APPENDIX 2G

STATEWIDE CALVIN MODEL RESULTS

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ABSTRACT

This appendix presents CALVIN model results comparing a Base Case model run to two unconstrained model runs, and is intended to supplement results and conclusions presented in Chapter 4. The Base Case represents the current infrastructure, contractual agreements, and legislative requirements with 2020 demands. A Statewide Unconstrained model run, the focus of this appendix, represents the same statewide system but allows an unconstrained water market on a statewide scale which is driven by relative economic values and only inhibited by physical capacity constraints and environmental flow requirements. Following a description of the model, statewide results are presented and discussed in comparison to the Base Case and Regional Unconstrained modeling alternatives. These results are used to suggest potential water management changes and their implications.

INTRODUCTION

The CALVIN (California Value Integrated Network) model is a water resource optimization model for California's extensively intertied water supply system. The objective of the model is to maximize economic benefit to agricultural and urban water users statewide, subject to environmental and physical constraints, by optimally operating and allocating water supplies to meet demands most productively. Model results suggest not only economically optimal supply and allocation mixes for urban, agricultural, and environmental demands and improvements in the operation of existing facilities, but also how the expansion of individual facilities would benefit the state.

Two scales of analysis have been considered within this report. On a smaller scale, the statewide system was initially subdivided into five regions. This allowed for calibration of the model to simulation planning models currently used by the state of California. This approach also provided useful insights into the benefits derived from intra-regional water markets, predicting how the state might benefit from inter-regional trading, conjunctive use, and other forms of cooperation. The culmination of the CALVIN project is the larger scale statewide model, where water is allowed to move freely throughout the entire intertied system to maximize economic benefits.

Since the details of the geography, hydrologic characteristics, and infrastructure are presented in the regional appendices (see Appendices 2A through 2E of this report), this appendix focuses on the statewide model results and the implications for water management from a statewide perspective. Chapter 4 of the report synthesizes results from the regional and statewide analyses into general implications for water marketing. The major difference between the statewide and regional unconstrained model runs, aside from scale, is that flows crossing inter-regional boundaries are no longer fixed, unless they represent environmental requirements or inter-regional groundwater fluxes.

STATEWIDE MODEL DESCRIPTION

The CALVIN model is a representation of the intertied water supply system in the state of California. Geographically, it includes the Sacramento and Central Valleys, the Bay Delta, the San Francisco Bay area, and Southern California (see Figure 2G-1). For the sake of model calibration and to explore the benefits of local water markets, this intertied system is divided into five regions (detailed descriptions of the geography and infrastructure of each of these regions can be found in Appendices 2A through 2E):

- Region 1: the Upper Sacramento Valley
- Region 2: the Lower Sacramento Valley and Bay Delta
- Region 3: the San Joaquin Valley and South Bay
- Region 4: the Tulare Lake Basin
- Region 5: Southern California

Benefits derived from trading water across the entire state are then assessed by removing constraints on boundary flows between the regions.

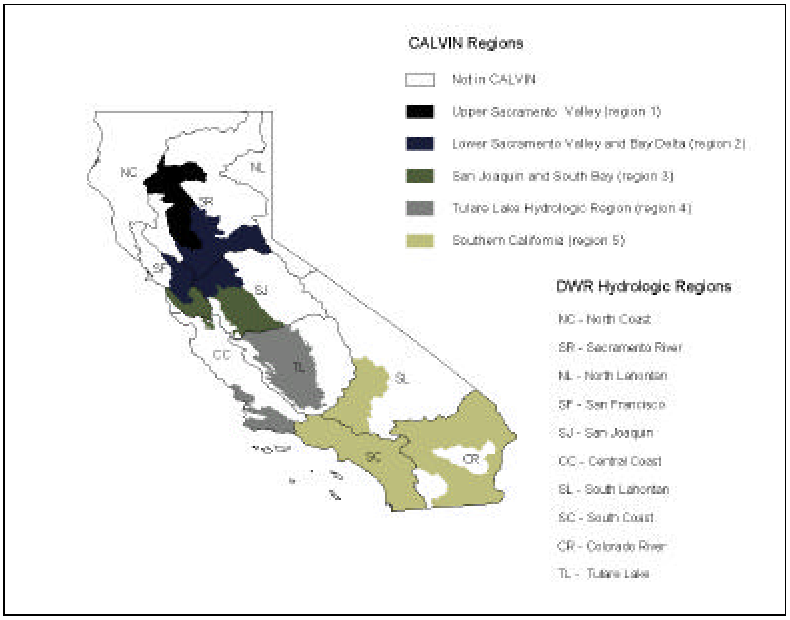

Figure 2G-1. CALVIN Regions and DWR Hydrologic Regions

Three types of demands are modeled in CALVIN. Agricultural demands are generally represented using economic value functions for water generated by the Statewide Water and Agricultural Production Model (SWAP, see Appendix A).

Urban demands are characterized in two ways. Larger metropolitan areas are represented by an urban economic value function for water use incorporating both residential and industrial demands. Water value data was unavailable for some urban areas (typically in the Sacramento and Central Valleys), so deliveries for these areas were fixed at 2020 projected demands. Urban scarcity data throughout this appendix therefore represents scarcity only to the larger urban areas that are economically modeled (see Appendix B). This closely represents reality, since fixed urban demands generally rely on groundwater.

Environmental water allocations, such as minimum instream flows and wildlife refuge allocations, have an increasingly important role in California. Because the economic value of environmental water use is extremely difficult and controversial to quantify, environmental demands in CALVIN have been modeled by constraining the system to meet minimum instream flow requirements and mandatory refuge deliveries in all alternatives.

General Overview

In the regional model analyses, two alternatives are considered. The Base Case alternative characterizes the operations, demands, and deliveries of existing operating policies at projected 2020 levels of demand, as represented largely by DWRSIM Run 514 and CVGSM NAA 1997 (see Appendix 2I).

The Regional Unconstrained Alternative (also referred to as “RWM” for “Regional Water Market”), where Base Case operating and delivery constraints (storages and deliveries) are removed, allocates the region’s water resources to derive the greatest economic benefit. The only constraints imposed on the system in the Unconstrained Case are physical capacities, boundary flows (to maintain consistency with Base Case flows), minimum instream flows to meet environmental requirements, mandatory wildlife refuge deliveries, flood operations, and ending groundwater and reservoir storages. Since boundary flows (i.e., conveyance flows originating from another region) are fixed in the regional model runs, the overall quantity of water available to any given region was constant between the Base Case and the Regional Unconstrained alternatives. Comparison of the Regional Unconstrained alternative to the Base Case provides useful insights into regional water marketing and operating potential and infrastructure capacities that limit even greater regional benefit.

The Statewide Unconstrained alternative (also labeled “SWM” for “Statewide Water Market”) then removes the constraints on inter-regional boundary flows, allowing water to be freely traded along the entire state, while continuing to enforce environmental flow requirements, physical capacity constraints, flood operations, and ending storages. Statewide Unconstrained model results are compared to operations under the Base Case alternative and regional water markets to identify new water management strategies and their implications. The assumptions and limitations of the modeling alternatives have been listed in each of the regional appendices.

These model runs are based on historic hydrologic data spanning the water years 1922 to 1993. Since computational demands for the Statewide model runs over this entire 72 year period become excessive, this period is divided into three shorter hydrologic periods for this analysis: 1922-1951, 1952-1968, and 1969-1993. The choice of 1951 and 1968 as the sub-period cutoff years was due to "wet" hydrologic conditions when reservoirs are full in the Base Case, reducing distortions to carryover storage in the Statewide Unconstrained alternative. The weighted average of the results for each of these time periods is reported for the Statewide Unconstrained alternative throughout this appendix.

At times, drought year results are listed along with average year results. Drought years throughout this analysis refer to the water years of 1929-1934, 1976-1977, and 1987-1992 (DWR, p. 3-7).

COMPARISON OF STATEWIDE RESULTS

In this section, results from the Statewide Unconstrained alternative are compared to those of the calibrated Base Case (and the Regional Unconstrained alternative when appropriate). Agricultural, urban, and environmental supply and water value results provide the basis for suggesting management alternatives. In addition, economic values for water at various locations in the region provide insight into water transfer and infrastructure expansion possibilities, which are discussed in the "Potential Water Management Changes" section of this appendix.

Statewide Overview

An initial overview of deliveries, surface and groundwater supplies, and scarcity costs given below will provide the context for a subsequent, more detailed analysis of the effect of an 'ideal market' statewide re-allocation of supplies on agricultural, urban, and environmental demands.

Water Delivery Results

Table 2G-1 quantifies the urban and agricultural demands on California's water resources included in the CALVIN model. For the year 2020, urban users represent 28% of the intertied system's non-environmental demands, while agricultural users constitute the remaining 72%. Agricultural demands are the same in every year (the slight difference in the average agricultural demand between alternatives is due to the inclusion of Owens Valley agriculture in the Unconstrained alternative, which is omitted in the Base Case). The urban demands fluctuate slightly from year to year, since year type demands were included for the Metropolitan Water District in Southern California (see Appendix 2E).

Table 2G-1. Statewide Water Demands and Deliveries

	Base Case Average (taf)	Statewide Unconstrained Average (taf)
Water Demands		
Urban*	10,932	10,932
Agricultural	27,780**	27,904
Total	**38,712**	**38,836**
Deliveries to Urban and Agricultural Users (less conveyance losses)		
Surface Water	23,268	23,606
Groundwater	10,385	10,531
Groundwater recharge	1,118	1,381
Reuse / Reclamation	2,347	2,428
Total	**37,118**	**37,946**
Scarcity	**1,594**	**890**
Notes: * *Includes fixed urban demands* ** *Owens Valley Ag not included in Base Case analysis*		

Water supplies meeting these agricultural and urban demands are shown to vary in absolute terms, though the supply mix changes little. Since surface water availability is constrained by total inflows into the model and groundwater end-of-period storages were fixed in the Unconstrained Cases to match corresponding Base Case storages, the total amount of available water is identical in each alternative. Water trading, conjunctive use, and to some extent perfect foresight, enables more efficient operation of surface sources in the Unconstrained alternatives, allowing more water to be "captured" or "recaptured" to meet demands. Using surface supplies to recharge groundwater is less expensive than direct treatment of surface supplies in some areas, resulting in 270 taf/yr of additional groundwater recharge. In addition, the model utilizes re-use and reclamation opportunities when they are economically beneficial.

The reliability chart in Figure 2G-2 depicts improved statewide system reliability in the Unconstrained alternatives, especially during critically dry periods. Since CALVIN attempts to move water spatially and temporally to minimize overall costs to the system, large drought scarcities are alleviated through more efficient conveyance use and storage in wet years.

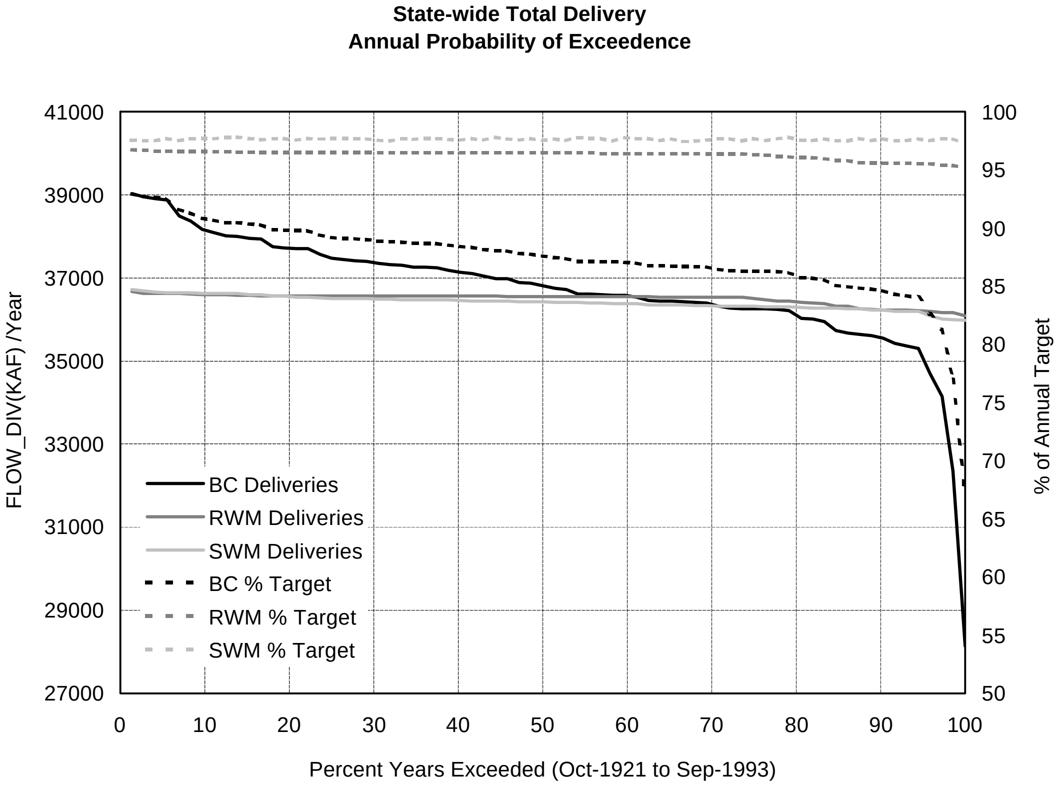

Figure 2G-2. Reliability of Statewide Economic Deliveries

Table 2G-2 displays how effectively California's water system is able to meet agricultural and urban demands under the three modeling alternatives. Large shifts in agricultural supplies to urban uses in the Regional Unconstrained alternative are somewhat mitigated in the Statewide Unconstrained run. Also, large scarcity increases in drought years are alleviated through more efficient operations and trading opportunities in regional and statewide markets.

Table 2G-2. Average Annual Scarcities and Scarcity Costs

		Agriculture			Urban		
	Model Case	Scarcity (taf)	% Scarcity	Cost ($$10^6$)	Scarcity (taf)	% Scarcity	Cost ($$10^6$)
Annual Average	Base Case	693	2.5	31.6	901	8.2	1564
	RWM	1182	4.2	51.3	227	2.1	227
	SWM	733	2.6	29.3	157	1.4	170
Drought Yr. Average	Base Case	N/A*	N/A*	N/A*	1392	12.7	2362
	RWM	1192	4.2	51.7	459	4.2	421
	SWM	730	2.6	29.2	160	1.5	174

Notes:
** Distortions to scarcities occur as a result of the calibration procedure, which attempts to match CALVIN agricultural demands (invariant from year to year) to Base Case deliveries (based on varying demands with year type). Drought costs are therefore unavailable. For a further discussion of these issues refer to Appendices 2H and 2I, as well as Chapter 5 of this report.*

Table 2G-3 summarizes the economics that drive CALVIN's operations and water re-allocations to derive the maximum benefit for the state. Comparison of the Total Cost estimates for the three alternatives suggest that most of the potential economic benefit is through re-allocating and re-operating water regionally, with only minimal additional benefits from statewide trading and re-operations.

Table 2G-3. Variable Economic Costs (Average Year)

	Base Case ($M/yr)	Regional Unconstrained ($M/yr)	Statewide Unconstrained ($M/yr)
Scarcity Cost	1,596	279	200
Operating Cost	2,573	2,559	2,583
Total Cost	**4,169**	**2,838**	**2,783**

Note:
Economic benefits from fixed-head hydroelectric power generation are included in this cost total as negative costs.

Water Supplies

System inflows are managed primarily by surface and groundwater storage. Groundwater storage trends throughout the state clearly follow hydrologic conditions (see Figure 2G-3). The drought periods of '29-'34, '76-'77, and '87-'93 show the sharpest decline in overall groundwater storage, indicating a dependence on groundwater during critically dry periods. Higher peaks and lower troughs in Figure 2G-3 convey trends toward greater conjunctive use in the Statewide Unconstrained alternative. The system utilizes abundant water in wet periods to alleviate subsequent drought scarcities.

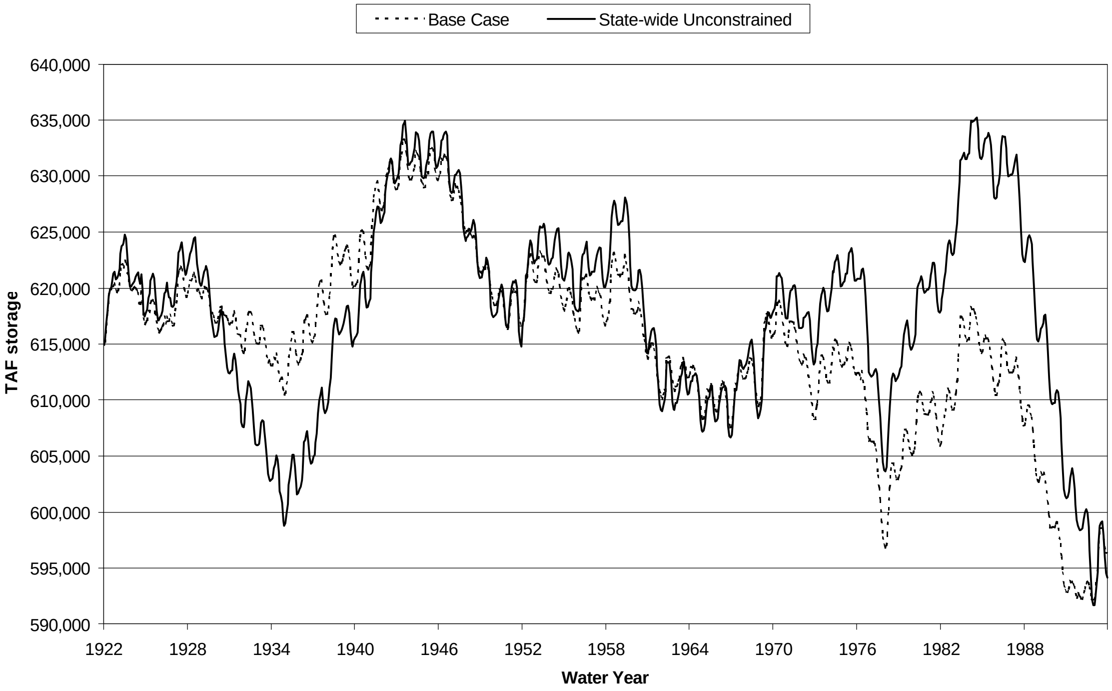

Figure 2G-3. Statewide Groundwater Storage

The CALVIN statewide model makes more use of groundwater storage to accommodate long over-year droughts. This effect amounts to ten to fifteen million acre-feet of storage without groundwater mining over the 72-year period. Some additional use of groundwater also is made seasonally, for "normal" operations.

Reservoir storage patterns display a somewhat different trend. Since fuller surface reservoirs result in greater evaporation, CALVIN seeks to reduce losses by keeping reservoirs emptier. The Statewide model's surface storage pattern shown in Figure 2G-4, contrasted with the groundwater pattern in Figure 2G-3, exhibits a "flatter"response to hydrologic conditions. Implications for reservoir operation and the effect of perfect foresight on these results are discussed further in the "Potential Water Management Changes" section of this appendix.

