APPENDIX 2D

REGION 4 RESULTS: TULARE BASIN

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ABSTRACT

The Tulare Basin is modeled as a single region with the CALVIN engineering-economic optimization model. Two policy alternatives are considered: projection of actual demands, operations, water allocations, and institutional framework to the year 2020 (Base Case) and an Unconstrained Alternative considering just physical and environmental constraints to simulate an "ideal water market" or other form of ideal economic water operations and allocation. Agricultural and urban demands are represented by economic value functions that simulate the economic loss incurred when demands are not fully satisfied. A 72-year time series of historic hydrologic data is used to represent hydrologic variability. The results show a more flexible water allocation under the Unconstrained Alternative supporting intense conjunctive/cooperative uses and leading to average economic benefits of up to $26.3 million/year as well as increases in supply reliability in both urban and agriculture sectors. High values for capacity expansion appear for Lake Kaweah (Terminus Dam) on the Kaweah River and Lake Success on the Tule River. Water transfers with the San Joaquin and South Bay Region are likely under larger scale unconstrained economic operations, including imports in dry months and exports in wet months. Additional exports to Southern California are also suggested, with Southern California users willing to pay $329 per additional af of water above operating costs.

INTRODUCTION

This appendix presents the Tulare Basin CALVIN model. To aid model development, the CALVIN model was calibrated in five regions; the Tulare Basin is Region 4. The statewide CALVIN model consists of the merger of these five regional models. This calibration strategy has allowed a far more detailed examination of each major region in California's inter-tied system and produced some results of interest within each region. It also has highlighted any major modeling difficulties within each region.

The Tulare Basin forms an internally draining basin at the southern end of the San Joaquin Valley. It stretches from the San Joaquin watershed south to the Tehachapi Mountains. It is enclosed by the Coastal Mountain range on the west and by the Sierra Nevada range on the east. The region covers 16,520 square miles. A raised sill formed by the Kings River alluvial fan hydraulically separates the region from the San Joaquin Valley. In wet years, flood water from the North Fork of the Kings River spills into Fresno Slough and into the Mendota Pool, thence to the San Joaquin River.

The major rivers in this region are the Kings, Kaweah, Tule, and Kern. Of these, the Kings and Kern are the most important. Each river rises high in the Sierra Nevada and discharges into lakes or sinks in the valley floor. Historically, the northern three rivers (Kings, Kaweah, and Tule) discharged into Tulare Lake, a wetland area of 200,000 acres. The Kern River historically flowed into the Kern, Buena Vista and Goose Lakes. These natural wetlands have now been drained for agriculture. However, under wet conditions, the lakes may re-form and water may flow from Kern Lake via Buena Vista Lake to Tulare Lake through a series of sloughs. Four dams (Pine Flat, Terminus, Success, and Isabella) built by the Army Corps of Engineers now regulate flow in the major rivers.

In many ways the Tulare Basin is California's second water "hub," after the Delta. Federal CVP water is imported into the region from the San Joaquin River at Millerton Lake via the Friant-Kern Canal, and from the Delta via the Delta Mendota Canal and Mendota Pool and via the California Aqueduct as part of the Joint-Use facilities with the CVP San Luis Unit. Additional SWP water is imported from the California Aqueduct, which also conveys water from Northern California through the Tulare Basin on its way to Southern California. Beyond its central location for water conveyance, the Tulare Basin also is the Central Valley's greatest user of water, consuming roughly 40% of the Valley's water and producing more than half the economic value of the Valley's agricultural production (Leu 2001).

REGION 4 MODEL DESCRIPTION

Figure 2D-1 shows Tulare Basin and the regions that are included in CALVIN. The model includes surface water and groundwater supplies, surface storage and conveyance facilities, and agricultural, urban and environmental demands. The major local surface supplies are inflows to the four major surface reservoirs: Pine Flat (Kings River), Lake Kaweah (Kaweah River), Lake Success (Tule River), and Lake Isabella (Kern River). Downstream of the reservoirs, stream accretion from local runoff and surface-groundwater interaction is included. The infrastructure network relies on the Friant-Kern Canal, the California Aqueduct and the Cross Valley Canal as the main conveyance facilities. Details on surface storage capacity appear in Table 2D-1. Eight separate basins represent the groundwater underlying the eight CVPM agricultural regions that lie within the Tulare Basin.

