APPENDIX 2C

REGION 3 RESULTS: SAN JOAQUIN AND SOUTH BAY AREA

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ABSTRACT

CALVIN, an economic optimization model, is used to assess the potential economic benefits to the San Joaquin and South Bay Region of re-operating and re-allocating water. The Base Case replicates the current water management system and the Unconstrained Case reflects how the system would be operated in an ideal regional water market. Model results indicate that slight urban scarcities in the Base Case are eliminated in the Unconstrained alternative. Operating costs, rather than scarcity, drive most of the supply mix changes under an ideal regional market. All scarcity is effectively eliminated in the Unconstrained alternative through supply re-allocation and facility re-operations, and marginal values on ending groundwater storages indicate potential to alleviate groundwater overdraft in the San Joaquin Valley.

INTRODUCTION

The California Value Integrated Network model, or CALVIN, 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 the state, subject to environmental and physical constraints, by optimally operating and allocating water supplies. Two distinct model runs are considered. The Base Case is calibrated to imitate operations and allocations from DWRSIM Run 514 and CVGSM NAA 1997 (current projected year 2020 operations and allocations). The Unconstrained Case then removes all non-environmental and flood control policy restrictions and allows CALVIN to re-operate and re-allocate water under ideal market conditions. Model results suggest not only optimal supply mixes for urban, agricultural, and environmental demands and improvements in the operation of existing facilities, but also how the expansion of key facilities would benefit the state economically.

To facilitate calibrating CALVIN to previous simulation models and analyzing regional benefits derived from alternative policies, the statewide CALVIN model has been divided into five sub-regions. Region 3, the San Joaquin and South Bay Region, is the subject of this appendix.

The next section reviews the physical characteristics of Region 3 and the approach CALVIN uses in representing water supply and demand. The remainder of the appendix reports CALVIN's results from the Base and Unconstrained Cases and discusses potential implications of these results for changes in the region's water resource operations and infrastructure.

REGION 3 MODEL DESCRIPTION

Geographically, Region 3 of the CALVIN model stretches across the middle of California (refer to Figure 2C-1), bordering the Sierra Nevada range on the east and extending westward to the urban areas of San Francisco Bay. The Upper San Joaquin River defines the southern boundary of the region, while the Stanislaus River to the east and the South Bay Aqueduct toward the west form the northern boundary. The region can be roughly divided into two main areas: the San Joaquin Valley, and the urban demand areas of San Francisco and the South Bay. North Bay communities (in Marin and Sonoma Counties) are not included in CALVIN since their water supply systems operate independently of the statewide network. Several North and East Bay area communities within East Bay Municipal Utilities District, Contra Costa Water District, and Napa and Solano Counties receive water from the Delta and Sacramento Valley directly, and therefore are included in the Lower Sacramento Valley and Bay Delta Region (or Region 2).

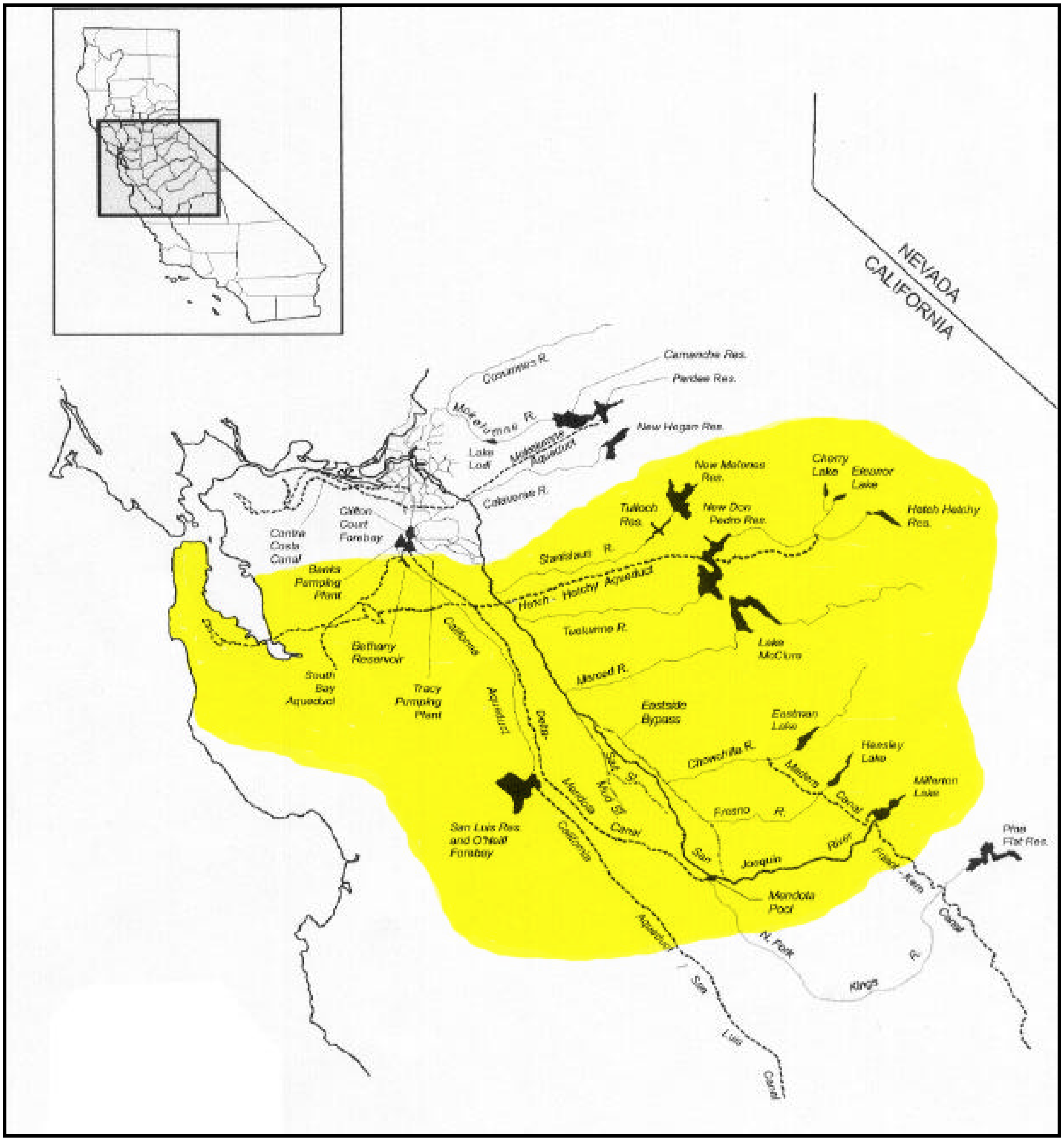

Figure 2C-1. San Joaquin and Bay Area Region

(*Adapted from CVPIA-PEIS, Figure III-3)*

Water demands for agricultural and urban areas throughout the San Joaquin Valley portion of the Region 3 are based on two kinds of spatial analysis units developed for planning purposes by the Department of Water Resources and the US Bureau of Reclamation: the Detailed Analysis Unit (DAU), and the agricultural regions of the Central Valley Production Model (CVPM regions). Two simulation models, the Department of Water Resources Planning Simulation Model

(DWRSIM) and the Central Valley Groundwater Simulation Model (CVGSM), provide the basis for comparison for CALVIN results. Supplies are derived mostly from CVGSM and DWRSIM, and demands are taken from DAU data. Table 2C-1 outlines how CALVIN represents agricultural water users within the San Joaquin Valley and how they relate to the CVPM and DAU spatial analysis units.

Table 2C-1. San Joaquin Valley Agricultural Water Users

CALVIN Demand	County	DAU	CVP Contractors	SWP Con-tractors	Others
CVPM 10	Madera, Merced, San Joaquin, Stanislaus	216	Central California ID, Panoche WD, Pacheco WD, Del Puerto, Hospital, Sunflower, West Stanislaus ID, Mustang, Orestimba, Patterson WD, Foothill, San Luis WD, Broadview, Eagle Field, Mercy Springs, Pool Exchange Contractors, Schedule II water rights, Grasslands WD	Oak Flat WD	None
CVPM 11	San Joaquin, Stanislaus	205 206 207	None	None	Stanislaus River water rights: Modesto ID, Oakdale ID, South San Joaquin ID
CVPM 12	Merced, Stanislaus	208 209	None	None	Turlock ID, part Stevinson WD, part Merced ID
CVPM 13	Madera, Merced	210-215	Chowchilla WD, Gravely Ford WD, Madera ID	None	majority of Merced ID

The dominant hydrologic feature of Region 3 is the San Joaquin River and its tributaries. In addition to several smaller streams like Cherry and Eleanor Creeks, major rivers such as the Fresno, Chowchilla, Merced, Tuolumne, Stanislaus, and San Joaquin are all explicitly modeled. Floods from the King's River in Region 4, which occasionally spill into the San Joaquin River, are represented by a time series inflow. For a detailed description of the approach used to model environmental flows, accretions and depletions, and external inflows, refer to Appendix I.

California has made extensive use of infrastructure to regulate the flow of water to meet agricultural, urban, and environmental demands. Fourteen reservoirs are represented in Region 3 (see Table 2C-2), nine of which are operated by the Central Valley Project or the State Water Project (indicated by an SR- prefix), and five of which are either locally owned and operated or represent an aggregation of several smaller local reservoirs. The capacities of these reservoirs range from 2.4 maf for the New Melones Reservoir on the Stanislaus River to Lake Del Valle on the South Bay Aqueduct, with a capacity of only 40 taf. Three aggregate reservoirs are modeled in Region 3 to simplify the representation of reservoir groupings that are operated cooperatively, since little data is available regarding actual operations. Information on reservoirs and their operations can be found in Appendix H.

Table 2C-2. Region 3 Reservoirs

CALVIN name	Description	Minimum Capacity (taf)	Physical Maximum Capacity (taf)
SR-10	New Melones	80	2400
SR-12	San Luis	80	2038
SR-15	Del Valle	10	40
SR-18	Millerton	120	521
SR-20	McClure	115	1024
SR-52	Hensley	4	90
SR-53	Eastman	10	150
SR-81	New Don Pedro	100	2030
SR-ASF	Aggregate SF (Calaveras, Crystal Springs, San Andreas, Pilarcitos, and San Antonio).	31	225
SR-HHR	Hetch Hetchy	36	360
SR-LL-LE	Aggregate Lloyd/Eleanor	30	301
SR-SCV	Aggregate Santa Clara (Anderson, Calero, Chesbro, Coyote, Guadalupe, Lexington, Pacheo, Uyas)	37	170
SR-TR	Turlock	11	67

Two key facilities instrumental in distributing much of the water needed by agricultural and urban users in Central and Southern California are the Delta Mendota Canal (DMC), owned by the Central Valley Project, and the California Aqueduct, owned by the State Water Project. The DMC, entirely contained within Region 3 with the exception of the Tracy Pumping Plant (located in Region 2) eventually flows into the Mendota Pool near the southern boundary. A portion of the California Aqueduct from Bethany Reservoir to Node 744 in DWRSIM includes the diversions serving the San Francisco and South Bay urban areas, as well as CVPM 10.