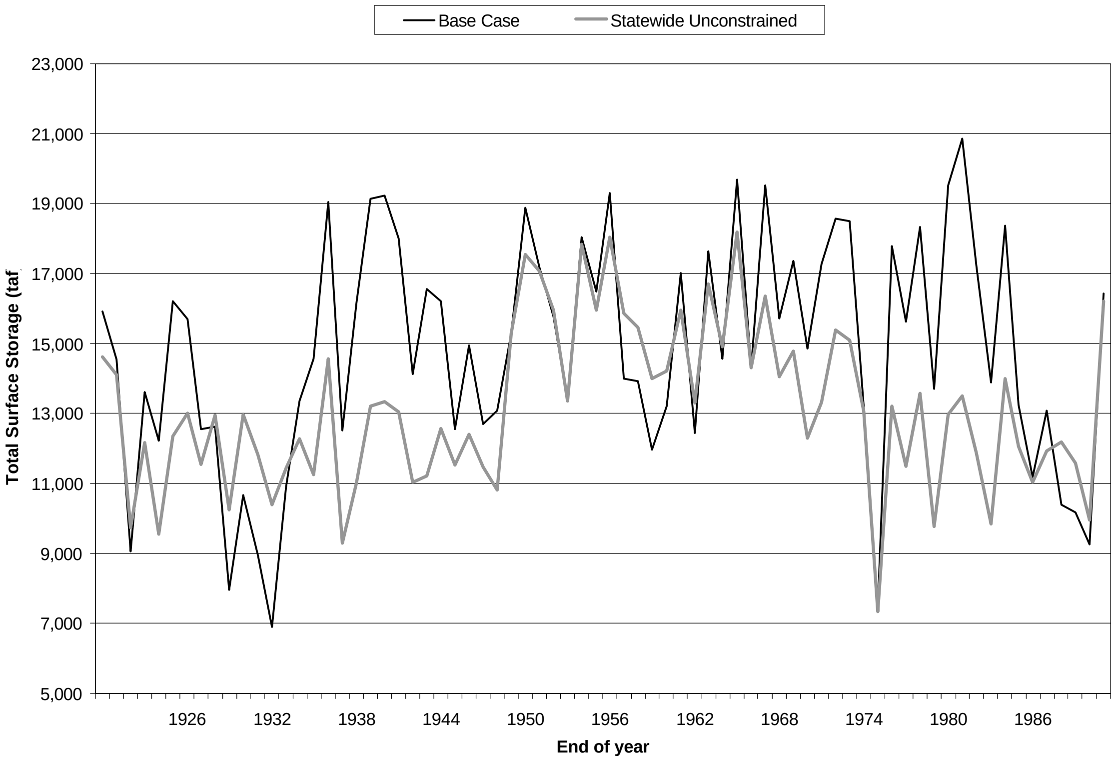

Figure 2G-4. Total Surface Storage (End of Year)*

** Note: Lake Oroville, the second largest reservoir in California, is not included in this total surface storage comparison. An inadvertent omission of a storage penalty in the statewide analysis distorted Oroville's storage results.*

Average surface water storage tends to be less for CALVIN than with current operations. This often amounts to about 4 MAF less surface storage statewide. The only exceptions are during major droughts, when statewide reservoir storage for CALVIN averages similar or slightly greater values than that for current operations. These results are likely to change when hydropower benefits (which often are directly affected by storage) are added to major reservoirs.

The storage operations discussed above are directly driven by agricultural and urban uses. The following sections contain a more detailed analysis of CALVIN's agricultural and urban demands.

AGRICULTURAL RESULTS

Scarcity and its corresponding costs, supply mixes, and agricultural supply reliability are the indicators of system performance in CALVIN. Data presented below contain results from the Regional Unconstrained model runs in addition to the Base Case and Statewide Unconstrained alternatives. Collectively, these results suggest how effectively California's intertied water supply system meets the needs of agricultural users under current operations, regional water markets, and statewide water markets.

“Scarcity” in this analysis refers to the difference between water deliveries and the estimated maximum amount of water a water user would desire if water were available without limit at a trivial price and tends to overestimate unmet economic demand. CALVIN generates economic losses for unmet demands using scarcity value functions.

Scarcity and Scarcity Costs

Table 2G-4 compares agricultural scarcity under current operating policy, regional water markets, and an ideal statewide water market. Though Appendices 2A through 2E outline in detail the estimated benefits of regional water markets, these results have been included in the Regional Unconstrained column of the table for comparison.

CVPM regions 1 through 4, contained in the Upper Sacramento Valley Region (Region 1 in CALVIN), exhibit the majority of the scarcity north of the Delta in both the Base Case and Regional Unconstrained alternatives. Scarcity decreases in the Regional Unconstrained alternative to the point where pumping less groundwater and incurring some scarcity is more beneficial than meeting agricultural demand. Scarcity increases in CVPM 4 are driven by a lack of Sacramento River water to meet all demands within the region (see Appendix 2A for a detailed discussion of these results).

However, when Sacramento River boundary flow constraints are removed in the Statewide alternative, agriculture in Region 1 utilizes greater amounts of surface water, ultimately resulting in reduced Sacramento River flows into the Lower Sacramento Valley and Bay Delta Region (Region 2 in CALVIN). Agriculture in Region 2 is able to compensate for decreased Sacramento River flows with other surface sources. Through water trading in Regions 1 and 2, agricultural scarcity is effectively eliminated as far south as the San Joaquin Valley (Region 3 in CALVIN). Specifics regarding water trading are discussed later in this appendix.

Several CVPM regions within the Tulare Basin (Region 4 in CALVIN) continue to incur scarcities even in the Statewide Unconstrained alternative, though the distribution of these scarcities is uneven throughout the three hydrologic sub-periods. Though the state of California experienced critically dry conditions in 1929-1934, the derived hydrologic inflows used in Region 4 for the 1922-1951 period still have the highest annual average inflows of the three sub-periods. Water supply during this sub-period is apparently sufficient to meet agricultural scarcities that are still incurred in the later sub-periods. CVPM 15 through 17 use higher groundwater inflows during this first sub-period to meet demands. The largest scarcities for Central Valley agriculture in the Base Case are found in CVPM 18; water marketing in the Statewide Unconstrained alternative effectively eliminates this scarcity.

Table 2G-4. Average Agricultural Scarcity (taf/yr)

Ag Region	Base Case	Regional Unconstrained	Statewide Unconstrained
CVPM 1	1	1	**0**
CVPM 2	57	11	**0**
CVPM 3	86	79	**0**
CVPM 4	0	66	**0**
CVPM 5	0	0	**0**
CVPM 6	0	0	**0**
CVPM 7	0	0	**0**
CVPM 8	0	0	**0**
CVPM 9	8	0	**0**
CVPM 10	0	0	**0**
CVPM 11	0	0	**0**
CVPM 12	0	0	**0**
CVPM 13	0	0	**0**
CVPM 14	0	0	**0**
CVPM 15	10	74	**20**
CVPM 16	0	5	**2**
CVPM 17	0	14	**8**
CVPM 18	222	168	**0**
CVPM 19	0	38	**0**
CVPM 20	0	0	**0**
CVPM 21	0	23	**0**
Palo Verde	127	241	**241**
Coachella	0	14	**14**
Imperial	182	448	**448**
Total	**693**	**1182**	**733**

Coachella, Palo Verde, and Imperial agricultural regions in Southern California demonstrate similar scarcities in both the Regional and Statewide Unconstrained alternatives. When deliveries enforced with a fixed time series in the Base Case are removed in the Unconstrained alternatives, Colorado River water is re-allocated from the agricultural regions to meet higher-valued urban demands in Coachella, San Diego, and Central Metropolitan Water District, limited by the capacity of the Colorado River Aqueduct. In this case, limited Colorado River water availability limits system deliveries to Southern California agricultural demands.

The equivalence in scarcities between drought and average year conditions indicates that CALVIN's expanded use of groundwater and surface storage and perfect foresight allows it to smooth out supplies to meet demands throughout the 72-year period. This suggests that capacity physically exists in the system to meet agricultural demand under various hydrologic conditions if the system could be managed with greater coordination and foresight, and if current contractual and policy constraints could be loosened.

In summary, while Regional Unconstrained runs increase agricultural water scarcity by

71%, statewide, unconstrained economic allocations and operations result in statewide agricultural scarcities only 6% greater than under the Base Case. However, these results vary considerably statewide. Six of 24 agricultural regions receive less water with statewide operations, while 4 regions receive more. Implications for agricultural scarcity costs are described next.

Regional water markets, as seen in Table 2G-5, would tend to incur an additional $20 million per year in agricultural scarcity costs, suggesting that regional benefits are typically limited to urban gains resulting from agriculture-to-urban water transfers. Presumably, in a market environment, these increases in scarcity costs would be more than compensated by water purchase or lease payments. However, Statewide Unconstrained results show marked decreases in agricultural scarcity costs from the regional markets, and are $2.5 million lower than the Base Case scarcity costs. Little of that benefit, however, is realized in Southern California, where the only surface water source is the Colorado River. Reduction in scarcities in the Tulare Lake Region contributes the most to statewide agricultural benefits.

Table 2G-5. Average Agricultural Scarcity Costs ($ millions/yr)

Ag Region	**Base Case**	**Regional Unconstrained**	**Statewide Unconstrained**
CVPM 1	0	0.2	**0**
CVPM 2	3.5	0.2	**0**
CVPM 3	3.1	2.9	**0**
CVPM 4	0	2.1	**0**
CVPM 5	0	0	**0**
CVPM 6	0	0	**0**
CVPM 7	0	0	**0**
CVPM 8	0	0	**0**
CVPM 9	0.2	0	**0**
CVPM 10	0	0	**0**
CVPM 11	0	0	**0**
CVPM 12	0	0	**0**
CVPM 13	0	0	**0**
CVPM 14	0	0	**0**
CVPM 15	0.4	2.9	**0.8**
CVPM 16	0	0.1	**0**
CVPM 17	0	0.4	**0.2**
CVPM 18	18.8	10.4	**0**
CVPM 19	0	2.5	**0**
CVPM 20	0	0	**0**
CVPM 21	0	1.4	**0**
Palo Verde	1.4	6.9	**6.9**
Coachella	0	0.9	**0.9**
Imperial	4.3	20.5	**20.5**
Total	**31.7**	**51.3**	**29.3**

While overall water scarcity volumes increase for agriculture with both regional and statewide economic optimization, agricultural regions overall receive slightly greater economic benefits with statewide optimal operations than under the Base Case, averaging about $2 million/year. This contrasts with increases in scarcity costs to agriculture statewide with regional water optimization of about $20 million/year. Thus, even without payments for water reallocations, farmers statewide could benefit slightly from a statewide water market.

As with scarcity volumes, these results vary a great deal regionally. Five of the 24 agricultural regions benefit economically from statewide economic water management; these areas tend to be in the Central Valley. Four agricultural regions suffer economically from reduced water deliveries (if uncompensated); three of these are in Southern California on the Colorado River and one is in the Tulare Basin.

Agricultural Supplies

Changes in agricultural supply mixes are driven by both scarcity and operating costs. In the Sacramento and San Joaquin Valleys, where scarcities in both the Base Case and Statewide Unconstrained alternatives are minimal, operating costs have the predominant role in determining supply mixes. Tables 2G-6 through 2G-10 outline surface water and groundwater supply mixes for each agricultural demand region in the state, as well as their associated operating costs.

CVPM 2 and 3 in the Upper Sacramento Valley collectively increase diversions from the Sacramento River by over 50 taf/yr. Increased surface supplies result in greater groundwater availability through return flows, ultimately fully meeting demand.

Table 2G-6. Upper Sacramento Valley Agricultural Supplies (taf/yr)

Supply Source	**Base Case**		**Statewide Unconstrained**		***Supply Change***
	Flow	**%**	**Flow**	**%**	
CVPM 1					
Sacramento River	103	*67%*	107	*70%*	***4***
Whiskeytown Lake	14	*9%*	9	*6%*	***-5***
Groundwater	36	*24%*	37	*24%*	***1***
Total	**153**		**153**		***0***
CVPM 2					
Tehema-Colusa Canal	2	*0%*	4	*1%*	***2***
Corning Canal	32	*5%*	72	*10%*	***40***
Black Butte Lake	92	*14%*	90	*13%*	***-2***
Other diversions	5	*1%*	11	*2%*	***6***
Groundwater	508	*79%*	520	*75%*	***12***
Total	**639**		**697**		***58***
CVPM 3					
Tehema-, Glenn-Colusa	882	*60%*	838	*56%*	***-44***
Colusa Basin Drain	55	*4%*	128	*9%*	***73***
Sacramento River	194	*13%*	174	*12%*	***-20***
Groundwater	338	*23%*	357	*24%*	***19***
Total	**1469**		**1497**		***28***
CVPM 4					
Sacramento River	673	*69%*	673	*69%*	***0***
Groundwater	299	*31%*	299	*31%*	***0***
Total	**972**		**972**		***0***

CVPM regions 5 through 9 (refer to Table 2G-7) alter supply mixes to achieve the lowest operating costs and are not driven by scarcity. Combined diversions from the Sacramento River and the Yolo Bypass are reduced by 215 taf/yr. This decrease in Delta inflows provides the first indication that water transfers from low-valued agricultural areas in Northern California to high valued urban uses in the south are not occurring in an ideal statewide market. Ample water supplies are able to meet demands in the north but cannot be economically transferred to the southern portion of the state. Overall, supply mixes change little in the Upper Sacramento Valley, with the exception of CVPM 6 and 7.

Table 2G-7. Lower Sacramento Valley Agricultural Supplies (taf/yr)

Supply Source	Base Case		Statewide Unconstrained		*Supply Change*
	Flow	%	Flow	%	
CVPM 5					
Bear River	21	*1%*	13	*1%*	***-8***
Feather River	959	*57%*	929	*56%*	***-30***
Yuba River	165	*10%*	210	*13%*	***45***
Sacramento River	18	*1%*	11	*1%*	***-7***
Lake Oroville	8	*0%*	9	*1%*	***1***
Groundwater	498	*30%*	498	*30%*	***0***
Total	**1669**		**1670**		***1***
CVPM 6					
Cache Creek	118	*15%*	114	*14%*	***-4***
Putah South Canal	139	*18%*	53	*7%*	***-86***
Knights Landing Ridge Cut	90	*11%*	180	*23%*	***90***
Groundwater	447	*56%*	447	*56%*	***0***
Total	**794**		**794**		***0***
CVPM 7					
Bear River	99	*19%*	157	*30%*	***58***
Sacramento River	135	*26%*	271	*52%*	***136***
Feather River	9	*2%*	17	*3%*	***8***
Groundwater	281	*54%*	79	*15%*	***-202***
Total	**524**		**523**		***-1***
CVPM 8					
Folsom South Canal	45	*6%*	83	*10%*	***38***
Cosumnes River	11	*1%*	8	*1%*	***-3***
Stanislaus River	17	*2%*	7	*1%*	***-10***
Mokelumne River	79	*10%*	83	*10%*	***4***
Groundwater	661	*81%*	633	*78%*	***-28***
Total	**813**		**813**		***0***
CVPM 9					
Sacramento River	300	*28%*	320	*30%*	***20***
Delta Cross Channel	203	*19%*	222	*21%*	***19***
San Joaquin River	455	*43%*	422	*39%*	***-33***
Groundwater	112	*10%*	113	*10%*	***1***
Total	**1070**		**1077**		***7***

Several trends are evident south of the Delta (see Table 2G-8). Surface supplies for CVPM regions 10 through 13 in the San Joaquin Valley are the San Joaquin River and its tributaries, and both the California Aqueduct and the Delta Mendota Canal. Overall reliance on Delta exports increases only slightly in a statewide water market. Perhaps the most significant change in the San Joaquin Valley is the reduction of supplies from Millerton Reservoir through the Madera Canal in CVPM 13, which compensates with increased supplies from the Merced River. This transfer frees more water for higher-valued demands in Region 4.

Table 2G-8. San Joaquin Valley Agricultural Supplies (taf/yr)

Supply Source	**Base Case**		**Statewide Unconstrained**		***Supply Change***
	Flow	**%**	**Flow**	**%**	
CVPM 10					
San Joaquin River	698	*43%*	629	*39%*	***-69***
DMC Diversion	430	*27%*	581	*36%*	***151***
California Aqueduct	82	*5%*	0	*0%*	***-82***
Groundwater	408	*25%*	408	*25%*	***0***
Total	**1618**		**1618**		***0***
CVPM 11					
Stanislaus River	523	*63%*	514	*62%*	***-9***
Tuolumne River	300	*36%*	298	*36%*	***-2***
San Joaquin River	10	*1%*	19	*2%*	***8***
Groundwater	0	*0%*	2	*0%*	***2***
Total	**833**		**833**		***-1***
CVPM 12					
Merced River	69	*9%*	67	*9%*	***-2***
Tuolumne River	472	*65%*	461	*63%*	***-11***
San Joaquin River	16	*2%*	28	*4%*	***13***
Groundwater	174	*24%*	174	*24%*	***0***
Total	**730**		**730**		***0***
CVPM 13					
Madera Canal/Millerton	216	*13%*	59	*3%*	***-157***
San Joaquin River	50	*3%*	67	*4%*	***17***
Fresno River	44	*3%*	49	*3%*	***4***
Chowchilla River	48	*3%*	60	*4%*	***13***
Merced River	450	*26%*	574	*33%*	***124***
Groundwater	911	*53%*	911	*53%*	***0***
Total	**1719**		**1719**		***0***

The Tulare Lake Region sees significant shifts in its surface supplies. Agricultural diversions from the California Aqueduct decrease by over 550 taf/yr. This supply shift allows an additional 90 taf/yr to be exported to Southern California and 70 taf/yr to be allocated to Bakersfield.

Conversely, diversions into Region 4 from the San Joaquin River system increase by over 350 taf/yr. Efficient operation of the Kern, Kings, Kaweah, and Tule Rivers enable Region 4 to gain an additional 335 taf/yr in regional surface supplies.