Table 2D-1. Tulare Basin Reservoirs

Reservoir (Date Built)	Stream	Storage Capacity (taf)	Owner
Pine Flat (1954)	Kings River	1,000	USACE
Isabella (1953)	Kern River	568	USACE
Terminus (Lake Kaweah) (1962)	Kaweah River	143	USACE
Success (1961)	Tule River	82	USACE

Source: California Water Plan Update, Bulletin 160-98

The CALVIN Region 4 sub-model represents all agriculture within the Valley floor comprising 99.7% of irrigated land within the Tulare Basin (8,200 acres in the Uplands PSA are not included). Agricultural water demand is represented by eight model elements (CVPM regions 14 to 21). Details are given in Tables 2D-2 and 2D-3. The "maximum" economic demand is the quantity of water that farmers would demand if water were infinitely available at zero cost.

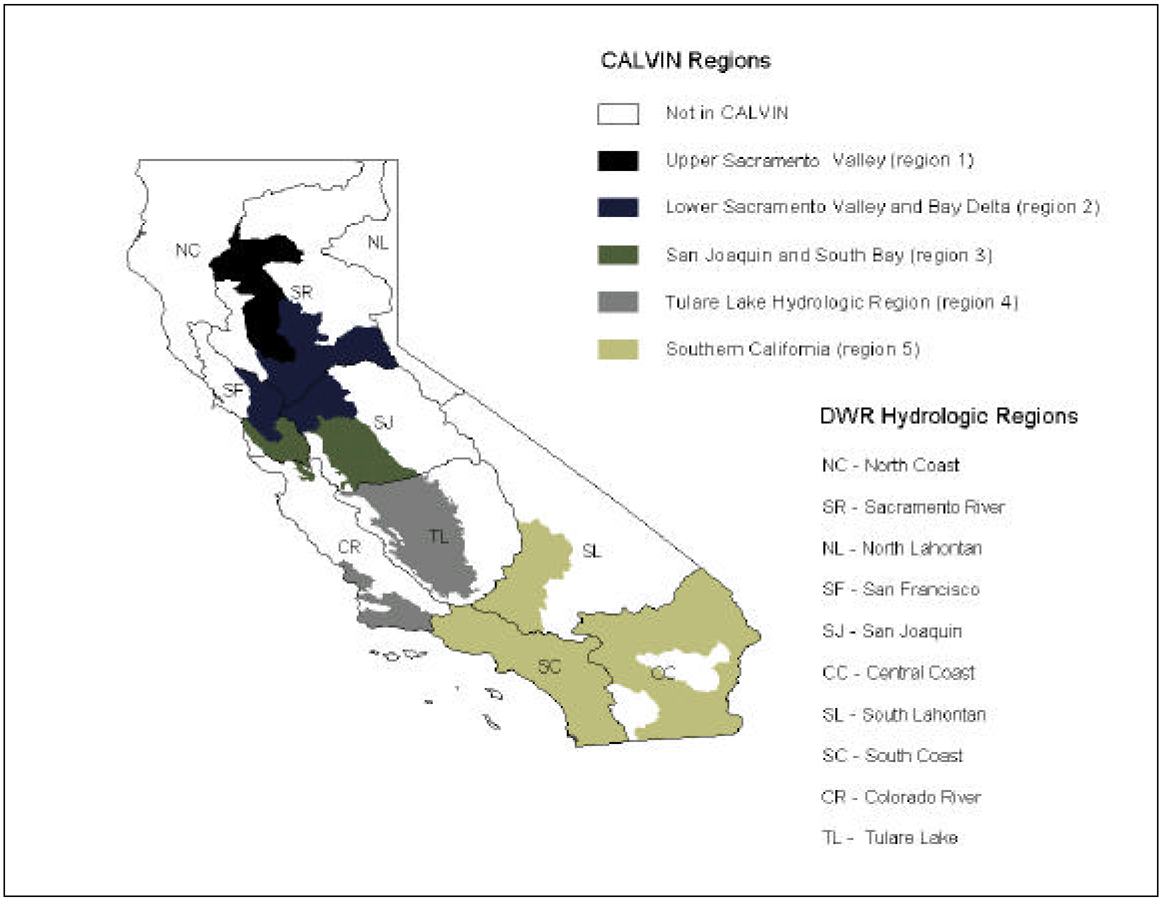

Figure 2D-1. CALVIN regions and DWR hydrologic regions

Table 2D-2. CALVIN Agricultural Demands by CVPM Region

Region	Maximum Economic Demand (taf/yr)
CVPM14	1,496
CVPM15	1,992
CVPM16	496
CVPM17	835
CVPM18	2,160
CVPM19	956
CVPM20	676
CVPM21	1,162
TOTAL	**9,773**