The Hetch Hetchy Aqueduct, another key facility, provides water to Bay area cities through diversions from several reservoirs at the headwaters of the Tuolumne River. It is the primary water source for the City and County of San Francisco and supplements supplies for urban areas in the South Bay.

An important feature of CALVIN is its integration of surface and groundwater resources. Five groundwater basins are modeled in Region 3. Four represent the groundwater basins underlying the four CVPM regions in the San Joaquin Valley (10 to 13). The fifth represents the aggregated groundwater resources of the Santa Clara Valley Water District, the Alameda County Water District, and Alameda County Zone 7, which all extensively use groundwater to augment and operate their supplies.

Due to limitations of CALVIN's network solver and time and data available to calibrate the model, several considerations were difficult to represent and were therefore excluded, including variable head hydroelectric operations, water quality, and variable head groundwater pumping (see Chapter 5). However, economic benefits derived from two fixed head hydroelectric facilities, the Gianelli and O'Neill Powerplants, are included. Treatment costs were also incorporated in appropriate locations to reflect water quality management costs (see Appendix G).

Demands on California's water can be categorized into three sectors: urban, agricultural, and environmental. These demands are represented in various ways in Region 3. 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 to quantify, environmental demands in CALVIN have been modeled by constraining the system to meet minimum instream flow requirements and mandatory deliveries to the two aggregated refuge areas modeled in Region 3, the Volta and San Joaquin Wildlife Refuges.

Implementation of the increased environmental water allocations outlined in the Central Valley Project Improvement Act (CVPIA) will have an important role in water allocation decisions in the future. However, for the purpose of comparison to the CVGSM and DWRSIM simulation models, the two alternatives considered in this appendix enforce historic refuge allocations (Level 2), not the recently mandated CVPIA (Level 4) demands. For an in-depth description of the Volta and San Joaquin Refuges, as well as the environmental flow requirements included in CALVIN, see Appendix F.

Agricultural demands are modeled using economic value functions for water generated by the Statewide Water and Agricultural Production Model, or SWAP. Details regarding the modeling approach used to represent agricultural demands can be found in Appendix A.

Urban demands within the San Joaquin Valley portion of Region 3, including cities like Modesto, Turlock, Merced, Manteca, and Madera are not economically modeled since water value data was unavailable. Deliveries to these urban regions are fixed at 2020 projected demands in both the Base and Unconstrained Cases (see Appendix B). These urban areas rely almost exclusively on groundwater.

In contrast to the fixed urban demands in the San Joaquin Valley, urban demands in San Francisco, Santa Clara Valley, and southern Alameda County are represented economically using water value functions. The “San Francisco Public Utilities Commission” demand area (SFPUC) is an aggregation of the city and county of San Francisco and most of San Mateo County. This area depends on two sources for water: the Hetch Hetchy system, which is owned by San Francisco and delivers water from the Sierras, and five local reservoirs.

The “Santa Clara Valley” urban demand area (SCV) is an aggregation of the Santa Clara Valley Water District, Alameda County Water District, and Alameda County Zone 7. It includes cities such as San Jose, Santa Clara, Palo Alto, Hayward, Fremont, Dublin, and Livermore. Supplies to the SCV area include SWP water from the California Aqueduct, CVP water from the San Felipe Unit, Hetch Hetchy water purchased from SFPUC, groundwater, and local surface water. Documentation and further references on CALVIN’s representation of these urban areas can be found in Appendix B.

Economic performance of the region’s water supply system is judged by the economic value of water for agricultural and urban uses. The difference between water deliveries and the estimated maximum amount of water a water user would desire if the price were zero is termed “scarcity” and is thus a pessimistic indicator of unmet demand. CALVIN generates economic penalties for unmet demands using scarcity value functions.

Modeling Alternatives

Two alternatives have been evaluated in this appendix. 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 Unconstrained Alternative, 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 enforced 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 storages.

Base Case Assumptions and Limitations

The Base Case model is used to compare possible alternatives to water allocations under current operating policies and existing infrastructure. It is constrained to meet projected 2020 agricultural, urban, and environmental water demands using existing/planned facilities and current operating rules.

Of the thirteen reservoirs modeled in Region 3, eight reservoirs were constrained to match operations in DWRSIM Run 514. Turlock Reservoir on the Stanislaus River below New Melones was included to more accurately depict operations on the Stanislaus. Storage data for New Melones was taken from the No Action Alternative (1997) of SANJASM, a simulation model used extensively in the CVPIA studies. Storage and release data for Hetch Hetchy, aggregate Lloyd/Eleanor, aggregate San Francisco, and aggregate Santa Clara Reservoirs were not available. SR-ASF and SR-SCV were therefore left unconstrained in the Base Case, while SR-HHR and SR-LL-LE storages were implicitly constrained by downstream Tuolumne flows and Hetch Hetchy Aqueduct flows.

The least constrained operations in Region 3 are those within the Bay Area. Imports from SWP, CVP, and the Tuolumne River to SFPUC and SCV urban demands are constrained to Base Case levels. However, operations and allocations between and within the two demand regions are fully optimized, bound only by physical capacities, since little data is currently available to properly represent Base Case local operations within these demand regions.

Output data from CALVIN reflect several of the model's limitations. Because detailed data were often unavailable and to reduce computation times, elements within the model often had to be aggregated. A complex network requires additional computing time and data. Furthermore, CALVIN uses average urban and agricultural demands to drive its economic optimization algorithm, not demands based on year type (where water demands vary with precipitation and temperature conditions).

Another important limitation is the perfect foresight with which CALVIN optimizes economic benefit. Because it solves for optimal storages, flows, and diversions over a 72-year period simultaneously, it effectively has no hydrologic uncertainties to consider, allowing the system to prepare for droughts and surpluses in advance. Scarcity, economic benefits, and costs are therefore generally reduced compared to operations with imperfect foresight. The effects of hydrologic foresight seem to diminish considerably in terms of water supply when more groundwater is available for use, representing considerable carryover storage. See Appendix 2K for a more detailed explanation of this limitation and efforts under way to address it.

Other simplifications and limitations in CALVIN mean that results obtained from CALVIN become most meaningful when overall trends are considered. Chapter 5 presents an extensive discussion of the limitations to the CALVIN model and its underlying data.

Unconstrained Case Assumptions and Limitations

As noted earlier, the Unconstrained Case optimizes water allocation to maximize economic benefit to agricultural and urban water users, given available water and infrastructure. Allocations are constrained only by physical capacities of reservoirs and conveyance facilities, imposed environmental requirements, and seasonal flood control requirements on reservoirs. Surface and groundwater storages are constrained to the same end-of-period storage in the Unconstrained Case as in the Base Case, ensuring that the overall amount of water in the system remains constant between the two model runs. In the Unconstrained Case, CALVIN seeks to allocate and operate water solely to minimize urban and agricultural scarcity costs plus variable operating costs associated with allocations and operations, thus maximizing economic benefit to the entire region.

In short, this alternative represents ideal water market or other economics-base water operations and allocations, without consideration of contractual or other water rights. As in the Base Case, perfect foresight can reduce scarcity and costs below realistic levels.

Once the regional Base Case models were calibrated and Unconstrained Alternative results evaluated, the five regions were meshed together to examine economic benefits and water allocations under a statewide model of the Unconstrained Alternative. These statewide model results can be found in Chapter 4 and Appendix F of this report.

COMPARISON OF MODEL RESULTS

In this section, results from the Unconstrained Alternative are compared to the calibrated Base Case results. An initial regional 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' re-allocation of supplies on agricultural and urban demands. 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 for Changes" section of this appendix.

Water Delivery Results

A cursory comparison of overall urban and agricultural deliveries suggests that unlike the southern portion of the state, surface inflows from the Sierras and ample groundwater supplies are sufficient to meet demands within Region 3 for the conditions assumed. Table 2C-3 provides a summary of the demands and supplies for the entire San Joaquin Valley and Bay Area Region.

Table 2C-3. Region 3 Water Budget

	Base Case	Unconstrained Case

		Average (taf)	Average (taf)	Drought** (taf)
Water Demands				
	Urban	1440	1440	1440
	Agricultural	5259	5259	5259
	Environmental*	273	273	273
	Total	**6972**	**6972**	**6972**
Deliveries (less conveyance losses)				
	Surface Water***	3699	3697	2716
	Groundwater	2393	2404	3385
	Reuse/Reclamation	864	871	870
	Total	**6956**	**6972**	**6972**
Scarcity		**16**	**0**	**0**

Notes:
** Based on CALVIN results*
*** Drought years throughout this appendix refer to the water years of 1929-1934, 1976-1977, and 1987-1992 (DWR, pg. 3-7)*
**** Does not include surface water used for artificial recharge (this is included in groundwater deliveries).*

The minor scarcities in the Base Case, all of which are from the urban sector, are eliminated in the Unconstrained alternative for both average and dry year conditions. The reliability chart below portrays total deliveries for the agricultural and urban sectors and provides an introductory glance at how an ideal market policy might compare to allocations under current operating policies and infrastructure.

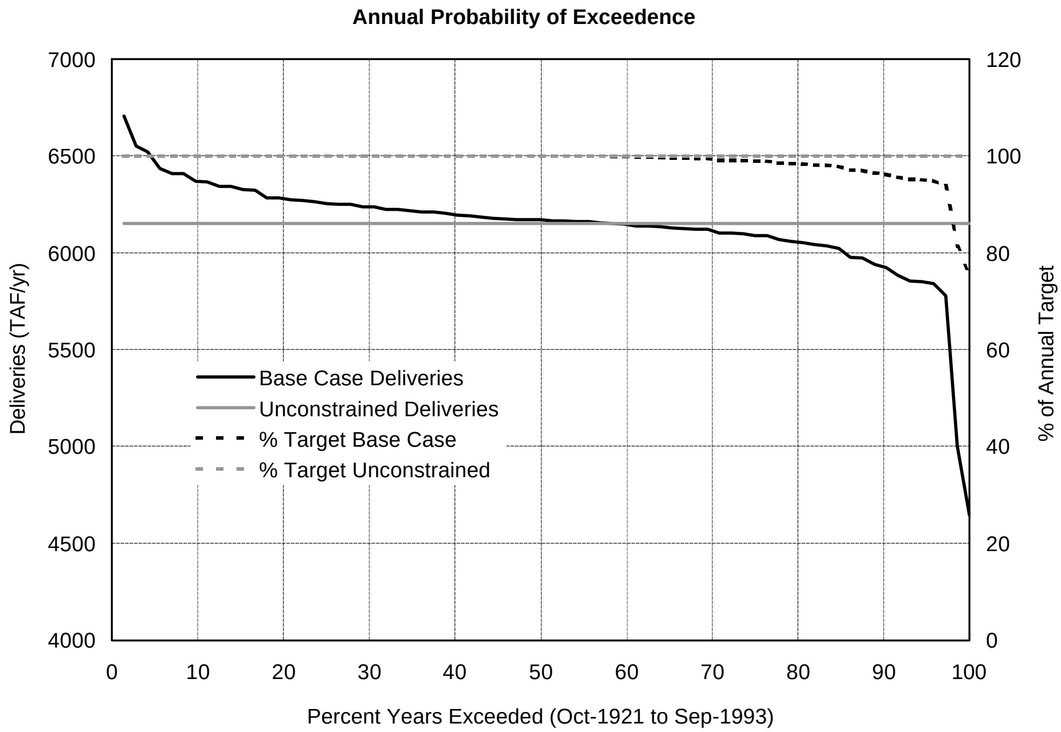

Figure 2C-2. Total Agricultural and Urban Deliveries

The "over-deliveries" shown in the above chart are an unfortunate byproduct of CALVIN's current approach to modeling agricultural demands. The simulation models used to calibrate CALVIN vary agricultural demands according to year type, whereas CALVIN uses fixed demands from year to year. Thus when agricultural deliveries are constrained to match CVGSM deliveries in the Base Case, the model is occasionally forced to deliver more water than CALVIN's demands would call for.