Table 2G-9. Tulare Basin Agricultural Supplies (taf/yr)

Supply Source	Base Case Flow	Base Case %	Statewide Unconstrained Flow	Statewide Unconstrained %	*Supply Change*
CVPM 14					
California Aqueduct	756	*51%*	727	*49%*	***-29***
Mendota Pool	15	*1%*	44	*3%*	***29***
Groundwater	726	*48%*	725	*48%*	***0***
Total	**1497**		**1496**		***-1***
CVPM 15					
Kings River	394	*21%*	459	*25%*	***65***
Kaweah River	6	*0%*	18	*1%*	***12***
California Aqueduct	138	*7%*	2	*0%*	***-136***
Mendota Pool	45	*2%*	97	*5%*	***52***
Groundwater	1304	*69%*	1301	*70%*	***-3***
Total	**1888**		**1870**		***-18***
CVPM 16					
Friant Kern Canal	22	*5%*	10	*2%*	***-12***
Kings River	369	*82%*	411	*92%*	***42***
San Joaquin River	5	*1%*	12	*3%*	***7***
Groundwater	56	*12%*	16	*4%*	***-40***
Total	**452**		**447**		***-4***
CVPM 17					
Kings River	311	*41%*	327	*44%*	***16***
Friant Kern Canal	39	*5%*	16	*2%*	***-23***
Groundwater	410	*54%*	409	*55%*	***-1***
Total	**759**		**746**		***-13***
CVPM 18					
Kaweah River	315	*16%*	271	*13%*	***-44***
Tule River	36	*2%*	84	*4%*	***48***
Friant Kern Canal	592	*31%*	754	*35%*	***162***
Groundwater	995	*51%*	1051	*49%*	***55***
Total	**1938**		**2160**		***222***
CVPM 19					
Friant Kern Canal	13	*1%*	23	*2%*	***10***
Kern River	65	*7%*	228	*24%*	***164***
California Aqueduct	522	*55%*	349	*36%*	***-173***
Groundwater	356	*37%*	356	*37%*	***0***
Total	**957**		**957**		***0***

Table 2G-9 (continued). Tulare Basin Agricultural Supplies (taf/yr)

Supply Source	Base Case Flow	 %	Statewide Unconstrained Flow	 %	*Supply Change*
CVPM 20					
Friant Kern Canal	230	*36%*	270	*43%*	***40***
Kern River	107	*17%*	67	*11%*	***-40***
Groundwater	295	*47%*	295	*47%*	***0***
Total	**632**		**632**		***0***
CVPM 21					
Friant Kern Canal	102	*9%*	179	*15%*	***77***
Cross Valley Canal	75	*7%*	71	*6%*	***-4***
Kern River	169	*15%*	241	*21%*	***72***
California Aqueduct	283	*24%*	67	*6%*	***-216***
Groundwater	533	*46%*	603	*52%*	***70***
Total	**1162**		**1162**		***0***

Southern California experiences dramatic agriculture-to-urban transfers due to limited surface supplies (see Table 2G-10). Colorado River water allocated to agriculture in the Base Case is transferred to urban areas. The three Southern California agricultural areas incur the only increases in agricultural scarcity in the state under a statewide water market compared with the Base Case.

Table 2G-10. Southern California Agricultural Supplies (taf/yr)

Supply Source	Base Case Flow	 %	Statewide Unconstrained Flow	 %	*Supply Change*
Palo Verde					
Colorado River	661		548		***-113***
Imperial					
IID Canal	2550	*100%*	2225	*97%*	***-325***
Groundwater	0	*0%*	60	*3%*	***60***
Total	**2550**		**2285**		***-265***
Coachella					
Coachella Canal	195	*100%*	181	*100%*	***-14***
Groundwater	0	*0%*	0	*0%*	***0***
Total	**195**		**181**		***-14***

Table 2G-11 portrays how the supply mixes described above translate into operating costs. Agricultural operating costs are typically due to conveyance or groundwater pumping. Southern portions of the Central Valley incur the highest operating costs, where groundwater is more expensive to pump and a portion of the surface supplies are from the California Aqueduct.

Table 2G-11. Average Agricultural Operating Costs ($ millions/yr)

Ag Region	Base Case	Regional Unconstrained	Statewide Unconstrained
CVPM 1	1.1	1.1	1.1
CVPM 2	14.3	14.6	14.7
CVPM 3	8.0	8.0	8.5
CVPM 4	4.8	4.7	4.8
CVPM 5	9.4	9.4	9.4
CVPM 6	8.1	8.1	8.1
CVPM 7	8.1	2.3	2.3
CVPM 8	18.9	18.2	18.1
CVPM 9	2.3	2.3	2.3
CVPM 10	31.8	29.7	29.7
CVPM 11	0.0	0.0	0.0
CVPM 12	4.1	4.1	4.1
CVPM 13	28.4	28.1	28.6
CVPM 14	81.5	81.4	81.1
CVPM 15	67.5	63.0	63.2
CVPM 16	1.7	0.4	0.5
CVPM 17	12.9	12.9	12.9
CVPM 18	45.0	46.2	47.5
CVPM 19	42.3	39.2	36.4
CVPM 20	19.8	19.8	19.8
CVPM 21	49.8	49.2	46.9
Palo Verde	0.0	0.0	0.0
Coachella	0.0	0.0	0.0
Imperial	0.0	1.5	1.5
Total	**459.8**	**444.3**	**441.4**

Changes in Agricultural Costs

Figure 2G-5 displays how economic re-allocation of supplies affects agriculture in the state. The Lower Sacramento and San Joaquin Valleys derive minor benefits from more efficient allocation of supplies. The Tulare Basin gains significant benefits from a statewide market due mainly to greater availability of Friant Kern water. Southern California agriculture shifts its supplies to higher-valued urban demands.

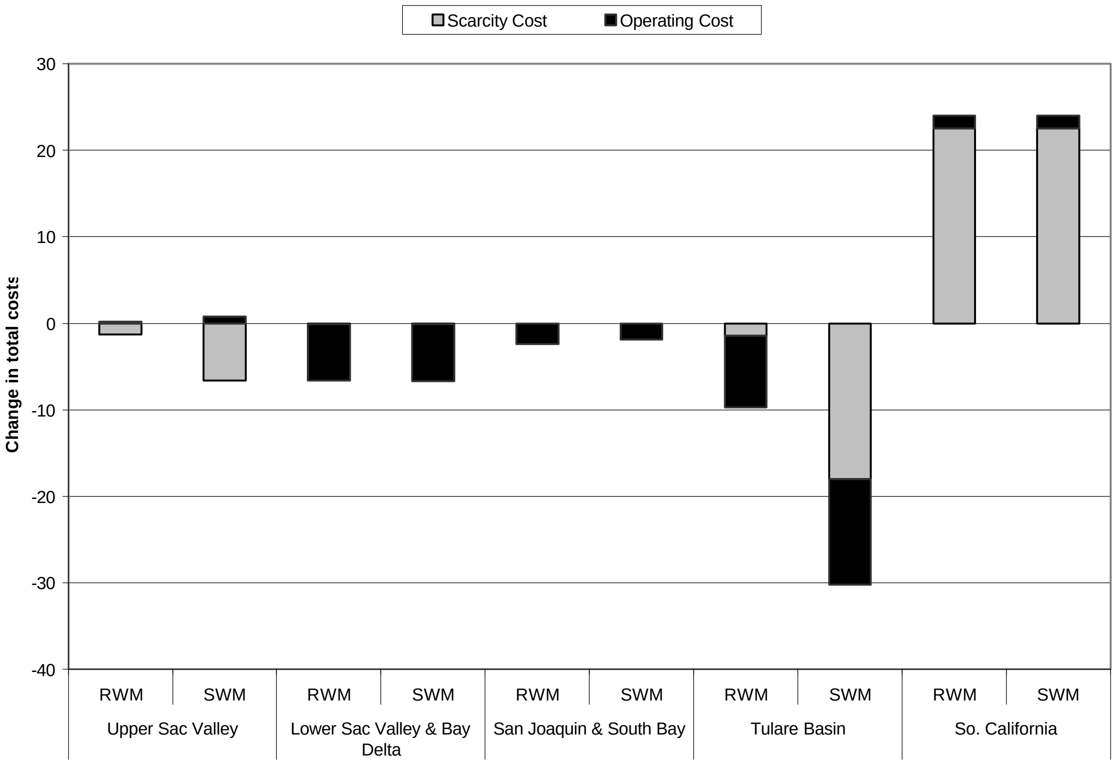

Figure 2G-5: Change in Total Agricultural Costs from Base Case (in $ millions)

Agricultural Supply Reliability

Figure 2G-6 shows system reliability from a statewide agricultural perspective. The Statewide Unconstrained alternative is especially effective at improving agricultural supply reliability during critically dry periods, although the model does not incorporate inter-annual variability in agricultural water demands.

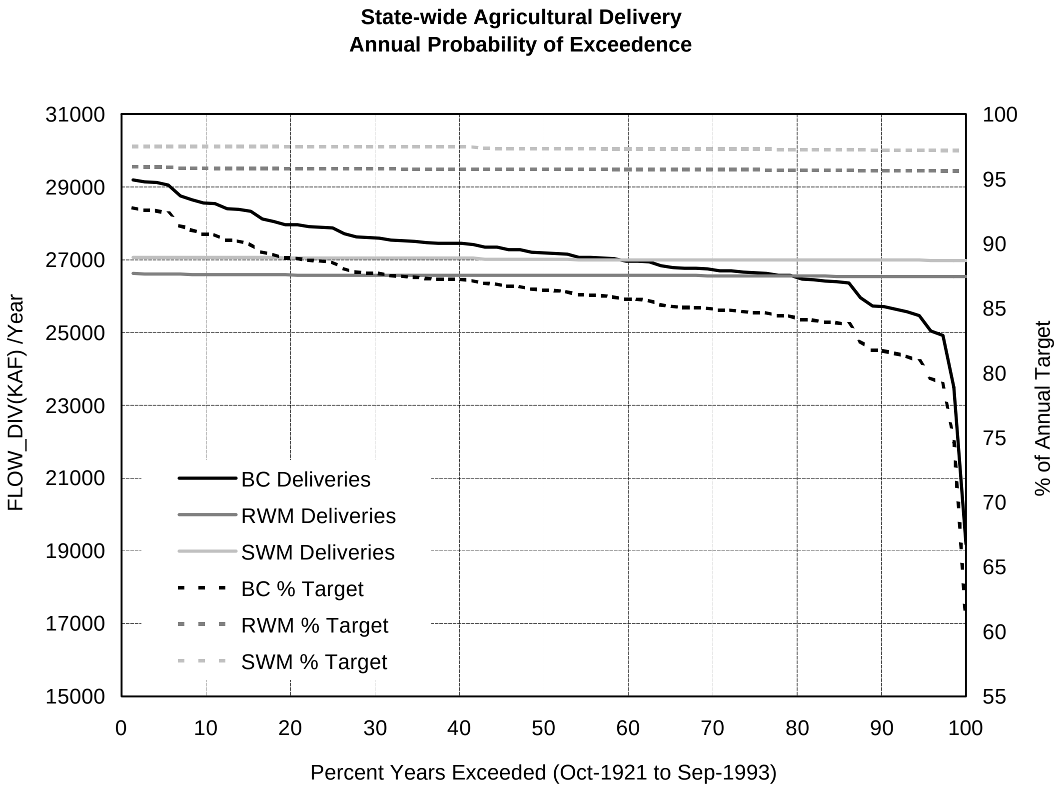

Figure 2G-6. Statewide Agricultural Reliability

URBAN RESULTS

Since urban water values are significantly greater than agricultural values, CALVIN attempts to operate the statewide system as efficiently as possible to primarily meet urban needs, and reduces allocations to the agricultural sector to prevent urban scarcity.

Urban Scarcity and Scarcity Costs

As shown in Table 2G-12, the Statewide Unconstrained alternative eliminates 744 taf/yr of urban scarcity on an annual average. Drought year scarcity is reduced by up to 1232 taf/yr. Residual scarcities occur in only 4 urban regions (East Bay MUD, Fresno, Castaic, and Coachella), with Coachella scarcities being the most significant.

East Bay MUD scarcities occur only in the 1976-1977 drought, when Mokelumne River supplies are insufficient to meet demand. A shift of 40 taf/yr in groundwater supplies from CVPM 16 to Fresno alleviates all but a small percentage of Fresno's annual average scarcity. Remaining scarcity is caused not by pumping capacity, but by alternative downstream demands with higher water values.

Likewise, the 4.5 taf/yr scarcity in Castaic in the Statewide Unconstrained alternative is not caused by capacities on the California Aqueduct. The cost of pumping additional water down the Aqueduct from the Delta is greater than the marginal value on the last 4.5 taf/yr urban demand in Castaic.

The Coachella urban area has access only to an inadequate groundwater supply to meet its demands. Pumping is limited to Coachella's capacity to recharge its groundwater basin with Colorado River water. Despite the elimination of agricultural groundwater pumping from re-allocation to urban needs in the Statewide Unconstrained alternative, supplies fall short of demand by 150 taf/yr.

Table 2G-12. Average Urban Scarcity (taf/yr)

Urban region	Base Case	Regional Water Markets	Statewide Water Markets
Regions 1 & 2			
Yuba	0.8	0	0.0
Napa	10.4	0	0.0
Contra Costa	0.1	0	0.0
East Bay MUD	7.6	0.7	0.7
Sacramento	0	0	0.0
Stockton	0.1	0	0.0
Regions 3 & 4			
San Luis Obispo	0	0	0.0
San Francisco	5.8	0	0.0
Fresno	42.1	0	2.3
Bakersfield	0	0	0.0
Santa Clara Valley	10.2	0	0.0
Region 5: LA			
Castaic Lake	83.3	7.9	4.6
San Bernardino	3.9	3.8	0.0
E & W MWD	34	8.1	0.0
Central MWD	197	45.1	0.1
Antelope Valley	91.3	4.2	0.0
Region 5: SD & Desert			
San Diego	34.4	8.4	0.0
Coachella	252.5	149.3	149.3
Mojave	127	0	0.0
Total	**900.5**	**227.2**	**156.9**

Ensuing costs from urban scarcities are outlined in Table 2G-13. CALVIN is able to successfully mitigate individual drought scarcity costs as high as $660 million in the Statewide Unconstrained alternative. Average year urban scarcity costs drop from almost

$1.7 billion/yr in the Base Case to $170 million/yr, while in drought years cost reduction "saves" almost $3 billion/yr.

Table 2G-13. Average Urban Scarcity Costs ($ millions/yr)

Urban region	Base Case	Regional Water Markets	Statewide Water Markets
Regions 1 & 2			
Yuba	0.9	0	0.0
Napa	22	0	0.0
Contra Costa	0.1	0	0.0
East Bay MUD	12.5	0.6	0.6
Sacramento	0	0	0.0
Stockton	0.1	0	0.0
Regions 3 & 4			
San Luis Obispo	0	0	0.0
San Francisco	5.1	0	0.0
Fresno	17.7	0	0.7
Bakersfield	0	0	0.0
Santa Clara Valley	10.2	0	0.0
Region 5: LA			
Castaic Lake	507.8	5.1	2.7
San Bernardino	3.5	2.2	0.0
E & W MWD	32.7	6.9	0.0
Central MWD	183.4	36.6	0.1
Antelope Valley	185.2	3.3	0.0
Region 5: SD & Desert			
San Diego	34.7	7.4	0.0
Coachella	367.4	165	166.1
Mojave	180.7	0	0.0
Total	**1858.6**	**227.1**	**170.2**

Urban Supplies

Urban supplies north of the Delta are driven primarily by operating costs. Since water is plentiful, CALVIN seeks to maximize net benefit by choosing supplies that have the lowest cost. The Sacramento urban area (refer to Table 2G-14) experiences the greatest shift in supplies, due to water quality cost differentials. Treatment costs for surface water from the Lower American and Sacramento Rivers are higher than groundwater pumping costs from GW-7 and GW-8. Sacramento's demands are met first by groundwater pumping, then an additional 205 taf/yr from Folsom Lake (an increase of 57 taf/yr over the Base Case). Stockton chooses to trade 16 taf/yr of groundwater pumping to surface supplies from the Calaveras River, since treatment costs are $30/af lower than pumping.

Table 2G-14. Sacramento Valley Urban Supplies (taf/yr)

Supply Source	Base Case		Statewide Unconstrained		*Supply Change*
	Flow	*%*	Flow	*%*	
Yuba City					
Upper Feather River	5	*10%*	11	*20%*	***6***
Yuba River	5	*9%*	26	*50%*	***22***
Lake Oroville	42	*81%*	16	*30%*	***-26***
Total	**52**		**53**		
Sacramento					
Sacramento River	74	*11%*	0	*0%*	***-74***
Lower American River	229	*34%*	0	*0%*	***-229***
Groundwater (GW-7)	61	*9%*	263	*39%*	***202***
Groundwater (GW-8)	166	*24%*	210	*31%*	***44***
Folsom Lake	148	*22%*	205	*30%*	***57***
Recycled	0	*0%*	0	*0%*	***0***
Total	**679**		**679**		
Stockton					
Calaveras River	16	*17%*	32	*34%*	***16***
Stanislaus River	43	*46%*	43	*45%*	***0***
Groundwater (GW-8)	35	*37%*	20	*21%*	***-16***
Recycled	0	*0%*	0	*0%*	***0***
Total	**95**		**95**		
Napa-Solano					
Putah South Canal	51	*48%*	115	*100%*	***65***
North Bay Aqueduct	54	*52%*	0	*0%*	***-54***
Groundwater (GW-6)	0	*0%*	0	*0%*	***0***
Recycled	0	*0%*	0	*0%*	***0***
Total	**105**		**115**		
Contra Costa					
Contra Costa Canal	131	*97%*	133	*99%*	***3***
Recycled	4	*3%*	2	*1%*	***-2***
Total	**135**		**135**		
EBMUD					
Mokelumne River	282	*97%*	296	*100%*	***14***
Recycled	8	*3%*	1	*0%*	***-7***
Total	**290**		**297**		

The San Francisco and Santa Clara urban areas have very similar supply mix changes as in a regional water market (see Table 2G-15 and Appendix 2C). Additional imports of 42 taf/yr of Hetch Hetchy water meets San Francisco's Base Case scarcity and is substituted for more expensive Delta imports from the California Aqueduct (a decrease of 50 taf/yr) for Santa Clara. In addition, more aggressive reclamation and groundwater recharge fulfills an additional 24 taf/yr of demand.

Bakersfield is the one demand region in the Tulare Basin that uses more California Aqueduct water in the Statewide Unconstrained alternative than in the Base Case. Groundwater pumping costs are higher in the southern portion of the Central Valley, making it more economical to treat imported Delta water than to pump groundwater.

Table 2G-15. Central Valley and Bay Area Urban Supplies (taf/yr)

Supply Source	Base Case		Statewide Unconstrained		*Supply Change*
	Flow	*%*	Flow	*%*	
San Francisco					
Hetch Hetchy	232	*98%*	238	*100%*	***6***
Recycling	0	*0%*	0	*0%*	***0***
Total	**232**		**238**		
Santa Clara					
Santa Clara Local Recharge	2	*0%*	1	*0%*	***-2***
Santa Clara Local Surface	117	*18%*	118	*18%*	***2***
Pacheco Tunnel Recharge	104	*16%*	162	*25%*	***59***
Pacheco Tunnel direct	15	*2%*	64	*10%*	***49***
South Bay Aq. Recharge	72	*11%*	0	*0%*	***-71***
South Bay Aqueduct direct	87	*14%*	0	*0%*	***-87***
Hetch Hetchy	58	*9%*	93	*14%*	***36***
Reclamation Recharge	48	*7%*	72	*11%*	***24***
Recycling	14	*2%*	15	*2%*	***2***
Groundwater inflow	130	*20%*	130	*20%*	***0***
Total	**646**		**656**		
Fresno					
Groundwater	**338**		**378**		***40***
Bakersfield					
California Aqueduct	72	*28%*	142	*54%*	***70***
Groundwater	189	*72%*	119	*46%*	***-70***
Total	**261**		**261**		
San Luis Obispo					
Coastal Aqueduct	**139**		**139**		***0***

Southern California urban supply mixes vary greatly between the Base Case and Statewide Unconstrained alternatives (refer to Table 2G-16). Urban scarcities of 823 taf/yr in the Base Case are partially alleviated through a combination of an increase of 90 taf/yr of Delta imports, 47 taf/yr of Los Angeles Aqueduct water, 450 taf/yr of Colorado River imports, and agriculture-to-urban transfers. Distribution and conveyance systems are highly integrated, allowing CALVIN to optimize available sources to derive the greatest benefit.