Table 2D-3. Agricultural Water Demand Areas for Region 4

Region	County	DAU	CVP Agricultural Contractors	SWP Agricultural Contractors
CVPM 14	Fresno, Kings, San Benito	244	Westlands WD	
CVPM 15	Fresno, Kings, Tulare	235, 237, 238, 241, 246	Fresno Slough WD, James ID, Laguna ID, Real. Dist. 1606, Traction Ranch, Tranquillity ID	Dudley Ridge WD, Empire West Side ID, Part of Kings Co WD, Tulare Lake Bed WSD
CVPM 16	Fresno	233, 234,	Fresno ID, Garfield WD, International WD	
CVPM 17	Fresno, Kings, Tulare	236, 239, 240	Hills Valley ID*, Orange Cove ID, Tri-Valley WD*	
CVPM 18	Kings, Tulare	242, 243	Alpaugh ID*, Atwell Island WD*, Corral ID, Co of Fresno*, Co of Tulare*, most of Delano Earlimart ID, Ducor ID, Exeter ID, Ivanhoe ID, Lewis Creek WD, Lower Tule River ID*, Lindmore ID, Lindsay-Strathmore ID, Pixley ID*,Porterville ID, portion of Rag Gulch WD*, Sausalito, Stone Tea Pot Dome, Terra Bella ID, Tulare ID,	Part of Kings Co WD
CVPM 19	Kern (West side)	255, 259, 260	Part of Delano Earlimart, Part of Rag Gulch WD	Belridge WSD, Berrenda Mesa WD, Buena Vista WSD, Buttonwillow ID, Lost Hills WD, Pond Poso ID, Semitropic WSD, West Kern WD
CVPM 20	Kern (East Side), Tulare	256, 257	Shafter-Wasco ID, South San Joaquin MUD	Cawelo WD
CVPM 21	Kern (South Side)	254, 258, 261	Arvin Edison WSD	Tehachapi-Cummings Co WD, Kern Delta WD, Wheeler Ridge-Maricopa WSD, Rosedale Rio-Bravo WSD, Improvement District #4, Tejon-Castac WD, Henry Miller WD

Except for the City of Fresno (in CVPM 16), the City of Bakersfield (CVPM 21), and the Santa Barbara-San Luis Obispo urban area in the Central Coast Hydrologic Region, urban demands within each CVPM region are aggregated and represented as fixed constraints (see Appendix B1, Howitt, et al. 1999 for further details). Urban demands vary monthly but with no inter-annual variation. The cities of Fresno, Bakersfield, Santa Barbara and San Luis Obispo are represented as economic demands, with monthly economic water value functions. The annual urban demands are given in Table 2D-4.

Table 2D-4. Urban Demands

Region	Target Demand (taf/yr)
City of Fresno	380
Cities of Santa Barbara and San Luis Obispo	139
City of Bakersfield	260
Urban fixed demands in region CVPM 14	15
Urban fixed demands in region CVPM 15	62
Urban fixed demands in region CVPM 17	84
Urban fixed demands in region CVPM 18	146
Urban fixed demands in region CVPM 19	23
Urban fixed demands in region CVPM 20	57
Urban fixed demands in region CVPM 21	30
TOTAL	**1,196**

Two national wildlife refuges are located within the Tulare Basin: Pixley NWR in CVPM region 18 and Kern NWR in CVPM region 19. Pixley NWR's current level 2 deliveries are small (1.28 taf/year) and its demands have been incorporated into the CVPM region 18 agricultural demand. Kern NWR deliveries are represented explicitly from the California Aqueduct as a fixed constraint corresponding to 11.24 taf/year (level 2 demand). The Mendota Wildlife Area, despite lying physically within Region 4, is included in Region 3, as it lies adjacent to and is directly supplied from the Mendota Pool jointly with San Joaquin wildlife/grasslands areas.

Boundary inflows from CALVIN Region 3 are the Friant-Kern Canal diversion from Millerton Lake, riparian agricultural diversions on the left bank of San Joaquin River, supplies from Mendota Pool to CVPM region 15 and CVPM region 14 (Westlands Water District) and from the California Aqueduct and San Luis Canal. Boundary outflows include flood releases from Pine Flat reservoir that enter Region 3 via the North Fork of the Kings River (St. James Bypass and Fresno Slough), wastewater from the City of Fresno, and outflow through the California Aqueduct to Southern California (CALVIN Region 5) at the Tehachapi Mountains.