Table 2C-4 compares urban and agricultural deliveries under Base Case allocations to those under the Unconstrained alternative. The slight increase in urban deliveries in the Unconstrained run eliminates the 16 taf urban scarcity in the Base Case. Results reported throughout this appendix will indicate that operating costs, rather than scarcity costs, play the most significant role in determining supply mix changes in an ideal market.

Results indicate little difference in overall conjunctive surface and groundwater use as well, though CALVIN was able to satisfy urban scarcities in the Base Case through more efficient use of surface water supplies. Groundwater deliveries are the same between the two runs, since ending groundwater storage in the Unconstrained Run was fixed to match the Base Case.

Table 2C-4. Region-wide Average Annual Deliveries by Source

Water Source	Base Case (taf/yr)	Unconstrained (taf/yr)

	Agricultural	Urban	Total	Agricultural	Urban	Total
Surface Water	3,408	748	4,156	3,406	764	4,170
Groundwater	1,492	676	2,168	1,492	676	2,168
Total	**4,900***	**1,424**	**6,324**	**4,898***	**1,440**	**6,338**

Note:
**Deliveries may differ from the demands reported in Table 2C-3 because some water supplies are recycled.*

Scarcity and Operating Costs

As stated earlier, CALVIN attempts to maximize economic benefit to Region 3 by minimizing both the cost of water scarcity and operating costs to the system. Table 2C-5 indicates that scarcities were found only in the San Francisco and Santa Clara urban areas in the Base Case. A combined annual average scarcity of 16 taf "cost" roughly $16 million in unrealized economic benefit. These estimates rise to nearly $61 million in Base Case drought years, when urban scarcities rise to nearly 62 taf/yr. Urban scarcity costs are effectively eliminated in the Unconstrained Run in both average and drought year conditions.

Table 2C-5. Average Annual Scarcities and Scarcity Costs in Region 3

		Agriculture			Urban		
	Model Case	Scarcity (taf)	% Scarcity	Cost ($1000)	Scarcity (taf)	% Scarcity	Cost ($1000)
Annual Average	Base Case	0	0	0	16.0	1.8	15,290
	Unconstrained	0	0	0	0	0	0
Drought Yr. Average	Base Case	N/A*	N/A	N/A	61.5	6.9	60,900
	Unconstrained	0	0	0	0	0	0

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.*

In addition to reducing scarcity costs throughout Region 3, the ideal market represented by the Unconstrained Run was successful at reducing operating costs by an additional $21 million dollars on an annual average basis. These operating costs were mainly due to groundwater pumping or recharge, and conveyance pumping. Table 2C-6 depicts how the reduction of both scarcity and variable operating costs result in a $36 million annual benefit to the Bay Area and San Joaquin Valley.

Table 2C-6. Variable Economic Costs (Average Year)

	Base Case ($M/yr)	Unconstrained ($M/yr)	**Cost Difference ($M/yr)**
Scarcity Cost	15.3	0	**15.3**
Operating Cost	379.1	358.3	**20.8**
Total Cost	**394.4**	**358.3**	**36.1**

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

Agricultural Supply Sources

Agriculture within the San Joaquin Valley depends heavily on irrigation from surface water (diverted from a network of rivers and canals), and groundwater. The four agricultural areas represented in Region 3, all of which are located in the San Joaquin Valley, show differing supply mixes of groundwater and surface diversions, depending on their access to "free" surface water.

To gain an accurate understanding of the dynamics of the region, the ending groundwater storage in the Unconstrained Run at the end of the 72-year hydrologic period was constrained to match the Base Case ending storage, thus ensuring that the overall amount of groundwater pumping between the two alternatives was kept constant. Because there was no agricultural scarcity in the Base Case, Unconstrained Run results showed no average overall change in the mix between groundwater and surface water usage throughout the agricultural sector. However, CALVIN attempted to re-allocate surface sources to reduce overall operating costs, resulting in significant supply mix changes in several CVPM regions.

CVPM 10 (see Table 2C-7), located along the western portion of the San Joaquin Valley, showed a slight decrease in reliance on San Joaquin River water, while State Water Project diversions from the California Aqueduct were eliminated (for reasons discussed later). These reductions were compensated by greater Central Valley Project diversions from the Delta Mendota Canal.

Table 2C-7. CVPM 10 Supplies (taf/yr)

Supply Source	Base Case Supply	Base Case %	Unconst. Supply	Unconst. %
Lower San Joaquin River	169.2	9.7%	261.0	14.9%
DMC Diversion	477.3	27.2%	621.2	35.5%
Lower Cal. Aqueduct	86.3	4.9%	0.1	0.0%
Upper San Joaquin River	607.2	34.7%	462.1	26.4%
Upper Cal. Aqueduct	4.5	0.3%	0.0	0.0%
GW-10 pumping	*407.6*	*23.3%*	*407.6*	*23.3%*
TOTAL	**1752.0**		**1752.0**	

CVPM 11 in the northeast corner of the San Joaquin Valley, showed almost no change in surface supplies (see Table 2C-8). The assumption of no groundwater pumping was made to force CALVIN to mimic CVGSM's approach to groundwater allocations in both alternatives.

Table 2C-8. CVPM 11 Supplies (taf/yr)

Supply Source	Base Case Supply	Base Case %	Unconst. Supply	Unconst. %
Upper Stanislaus River	582.1	58.0%	562.3	56.0%
Upper Tuolumne River	352.0	35.1%	322.9	32.2%
Lower Tuolumne River	9.6	1.0%	18.5	1.8%
Lower Stanislaus River	48.0	4.8%	75.2	7.5%
San Joaquin River	12.5	1.2%	22.9	2.3%
GW-11 pumping	*0.0*	*0.0%*	*1.6*	*0.2%*
TOTAL	**1004.3**		**1003.5**	

CVPM 12 results, shown in Table 2C-9, also show little difference in supply mixes between alternatives. Diversions from the Merced River decrease slightly, to allow for more diversions to CVPM 13. The difference is met by San Joaquin River water.

Table 2C-9. CVPM 12 Supplies (taf/yr)

Supply Source	Base Case Supply	Base Case %	Unconst. Supply	Unconst. %
Upper Merced River	23.0	2.7%	19.4	2.3%
Lower Merced River	59.9	7.1%	50.2	6.0%
Upper Tuolumne River	561.0	66.5%	553.8	65.6%
Lower Tuolumne River	7.4	0.9%	14.6	1.7%
San Joaquin River	18.8	2.2%	32.0	3.8%
GW-12 pumping	*173.6*	*20.6%*	*173.6*	*20.6%*
TOTAL	**843.8**		**843.8**	

CVPM 13, as shown in Table 2C-10, displays perhaps the greatest supply mix changes in the agricultural sector. Diversions from the Merced River increase by over 170 taf/yr on average. Madera Canal water from Millerton Reservoir on the San Joaquin, however, decreases by 171 taf/yr. This, in turn, frees more water for San Joaquin River flows. This may become important when considering San Joaquin River exports to the Delta, as well as transfers to agricultural areas in Region 4 (the Tulare Basin).

Table 2C-10. CVPM 13 Supplies (taf/yr)

Supply Source	Base Case Supply	Base Case %	Unconst. Supply	Unconst. %
Madera Canal/Millerton	251.3	13.6%	93.0	5.0%
Upper San Joaquin River	5.8	0.3%	7.8	0.4%
Fresno River	51.7	2.8%	52.9	2.9%
Chowchilla River	55.5	3.0%	65.3	3.5%
Upper Merced River	502.2	27.1%	652.2	35.2%
Lower Merced River	20.9	1.1%	28.9	1.6%
Lower San Joaquin River	2.1	0.1%	3.5	0.2%
San Joaquin River, Mendota Pool	50.6	2.7%	36.4	2.0%
GW-13 pumping	*910.5*	*49.2%*	*910.5*	*49.2%*
TOTAL	**1850.6**		**1850.6**	

<u>Urban Supply Sources</u>

In many ways, analysis of the water supply mix to SFPUC and SCV urban demand regions affords the most interesting results in Region 3. Though in some ways these urban areas may suffer the effects of aggregation and system simplification in CALVIN, comparison of facility operations under current policies to those under the ideal market may prove helpful in generating new perspectives. A complete description of the urban demand modeling approach for these regions appears in Appendix B.

Tables 2C-11 and 2C-12 outline the various urban supplies included in the CALVIN model. San Francisco, though shown to derive its entire water supply from the Hetch Hetchy project, actually depends on local supplies for approximately 15% of its supply (DWR 1998). Details regarding these local inflows were difficult to acquire, however, and were therefore omitted.

CALVIN results show that in an ideal market San Francisco attempts to maximize imports of low-cost, high-quality Hetch Hetchy water, resulting in capacity flows in every month of the 72 year modeling period. It is important to note that the San Francisco area is almost completely dependent on surface supplies, and therefore has limited capacity for conjunctive groundwater banking and use.

Table 2C-11. San Francisco Supplies (taf/yr)

Supply Source	Base Case Supply	Base Case %	Unconst. Supply	Unconst. %
Hetch Hetchy	232.3	100.0%	238.0	100.0%
SFPUC Recycling	0.0	0.0%	0.0	0.0%
TOTAL	**232.3**		**238.0**	

Conversely, the Santa Clara Valley urban demand region has one of the most diverse supply systems in California. The region makes extensive use of surface supplies to recharge groundwater; almost 35% of total supplies in the Base Case is surface or reclaimed water that has been routed via groundwater storage and subsequent pumping. SWP and CVP water from the California Aqueduct and Delta Mendota Canal is diverted through the South Bay Aqueduct and the San Luis Reservoir/Pacheco Tunnel system for use in groundwater recharge or is treated for direct use. The SCV region also purchases Hetch Hetchy water from SFPUC.

Table 2C-12. Santa Clara Valley Supplies (taf/yr)

Supply Source	Base Case Supply	Base Case %	Unconst. Supply	Unconst. %
Santa Clara Recharge	2.5	0.4%	0.6	0.1%
Santa Clara Local	116.5	18.0%	118.4	18.0%
Pacheco Tunnel Recharge	103.9	16.1%	200.9	30.6%
Pacheco Tunnel	14.9	2.3%	63.9	9.7%
South Bay Aq. Recharge	71.5	11.1%	0.0	0.0%
South Bay Aqueduct	87.5	13.5%	0.2	0.0%
Hetch Hetchy	57.7	8.9%	93.2	14.2%
SCV Reclam. Recharge	48.0	7.4%	34.1	5.2%
SCV Recycling	0.0	0.0%	0.0	0.0%
SCV GW inflow	130.0	20.1%	130.0	19.8%
TOTAL	**646.1**		**656.3**	

In the Unconstrained Alternative, supplies through the South Bay Aqueduct are minimized, due to relatively high pumping costs. California Aqueduct water is instead routed through San Luis Reservoir and the Pacheco Tunnel to the SCV groundwater basins. Hetch Hetchy water purchases from San Francisco increase from 58 taf/year to 93 taf/yr. As in the SFPUC region, all scarcities in both average and drought years are met in the SCV region (see Table 2C-13).