Table 2G-16. Southern California Urban Supplies (taf/yr)

Supply Source	Base Case		Statewide Unconstrained		*Supply Change*
	Flow	%	Flow	%	
Castaic Lake					
California Aqueduct (West)	**44**		**123**		***79***
San Bernardino					
California Aqueduct (East)	83	*27%*	91	*29%*	***8***
Recycling	4	*1%*	0	*0%*	***-4***
Local Supply	217	*71%*	217	*71%*	***0***
Less local ag supplies	n/a	*n/a*	-6		
Total	**304**		**302**		
E & W MWD					
Auld Valley Pipeline	118	*20%*	198	*31%*	***80***
California Aqueduct	163	*27%*	117	*18%*	***-46***
Local Supply (incl. recycling)	316	*53%*	316	*50%*	***0***
Total	**597**		**631**		
Central MWD					
Local Supply	1487	*45%*	1487	*42%*	***0***
Los Angeles Aqueduct	343	*10%*	390	*11%*	***47***
Castaic Lake	591	*18%*	955	*27%*	***364***
Rialto Pipeline	521	*16%*	210	*6%*	***-311***
MWD Feeders	394	*12%*	496	*14%*	***102***
Less local losses	-180	*0%*	-180	*0%*	
Total	**3155**		**3358**		
Antelope Valley					
California Aqueduct (East)	129	*70%*	222	*80%*	***93***
California Aqueduct (West)	2	*1%*	0	*0%*	***-2***
California Aq: Recharge	0	*0%*	0	*0%*	***0***
Recycling	6	*3%*	6	*2%*	***0***
Reclamation Recharge	0	*0%*	0	*0%*	***0***
Groundwater inflow	49	*26%*	49	*18%*	***0***
Total	**186**		**277**		
San Diego					
Local Supply	150	*18%*	150	*17%*	***0***
San Diego Pipelines 1 to 4	541	*65%*	520	*60%*	***-21***
San Diego Pipelines 5 and 6	137	*17%*	193	*22%*	***55***
Tijuana Canal	0	*0%*	0	*0%*	***0***
Total	**829**		**864**		

Table 2G-16 (continued). Southern California Urban Supplies (taf/yr)

Supply Source	Base Case		Statewide Unconstrained		*Supply Change*
	Flow	*%*	Flow	*%*	
Coachella					
Groundwater	**348**		**451**		***103***
Mojave					
California Aqueduct (East)	0	*0%*	0	*0%*	***0***
California Aqueduct: Recharge*	65	*29%*	141	*40%*	***76***
Reclamation Recharge	90	*40%*	141	*40%*	***51***
Recycling	0	*0%*	0	*0%*	***0***
Groundwater inflow	70	*31%*	70	*20%*	***0***
Total	**225**		**352**		

* Note: Modeling error in capacity of Mojave connection to the California Aqueduct

ENVIRONMENTAL WATER REQUIREMENTS

CALVIN recognizes two specific types of environmental flow requirements. First, refuge demands are fixed diversions from streams and canals for the purpose of maintaining wetland ecosystems. Refuge diversions typically render some water unavailable for downstream needs by removing it from the system. Two environmental diversions treated similarly to refuge deliveries are the diversions to Owens (for dust-mitigation) and Mono Lakes. Second, minimum instream flows are placed on rivers meeting downstream needs, but flow requirements often are maintained by reservoir releases during periods of non-peak economic demand. Similar minimum outflows are specified on the Delta, with the potential to affect upstream allocations and operations. CALVIN represents environmental flow requirements on rivers and the Delta as lower bound constraints and wildlife refuge allocations as fixed deliveries (see the Appendix F).

Minimum Instream Flows

Table 2G-18 lists the minimum instream flow requirements modeled in CALVIN in comparison to the average flows for the three alternatives. Specifics regarding each of these flows can be found in the regional appendices as well as Appendix F.

Table 2G-18. Annual Average Environmental Stream Flows (taf/yr)

	Flow Requirements	Base Case	Regional Unconstrained	Statewide Unconstrained
Region 1				
Trinity River	357	357	357	357
Clear Creek	42	68	137	118
Sacramento River	3117	8161	8194	8114
Region 2				
Feather River	936	2990	3448	3532
American River	1076	2463	2360	2363
Mokelumne River	88	970	959	956
Calaveras River	1	151	150	151
Yuba River	170	1635	1603	1588
Sacramento River	3619	15948	15775	15595
Region 3				
Merced River (Upper)	79	395	265	274
Merced River (Lower)	79	375	247	250
Stanislaus River	196	389	418	456
Tuolumne River	119	544	594	581
SJ River (Vernalis)	1031	2889	3081	2571

On an annual average basis, instream flows vary little between the three modeling alternatives. Exceptions are flow increases of up to 540 taf/yr on the Feather River, and decreases of 350 taf/yr and 320 taf/yr on the Sacramento and San Joaquin Rivers, respectively. Though these average flows are useful, a complete analysis would need to include marginal values on these river reaches, to see whether changes in average flows are realized throughout the year or whether they are seasonal in nature. Variability in streamflows between wet and dry years in particular months is also likely to be important.

Delta Flows

Potential implications of water management changes on the Delta, discussed later in this appendix, are based largely on results outlined in Table 2G-19. Greater utilization of surface supplies north of the Delta result in decreased inflows into the Delta. Optimal re-allocation and re-operation of supplies south of the Delta, however, decrease reliance on Delta exports in the Statewide Unconstrained alternative. Surplus Delta outflows, critical for retaining the ecological integrity of the Delta, are equivalent in the Base and Statewide Unconstrained Cases. This appears to be one of the most significant benefits of a statewide water market.

Table 2G-19. Delta Flow Comparison (taf/yr)

Delta Flows	Base Case	Regional Unconstrained	State-wide Unconstrained	*% Change Base Case to Statewide*
Delta inflows:				
Yolo Bypass	1997	2063	2133	***6.8%***
Sac. River	15948	15775	15595	***-2.2%***
Eastside streams	868	857	854	***-1.6%***
San Joaquin River	2728	2728	2571	***-5.8%***
Total	**21541**	**21423**	**21153**	***-1.8%***
Delta outflows:				
Cal Aqueduct	3544	3544	4142	***16.9%***
Delta Mendota Canal	2646	2646	1691	***-36.1%***
Delta outflow	14331	14248	14330	***0.0%***
Total	**20521**	**20438**	**20164**	***-1.7%***

ECONOMIC VALUES OF WATER

CALVIN reports marginal values of water in two ways. Where constraints placed on river, conveyance, or storage capacity are binding, CALVIN reports the time series of shadow cost on that element. This shadow cost is the additional net cost to the region if the constraint is tightened by one unit (or the benefit if the corresponding constraint is slackened by one unit). Negative marginal costs on reservoirs or conveyances indicate a net benefit to the entire region if the limiting capacity is increased. River reaches with binding minimum instream flows, reservoirs drawn down to dead pool, and conveyances without flow generate positive shadow costs, since lower bounds are binding in these cases.

In addition to generating shadow costs, CALVIN also reports the marginal value (net benefit to the region) at any *location* in the system of an additional unit of water from an external source. This value, also called the ‘willingness to pay’ at the location in consideration.

Agricultural Willingness-to-Pay

Table 2G-20 indicates that though regional water markets are effective at mitigating high WTP values by spreading scarcity over the region, a statewide water market would be more effective at eliminating most of the WTP values throughout the state. Average WTP values range from $9 to $14 for several agricultural regions in the Tulare Basin, but unresolved Statewide Unconstrained scarcities in Southern California induce the highest WTP values in the state.

Table 2G-20. Agricultural Willingness-to-Pay (WTP) for Additional Water

Agricultural Region	Average WTP ($/af)			Maximum WTP ($/af)	
	BC	RWM	SWM	RWM	SWM
CVPM 1	0	11.9	0	19.0	0
CVPM 2	42.2	14.6	0	21.7	0
CVPM 3	25.2	26.7	0	37.2	0
CVPM 4	0	23.5	0	34.7	0
CVPM 5	0	0	0	0	0
CVPM 6	0	0	0	0	0
CVPM 7	0	0	0	0	0
CVPM 8	0	0	0	0	0
CVPM 9	24.8	0	0	0	0
CVPM 10	0	0	0	0	0
CVPM 11	0	0	0	0	0
CVPM 12	0	0	0	0	0
CVPM 13	0	0	0	0	0
CVPM 14	0	0	0	0	0
CVPM 15	39.5	26.2	14.3	39.5	39.5
CVPM 16	0	16.6	9.9	25.7	25.5
CVPM 17	0	17.6	11.0	32.0	32.0
CVPM 18	162	40.0	0	61.6	0
CVPM 19	0	31.8	0	65.5	0
CVPM 20	0	4.6	0	67.2	0
CVPM 21	0	41.1	0	61.6	0
Palo Verde	20.9	56.8	57.1	71.1	71.1
Coachella	0	61.4	61.4	61.8	61.8
Imperial	23.9	67.7	67.7	67.7	67.7

Urban Willingness-to-Pay

Urban WTP values show a similar trend to agriculture. WTP values as high as $10,500/af in the Castaic Lake in the Base Case are dramatically decreased in the Statewide Unconstrained run, due to increased Delta imports and more efficient regional conveyance operations. Coachella urban region in Southern California, constrained by its limited access to Colorado River water, shows the highest WTP in the state in a statewide water market. WTP values generated for East Bay MUD are caused only scarcity costs incurred during the 1976-1977 drought.

Table 2G-21. Urban Willingness-to-Pay (WTP) for Additional Water

Urban Region	Average WTP ($/af)			Maximum WTP ($/af)	
	BC	RWM	SWM	RWM	SWM
Yuba	66.1	0	0	0	0
Napa	694	0	0	0	0
Contra Costa	23.4	0	0	0	0
East Bay MUD	351	27.6	27.6	1,130	1,130
Sacramento	0	0	0	0	0
Stockton	7.5	0	0	0	0
San Francisco	291	0	0	0	0
Santa Clara Valley	249	0	0	0	0
SLO	0	0	0	0	0
Fresno	472	0	42.4	0	343
Bakersfield	0	0	0	0	0
Castaic Lake	10,495	645	519	1,039	585
Antelope Valley	2,574	238	0	896	0
Coachella	1,520	1,358	1359	1,952	1,952
Mojave*	1,527	0	0	0	0
San Bernardino	315	145	0	753	0
Central MWD	897	218	0	1,095	0
E & W MWD	831	219	1.8	1,020	800
San Diego	622	194	0	1,060	0

* neglects conveyance capacity constraint entering Mojave region

Opportunity Costs for Environmental Flows

Table 2G-22 reports the marginal values, or the opportunity costs, of environmental flow constraints. These opportunity costs represent unrealized economic benefit to agricultural or urban users caused by binding environmental flow constraints. Results from both the Regional Unconstrained and Statewide Unconstrained runs suggest that increasing minimum instream flows for all the rivers modeled in CALVIN would cost agricultural and urban users little. The only exception is the Trinity River, which has high marginal values in the Regional Unconstrained alternative. However, these high values are almost eliminated in a statewide water market.

Table 2G-22. Opportunity Costs for Minimum Instream Flows ($/af per month)

River reaches with minimum instream flow requirements	Opportunity Costs			
	Regional Unconstrained		Statewide Unconstrained	
	Monthly Average	Max Monthly	Monthly Average	Max Monthly
Region 1				
Trinity River	45.57	49.61	0.76	6.31
Clear Creek	0.49	46.39	0.35	5.08
Sacramento River	0.69	47.96	0.17	3.66
Region 2				
Feather River	0.00	0.00	0.08	0.76
American River	0.01	0.16	0.03	1.05
Mokelumne River	0.00	0.00	0.00	0.18
Calaveras River	0.00	0.00	0.00	0.00
Yuba River	0.00	0.16	0.02	0.54
Sacramento River	0.00	0.00	0.00	0.00
Region 3				
Merced River (Upper)	3.11	13.47	2.00	22.34
Merced River (Lower)	1.76	13.62	1.86	23.47
Stanislaus River	4.42	13.75	1.30	24.51
Tuolumne River	2.43	13.61	0.64	23.75

Fixed environmental deliveries typically have higher opportunity costs than minimum instream flows, mainly since a large percentage of refuge diversions are effectively removed from the system and are unavailable for downstream users. Allocations to Mono and Owens Lakes divert water from the highest valued demands in the state, causing their opportunity costs to be as high as $963/af per month (most of which is lost hydropower benefits). Sacramento Refuge shadow costs are almost eliminated in the Statewide Unconstrained alternative, while refuge values in the San Joaquin and Central Valleys increase.

Table 2G-23. Fixed Environmental Deliveries (taf/yr) and Opportunity Costs ($/af per month)

Refuges	Flow Requirements (taf/yr)	Opportunity Costs			
		Regional Unconstrained		Statewide Unconstrained	
		Monthly Average	Max Monthly	Monthly Average	Max Monthly
Sacramento West	106	42	45	0.4	4
Sacramento East	57	0	1	0.2	1
Volta	35.5	8	20	20	23
San Joaquin/Mendota	237.3	7	18	16	22
Kern	11.2	43	86	34	37
Mono Lake	115.3	963	1,716	818	1,215
Owens Lake	40.8	750	1,171	611	666

POTENTIAL WATER MANAGEMENT CHANGES

In this section, water values reported in the previous section are used to assess the benefits of potential infrastructure expansion, alteration of environmental flows, conjunctive use, cooperative operations, and reservoir re-operation. Overall trends provide indications for promising solutions to the state's multiplying water supply issues. The following sections outline a number of these trends as they pertain to operations, facility expansion, and water marketing or other forms of transfers.

Operations Opportunities

Re-operation of surface water reservoirs and increased conjunctive use opportunities alter the way water is distributed and stored with existing infrastructure. It should be noted that the CALVIN model results are idealized in the sense of perfect foresight, and do not reflect hydropower, water temperature, and real time flood control operations. The results are interesting and useful, but are not necessarily conclusive for the broader operating context.

Conveyance Operations

Results presented earlier in this report provide initial indications that the re-operation of many of California’s conveyance facilities could provide significant economic benefit, even without facility expansion. Two main areas of conveyance re-operation come to the forefront in a statewide water market: 1) the network of South-of-Delta conveyance facilities (including the California Aqueduct, the Delta Mendota Canal, and the Friant-Kern Canal) which supply water to the lower portion of the state, and 2) the enhanced economic rationale of recycling and reclamation efforts.

South-of-Delta Conveyance Re-operations

Table 2G-24 displays how major conveyance facilities might be used within both regional and statewide market frameworks.

Table 2G-24. South-of-Delta Flows on Major Conveyances (taf/yr)

	Average Annual Flows		
	BC	RWM	SWM
California Aqueduct			
Banks Pumping Plant	3544*	3544**	4142
Region 3 to 4	4174	4174**	3736
Region 4 to 5	2079	2079**	2169
Delta Mendota Canal			
Tracy Pumping Plant	2646*	2646**	1691
Entering Mendota Pool	857	877	996
TOTAL SOUTH OF DELTA PUMPING	6190	6190**	5833
Hetch Hetchy Aqueduct			
Into Bay Area	297	336	336
Friant Kern Canal			
Diverted from Millerton Reservoir	1125	1125**	1470
After CVPM 16 and 17	1052	1037	1373
After CVPM 18 and 19	366	316	492
Los Angeles Aqueduct			
Owens Valley Power Plant	n/a	387	390
After Agricultural Diversions	343	387	390
Colorado River Aqueduct			
Pumped from Colorado River Aqueduct	850	1303	1303
Emptying into Lake Matthews	402	509	505

BC = Base Case, RWM = Regional Water Markets, SWM = Statewide Water Market

* Though it appears Delta pumping shifts dramatically away from the DMC to the California Aqueduct in the SWM, CALVIN routes DMC water through the Aqueduct and the O'Neill power station.

** Constrained to value in the Base Case, as a regional boundary

Under the statewide water market the areas south of the Delta experiences significant changes in conveyance and reservoir operations. These changes are driven by both agricultural-to-urban transfers and through re-operation of the SWP and CVP facilities, which export water from the Delta to the Bay Area, to agricultural users in the San Joaquin and Tulare Basin portion of the Central Valley, and to urban areas of Southern California.

CALVIN routes Delta water allocated to the DMC through the O'Neill power station to gain additional benefit, ultimately resulting in a 300 taf/yr increase in DMC flows. However, a net decrease in California Aqueduct flows of 660 taf/yr reduces total exports from the Delta by an average of 360 taf/yr. In addition, California Aqueduct diversions to demands in the Tulare Basin decrease by almost 440 taf/yr, while exports to Southern California increase by only 90 taf/yr despite significant scarcities. In summary, decreased Delta exports prioritize agriculture in the San Joaquin Valley (and Southern California urban use to a small extent), and reduce Delta exports to the Tulare Basin (see Figures 2G-7 and 2G-8).

Consequently, diversions through the Mendota Pool and the Friant-Kern Canal play a greater role in meeting Tulare Basin demands. Friant-Kern Canal diversions from Millerton Lake increase by almost 350 taf/yr and Tulare Basin agricultural supplies from the Mendota Pool increase by 81 taf/yr. Since these increased flows equate to less available water to the San Joaquin River system, the Delta Mendota Canal plays a greater role in supplying water to the San Joaquin River through the Mendota Pool.

