents them from transferring additional water to southern urban users. Urban areas of Southern California compete with agriculture in the southern Central Valley for water from the Delta. As the MNDO is increased, urban Southern California purchases additional water from San Joaquin and Tulare Basin farmers, while also increasing urban wastewater recycling programs. Urban areas heavily dependent upon the east and west branch of the SWP are the hardest hit by reductions in exports resulting from increased MNDO requirements.

Table F1.6 - Sacramento Valley and Delta region average scarcity, scarcity cost, and marginal willingness to pay with increasing minimum net Delta outflows

	Average Scarcity (taf/year)			Average Scarcity Cost ($M/year)			MWTP[a] ($/af)		
Economic User	**BC**	**1600**	**2218**	**BC**	**1600**	**2218**	**BC**	**1600**	**2218**
CVPM 1	7	137	153	0	9	10	6	80	89
CVPM 2	58	287	337	1	20	29	9	106	75
CVPM 3	0	774	1349	0	75	152	0	124	184
CVPM 4	13	713	741	0	43	45	3	95	101
CVPM 5	97	1481	1632	1	122	136	4	107	125
CVPM 6	0	184	630	0	18	87	0	80	96
CVPM 7	27	349	392	0	30	34	8	116	131
CVPM 8	13	265	457	0	19	48	6	130	171
CVPM 9	103	916	1092	1	45	58	5	76	85
Napa	0	0	0	0	0	0	0	0	0
CCWD	0	0	0	0	0	0	0	0	13
EBMUD	0	1	1	0	2	2	0	165	167
Stockton	0	1	1	0	1	1	0	81	86
Redding	0	0	0	0	0	0	0	0	0
Galt	0	0	0	0	0	0	0	0	0
Sacramento	0	0	2	0	0	2	0	0	35
Yuba	0	2	2	0	1	2	0	187	206
Regional Agricultural	317	5105	6783	4	380	599	-	-	-
Regional Urban	0	3	5	0	4	6	-	-	-
Regional Total[b]	317	5108	6788	4	384	606	-	-	-

[a]Marginal willingness to pay.
[b] Regional total may not sum due to rounding.

Table F1.7 - San Joaquin, Bay Area, and Tulare Basin average scarcity, scarcity cost, and marginal willingness to pay with increasing minimum net Delta outflows

	Average Scarcity (taf/year)[a]			Average Scarcity Cost ($M/year)			MWTP[a] ($/af)		
Economic User	**BC**	**1600**	**2218**	**BC**	**1600**	**2218**	**BC**	**1600**	**2218**
CVPM 10	168	919	1485	3	88	172	20	130	183
CVPM 11	19	630	662	0	52	56	2	60	62
CVPM 12	139	810	831	3	59	60	21	118	123
CVPM 13	277	1108	1437	9	117	165	39	161	178
CVPM 14	106	238	626	4	24	132	35	111	203
CVPM 15	212	690	874	9	67	105	46	215	227
CVPM 16	19	57	189	0	3	29	26	136	250
CVPM 17	159	465	577	4	48	66	52	168	183
CVPM 18	236	990	1379	6	108	183	18	93	109
CVPM 19	95	265	997	4	27	190	34	125	176
CVPM 20	67	191	582	2	19	128	50	249	389
CVPM 21	110	296	1018	6	36	223	44	143	207
SFPUC	0	3	4	0	5	6	0	270	394
Modesto	0	0	3	0	0	2	0	0	86
Merced	0	0	0	0	0	0	0	0	0
Turlock	0	0	1	0	0	0	0	0	64
SCVWD	0	6	6	0	11	11	0	265	268
Fresno	0	0	0	0	0	0	0	0	0
Bakersfield	0	0	0	0	0	0	0	0	0
Sanger	0	0	0	0	0	0	0	0	0
Visalia	0	0	0	0	0	0	0	0	0
Delano	0	0	0	0	0	0	0	0	0
SB-SLO	0	0	0	0	0	0	0	0	0
Regional Agricultural	1608	6660	10658	50	648	1510	-	-	-
Regional Urban	0	9	14	0	16	20	-	-	-
Regional Total[b]	1608	6669	10672	50	664	1530	-	-	-

[a] Marginal willingness to pay.
[b] Totals may not add due to rounding.