Table 2C-13. Urban Scarcities

	Annual Average	Drought years

		Scarcity (taf)	% scarcity	Scarcity (taf)	% scarcity
San Francisco Urban Region	Base Case	5.8	2.4	20.6	8.7
	Unconstrained	0	0	0	0
Santa Clara Urban Region	Base Case	10.2	1.6	40.8	6.2
	Unconstrained	0	0	0	0

Changes in Deliveries and Scarcity Costs

The following plots provide a summary of the changes in deliveries and scarcity costs for the two urban demand regions (see Figures 2C-3 and 2C-4). Plots for the agricultural sector were omitted since there were no scarcities or changes in deliveries between modeling alternatives. Each box reports the change in the Unconstrained maximum (usually occurring in drought years), minimum, and average deliveries and scarcities to Base Case values.

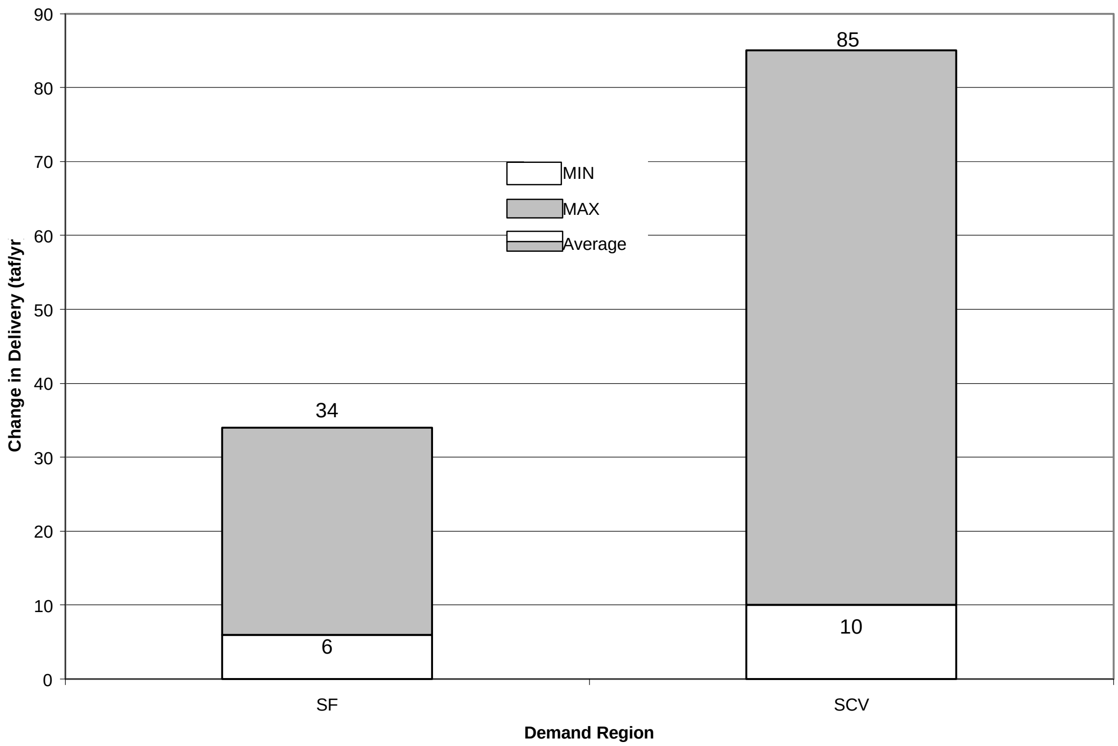

Figure 2C-3. Changes in Annual Deliveries from Base Case to Unconstrained Alternative

An average increase in deliveries of 6 taf/yr for San Francisco and 10 taf/yr for Santa Clara effectively alleviates Base Case scarcities in the Unconstrained Run. The worst annual scarcity faced by either urban area was 85 taf in Santa Clara, corresponding to a scarcity cost of over $103 million. CALVIN's re-allocation of surface supplies reduced even this scarcity to zero.

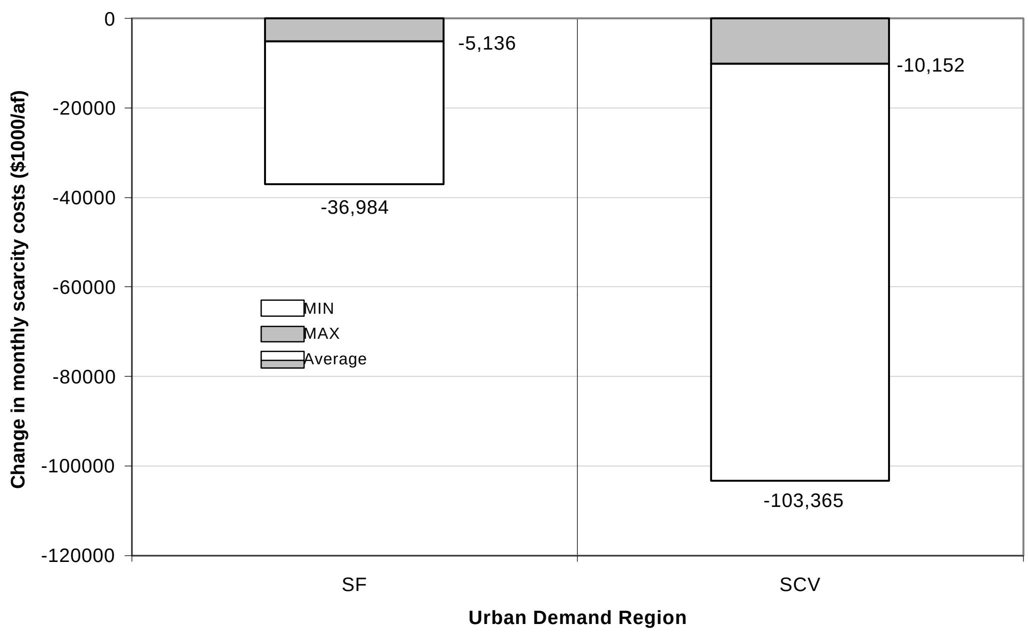

Figure 2C-4. Changes in Annual Urban Scarcity Costs ($M/year)

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 often make water unavailable for downstream needs by removing it from the system. Secondly, minimum instream flows are placed on rivers meeting downstream needs, but flow requirements often are maintained by reservoir releases during non-peak economic demand periods.

CALVIN represents environmental flow requirements on rivers as lower bound constraints and wildlife refuge allocations as fixed deliveries (see the Appendix F). In Region 3, the minimum monthly instream requirements on the Merced, Stanislaus, and Tuolumne were developed from input data to SANJASM NAA and represent a variety of environmental purposes (USBR 1997). Refuge deliveries in Region 3 are set at the DWRSIM 514 diversion levels. These environmental requirements remain the same in both model runs. Table 2C-14 compares the Base Case and Unconstrained flows for each location where flow requirements are imposed. In both modeling cases, all environmental requirements are met; however, flow regimes change considerably on some rivers.

Table 2C-14: Annual Average Environmental Flows

	Minimum Flow Requirement (taf)	Base Case (taf)	Unconstrained (taf)	% Difference
Merced River (Upper)	78.9	395.0	265.2	-32.9%
Merced River (Lower)	78.9	374.7	246.6	-34.2%
Stanislaus River	195.6	389.2	417.7	7.3%
Tuolumne River	118.8	543.5	593.9	9.3%
Volta Refuges	35.5	35.5	35.5	0.0%
San Joaquin/Mendota Refuges	237.3	237.3	237.3	0.0%
San Joaquin River (Vernalis)	1030.9	2889.2	3080.7	6.6%

The Tuolumne River is a key location for the system due to keenly competing agricultural, urban, and environmental demands. High quality Tuolumne water appeals to urban users, while farmers depend on Tuolumne diversions in CVPM Regions 11 and 12 for irrigation. Hetch Hetchy Reservoir and the upper Tuolumne are located in a region of great natural beauty, making the reduction or perhaps even elimination of facilities environmentally attractive. Despite its importance, data concerning flows, diversions, and reservoir operations for the Tuolumne were difficult to obtain. Appendix 2I (Base Case) and Appendix I (Surface Water Hydrology) describe the modeling method used to represent the Tuolumne River and Hetch Hetchy system, and how inflows, diversions, and operations were determined.

As Figure 2C-5 shows, Tuolumne flows far exceed requirements for most of the year. Peak flows occur in early summer, corresponding to seasonal agricultural demands. Flow requirements are usually binding in September and October from the re-operation of New Don Pedro Reservoir to maximize stored water for peak summer demands. In drier periods, the requirements become binding for longer periods, often between September and March.

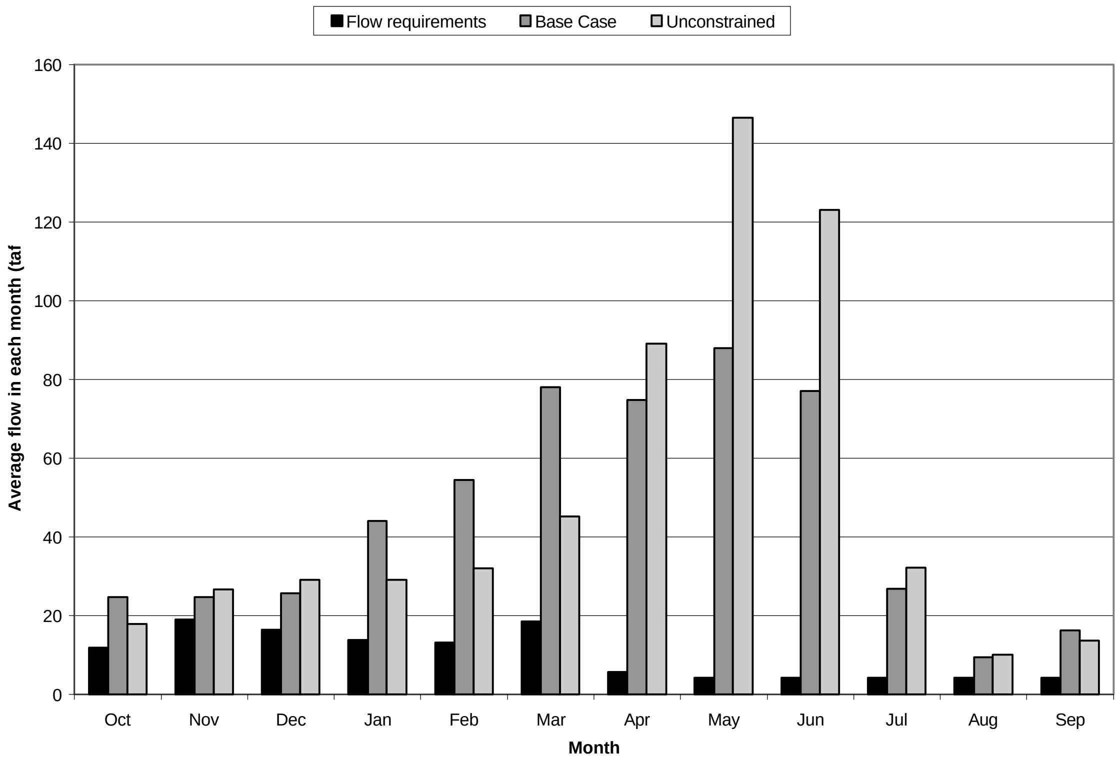

Figure 2C-5. Tuolumne River Average Monthly Flows Below New Don Pedro Reservoir

The San Joaquin River, a major water source for the San Joaquin Delta, also has significant instream flow requirements enforced by the State Water Resources Control Board to ensure adequate water quality and flow levels in the Delta. Historically, these requirements have been placed at Vernalis, just upstream of the Delta. In CALVIN, the San Joaquin River below Vernalis is represented by a boundary flow into Region 2. The Vernalis flow requirements are placed on a link just downstream of the Stanislaus confluence and upstream of agricultural diversions into CVPM 10. Figure 2C-6 depicts flow patterns for the two alternatives in relation to SWRCB flow requirements. In both cases, flows are substantially greater than the requirements on an average basis.