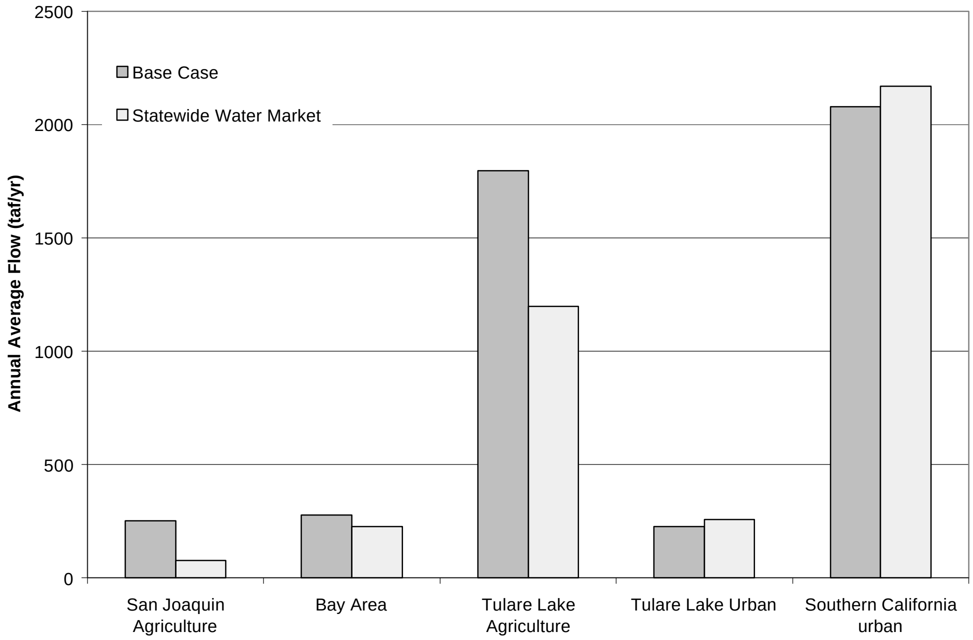

Figure 2G-7. California Aqueduct Diversions in a Statewide Water Market

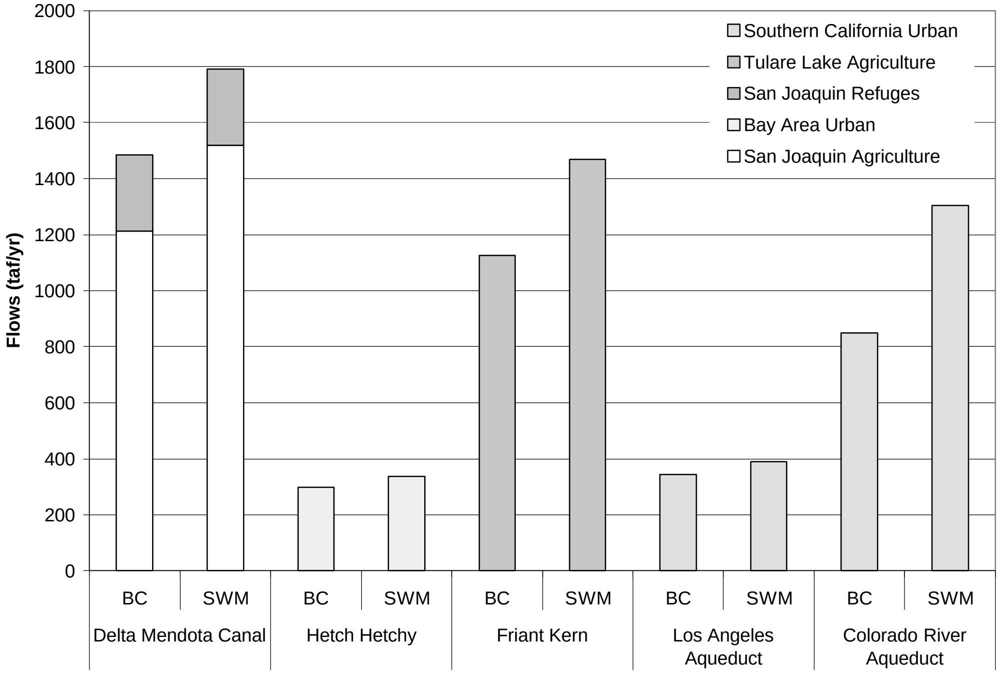

Figure 2G-8. Major Conveyance Re-operation with a Statewide Water Market

Local Facilities

Table 2G-25 outlines the marginal benefits derived from each acre-foot of expanded local facility capacity. The highest expansion value in the state by far is artificial groundwater recharge capacity in the Coachella region from the Colorado Aqueduct, reflecting high water values driven by scarcity. Antelope Valley values show significant benefit to increasing either recycling or artificial recharge, due to averted treatment or operating costs from the California Aqueduct. A $178/af expansion value on pumping capacity in the Santa Clara Valley, as well as the significant marginal values of artificial recharge, reclamation recharge, and recycling in the area, reflects the value of increasing operational flexibility of the SCV groundwater basin. Such flexibility would decrease dependence on imports and associated surface water treatment costs. Several other urban areas also show high values on recycling, including San Francisco and the East Bay Municipal Utility District. Groundwater recharge links consistently show high values throughout the state; in addition to those already mentioned, Metropolitan Water District and Fresno would benefit from greater recharge capacity under a statewide water market.

Table 2G-25. Expansion Values for Local Facilities ($/af/month)

Facility	Value
Coachella artificial recharge	2796
Antelope Valley recycling	288
Antelope Valley artificial recharge	275
Santa Clara Valley groundwater pumping capacity	178
Proposed Contra Costa Canal transfers with Mokelumne Aqueduct	146
Fresno reclamation recharge to groundwater	132
Proposed Tijuana Canal	132
Imperial Valley groundwater pumping	77
San Francisco recycling	72
Santa Clara Valley artificial recharge	66
Imported surface water recharge to MWD groundwater	56
Santa Clara Valley recycling	47
Kern River Intertie	33
Folsom South Canal diversion, to Mokelumne River Aqueduct	26
EBMUD recycling	20
Santa Clara Valley reclamation recharge	20
Mendota Pool ag diversions to CVPM 14	12

Several proposed facilities show significant value, including the proposed Contra Costa Canal transfers to and from the Mokelumne Aqueduct. The proposed Tijuana Canal, with an expansion value of $132/af, would provide Colorado River water to the San Diego area.

Surface Storage Operations

Reservoirs are extensively used throughout California to provide reliable water supplies, flood control, hydroelectric power, and recreational venues. Reservoir storage is especially crucial in times of drought. Because reservoir operators are unable to forecast drought durations, reservoirs are typically kept full to reduce the risk of water scarcities. However, evaporation losses are greater when reservoirs are filled. Under the

Unconstrained Policy, CALVIN has the advantage of maximizing the conjunctive use of all sources and storage capacity in the region, allowing it to keep reservoirs emptier during average and drought years to minimize scarcity and operating costs (refer again to Figure 2G-4 at the beginning of this appendix). Reservoir re-operation effectively maximizes wet year surface water by minimizing spills, replacing groundwater, and minimizing total pumping costs.

Though recommendations on specific reservoir operations are difficult to interpret from model results in CALVIN, overall storage trends provide insight into the potential benefits of improved surface storage management. Recall that Unconstrained surface storages are constrained to match the Base Case storages at the end of each of the three time periods, i.e. in October of 1952, 1968, and 1993. Figures 2G-9 and 2G-10 show how CALVIN operates surface storage north and south of the Delta.

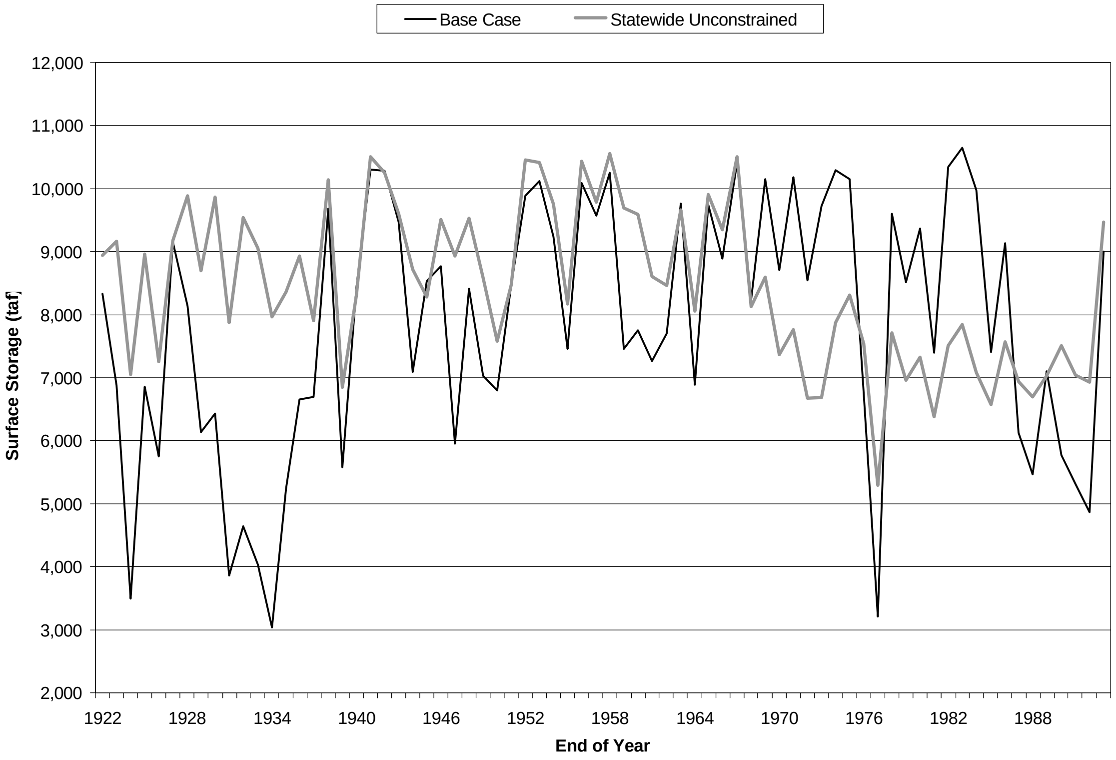

Figure 2G-9. North-of-Delta Surface Storage [end-of-year]*

** Note: Lake Oroville, the second largest reservoir in California, is not included in this total surface storage comparison. An inadvertent omission of a storage penalty in the statewide analysis distorted Oroville's storage results.*

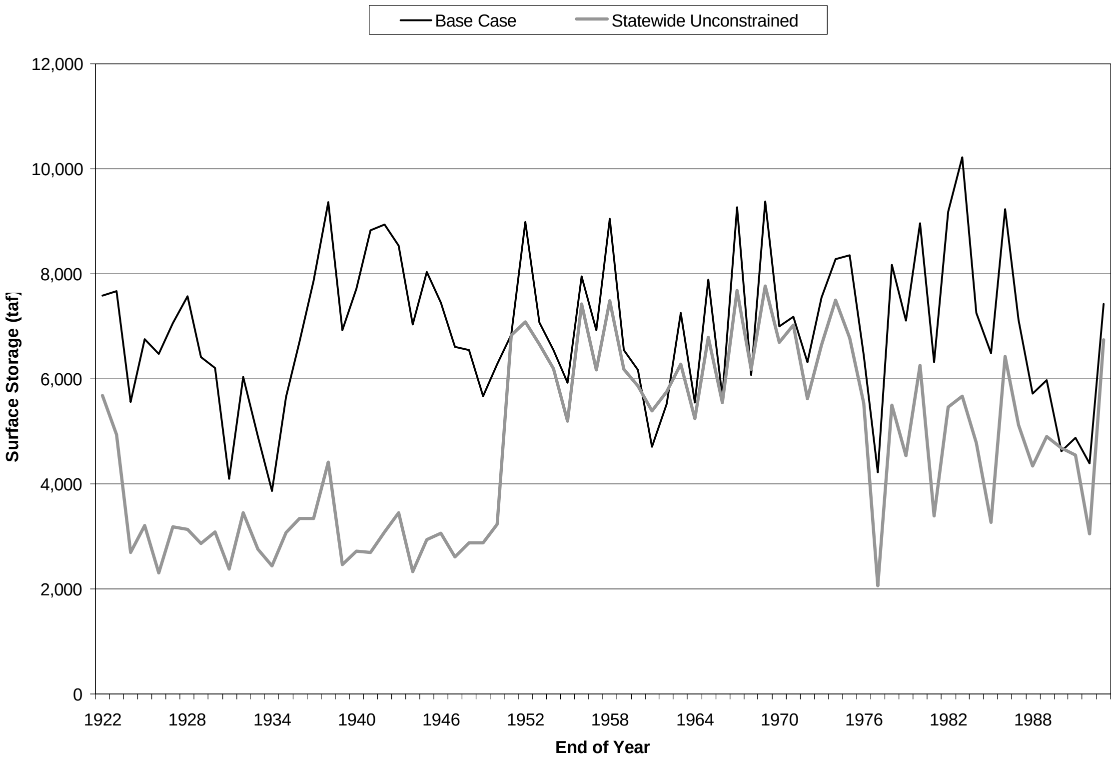

Figure 2G-10. South-of-Delta Surface Storage [end-of-year]

Conjunctive Use Operations

Conjunctive use refers to the coordinated use of both groundwater and surface water to meet a region's demands. The regional and statewide water markets use groundwater in conjunction with surface water to a greater extent than the Base Case (Figure 2G-11). On an average monthly scale, the regional water market decreased groundwater pumping during the wet months (January and February) and increased pumping during the drier months (July and August). See Figure 2G-12 for details.

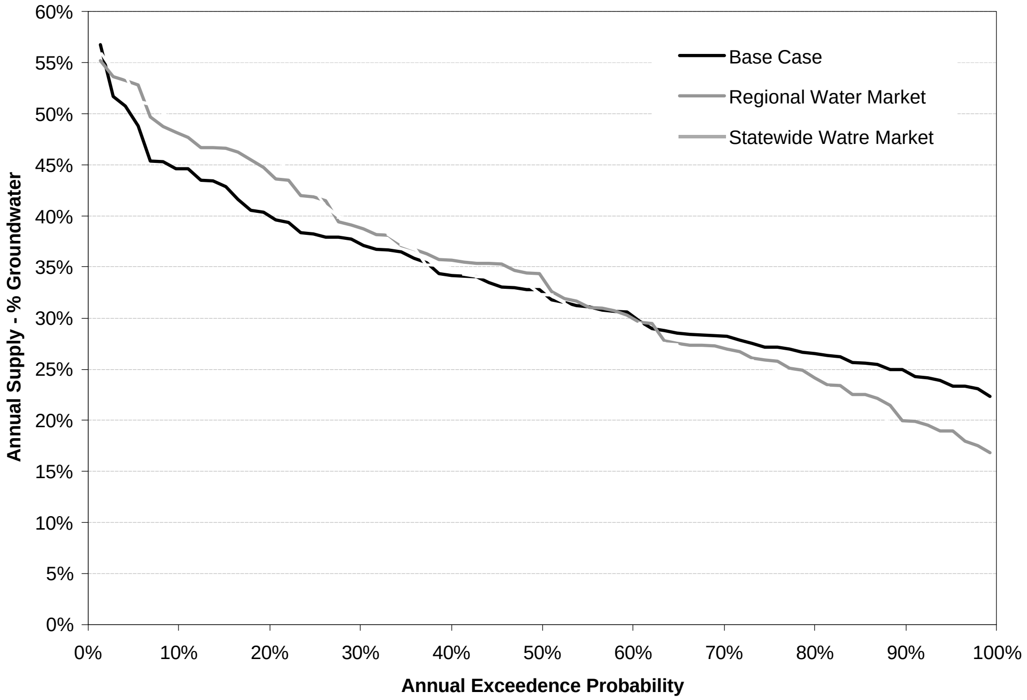

Figure 2G-11. Reliance on Groundwater and Conjunctive Use

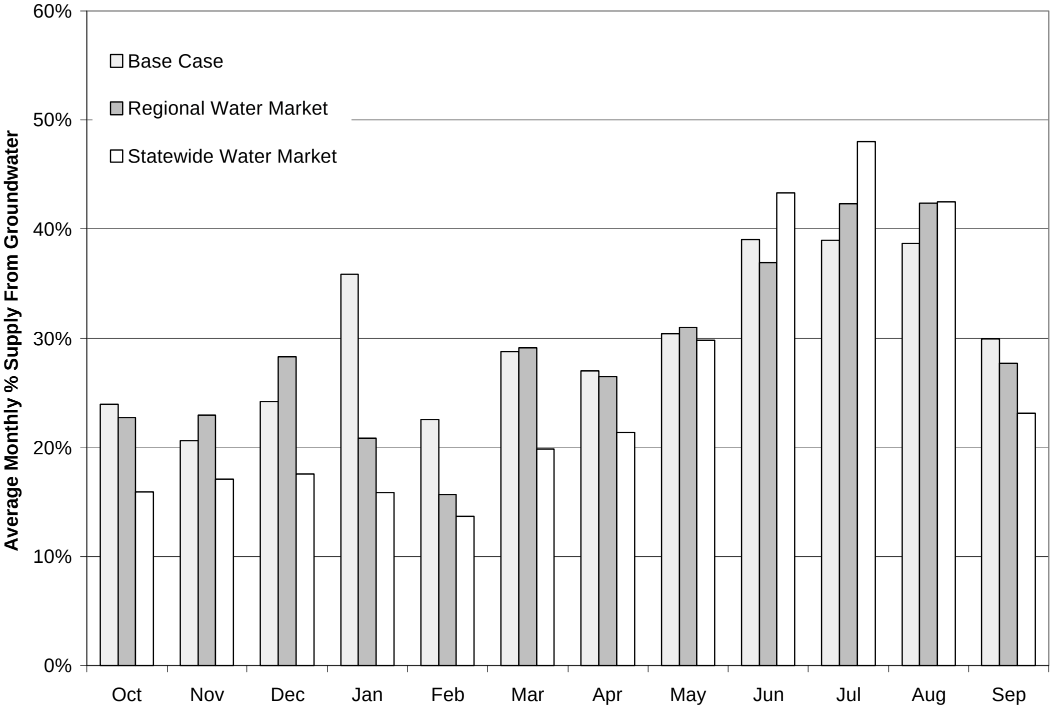

Figure 2G-12. Monthly Percent Supply From Groundwater

Figure 2G-13 looks specifically at agricultural pumping trends in the Statewide Unconstrained alternative. Conjunctive use trends are strong, as evidenced by the virtual mirror image of surface vs. groundwater supplies. Drought periods are easily identified- they are the periods where groundwater supplies exceed cheaper surface supplies.

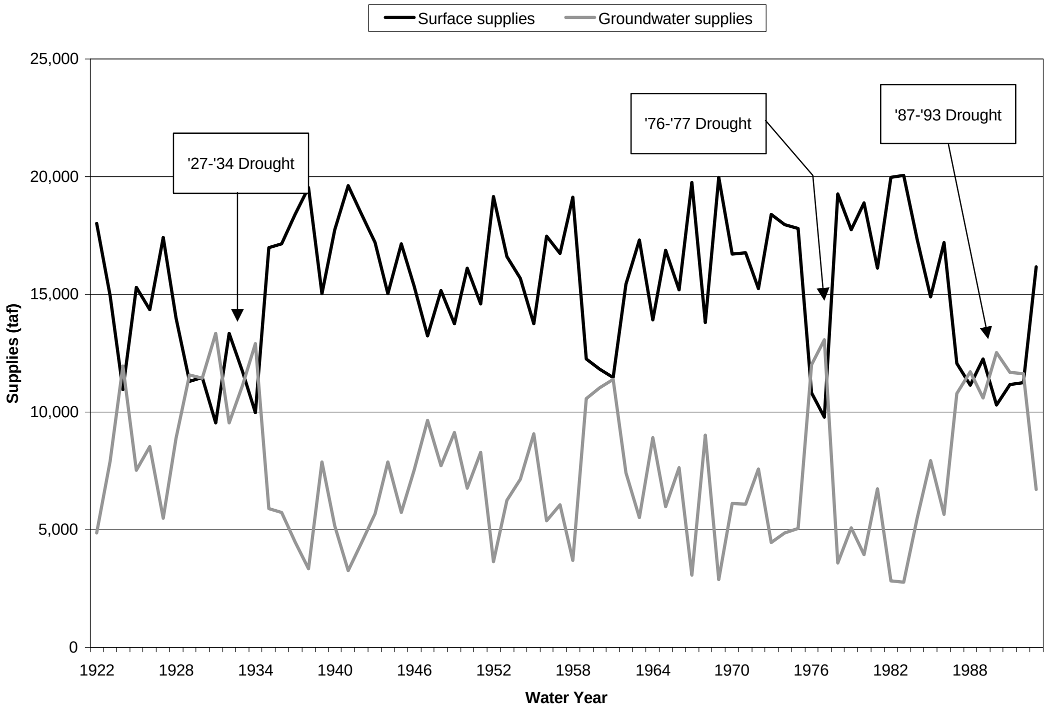

Figure 2G-13. Statewide Water Market Agricultural Conjunctive Use Patterns (CVPM regions only)

Finally, Figure 2G-14 compares the percentage of statewide agricultural supplies attributable to groundwater in the Base Case to the Statewide Unconstrained alternative. The SWM results display greater amplitudes than the Base Case, suggesting once again that supplies are being operated conjunctively.