Table F1.8 - Southern California average scarcity, scarcity cost, and marginal willingness to pay with increasing minimum net Delta outflows

	Average Scarcity (taf/year)			Average Scarcity Cost ($M/year)			MWTP[a] ($/af)		
Economic User	**BC**	**1600**	**2218**	**BC**	**1600**	**2218**	**BC**	**1600**	**2218**
Palo Verde	185	185	185	24	24	24	179	179	179
Coachella Ag	44	44	44	7	7	7	449	449	449
Imperial	712	712	712	160	160	160	290	291	290
SBV	0	0	8	0	0	9	0	0	624
SDMWD	7	7	18	12	12	30	227	227	591
Coachella Urban	0	0	0	0	0	0	0	0	0
EMWD	19	19	27	31	31	43	508	508	885
Mojave	28	50	85	19	37	72	698	790	970
Ventura	0	0	0	0	0	0	4	4	4
El Centro	0	0	0	0	0	0	0	0	0
CLWA	2	6	12	2	6	15	421	782	1473
CMWD	0	0	53	0	0	77	0	0	600
Blythe	2	2	2	1	1	1	501	501	501
Antelope Valley	0	3	13	0	4	18	0	348	1428
Regional Agricultural	941	941	941	191	191	191	-	-	-
Regional Urban	60	88	219	66	92	265	-	-	-
Regional Total[b]	1001	1030	1160	257	283	456	-	-	-

[a] Marginal willingness to pay.
[b] Totals may not add due to rounding.

As the MNDO is increased, water used for lower valued agriculture on the Sacramento River and its tributaries as well as some water in importing regions is transferred to higher valued agricultural and urban uses throughout California.

Addendum F2. SWAP Results for San Joaquin and Tulare Basins

Introduction

Measuring the effect of water delivery reductions on the San Joaquin Valley (including the San Joaquin and Tulare Basins) in terms of scarcity costs can understate the social impacts on specific regions. The economic impacts on agriculture in the San Joaquin Valley were measured using the optimal water allocations from the CALVIN (California Value Integrated Network) model to constrain the SWAP (Statewide Agricultural Production) model.

The SWAP results indicate that the costs of eliminating Delta exports are disproportionately borne by the economy and residents in the San Joaquin Valley (CVPM regions 10 through 21). This occurs because the CALVIN model optimizes the economic returns to water for the entire state and thus assumes that lower valued agricultural water in the San Joaquin Valley will be sold from valley agriculture to higher valued urban uses. Agricultural water deliveries in the San Joaquin Valley are reduced by 4.9 maf per year; note this cut in deliveries is greater than the agricultural Delta exports (3.7 maf per year) because additional water is purchased by cities to offset urban cuts from the Delta. The net result is that 877 thousand acres[20] are taken out of irrigated crop production in the San Joaquin Valley (Table F2.1). The resulting loss in revenue is $3.27 billion per year (in 2008 dollars). Using a regional input-output model (REMI) calibrated to the Central Valley economy for a previous study, the income multiplier of agricultural production is 1.34. Thus this revenue reduction could result in the loss of income in the southern Central Valley of $4.38 billion per year. In addition, using the REMI multiplier that relates jobs to agricultural output as the rate of 46.55 jobs per $1.0 million per year (in 2004 dollars) of agricultural output, the job impact of the loss of Delta exports to agriculture will be in the order of 103,000 jobs.[21]

Under optimized scenarios, the percent of target deliveries to the 21 CVPM regions are shown in Table F2.1. Percent reductions in southern Central Valley and statewide agricultural acreage, by crop, are shown in Table F2.2. From a statewide agricultural acreage perspective, the largest acreage losses are for grains, cotton, and field crops. For the southern Central Valley, the largest acreage losses are for grains, field crops, and tomatoes.

Overall, agriculture would see a 15 percent reduction in acreage statewide from ending exports, but this loss would not be distributed equally among all agricultural users. Of the San Joaquin Valley agricultural areas, CVPM 17 see a small gain in acreage when exports are eliminated and CVPM 11 is unchanged (Table F2.3). The agricultural areas in the Sacramento valley (northern half of the Central Valley, CVPM 1 through 9) are either unchanged or experience small gains in acreage when exports are eliminated. The largest reductions are to

[20] A total of 1,252 million acres are taken out of production if water shortages in the base case are taken into account.