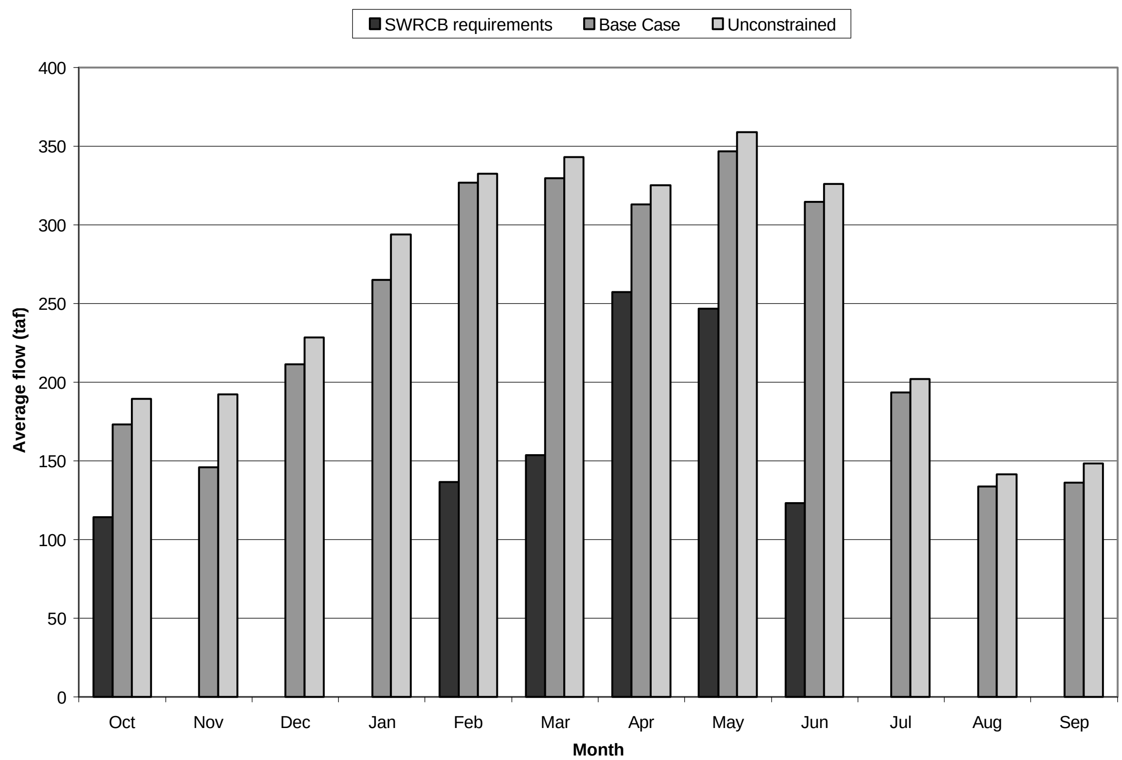

Figure 2C-6. Monthly Average Flow in San Joaquin River at Vernalis

Unfortunately time limitations did not permit detailed post-processing of environmental flows against details of particularly complex flow requirements.

Economic Values of Additional Water

CALVIN reports marginal values of water in two ways. Where constraints placed on river, conveyance, or storage capacity links are binding, CALVIN reports the shadow cost on that element. This shadow cost shows 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.

Because negative and positive marginal values refer to different binding constraints on a link, averages of positive marginal values consider positive values and zeros for all other values (negative values are treated as zero values in positive averages). The converse is true for negative marginal value averages. For example, when reservoir storage shadow cost results included both positives (indicating the reservoir was emptied to dead pool) and negatives (indicating the reservoir was filled to capacity), positive values were considered zero values when analyzing the average value of capacity expansion.

In addition to generating shadow costs, CALVIN also reports the marginal value (net benefit to the region) at any *point* in the system of an additional unit of water from an external source. This value, also called the ‘willingness to pay’ at the point in consideration, is useful in investigating intra- and inter-regional water transfers.

Water Users’ Willingness to Pay for Additional Water

Table 2C-15 shows the willingness to pay for an additional unit of water under the Base and Unconstrained Cases at each of the demand areas of Region 3.

Table 2C-15. Willingness-to-Pay of Region 3 Demands

CALVIN Demand Region	Base Case ($/af)		Unconstrained ($/af)	
	Average	Droughts *	Average	Droughts
CVPM 10	0	N/A	0	0
CVPM 11	0	N/A	0	0
CVPM 12	0	N/A	0	0
CVPM 13	0	N/A	0	0
San Francisco	639	1,204	0	0
Santa Clara Valley	597	1,147	0	0

Notes:
** Drought year WTP values for Base Case agriculture cannot be determined, due to highly constrained system (see Chapter 5).*

The elimination of Willingness-to-Pay values in the Unconstrained Run reflects the elimination of scarcities; users are unwilling to pay for additional water if they already have all that they need. The advantages of water trading and flexible storage operations, enhanced by CALVIN’s perfect foresight, allow the urban sector to weather even drought conditions successfully.

Demand for Inter-regional Transfers

Comparison of marginal values of flows leaving or entering Region 3 with values in adjacent regions provides a preliminary indication of how water will be re-allocated and traded in the statewide model under the Unconstrained Alternative.

Willingness-To-Pay values shown in Table 2C-16 indicate that exported Delta water is more valuable to Region 2 (Sacramento Valley) than Region 3, as evidenced by the Delta Mendota Canal and the California Aqueduct values (negative values in the “Difference” column indicate that water will tend to leave Region 3 in an ideal market). Ironically, San Joaquin River water, important for Delta flow requirements, proves to be more valuable to the Region 3 agricultural sector than for users downstream. Analysis of the interaction of the San Joaquin River, Delta flows, and ultimately demands downstream of the Delta in the statewide model will yield clearer results.

Table 2C-16. Average WTP for Additional Imports/Exports Between Regions 3 and 2

Type	Description	Region 3 ($/af)	Region 2 ($/af)	Diff. ($/af)
Out	San Joaquin outflow at Vernalis	7.15	0.01	7.14
Out	Stanislaus export to SEWD and SJID	11.62	12.11	-0.49
In	Banks Pumping Plant: Cal. Aqueduct import	-10.34	0.00	-10.34
In	Tracy Pumping Plant: DMC import	-13.87	0.00	-13.87

Boundary flow marginal values between Regions 3 and 4 (see Table 2C-17) suggest that exports to Region 4 will increase in the statewide model. High values on the Friant-Kern Canal, agricultural diversions off the Delta Mendota Canal and the San Joaquin River, and downstream demands for SWP water could shift supplies to meet Region 4's higher valued agricultural scarcities and groundwater pumping costs.

Table 2C-17. Average WTP for Additional Imports/Exports Between Regions 3 and 4

Type	Description	Region 3 ($/af)	Region 4 ($/af)	Difference ($/af)
Out	DMC export to CVPM 14 and CVPM 15	8.18	40.70	-32.52
Out	Friant-Kern Canal/Millerton export	13.19	49.10	-35.91
Out	SJ River riparian export to CVPM 16	8.52	55.40	-46.48
Out	California Aqueduct export	23.14	43.00	-19.86*
In	St. James/N. Kings River inflow from Region 4	8.18	42.30	-34.12
In	Urban return flow to SJ River from Fresno	8.68	0.00	8.68
In	Ag return flow from CVPM 14 to SJ Refuges	7.44	0.00	7.44

*Note: *Results for the California Aqueduct show that trading would increase from Region 3 to Region 4 if the boundary constraint were removed. This, however, assumes that Delta exports through the Banks and Tracy Pumping plants would remain fixed, and trading would be re-allocation of existing water in the two regions, and not due to changes in Delta pumping.*

Shadow Values of Environmental Flows

In the case of river flows, shadow costs are generated whenever diversions are sufficient to lower flows down to the minimum instream requirements. Refuge deliveries are always "binding", because in both alternatives they are represented as fixed time series constraints. Table 2C-18 reports both maximum and average positive shadow values, reflecting the region-wide net cost if the minimum instream flows or mandatory refuge deliveries are increased by one acre-foot. The highest values are refuge deliveries, since most of the water delivered to refuges is unavailable for downstream uses.

Table 2C-18. Shadow Values of Environmental Water in Unconstrained Case

	Maximum ($/af)	Average ($/af)
Volta Refuges	20.49	8.28
San Joaquin/Mendota Refuges	17.71	6.60
Stanislaus River	13.75	4.42
Merced River (Upper)	13.47	3.11
Tuolumne River	13.61	2.43
Merced River (Lower)	13.62	1.76

Operating costs, as stated earlier, drive substantial supply mix changes to a number of demand regions. Because operating costs are estimated and at times speculative, and CALVIN representations of water supplies and demands are often aggregated, overall water value and supply trends are of greatest importance.

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. Only Unconstrained Case results are used for this analysis. In effect, system operations are optimized to receive the greatest economic benefit for the region through water transfers *before* expensive facility expansion is considered.

Overall trends within the region provide indications for promising solutions to the region's multiplying water supply issues. The following sections outline a number of these trends as they relate to operations, facility expansion, and water marketing or forms of transfers.

Operations and Conjunctive Use Opportunities

The following section discusses implications of the data presented in the previous section regarding surface and groundwater operations. Significant operational and water transfer potential exists, even without the consideration of facility expansion.