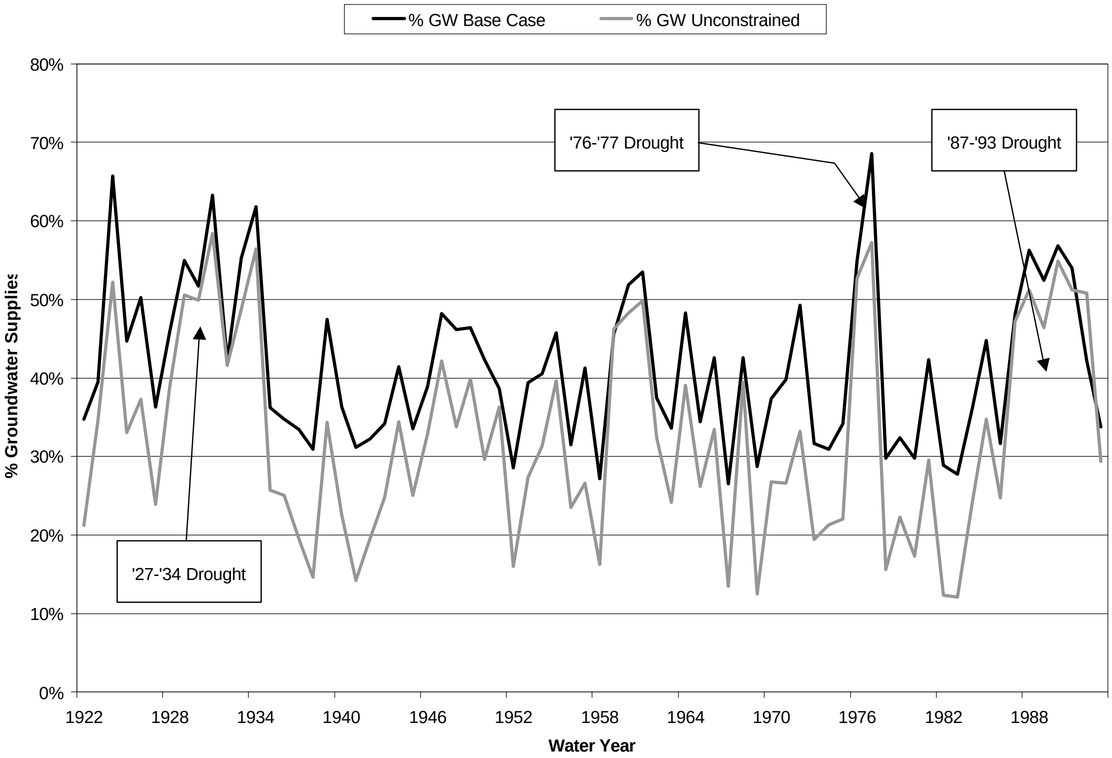

Figure 2G-14. Agricultural Groundwater Use Comparison

Significant portions of agricultural regions in California are experiencing overdraft of their groundwater supplies. Analysis of ending groundwater storage values show that water marketing may help alleviate groundwater overdraft in some regions. Table 2G-26 provides the basis for understanding this overdraft reduction potential by reporting the marginal values of each of the sub-periods used in the 72-year hydrologic period. The marginal ending storage value indicates the cost to the system if the ending storage constraint was increased by one unit. In other words, it indicates how the system would respond to allowing the ending storage to remain unconstrained. These results suggest that potential exists for alleviating groundwater overdraft if water could be traded more freely through the system, reducing overall demand on groundwater pumping. Further analysis is needed, however, to determine the effect of CALVIN's perfect foresight in generating these marginal values. Some insights into this matter are presented in Appendix 2K.

Table 2G-26. Marginal Value of End-of-Period Groundwater Storage (Cost in $ if 1 af is not pumped)

Groundwater Basin	1922-1951	1952-1968	1969-1993
CVPM 1	-29.1	-29.6	-29.2
CVPM 2	-27.3	-27.5	-27.2
CVPM 3	-22.9	-23.4	-23.0
CVPM 4	-15.1	-15.6	-15.2
CVPM 5	-18.3	-18.7	-18.6
CVPM 6	-17.7	-18.1	-18.0
CVPM 7	-21.9	-22.0	-22.0
CVPM 8	-28.1	-28.5	-28.4
CVPM 9	-19.9	-20.3	-19.4
CVPM 10	6.0	8.5	8.8
CVPM 11	5.0	-19.1	9.5
CVPM 12	0.0	-22.7	4.4
CVPM 13	-7.4	-5.0	-3.7
CVPM 14	-41.9	-39.6	-39.3
CVPM 15	-23.5	-5.1	-6.3
CVPM 16	-6.7	263.4	263.6
CVPM 17	-7.6	11.4	10.2
CVPM 18	-6.4	-3.8	-3.5
CVPM 19	-34.3	-32.0	-31.7
CVPM 20	-28.8	-26.2	-25.9
CVPM 21	-33.6	-31.2	-30.9
GW-AV	567.0	569.3	569.5
GW-CH	3,141.6	3142.2	3141.6
GW-IM	0.0	0.0	0.0
GW-MJ	349.2	351.5	351.5
GW-MWD	555.8	558.0	558.3
GW-OW	602.3	594.9	602.5
GW-SC	79.1	294.3	78.8

Sacramento Basin Conjunctive Use

Perhaps the most promising conjunctive use opportunity in the Statewide Unconstrained alternative is located in the Sacramento Basin. The Sacramento Basin includes demands in the Delta and extends northward to include CVPM 1 through 9, Yuba, Sacramento, Stockton, CCWD, EBMUD, and Napa-Solano. In addition to these economic demands is the Delta itself, one of the state's most important and sensitive environmental demands. Many of the upstream rivers such as the Sacramento and American are subject to minimum instream flows to insure that sufficient water is available for environmental purposes.

The Sacramento and American Rivers not only have two of the largest minimum instream flow requirements, but also are shared major water sources for a number of the area's users. The charts shown in Figures 2G-15 through 2G-18 illustrate increased conjunctive operation of the Sacramento basin-wide surface and groundwater resources under a statewide water market. These charts compare Base Case and statewide water market allocations from three sources in drought and non-drought years. In both the Base Case and statewide water market during non-drought years (normal and wet), the largest supply source is the Sacramento River, with groundwater pumping a close second and the American River a distant third (Figure 2G-15 and 2G-16). However, under the statewide water market optimized operations, Sacramento River allocations in the basin are significantly higher than in the Base Case, contributing over half of the supply (Figure 2G-18 and Table 2G-26 for details). At the same time non-drought year diversions from the American River and pumping from groundwater are minimized compared to Base Case operations.

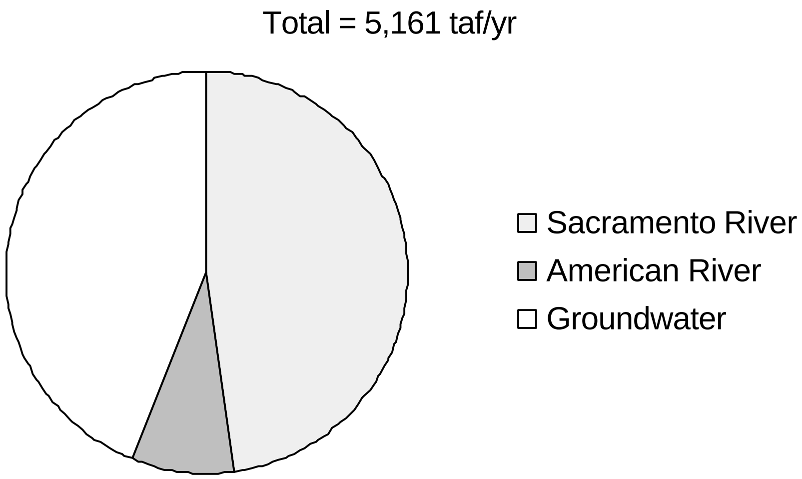

Figure 2G-15. Base Case Non-Drought Year Sacramento Basin Supplies

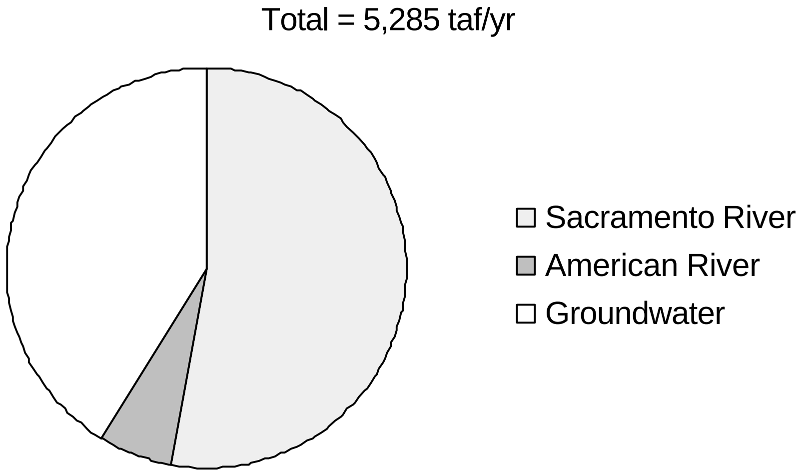

Figure 2G-16. Statewide Water Market Non-Drought Year Sacramento Basin Supplies

During drought years (14 out of the 72-year hydrologic sequence) the situation is markedly different. While the Base Case obtains a little more than half (53%) of its supply from groundwater during drought years (Figure 2G-17), the statewide water market uses significantly more groundwater, providing 64% of drought year supply (Figure 2G-18). Simultaneously, withdrawals from the Sacramento and American Rivers significantly drop in the statewide water market operations during drought years compared to Base Case drought year operations (Table 2G-27).

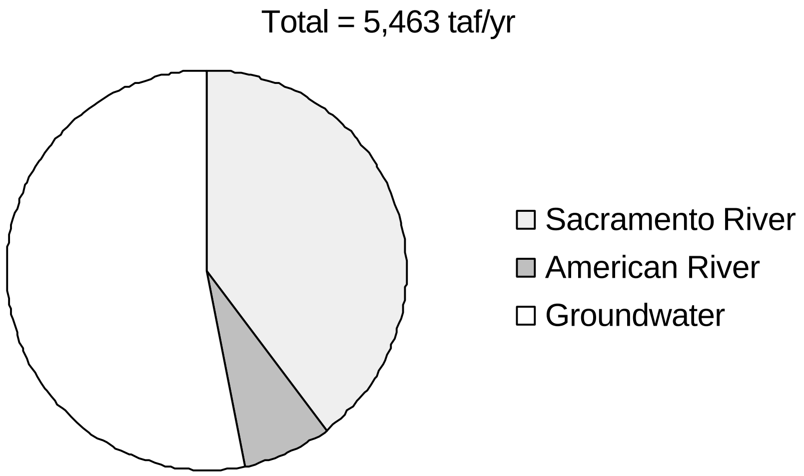

Figure 2G-17. Base Case Drought Year Sacramento Basin Supplies

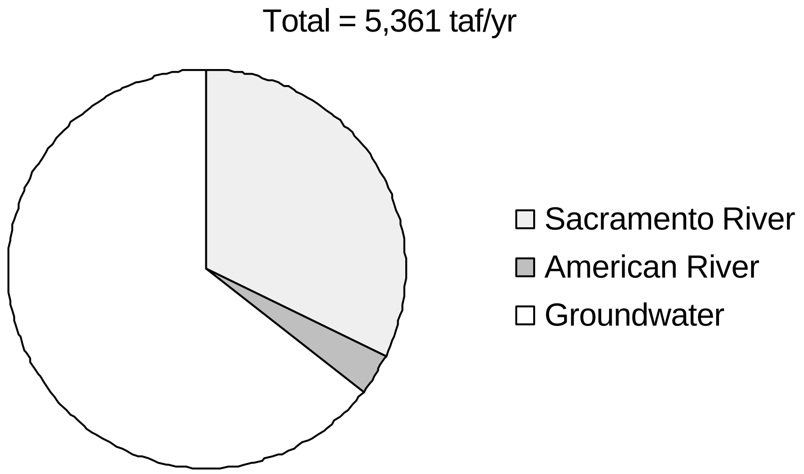

Figure 2G-18. Statewide Water Market Drought Year Sacramento Basin Supplies

Table 2G-27. Sacramento Basin Conjunctive Operational Changes

		Non-Drought		Drought	
		Average Diversions/Pumping (taf/yr)	% of Supply	Average Diversions/Pumping (taf/yr)	% of Supply
Sacramento River	BC	2468	48%	2164	40%
	SWM	2794	53%	1734	32%
American River	BC	432	8%	406	7%
	SWM	324	6%	178	3%
Groundwater	BC	2262	44%	2894	53%
	SWM	2167	41%	3449	64%
Total	**BC**	**5161**		**5463**	
	SWM	**5285**		**5361**	

BC = Base Case, SWM = Statewide Water Market

An important caveat to these results is that minimum groundwater pumping requirements are not imposed in CALVIN. In practice not all water users have access to surface water, and must pump groundwater. Every CVPM region has some minimum amount of groundwater pumping which may not be respected in the CALVIN results.

Changes in diversions from the Sacramento and American Rivers under the statewide water market re-operations can have significant consequences for the environmental concerns in the region. In the Base Case, diversions from both the Sacramento and American Rivers are fairly consistent across all years, even during critically dry periods (Figures 2G-19 and 2G-20). In contrast, under the greater basin-wide conjunctive operations of the statewide water market, diversions are much more variable, depending on hydrologic conditions. They frequently drop to much lower levels than in the Base Case, especially during critically dry periods (Figures 2G-21 and 2G-22) and rise to higher levels during wet years.

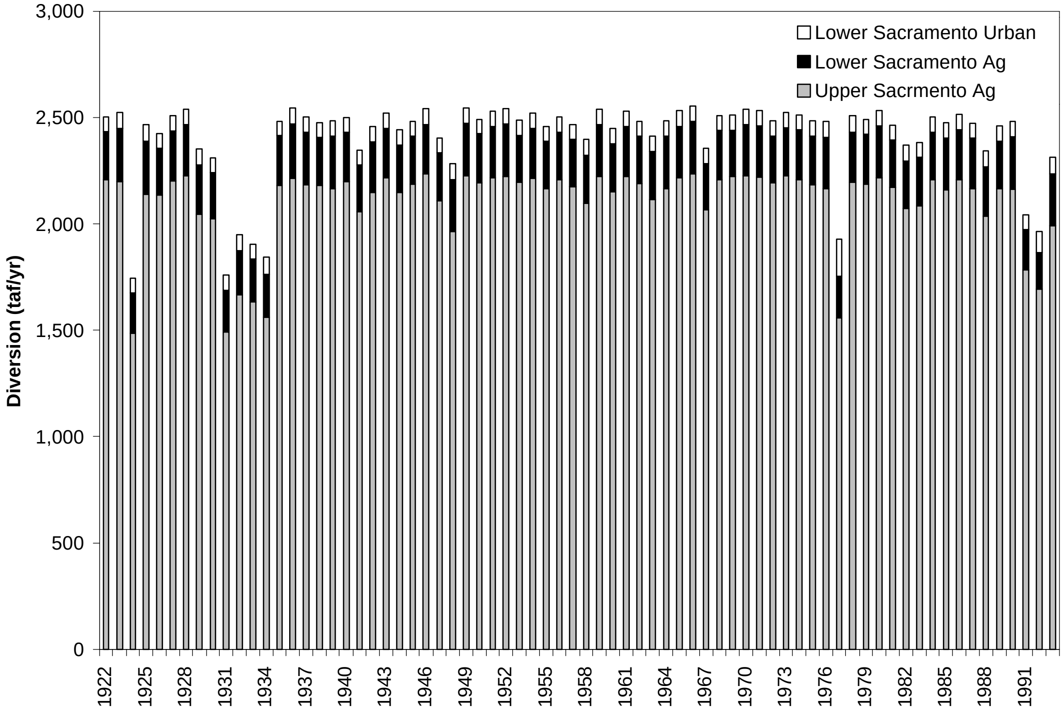

Figure 2G-19. Base Case Sacramento River Diversions (taf/yr)

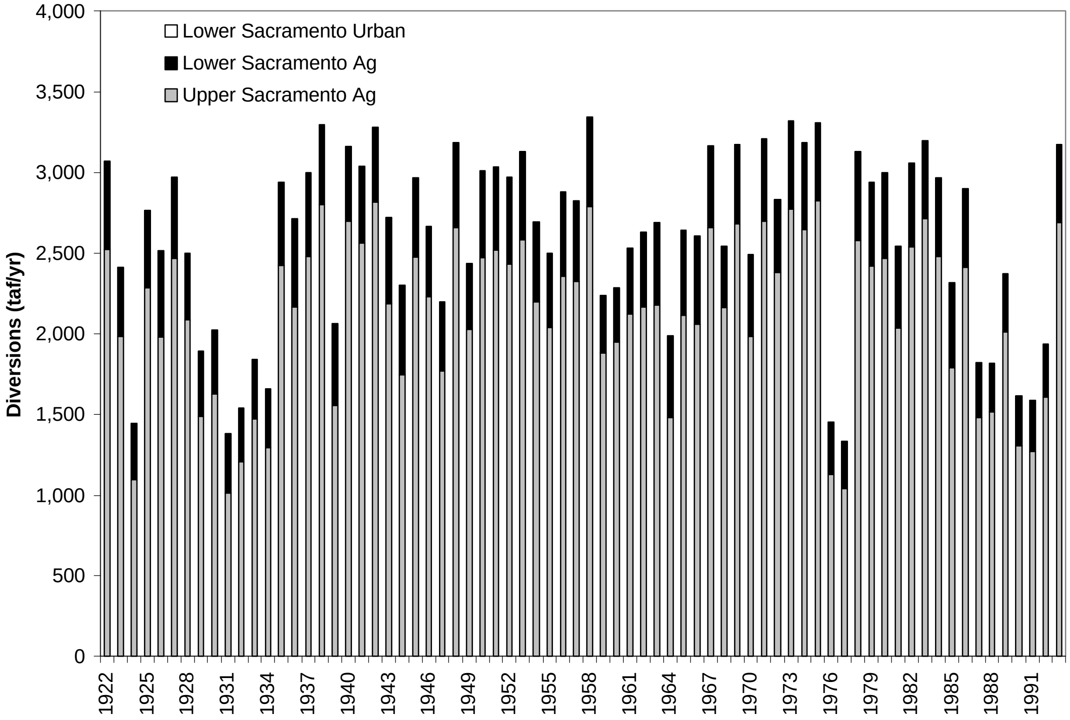

Figure 2G-20. Statewide Water Market Sacramento River Diversions (taf/yr)