[21] The estimated job loss of 103,000 in San Joaquin Valley might not translate into an equivalent loss of jobs to the state economy as a whole, because some reallocation to other sectors and regions is likely.

the west-side San Joaquin agricultural users (those dependent upon Delta exports) and Tulare Basin agriculture (able to sell water to urban Southern California); the reduction in acreage for these agricultural users ranges from 10 percent to 56 percent (Table F2.4).

Table F2.1 - Comparison of Base Case and No Delta Exports (CVPM regions 10 thru 21)

	Southern Central Valley Crop Losses with No Delta Exports*		
	Base (2050)	No Exports (2050)	Reduction
Water Delivery (maf)	15.0	10.1	4.9 (29%)
Irrigated Crop Acres (million acres)	3.399	2.522	0.877 (26%)
Agricultural Crop revenue ($billion)	19.0	15.7	3.3
Water Scarcity Costs# ($billion)	-	-	0.814
Valley Crop Income ($billion)	25.5	21.1	4.4
Valley Crop Agricultural Jobs	598,000	495,000	103,000

* 2050 crop projections (in 2008 dollars). #Estimated from SWAP post-processing

Table F2.2 - Water deliveries to agricultural CVPM regions under the CALVIN Base Case and No Delta Exports optimized scenarios

Region	Base Case (% target delivery)	No Export (% target delivery)	No Export as a Percent of Base Case
CVPM 1	95.8	95.8	-0.1
CVPM 2	92.6	97.5	5.3
CVPM 3	100	100	0
CVPM 4	98.7	100	1.3
CVPM 5	94.7	99.5	5.1
CVPM 6	100	100	0
CVPM 7	94.6	95.7	1.1
CVPM 8	98.4	97.9	-0.5
CVPM 9	93.1	95.8	2.9
CVPM 10	91.9	45.4	-50.6
CVPM 11	97.9	97.4	-0.5
CVPM 12	85.5	84.9	-0.7
CVPM 13	87.7	76.2	-13.2
CVPM 14	90	39.2	-56.5
CVPM 15	90.9	75	-17.5
CVPM 16	95.2	85.3	-10.4
CVPM 17	81.8	72.2	-11.7
CVPM 18	90.1	45	-50.1
CVPM 19	91.9	52.9	-42.4
CVPM 20	90.4	63	-30.3
CVPM 21	91.3	21.4	-76.6
Total	92.5	74.3	-19.7

Table F2.3 - San Joaquin Valley and Statewide percent reductions in acreages per crop

	San Joaquin Valley			Statewide
Crop	Base Case	No Export	No Export as a Percent of Base Case	No Export as a Percent of Base Case
Alfalfa	380,413	262,442	-31.0	-18.4
Citrus	222,135	215,610	-2.9	-2.6
Cotton	589,463	373,434	-36.7	-36.7
Field Crops	294,990	128,843	-56.3	-25.8
Grains	144,921	34,271	-76.4	-39.8
Orchards	766,653	713,414	-6.9	-3.8
Pasture	179,452	133,541	-25.6	-12.8
Raisins	26,287	25,293	-3.8	-3.8
Rice	6,278	5,184	-17.4	0.3
Sugar Beet	36,485	28,919	-20.7	-15.6
Table Grapes	17,184	17,021	-1.0	-1.0
Tomato	245,225	144,664	-41.0	-23.6
Truck Crops	398,661	356,093	-10.7	-8.3
Wine Grapes	91,451	83,671	-8.5	-4.4
Total	3,399,598	2,522,400	-25.8	-15.3

Table F2.4 - Percent change in statewide acreage per CVPM region and crop under No Delta Exports alternative relative to Base Case