Surface Water Operations- Conveyance

Nowhere in Region 3 do surface water supply operations change as significantly in the Unconstrained Case as in the urban demand areas of San Francisco and the Santa Clara Valley (see Tables 2C-11 and 2C-12). In addition to local supplies, these two urban areas depend on imports from the Hetch Hetchy Aqueduct, DMC, and California Aqueduct. Hetch Hetchy water is of extremely high quality and requires minimal treatment ($5/af operating cost estimate). Conveyance costs for this water are also minimal (perhaps even negative if hydropower benefits were included), since water is transported by gravity from the Sierras to the Bay region. Delta water, conveyed by the California Aqueduct and DMC and fed to the Santa Clara area through the South Bay Aqueduct and the San Felipe system, requires significant treatment to remove disinfection byproduct precursors (bromide and TOC), and other contaminants from agricultural runoff. Treatment costs in CALVIN for direct urban use of Delta surface water are estimated to be $254/af in 2020 without an Isolated Facility. Additionally, pumping costs on the South Bay and via the DMC/San Felipe Unit are $60.40/af and $30.60/af, respectively. Consequently, CALVIN maximizes the use of Hetch Hetchy water in the Unconstrained Case. Flows in the Hetch Hetchy Aqueduct increase by over 41 taf/year in the Unconstrained Case, resulting in flows at capacity for every month during the 72-year hydrologic period. Most of this water flows directly into the San Francisco urban area through the Crystal Springs Bypass Tunnel, with excess water being diverted into the aggregate SR-ASF reservoir for transfers into the Santa Clara region.

With an additional 35 taf/yr of increased Hetch Hetchy imports from SFPUC, the Santa Clara Valley urban area is able to reduce its SWP and CVP imports from the Delta by an average of 13 taf/yr. The 265 taf/yr of Delta water it still uses is routed entirely through the San Luis Reservoir and the Pacheco Tunnel, since pumping costs are roughly $30/af lower through the San Felipe system than the South Bay Aqueduct. CALVIN essentially re-operates the California Aqueduct for two purposes: to meet outflow requirements into Region 4 (and ultimately to Southern California) and to provide water to the SCV urban demand region. Virtually all SWP agricultural diversions to CVPM 10 are eliminated and replaced by DMC diversions.

Re-operation of the California Aqueduct effectively lessens urban dependence on Delta Mendota Canal water (CVP) by decreasing pumping through the O'Neil pumping station (which transfers water between the DMC and the California Aqueduct) from 1161 taf/yr to 997 taf/yr, and substituting SWP water via the San Felipe system. The elimination of California Aqueduct agricultural diversions into CVPM 10 is compensated by direct DMC agricultural diversions.

Surface Water Operations- Storage

Reservoirs are extensively used throughout California to provide reliable water supplies, flood control, hydroelectric power, and recreational venues. Reservoir storage is especially crucial for supply purposes in times of drought. Because reservoir operators are unable to forecast drought durations, reservoirs are typically kept full to avoid 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 in the region, allowing it to keep reservoirs emptier during average and drought years to minimize scarcity and operating costs (see Table 2C-19). Reservoir re-operation effectively maximizes wet year surface water by minimizing spills, replacing groundwater, and minimizing total pumping costs. The storage pattern shown for New Don Pedro Reservoir in Figure 2C-7 is typical of reservoir operations in Region 3 under the Unconstrained Alternative.

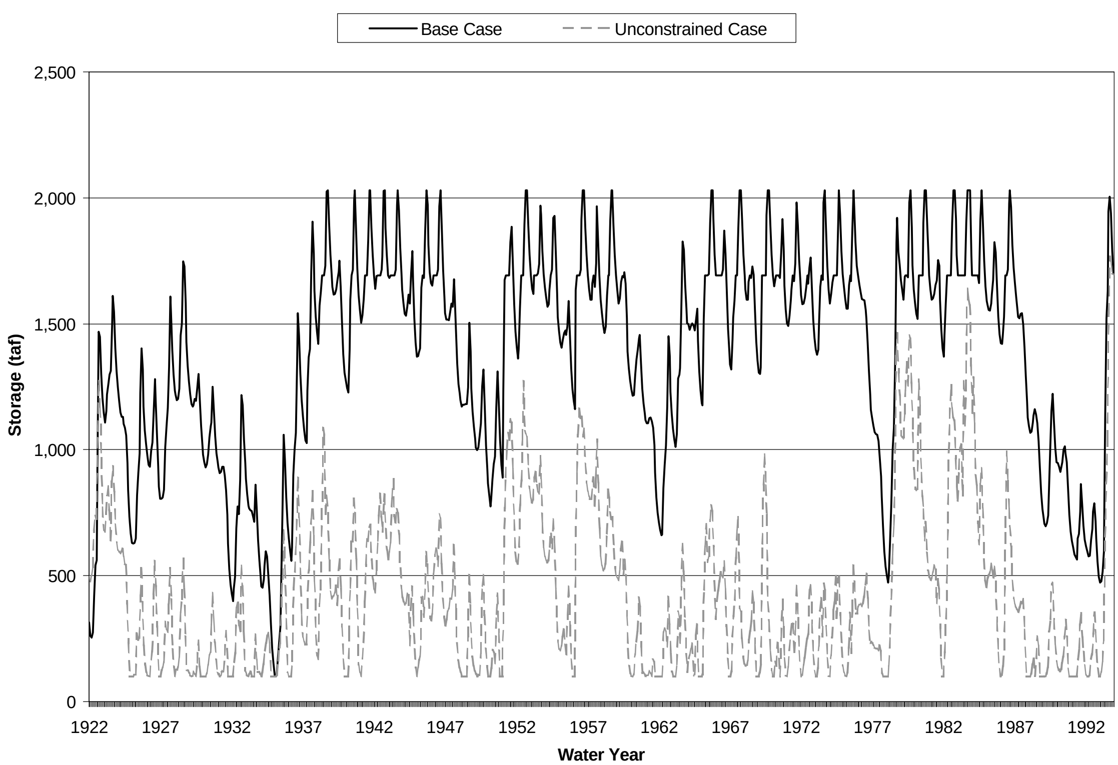

Figure 2C-7. Monthly Storage for New Don Pedro Reservoir (SR-81)

Table 2C-19. Monthly Average Reservoir Storage Comparison

CALVIN	Description	Base Case (taf)	Unconstrained

name			Case (taf)
SR-10	New Melones	1444	1338
SR-12	San Luis	1245	535
SR-15	Del Valle	32	12
SR-18	Millerton	291	273
SR-20	McClure	697	329
SR-52	Hensley	26	12
SR-53	Eastman	46	26
SR-81	New Don Pedro	1378	427
SR-ASF	Aggregate SF	84	55
SR-HHR	Hetch Hetchy	346	316
SR-LL-LE	Aggregate Lloyd/Eleanor	223	34
SR-SCV	Aggregate Santa Clara	76	75
SR-TR	Turlock	54	12

Figure 2C-8 graphically depicts surface storage trends between the two alternatives. Decreased storage across the region results in reduced evaporative losses. However, flood control benefits, as well as hydropower costs, could significantly change these storage trends when these economic factors are incorporated into CALVIN in the next phase of the project.

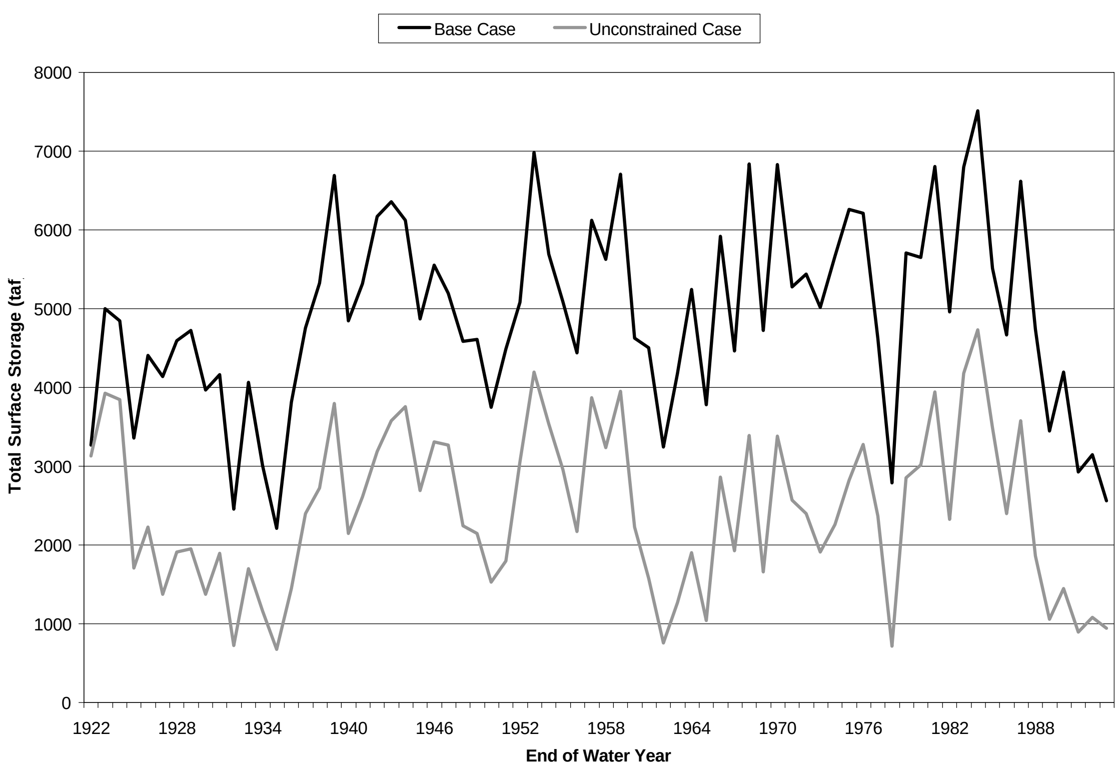

Figure 2C-8. Total Surface Storage (taf)

Conjunctive Use Operations

Historically, agriculture in the San Joaquin Valley has extensively used both surface water and groundwater for irrigation. Some farms do not have access to surface water irrigation diversions, and thus must rely solely on groundwater. Others who have access to surface water are able to conjunctively use inexpensive surface water when it is available and supplementary groundwater when surface supplies are insufficient. Comparison of surface and groundwater supply results between the Base and Unconstrained Cases indicate opportunities for conjunctive use, assuming that minimum pumping (representing farmers without access to surface water) is also considered. Similarly, urban areas such as the Santa Clara Valley who already extensively operate their supplies conjunctively, might benefit from considering how operations might change from a regional perspective.

CALVIN has represented groundwater aquifers in the San Joaquin Valley as four separate basins having no dynamic interaction. Because there may be some inter-basin interactions, it is useful to consider overall groundwater storage trends within the region as a more accurate depiction of groundwater results (see Figure 2C-9).