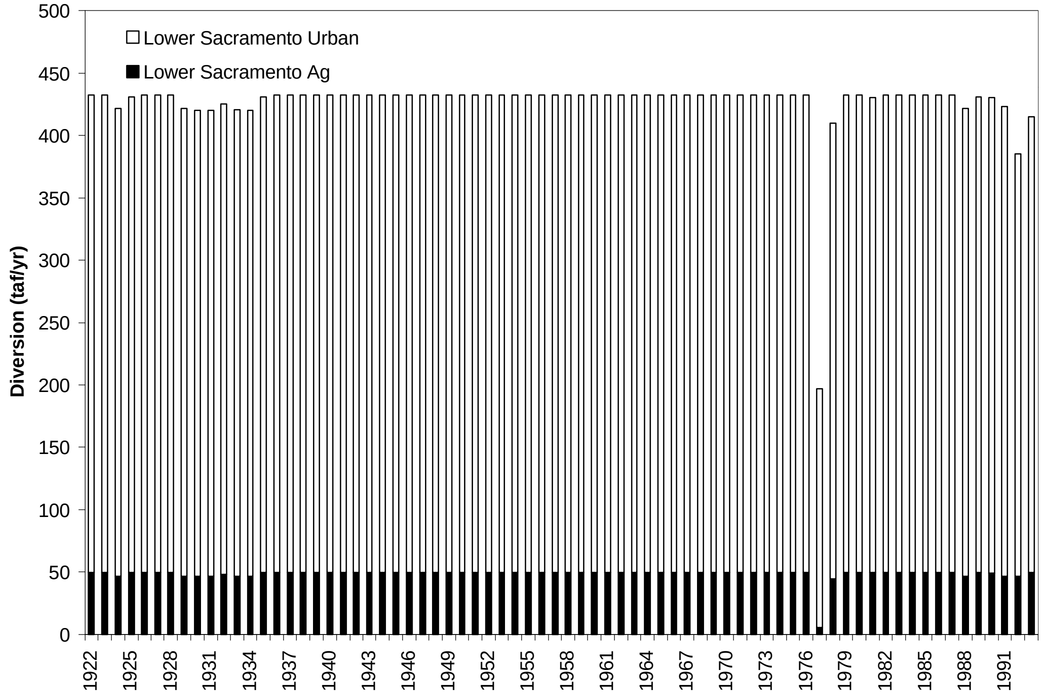

Figure 2G-21. Base Case American River Diversions (taf/yr)

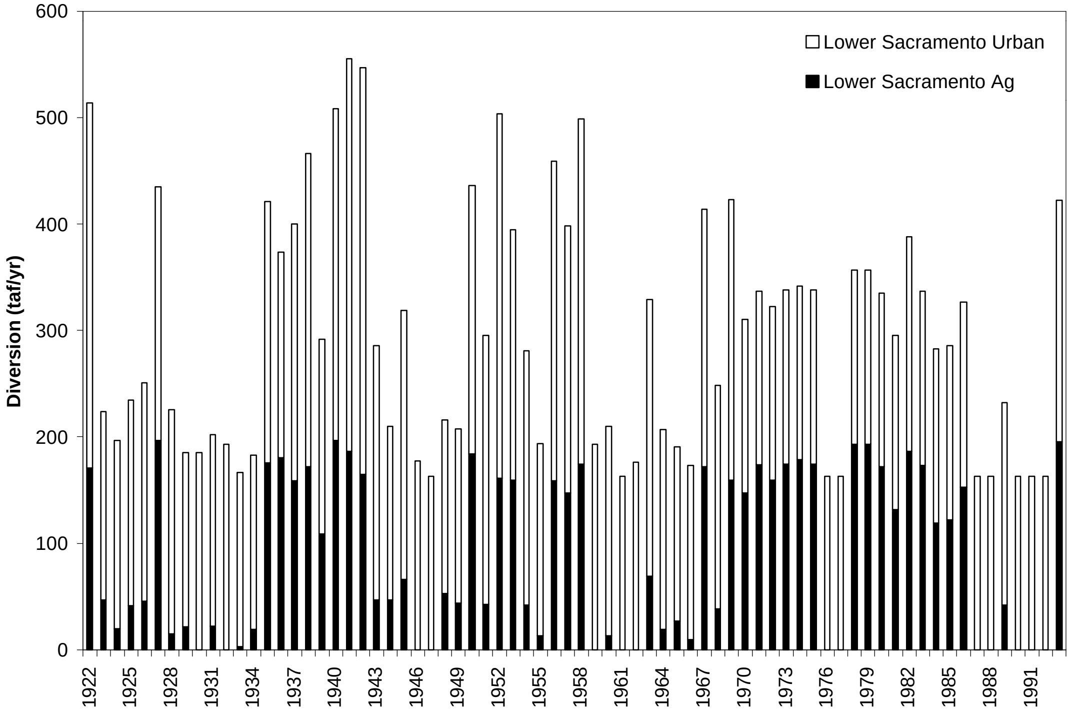

Figure 2G-22. Statewide Water Market American River Diversions (taf/yr)

In the statewide water market, Lower Sacramento urban demands (Greater Sacramento) completely eliminate diversions from the Sacramento River. Water from the Sacramento River has the highest treatment costs ($70/af) of the surface sources available, while pumping groundwater from the two available basins (CVPM 7 and 8) is only $57/af and $55/af, respectively, encouraging Greater Sacramento to more fully utilize groundwater supplies.

In non-drought years the Statewide Unconstrained market allocations from the Sacramento River increase by 326 taf/yr on average over the Base Case, while American River diversion and groundwater pumping decreases. During drought years, the situation reverses; statewide allocations from the Sacramento River drop by 430 taf/yr less compared to the Base Case. The difference is met in the statewide water market by increased groundwater pumping. Diversions from the American River drop even lower in drought years under a statewide water market and contrast with increases in Base Case drought year American River diversions (see Table 2G-28). Overall, under the statewide water market diversions are reduced during drought periods by 1206 taf/yr from non-drought year averages, compared to only 252 taf/yr reduction in diversion in the Base Case from non-drought to drought years.

Table 2G-28. Comparison of Diversions

	Sacramento River		**American River**	
Diversions	BC	SWM	BC	SWM
Drought Average Diversions (taf/yr)	2164	1734	427	178
Non-Drought Average Diversions (taf/yr)	2324	2794	419	342
Change in Diversions (taf/yr)	-260	-1060	8	-146

BC = Base Case, SWM = Statewide Water Market

PROMISING AREAS FOR FACILITY EXPANSION

When CALVIN re-allocates water to increase overall regional economic benefit, it is sometimes limited by the capacities of storage and conveyance infrastructure. Scarcities and higher operating costs can be caused either by insufficient water to meet demands or by insufficient infrastructure capacity to move the water to where it is needed. In situations where storage or conveyance capacities are binding, CALVIN's network flow solver generates the value of an additional unit of water if capacity could be increased.

Storage Expansion

As shown in Table 2G-29, significant expansion values remain on several South-of-Delta reservoirs in a statewide market, including Lake Kaweah and Lake Success in the Tulare Lake Region, and Grant Lake on the Los Angeles Aqueduct. Expansion of these reservoirs would allow greater flexibility in operations, particularly in dry periods.

Table 2G-29. Marginal Values for Surface Storage Expansion ($ per year/af)

Reservoir	Annualized Average Marginal Value			Max Value		
	1922-1951	1952-1968	1969-1993	1922-1951	1952-1968	1969-1993
Consistent high values:						
Grant	23.72	41.72	53.58	702.03	703.71	625.29
Kaweah	26.92	33.89	35.92	34.30	36.56	36.88
Success	24.15	27.33	28.42	34.22	36.55	36.71
High peak values:						
EBMUD	0.00	0.00	39.37	0.00	0.05	984.34
Hetch Hetchy	0.19	18.67	0.24	0.29	309.57	0.40
LAA Storage	0.00	0.00	21.61	0.00	0.00	526.34
Long Valley	0.04	0.00	21.10	0.62	0.00	526.80
Skinner	0.21	10.85	0.24	0.35	180.91	0.43
Pardee	0.25	0.32	41.22	0.57	0.97	1020.70
Santa Clara	6.96	0.00	27.35	192.97	0.00	249.20

Several facility expansion projects currently under consideration did not appear to have significant value in this analysis. Minimal expansion values on Lake Shasta indicated that raising Shasta Dam would have insignificant value in a statewide water market. In addition, expansion values of $14.34 per year/af on the proposed Los Banos Grandes storage facility were significantly reduced in the Statewide Unconstrained alternative.

Conveyance Expansion

Increased conveyance expansions could enable economically driven demand areas to receive more water than is currently available. In some cases the most significant benefits would come from implementing proposed conveyance facilities. However, the greatest benefits would come from expanding Coachella's artificial recharge facility in Southern California and the Hetch Hetchy Aqueduct in the San Joaquin and South Bay Region (Tables 2G-30 and 2G-31).

Table 2G-30. Marginal Value for Major Conveyance Facility Expansion ($/af per yr)

Conveyance	Current Max Capacity (taf/yr)	Monthly Average ($/af-yr)
Folsom South Canal	0	26
Mokelumne Aqueduct to/from Contra Costa Canal Link	0	126
Hetch Hetchy Aqueduct	336	280
Colorado River Aqueduct	1303	209
Los Angles Aqueduct	48	13

Table 2G-31. Marginal Value for Local Conveyance Facility Expansion ($/af per yr)

Conveyance	Current Max Capacity (taf/yr)	Monthly Average ($/af-yr)
EBMUD Recycled Water Facility	25	20
San Francisco Recycling	0	72
South Bay Groundwater Pumping	366	179
Santa Clara Valley Recycling	16	47
Coachella Artificial Recharge	10	2796

Water Transfers

Previous sections of this report outline how water is transferred throughout California's inter-tied water system in idealized regional and statewide water markets. With regional water markets, on average 610 taf/yr of the water "sold" in the markets is from agriculture and 180 taf/yr is from improved operational efficiencies. Of the water "purchased", 116 taf/yr goes to agricultural users and 673 taf/yr to urban users. With a statewide water market, agricultural users "sell" less water (417 taf/yr) and 700 taf/yr becomes available from operational improvements. Agricultural users "buy" 373 taf/yr and urban users 743 taf/yr.

Most agriculture-to-urban transfers occur in Southern California. Approximately 400 taf/yr of agricultural transfers of Colorado River water are used to alleviate urban scarcities in Southern California at costs less than SWP imports. Additional urban supplies from the Colorado River for Coachella, San Diego, and Metropolitan Water District demands allow some SWP imports to be reallocated to urban areas such as Mojave, Castaic Lake, and Antelope Valley in the statewide alternative.

Due to the re-operation of the California Aqueduct and the Friant-Kern Canals, about 440 taf/yr of California Aqueduct diversions into the Tulare Lake region are replaced with water from the San Joaquin system. This supply change facilitates more efficient use of surface supplies, reduces operating and scarcity costs, helping to eliminate the large Base Case agricultural scarcities in CVPM 18 (Appendix 2D further describes supply changes in the Tulare Region). This strategy, which emerges from the optimization model, of using San Joaquin River water for the Tulare Basin and Delta water for the San Joaquin Valley, accentuates a statewide water management strategy in place since the 1930 California Water Plan.

REGIONAL AGRICULTURAL ECONOMIC IMPACTS OF TRANSFERS

Results presented in this section are a regional summary of more detailed analyses contained in Appendix 2J, which reports economic impacts on agriculture of an ideal water market throughout the state at the CVPM agricultural demand area level. In addition to generating the agricultural demand functions utilized in CALVIN, the

Statewide Water Agricultural Production (SWAP) model generates estimates of the regional economic impacts on agriculture from CALVIN's agricultural deliveries. As Appendices A and K relate in detail, SWAP reacts to changes in water availability by changing cropping patterns within each agricultural demand region and by changing the water efficiencies of each crop. Thus, from CALVIN's agricultural delivery output, SWAP estimates changes in crop acreages, efficiencies, and gross and net revenues.

Table 2G-32. Regional Crop Acreages (thousands of acres)

	Base Case	Regional Unconstrained	Statewide Unconstrained
Region 1	941	944	944
Region 2	1502	1502	1502
Region 3	1379	1379	1379
Region 4	2958	2955	2966
Region 5	702	692	692
Total	**7482**	**7472**	**7483**

Table 2G-32 shows that changes in water availability have little overall effect on total crop acreages. Agriculture in Regions 1, 2, and 3 reacts to slight changes in deliveries primarily by changing their cropping mixes. The Regional Unconstrained runs experience a 0.46% reduction in agricultural deliveries, causing about 3,000 acres of cropland to be taken out of production in Region 4. The Statewide Unconstrained run allows water to be traded more freely, resulting in a 1.6% increase in agricultural deliveries and a subsequent increase of 11,000 acres of cropland under production. Acreage reduction in Region 5 (experienced in both runs) is offset by large SWM increases in CVPM 18 in Region 4, as well as several agricultural areas in Region 1.

Table 2G-32 below shows how regional Weighted Water Efficiencies (WWE's) are altered by changes in deliveries. WWE is defined as the sum of crop efficiencies multiplied by their respective shares of total applied water allocations (see Appendices A and 2J). The WWE is a measure of modifications in cropping patterns due to water allocation changes. Region 5 mitigates higher scarcity through more efficient allocations in both unconstrained cases. Greater flexibility in transfers in the Statewide Unconstrained run results in more ample supplies for several CVPM regions in the Upper Sacramento Valley and the Tulare Basin as compared to the Base Case, inducing a reduction in efficiency.

Table 2G-33. Change in Weighted Water Efficiencies

	BC - UC	BC - SWU
Region 1	1.0%	-3.5%
Region 2	0.0%	0.0%
Region 3	0.0%	0.0%
Region 4	1.0%	-1.6%
Region 5	12.3%	12.3%

Regional farm revenue from agricultural production effects of these changes in crop acreages and efficiencies appear in Table 2G-34. The prospect of increased revenues for Upper Sacramento Valley growers under regional and statewide water markets would provide strong incentives for growers to trade water. The Tulare Basin farmers would benefit by approximately $6 million under a statewide water market, but would experience a loss of $3 million under a regional market. Southern California suffers losses under any market in CALVIN's estimation, due to stiff competition from high urban values. The largest net revenue change in the state by crop occurs in the Southern California cotton market, where net revenue decreases by around 90% as compared to Base Case levels in both unconstrained runs (revenue changes for all other crops are less than 7.5%). Overall, agriculture in California would appear to incur annual net revenue decreases of approximately $8 million in a regional market, but would gain $2 million in net revenue from statewide water market.

Table 2G-34. Average Net and Gross Farm Revenue from Agricultural Production ($ millions/year)

	Gross Revenue			Net Revenue		
	BC	RU	SWU	BC	RU	SWU
Region 1	904	905	910	311	311	312
Region 2	1462	1462	1462	570	570	570
Region 3	1829	1829	1829	842	842	842
Region 4	4484	4477	4500	2008	2005	2014
Region 5	1268	1249	1249	593	588	588
TOTAL	**9947**	**9922**	**9949**	**4325**	**4317**	**4327**

WATER TRANSFERS AND ENVIRONMENTAL WATER

Water transfers and changes in operations would affect several areas of interest, including Delta flows, other environmental concerns, and water quality exchanges.

Impacts on the Delta

Re-operation of the state's water supply, both North and South of the Delta, leads to changes in the available water. The Delta is supplied from Rivers in the Northern portion of the state and is a major supply source for the South-of-Delta demands. Both the California Aqueduct and the Delta Mendota Canal deliver Delta exports (via Tracy and Harvey Banks Pumping Plants) to agricultural and urban demand areas in the San Joaquin and South Bay Region, Tulare Basin, and Southern California.

During drought years, Delta exports increase from 4.1 maf/yr in the Base Case to 4.9 maf/yr in the statewide water market. On average in the non-drought years, however, Delta exports decrease in the Statewide Unconstrained alternative (Table 2G-32).

Table 2G-32. Delta Exports

	Average Exports, Non-Drought (taf/yr)	Average Exports, Drought (taf/yr)
Base Case	6,086	4,097
Statewide Unconstrained	6,696	4,897
Change (BC – SU)	609	-800

The Statewide Unconstrained alternative increases Delta Exports in the summer months and decreases exports in the winter (Figure 2G-23). Much of these seasonal changes are the result of the different seasonal pattern of SWAP demands compared to that of Base Case agricultural deliveries. A similar pattern can be seen in the average Delta exports during the drought periods (Figure 2G-24). Despite the increased exports during the drought periods, in general the average year Delta exports decrease (Figure 2G-25). For example, in the Base Case there was a 27% chance of exporting more than 7021 taf/yr, while the probability of exceeding this level was 3% under the statewide water market.