Region	Alfalfa	Citrus	Cotton	Field Crops	Grains	Orchards	Pasture	Raisins	Rice	Sugar Beet	Table Grapes	Tomato	Truck Crops	Wine Grapes	Region Total
CVPM 01	10			-1	-6	1	0						5		0
CVPM 02	20	2		10	41	3	5		3	2			7		5
CVPM 03	9	1		-2	-5	0	-2		-1	1	-1	5	1	0	0
CVPM 04	11			0	4	1	0		0	2		6	2		1
CVPM 05	32	3		17		5	10		3			8	6		5
CVPM 06	7			-3	-7	1	-3		-3	1		6	1	1	0
CVPM 07	21	0		1		4	0		0			8	1	1	1
CVPM 08	8			-6	-27	1	-3		-3	1	-2	6	2	0	-1
CVPM 09	9			0	5	3	0		-1	2	-5	5	2	-1	3
CVPM 10	-100		-100			-44	-100	-59	-100	-31	-7	-46	-19	-37	-51
CVPM 11	11			-37		1	-4		-6	2	-1	6	2	1	0
CVPM 12	8		0	-13	-36	1	-3	-1			-1		2	2	-1
CVPM 13	-5	2	-6	-47	-60	-2	-17	-1	-13	-1	2	3	0		-13
CVPM 14	-100	-21	-100	-100	-100	-26	-100	-52		-37	-5	-50	-19	-36	-56
CVPM 15	-14	0	-11	-62	-46	-1	-43	-4	-19	-2	-1	1	0	-1	-18
CVPM 16		-10				-7					-3		-8	-100	-10
CVPM 17		3				4		7		5	0	20	4	8	4
CVPM 18	-12	-1	-16	-53	-91	-2	-35	-6		-3	-1	-1	-3	-2	-20
CVPM 19	-72	-6	-47	-100	-100	-17	-100	-15		-15	1	-18	-4	-10	-51
CVPM 20	-100	-13	-100	-100	-100	-36	-100	-32		-31	-3	-45	-11	-35	-41
CVPM 21	-43	-4	-43	-100	-100	-13	-73	-12		-11	-1	-13	-2	-10	-31
Total	-18	-3	-37	-26	-40	-4	-13	-4	0	-16	-1	-24	-8	-4	-15

About the Authors

Stacy K. Tanaka is a water resources planner with Watercourse Engineering, located in Davis. Her research focuses on development and use of modeling for management of environmentally sensitive water system, including the Sacramento-San Joaquin Bay Delta and Klamath River in Northern California. She received her bachelor's and master's degree in Civil Engineering and her Ph.D. in water resources from the University of California, Davis.

Christina R. Connell is a Ph.D. student in the Hydrologic Sciences Graduate Group at the University of California, Davis. She received her bachelor's degree in Hydrology with an emphasis in hydrogeology from the University of California, Davis. Her research interests include groundwater hydrology and its relation to water resources management.

Kaveh Madani is a Ph.D. candidate at Department of Civil and Environmental Engineering of University of California, Davis. His research interests include water resources planning and management, conflict resolution and climate change effects on hydropower in California. He received a bachelor's degree in Civil Engineering from University of Tabriz, Iran and a master's degree in Water Resources from Lund University, Sweden.

Jay Lund is the Ray B. Krone Professor of Environmental Engineering at the University of California, Davis and an Associate Director of the Center for Watershed Sciences. He served on the Advisory Committee for the 1998 and 2005 California Water Plan Updates, is a former Editor of the *Journal of Water Resources Planning and Management*, and has authored or co-authored over 200 publications.

Ellen Hanak is a senior fellow and associate director of research at the Public Policy Institute of California. Before joining PPIC in 2001, she held positions with the French agricultural research system, the President's Council of Economic Advisers, and the World Bank. She holds a Ph.D. in economics from the University of Maryland.

Josué Medellín-Azuara is a postdoctoral scholar in the Civil and Environmental Engineering Department at the University of California, Davis. He received a bachelor's degree in mechanical and electrical engineering and a master's in business administration from the Instituto Tecnologico de Monterrey (Mexico), a UC Davis master's degree in agricultural and resource economics and a PhD. in ecology with research on water management for restoring the Colorado River Delta.

PUBLIC POLICY INSTITUTE OF CALIFORNIA
500 Washington Street, Suite 600
San Francisco, California 94111
phone: 415.291.4400
fax: 415.291.4401

PPIC SACRAMENTO CENTER
Senator Office Building
1121 L Street, Suite 801
Sacramento, California 95814
phone: 916.440.1120
fax: 916.440.1121

www.ppic.org