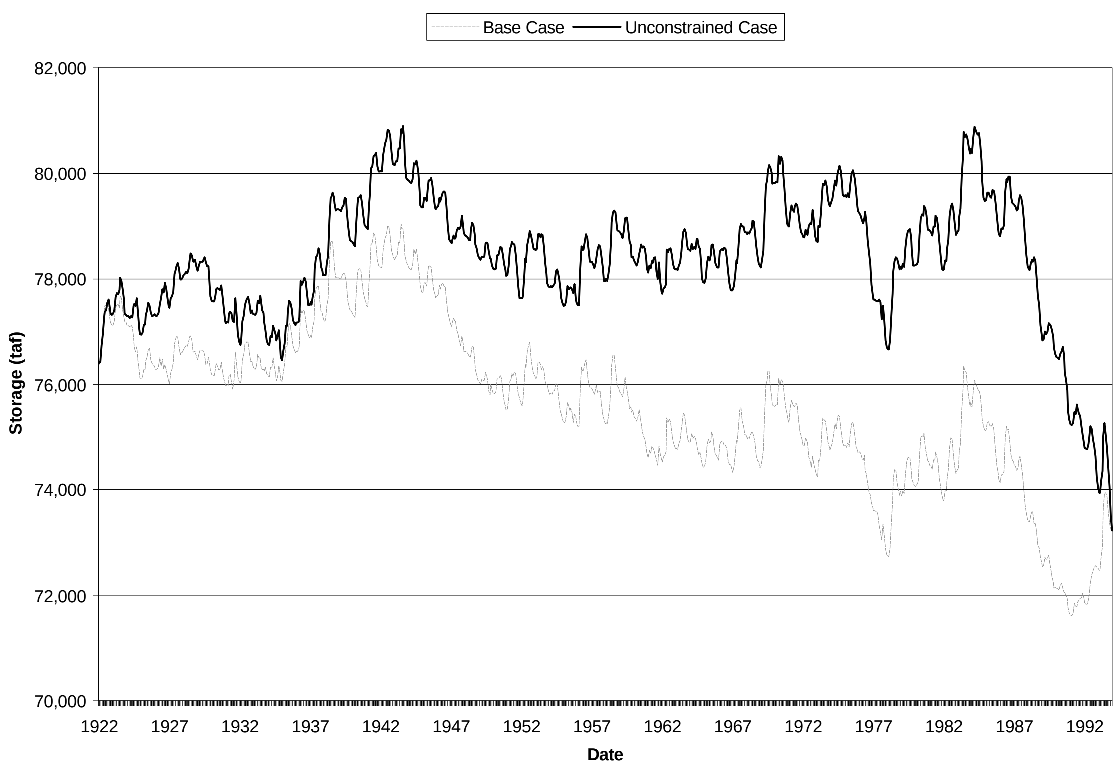

Figure 2C-9. Total Region 3 Groundwater Storage Pattern

The Unconstrained Case displays more conservative pumping, since CALVIN's re-operation of reservoirs makes more surface water available. Storages are higher in the Unconstrained Case until the drought period of 1987-1992, where groundwater pumping has the greatest value. Results indicate noticeable seasonal variations in groundwater storage, but drought cycle amplitudes appear much larger. For instance, a typical seasonal amplitude seems to be about 0.3-0.5 maf for the unconstrained case. But the 1976-77 drought seems to have about a 2.5 maf amplitude, and the 1988-92 drought has a 5 maf amplitude. Groundwater is therefore the major source of over-year storage for this system. Figure 2C-10 verifies this finding by displaying both seasonal and drought cycle groundwater pumping trends.

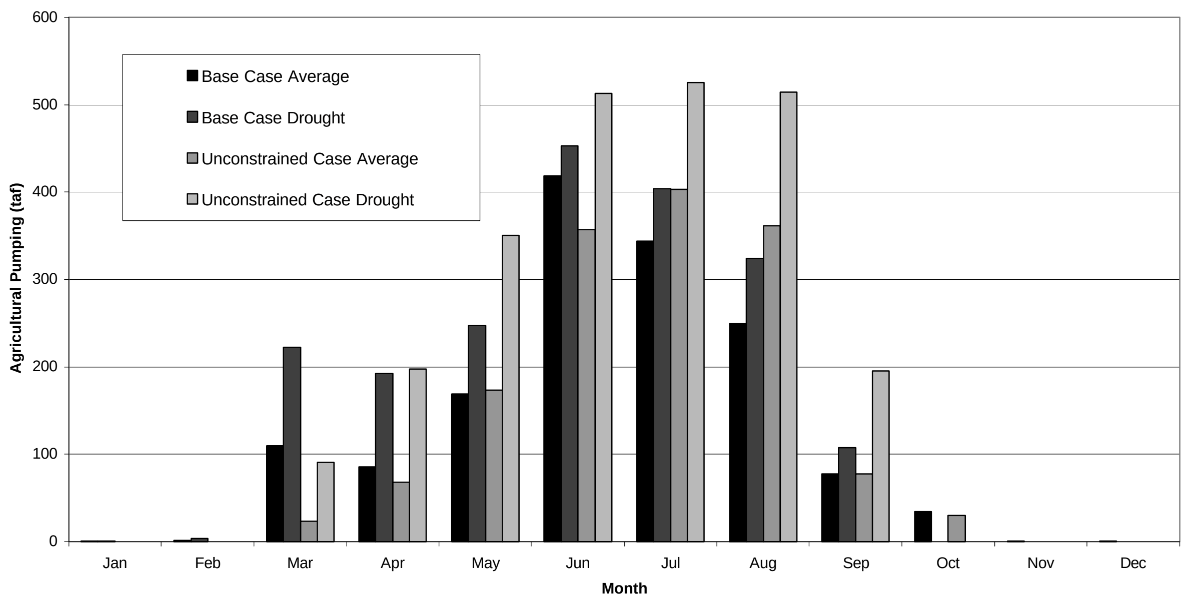

Figure 2C-10. Monthly Agricultural Groundwater Pumping

Agricultural conjunctive use trends evident in the Base Case become even more prevalent under an ideal market. In all four agricultural regions, there was no agricultural pumping in the winter months, but extensive pumping in the high-demand summer months to augment surface water supplies. Essentially, aquifers are recharged in wet winter months and pumped in the summer.

Santa Clara Valley urban demand region results also indicate that expanded conjunctive use might be beneficial. In the case of Santa Clara, it is less expensive to recharge their groundwater basins with imported Delta water than to treat the water and use it directly. More details are contained in a later section of this appendix, outlining promising areas for facility expansion.

As noted in Figure 2C-9, the San Joaquin Valley experiences approximately 43 taf/yr overdraft in both alternatives. Analysis of Unconstrained Run results show that water marketing may help alleviate groundwater overdraft in this region. Table 2C-20 provides the basis for understanding this overdraft reduction potential. Recall that the groundwater storages for the last year of the 72 year modeling period in the Unconstrained Run was fixed to equal the Base Case ending storages. The marginal ending storage value in the right column of the table 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. For the

San Joaquin aquifers, positive marginal values indicate that the system sees a benefit to allowing less groundwater overdraft, with benefits rising as high as $14.94/af in GW-13. Since pumping costs range from $15 to $30 throughout the Valley, conjunctive surface water use could lessen the agricultural sector's dependence on groundwater. These results suggest that potential exists for alleviating groundwater overdraft throughout the San Joaquin Valley 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.

Table 2C-20. Groundwater Pumping and Marginal Ending Storage Value

	Pumping Costs ($/af)	Marginal Ending Storage Value ($/af)*
GW-10	15.60	0.25
GW-11	20.60	3.94
GW-12	23.60	8.09
GW-13	30.00	14.94
GW-SC	85.00	-61.15
Note: ** Ending storage value valid for Unconstrained results only.*		

<u>Cooperative Operations</u>

The strongest example of cooperative operation changes has already been detailed in the previous section on groundwater operations. The California Aqueduct, operated by the SWP, and the Delta Mendota Canal, operated by the CVP, have historically served both the agricultural and urban sectors. CVP transfers across the O'Neill Pumping Station to the California Aqueduct contribute to diversions to the Santa Clara urban area. Likewise, a portion of SWP water is diverted in the Base Case to meet agricultural needs in Region 3 in addition to demands in Regions 4 and 5 to the south. In an ideal market setting in Region 3, less CVP water is transferred to the California Aqueduct. The end result is that a larger portion of CVP water is devoted to agricultural needs, while SWP facilities are more focused on meeting urban needs in the Santa Clara Valley, as well as downstream demands in the Tulare Basin (Region 4).

Urban cooperation appears stronger in the Unconstrained Case as well. As mentioned earlier, Santa Clara would purchase 40 taf/yr more water on average from SFPUC in an ideal market. Furthermore, marginal values on a theoretical SCV-SF connector in CALVIN indicate that in very dry periods, San Francisco would benefit from the ability to purchase water from Santa Clara sources (values are approximately $250/af in this situation). Earthquake and other unmodeled benefits also might support such a project.

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 some cases, there may be both a sufficient amount of water and conveyance capacity, but operating costs on supplies may cause CALVIN to favor one supply link over another. 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.

The following analysis considers only the Unconstrained Case, since many of the binding storage and flow constraints in the Base Case are artificially imposed to force CALVIN to imitate CVGSM NAA and DWRSIM 514 results.

Surface Storage

Only two reservoirs in Region 3 show strong promise for capacity expansion. The proposed Los Banos Grandes Reservoir is currently under consideration as one means of increasing storage capacity on the California Aqueduct. CALVIN output suggests (see Table 2C-21) that this off-stream storage reservoir would benefit Region 3. High marginal values normally occur in January and February, suggesting that filling Los Banos Grandes when Delta water is plentiful would reduce competition for Delta water in drier months. California Aqueduct export requirements to Regions 4 and 5 could be met in the summer months with less scarcity impact on peak summer demands in Region 3, especially those of Santa Clara Valley that must normally compete with these export requirements.

The aggregate reservoir node representing the Santa Clara Valley local reservoirs shows high marginal values as well, but only in drought conditions, implying that a small amount of additional storage might provide less expensive local water in place of lower quality, more costly Delta imports.

Table 2C-21. Candidate Reservoirs for potential storage expansion

Expected benefit of 1 unit increase in reservoir storage capacity (in $/af)	SR-22: Los Banos Grandes (proposed)	SR-SCV: Santa Clara aggregate
Average annual value	14	13
Maximum monthly value	12	252

Hetch Hetchy Reservoir (SR-HHR), though it is an inexpensive source of high quality water for both the San Francisco and Santa Clara urban regions, shows very little marginal value to storage expansion. This is due to the limiting conveyance capacity of the Hetch Hetchy Aqueduct as shown below; more storage in the reservoir is of little use if it cannot be transported to users.

In addition to regulating flow on the San Joaquin River, Millerton Reservoir is also used to divert water to the Tulare Basin (Region 4) through the Friant-Kern Canal for agricultural use. Though marginal values on Millerton storage to Region 3 are insignificant in the Unconstrained Case, the $36/af difference in marginal values on the Friant-Kern boundary flow between Regions 3 and 4 may cause the value of extra Millerton storage to increase in the statewide model. Millerton Reservoir operations also adjust significantly once the reservoir is allowed to meet Friant-Kern downstream needs under a Statewide Unconstrained policy.

New Melones Reservoir on the Stanislaus River, another reservoir with boundary flows into CVPM 8 in Region 2, is an unlikely candidate for expansion or operating changes, since marginal values for Stanislaus water in Region 2 are lower than in Region 3.

Lower bound marginal values on storage (useful for analyzing emergency pool storage reallocation) are not reported, since no Region 3 reservoirs have an emergency and stored water at dead pool cannot be accessed.

<u>Conveyance</u>

The conveyance structures showing promise for expansion were all urban supply links as shown in Table 2C-22. The highest expected values of capacity expansion in the entire region were those on the Hetch Hetchy Aqueduct. Though the Foothill and Coast Range Tunnels on the SFPUC system have a capacity of 620 cfs, the three San Joaquin pipelines carrying water from the SFPUC Sierra reservoirs across the Central Valley have a combined capacity of only 465 cfs. This capacity proves to be binding in every month of the 72 year hydrologic period under the Unconstrained Case.