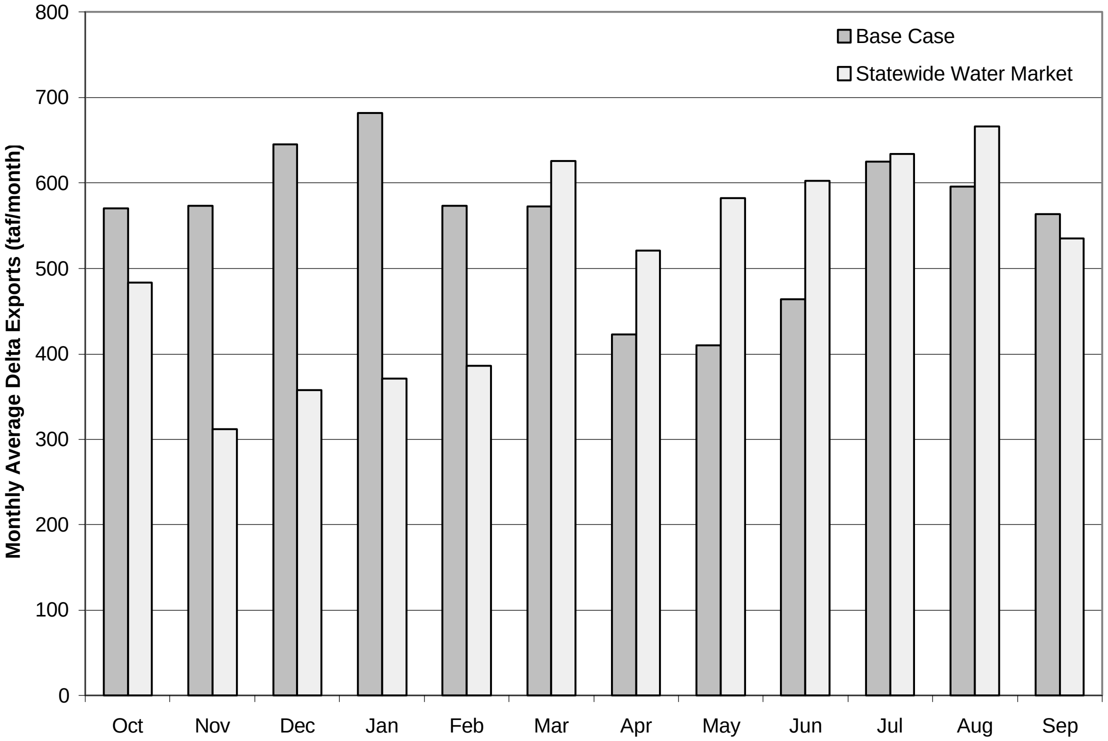

Figure 2G-23. Non-Drought Year Monthly Delta Exports (taf/month)

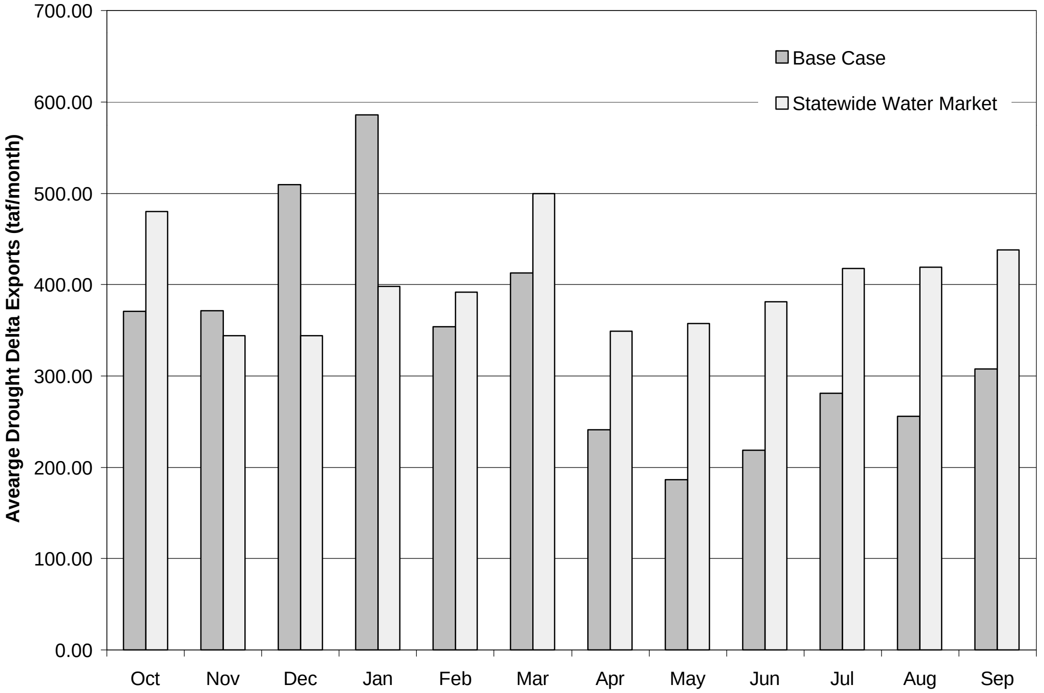

Figure 2G-24. Drought Year Average Monthly Delta Exports (taf/month)

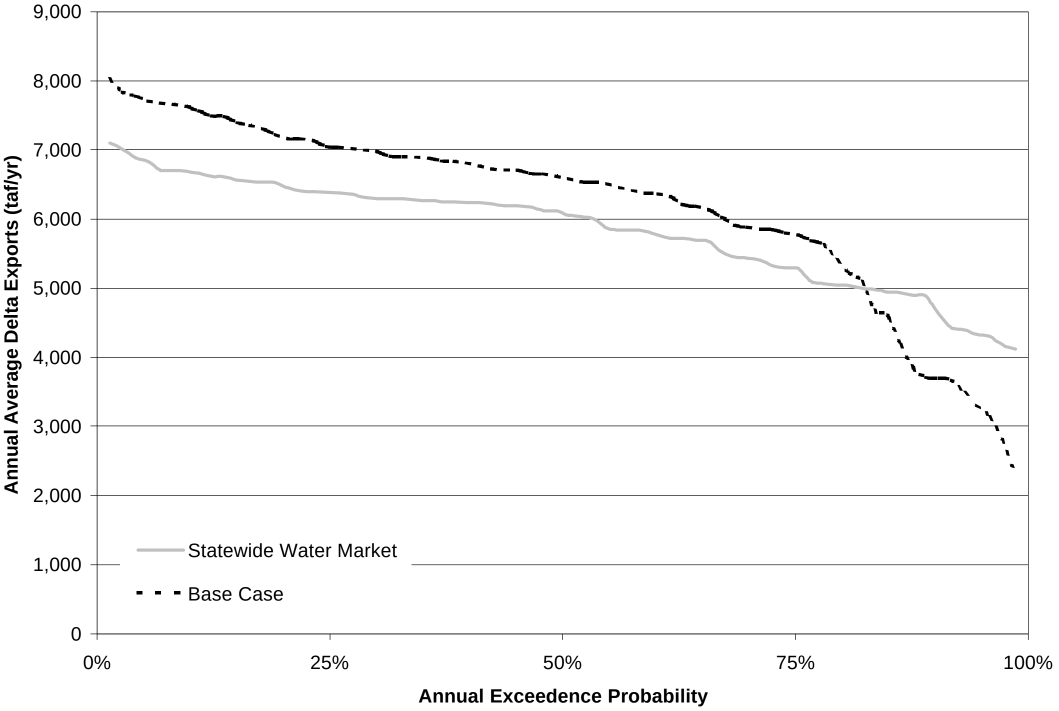

Figure 2G-25. Annual Exceedence Probability of Delta Exports (taf/yr)

Changes in Delta inflows and exports affect the amount of water available for Delta outflows to the Bay. Surplus Delta outflow is almost the same between the Base Case and the Statewide Unconstrained alternative (8738 taf/yr). This contrasts with the regional water markets, where surplus Delta outflows decrease by 78 taf/yr from the Base Case. However, surplus Delta outflows actually increase during the drought years with a statewide water market, largely due to the greater conjunctive use of surface and groundwater that occurs with statewide water market re-allocations and re-operations (Table 2G-33).

Table 2G-33. Surplus Delta Outflows

	Surplus Delta Outflow, Non-Drought Years (taf/yr)	Surplus Delta Outflow, Drought Years (taf/yr)
Base Case	10,550	1,016
Statewide Unconstrained	10,602	1,230
Change (BC – SU)	52	214

Despite having similar annual average values, the monthly distribution of the surplus Delta outflow varies between the Base Case and the Statewide Unconstrained run. Statewide Unconstrained outflows are slightly higher in the winter and early spring months, and less in the summer and fall months. The same seasonal trend appears during drought years, except that there is virtually no surplus Delta outflow in the summer months and significantly higher outflow in winter months. Thus the increased surplus Delta outflow presented in Table 2G-32 in drought years is due to higher winter flows, rather than increased flow in all months (Figures 2G-26 and 2G-27).

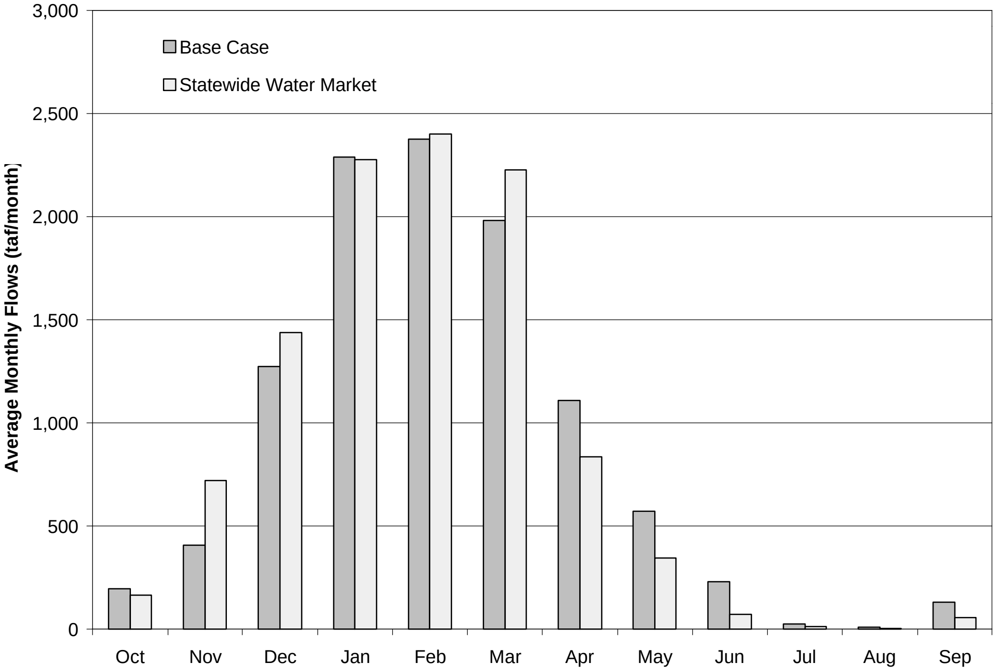

Figure 2G-26. Average Non-Drought Year Surplus Delta Outflow (taf/month)

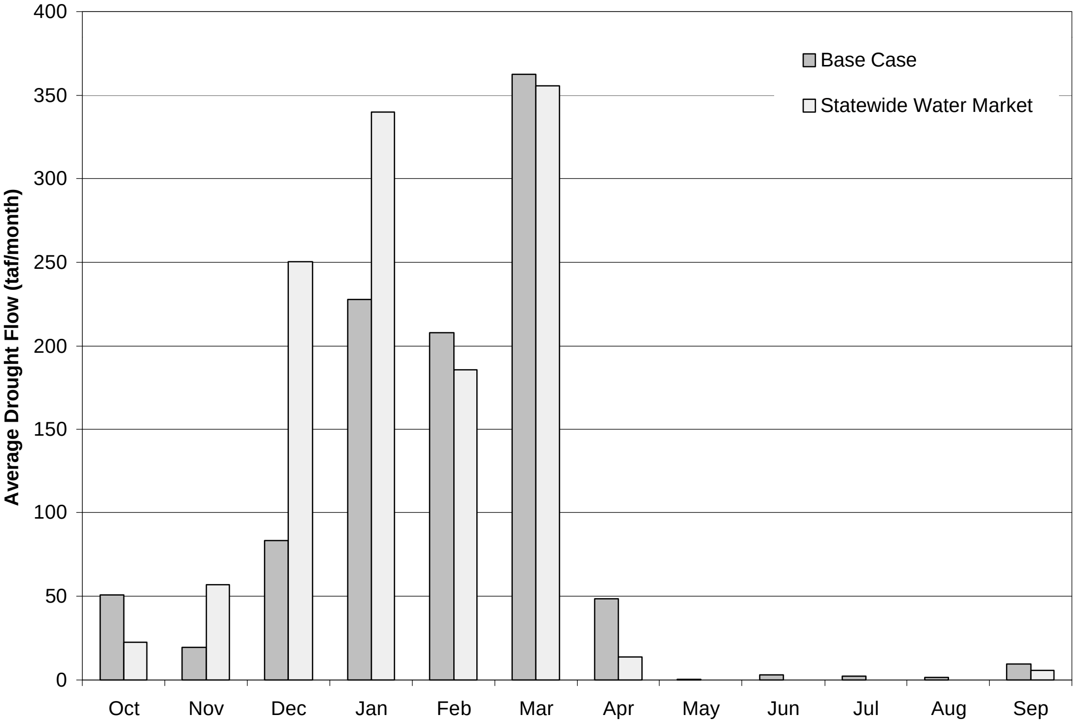

Figure 2G-27. Average Drought Year Surplus Delta Outflow (taf/month)

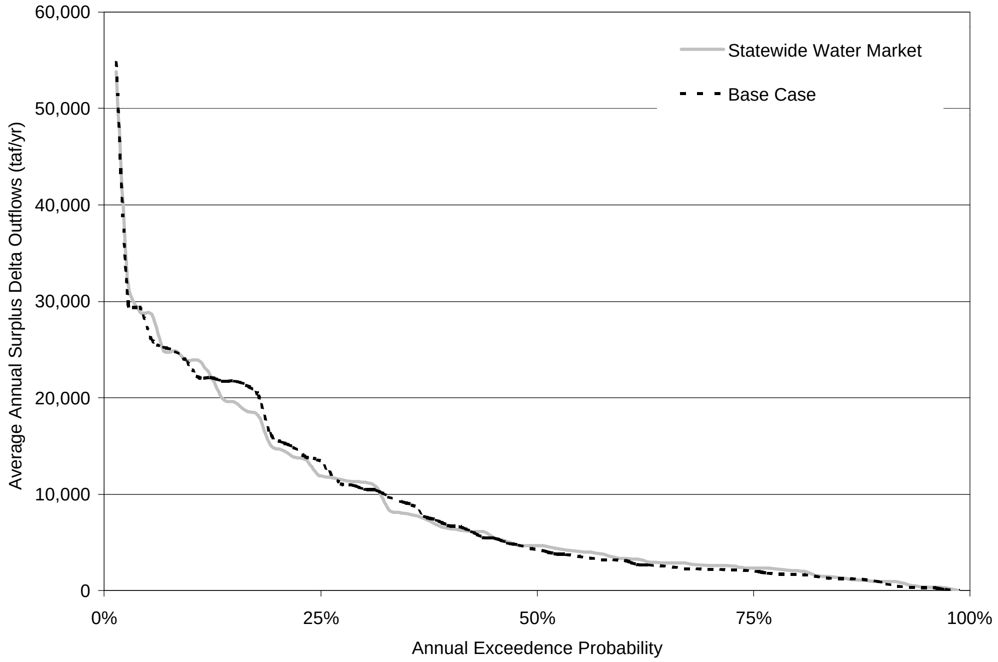

Figure 2G-28. Annual Exceedence Probability for Surplus Delta Outflow (taf/yr)

The annual exceedence curves are almost the same between the Base Case and the statewide water markets (Figure 2G-28). This reflects the similarity in flows between the two alternatives. The minimum and maximum annual surplus outflow differ slightly, but in general the flows have the same distribution. There are differences as the flows increase, but only by 200 taf/yr at most and by 48 taf/yr on average.

Water Exchanges for Urban Water Quality

Many urban areas alter supply mixes to increase deliveries from higher quality sources in the Statewide Unconstrained alternative. Each surface supply source for an urban area has an associated treatment cost that reflects the relative quality of the available water. Trades driven by water quality typically occur between urban and agricultural users. Agricultural users are less concerned with water quality than urban users (i.e., agricultural users do not, generally, pay treatment costs for surface water deliveries).

One example of water exchanges is the Napa-Solano urban area in the Lower Sacramento Valley, which relies entirely on water deliveries from the Putah South Canal (Putah Creek) in the regional water market. In the Base Case, the urban area relies on equal deliveries from the Putah South Canal and the North Bay Aqueduct (Sacramento River). Treatment and distribution costs of Putah South Canal water are $65/af, while treatment and distribution costs for the North Bay Aqueduct water are $75/af. By eliminating Sacramento River water, Napa-Solano reduces their surface water operating costs. In turn CVPM 6, which uses Putah Creek water in the Base Case, increased deliveries from the Sacramento River. For CVPM 6, Sacramento River water is economically equivalent to water from Putah Creek.

Another example of water quality-based trades and other exchanges for reduced operating costs occurs between the Bay Area and San Joaquin agricultural users. The Santa Clara Valley (SCV) eliminates deliveries via the South Bay Aqueduct and increases Hetch Hetchy supplies from SFPUC and Delta water via the Pacheco Tunnel, since the costs associated with pumping and treating Pacheco Tunnel water ($375/af) are less than those associated with the South Bay Aqueduct ($404/af). In turn CVPM 10, which diverts water from the California Aqueduct south of the South Bay Aqueduct and north of Pacheco Tunnel, eliminates deliveries from the California Aqueduct and substitutes Delta Mendota Canal water. Just as with CVPM 6, California Aqueduct and Delta-Mendota Canal water are economically equivalent in CALVIN to the agricultural region.

Trades between various users (primarily agricultural and urban) have the potential to reduce operating costs for both agricultural and urban users. If an urban user can substitute higher quality water for lower quality water, then treatment costs will decrease. Agricultural users rarely see differences between surface water supplies and therefore should not incur economic costs when these trading with urban users in most cases.

SUMMARY OF WATER MANAGEMENT TRENDS

Model results presented earlier in this appendix are instrumental in identifying the benefits accrued from changing how water supplies are managed in a statewide water market, as well as the expected benefit from expanding facilities whose capacities are binding to the system. This section will present overall implications of implementing these changes.

- *Conjunctive use plays an important role in managing water efficiently statewide*. Agricultural areas throughout the state are able to alleviate surface water scarcity by relying on over-year storage of groundwater. The Sacramento Basin participates in agriculture/urban water source exchanges in addition to conjunctive management of their groundwater and American River supplies.
- *Operations north of the Delta utilize surface water to a greater extent, slightly reducing inflows into the Delta*. Supply mix variability is driven primarily by operating cost differentials in water markets, expanding the role of water exchanges and trading. Areas such as Sacramento and Napa-Solano use water markets to improve the reliability of their supplies and reduce water quality treatment costs.
- *Increased efficiency in managing supplies south of the Delta reduces dependency on Delta exports in the southern portion of the state*. Furthermore, re-operation of the California Aqueduct in a statewide market shifts Delta supplies away from Tulare Basin agriculture in favor of San Joaquin Valley agriculture, as well as urban demands in Southern California and Bakersfield. Tulare Basin agriculture

relies more heavily on San Joaquin water routed through the Friant-Kern Canal to alleviate large Base Case scarcities.

- *The lack of inexpensive sources encourages large agriculture-to-urban transfers in Southern California*. Overall Delta imports into Southern California increase by only 90 taf/yr on average in the Statewide Unconstrained alternative. Southern California agricultural scarcities are the only substantial agricultural scarcities in a statewide water market.
- *Unlike the Regional Unconstrained alternative, statewide water marketing grants large statewide economic gains without apparently compromising the environmental integrity of the Delta*. Surplus Delta outflows in the Statewide Unconstrained alternative are almost equivalent to Base Case flows.
- *Decreases in many environmental flow opportunity costs suggest that water markets show potential for reducing pressure on environmental demands in the state*. Most of these decreased environmental opportunity costs, however, are on river reaches with minimum instream flow requirements.
- *Average annual estimates of economic benefits derived from water markets are as high as $1.3 billion under regional water markets, and almost $1.4 billion under a statewide water market.* These benefits are derived from alleviation of scarcity costs in conjunction with operating cost changes. The minimal additional benefits of the statewide water market in comparison to regional water markets suggest that the bulk of economic benefits derived from water marketing comes from optimization of local supplies rather than heavy reliance on imports.

As in all modeling efforts, simplification of element representations leads to limitations in the capabilities of the model, as well as the practical implementation of its results. Issues such as perfect foresight, invariability of agricultural demands according to year type, and the exclusion of minimum groundwater pumping to represent demands without full access to surface water are significant factors in the “interpretability” of CALVIN results. A full set of limitations is outlined in detail in Chapter 5 of this report. Efforts to address these limitations, as well as the addition of hydropower and flood control economic values to CALVIN, are currently under way.

REFERENCES

Department of Water Resources (DWR), 1998. *The California Water Plan Update, Bulletin 160-98*. Sacramento, California: DWR.