The proposed addition of a fourth San Joaquin Valley pipeline would bring the total capacity of the Hetch Hetchy system to 620 cfs. An Unconstrained model run using this proposed increased Hetch Hetchy capacity shows significant additional changes, beyond those reported in this appendix, on both supply mixes and marginal values of water throughout the Region.

Table 2C-22. Conveyance Capacity Expansion Values

Conveyance Facility	Expected Benefit of 1 af/mo Expansion	
	Average Annual ($/yr)	Maximum Monthly Value ($/af)
Hetch Hetchy Aqueduct	268	305
SCV groundwater pumping	230	272
SFPUC recycling	55	94
SCV recycling	30	68
SCV groundwater recharge	15	21
SCV/SF hypothetical transfer	5	254

Recycling of wastewater in the Bay Area, although no capacity was modeled for San Francisco, appears to be another promising alternative for expansion. Though recycling is expensive at $350/af, values average over $660/yr in San Francisco and $365/yr in SCV for an increase of 1af/month in recycling capacity in the Unconstrained Run. Base Case values, not reflected in the above table, range as high as $3500/yr for San Francisco and $3000/yr for Santa Clara for 1 af/month of additional capacity.

Groundwater pumping shows a markedly high value in the Santa Clara urban region, reflecting the area's desire for cheaper sources over Delta imports (see Table 2C-22). Ending storage for the SCV groundwater basin was fixed to its initial storage, ensuring that for these model runs, the basin under Santa Clara would not be depleted. Positive marginal values on pumping capacity in every month indicate pumping is operated at the estimated maximum capacity of 30.5 taf/mo. This is primarily due to SCV's use of groundwater recharge as a water treatment method. Further study is needed to assess whether the SCV groundwater basin could successfully "treat" additional recharge capacity. The 10 taf/yr increase in recharge in the Unconstrained Case occurs through a rise of 30 taf/yr in Delta water recharge and a 14 taf/yr drop in reclamation recharge from Santa Clara (see Table 2C-23).

The value of transfers from Santa Clara to San Francisco is assessed in CALVIN using a connector constrained to zero flow. Small average annual marginal values and a large maximum monthly value suggest that transfers from Santa Clara Valley to San Francisco would be economically beneficial in critically dry periods.

Table 2C-23. Santa Clara Valley Urban Recharge Comparison

Groundwater (GW-SCV) Recharge Sources	Base Case		Unconstrained Case	
	Average Recharge (taf/yr)	% Contribution	Average Recharge (taf/yr)	% Contribution
Pacheco Tunnel	103.9	16.1%	200.9	30.6%
South Bay Aqueduct	71.5	11.1%	0.0	0.0%
SCV Reclamation	48.0	7.4%	34.1	5.2%
Santa Clara Local	*2.5*	*0.4%*	*0.6*	*0.1%*
TOTAL	225.9		235.6	

Environmental Requirements

Though environmental demands are not modeled economically in Region 3, marginal values on environmental flows provide useful information regarding the interaction of environmental flows on agricultural and urban demands. This section will focus on discussion of results presented earlier.

<u>Increasing Environmental Flows</u>

This appendix is largely an analysis of water resource management alternatives for agricultural and urban water supply given environmental supply requirements. Results may be interpreted conversely to analyze what impacts environmental flow changes would have on urban and agricultural demands.

Table 2C-18 reports the shadow costs associated with increasing each environmental flow requirement in Region 3. Refuge deliveries exhibit the highest values, mainly because water diverted for the refuges (principally from the Delta Mendota Canal/Mendota Pool) becomes unavailable for other uses. Refuge values seem to be driven primarily by competition from the Santa Clara Valley urban area, since agricultural areas downstream of the refuges have both a fixed amount of groundwater to use (meaning pumping costs will not change) sufficient surface supplies (which have no cost). It is important to recall that the Base Case and Unconstrained Alternative utilize Level 2 refuge demands, which are included in DWRSIM Run 514 and CVGSM NAA 1997. Level 4 refuge demands mandated by the Central Valley Project Improvement Act are significantly higher and will be enforced in the near future.

Marginal costs of increasing environmental requirements on the San Joaquin and its tributaries in the unconstrained case reflect generally low impacts to the agricultural sector. Because no further Tuolumne exports to the Bay Area are possible with the Hetch Hetchy Aqueduct at capacity, the impacts of small increased environmental flows are limited to agricultural uses of lower economic value. The two rivers where environmental flow increases would least affect the agricultural sector in Region 3 are the Lower Merced River and the Tuolumne River. Lower Merced River flows are constrained by minimum flow requirements mainly in the months of September and October. Average marginal costs on increased environmental flow on the lower

Merced are under $2/af. However, marginal environmental costs on the upper Merced River exceed $3/af.

The Tuolumne River is the next most promising candidate for increased environmental flows with a marginal cost of only $2/af. However, an increase in San Francisco's Hetch Hetchy aqueduct capacity would likely increase the marginal costs of increases in Tuolumne environmental flows, as well as others in Region 3 given the high degree of inter-connectivity of agricultural supplies in the region.

The Stanislaus River has the highest marginal values at $4.27/af on average, making environmental flow requirement increases the most expensive in the region.

Water Transfers

As Lund and Israel (1995) point out, effective water transfers involve more than financial transactions. An extensive system of conveyance and storage infrastructure must be in place to move water spatially and temporally to provide end users with access at the right place and time. In CALVIN, willingness-to-pay values, and supply mix and scarcity changes between modeling alternatives, indicate the potential effectiveness of water transfers for substantially improving Bay area supply reliability and reducing costs of scarcity and reducing the opportunity costs of environmental water to the agricultural and urban sectors.

Costs and Benefits of Intra-regional Transfers

An analysis of region-wide flows indicates that agricultural-to-urban transfers account for the elimination of urban scarcities in an ideal regional market. An increase of 41 taf/yr on average of Hetch Hetchy imports into the San Francisco and Santa Clara urban areas is accompanied by a decrease of 13 taf/yr in lower quality Delta imports. Subsequently, an overall average transfer of 28 taf/yr occurs from the agricultural to urban sectors. 16 taf/yr of this amount covers urban scarcities, and the remaining 12 taf/yr replaces higher cost reclaimed water.

As stated earlier, CVP transfers to the California Aqueduct decrease by 164 taf/yr, but SWP agricultural diversions counter this urban-to-agriculture transfer by decreasing agricultural diversions by 91 taf/yr. The balance of 73 taf/yr of Delta water is then conserved for re-allocation. More efficient surface water operation in the San Joaquin Valley and Sierra reservoirs means that this extra Delta water ultimately flows from the region through the San Joaquin River. In fact, the San Joaquin boundary flow into Region 2 increases by 145 taf/yr in the Unconstrained run, showing that 72 taf/yr of extra water in the San Joaquin portion of the Region is conserved in addition to the 73 taf/yr of extra Delta water. The flows pumped from the Delta through both the Delta Mendota Canal and the California Aqueduct are both fixed boundary inflows in Region 3, resulting in the excess San Joaquin River outflow. If Delta pumping were not constrained, one would expect to see reduced pumping on the Delta Mendota Canal.

An important aspect of water transfer potential is the consideration of downstream demands in a statewide Unconstrained Alternative. Water in Region 3 is very "transferable" intra-regionally in terms of hydraulic interconnections and central location in the state. Significant scarcities in Region 4 would provide a strong market for sales by Region 3 water right holders. The Friant-

Kern Canal and the California Aqueduct prove to be important conveyances for transfers and wheeling in a statewide setting.

The additional capacity of a fourth San Joaquin pipeline on the Hetch Hetchy system, currently under consideration by San Francisco city planners, would increase the potential for agriculture-to-urban water transfers within Region 3. The Unconstrained Alternative has demonstrated demand for higher levels of urban imports from Hetch Hetchy to reduce Bay Area operating costs and scarcities. These transfers tend to alter supply mixes throughout the region.

Another potential transfer, from a statewide setting, is between the San Francisco Bay urban users and East Bay Municipal Utility District (EBMUD). This is demonstrated by high differences in willingness-to-pay values for these areas, which are geographically in close proximity, but only slightly connected hydraulically.

Regional Economic Impacts of Transfers

Agricultural delivery results show little economic change in the agricultural sector between the Base Case and Unconstrained runs. Agricultural scarcities in both runs are non-existent. Though agricultural supply mixes are altered, land use changes, crop mixes, and income changes are negligible.

Urban benefits derived from the elimination of scarcity, as discussed earlier, top $15 million in an average year and nearly $60 million in dry years. Additionally, as discussed earlier, the entire region accrues an additional $21 million in benefits in reduced operating costs.

As discussed earlier, the net 28 taf/yr transfer from the agricultural sector to the urban sector is not “felt” by agriculture, since agricultural scarcities in both cases are zero. This transfer is merely a result of more efficient surface water operations, which frees up water typically allocated to the agricultural sector to meet urban demands.

POTENTIAL MODEL REFINEMENTS

CALVIN’s representation of water supply and demand in the San Joaquin Valley, though adequate for general investigations of water marketing and facility operation and expansion potential, would provide more accurate output with a number of refinements. The following four improvements would greatly enhance CALVIN’s ability to shed light on new ways of managing the water resources of Region 3 and the statewide model.

1) *Representation of the San Francisco and Santa Clara Urban Demand Regions:*

In an urban region where water supply management is driven by both high water demands and significant operating costs, model representation becomes important. Over-aggregation of facilities and demands tend to distort results. The demands and supply operations aggregated into the Santa Clara Valley urban demand area are especially complex and would benefit from a less aggregated representation. The SR-ASF aggregate reservoir is actually a collection of five reservoirs that tie in to the Hetch Hetchy Aqueduct at different locations; since Hetch Hetchy water is extremely valuable, disaggregation of SR-ASF may give interesting results pertaining to Hetch Hetchy system operation.

In addition, 15% of San Francisco's water supply in reality is composed of local inflows, which have not been represented in CALVIN, due to lack of data. Addition of these local supplies would affect the urban results.

2) *Wildlife refuge representation*: The interaction of the Volta and San Joaquin/Mendota wildlife refuges with both agricultural areas and rivers like the San Joaquin is currently ambiguous. Greater accuracy in modeling these refuge flows would enhance understanding of their effect on urban and agricultural supplies.

3) *Variable head groundwater pumping:* The fixed groundwater pumping costs currently used in CALVIN do not portray the increased pumping costs of lowered groundwater tables as basins are depleted. GW-10 in the Unconstrained Case is completely depleted, while GW-12 and GW-13 are recharged to capacity. Variable head pumping costs would tend to even out groundwater pumping across the region, with consequent adjustments to allocation of agricultural surface water supplies.

4) *Imperfect foresight:* CALVIN's inability to model drought risk aversion causes scarcities and scarcity costs to be biased downward. Re-structuring CALVIN to reflect imperfect hydrologic foresight would make ideal market results and potential facility expansion values more realistic. Reservoir re-operation in the Unconstrained Case would also be more conservative.

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