MODEL ALTERNATIVES

The model was run for two alternatives. The first alternative is the "Base Cas -action" alternative. It applies constraints to reservoir storages, diversions, and pumping, to replicate projected current operating policies and water allocations at the 2020 level of demand, as they are modeled in the CVGSM No Action Alternative (NAA) run of the CVPIA PEIS (USBR 1997) and the DWRSIM 514 run. In the second alternative, referred to as Unconstrained Alternative, the model is constrained only by minimum environmental flows, capacity and flood storage constraints on reservoirs, and capacity constraints on conveyance facilities. Further details of the two alternatives are given in Appendices 2H: Calibration Process Details and 2I: Base Case Details.

Base Case Assumptions and Limitations

The assumptions and limitations of the Base Case alternative are presented below.

Reservoir Operations

No projected 2020 operations studies were found for the four USACE regional reservoirs. Instead storage operations for the Base Case were developed during the calibration process (see Appendices 2H and 2I). The model was run with the reservoirs unconstrained during the calibration process and the resulting optimized storages were used as constraints in the calibrated Base Case model. This assumption is reasonable since the space for optimization is highly limited by downstream Base Case delivery and flow constraints. The effects of evaporation were temporarily removed during the calibration to prevent reservoirs being artificially drawn down in the optimization process. Ending storage on Region 4 reservoirs is always constrained to equal the initial storage in all modeling cases. Reservoir operations for both Base and Unconstrained cases included restrictions on storage during winter months for flood control.

Surface Deliveries

Base Case deliveries to meet urban, agricultural and environmental demands are based on the CVGSM NAA and DWRSIM run 514. DWRSIM deliveries are used for the California Aqueduct, the Cross Valley Canal and the Mendota Pool. Deliveries from the Friant-Kern Canal and local stream diversions are based on CVGSM. To deal with incompatibilities and uncertainties within the data, sometimes leading to infeasibilities in the optimization run, calibration flows had to be added at various locations to the system (see Appendix 2H for details).

Another limitation regarding the data concerns the extensions of CVGSM deliveries from 1990 to 1993 to match the 72-year time period modeled in CALVIN. The extensions were extrapolated based on DWRSIM deliveries. Further details are presented in Appendix 2I: Base Case Details).

Groundwater Pumping and Storage

Groundwater pumping is taken from the CVGSM NAA run and end-of-period storage is left unconstrained as CALVIN has been calibrated to match CVGSM NAA groundwater storages in the Base Case. Extensions to CVGSM NAA pumping constraints for the last three years (1990-1993) are based on precipitation records (see Appendix J: Groundwater Hydrology and Appendix 2I: Base Case Details). We are aware of serious demands for additional water supplies for agriculture in various parts of the Tulare Basin, notably in the Westlands and Kern areas. Thus, it seems likely that CVGSM and others from whom we have taken our modeling data, do not adequately represent the supplies and water demands of these areas.

Unconstrained Policy Assumptions and Limitations

The surface storage facilities in Region 4 are constrained to end with the initial storage, as in the Base Case run. However, monthly storages are unconstrained but bounded by the dead pool and top of conservation pool, representing water supply storage capacity. Small persuasion penalties ($0.02/af) are applied to encourage reservoirs to retain water when there was no economic use elsewhere.

As described in the model alternatives section, all surface and groundwater deliveries have no constraints other than capacity limits. The agricultural demand links are limited by maximum demand calculated by SWAP (varying monthly) while the lower bound was set to equal the

SWAP adjustment in each month. Environmental demands of Kern NWR were fixed (level 2). To assure comparable water availability over the 72-year hydrologic sequence between the Base Case and Unconstrained Alternative, the end-of-period groundwater storage was constrained to match the ending storage in the Base Case run.

The calculated SWAP demands do not match the seasonal timing of boundary inflows to the region through the California Aqueduct, Mendota Pool, and Friant-Kern Canal, particularly during the months of November through February. This limitation causes a significant volume of Base Case agricultural supply to be “lost” in the Unconstrained Alternative and reduces the water available to the Tulare Basin compared to the Base Case. This limitation is important when comparing Base Case agricultural scarcities with those in the Unconstrained Alternative.

Rather than a sequential monthly/annual decision process, reservoir operations are determined simultaneously for the entire 72-year period-of-analysis. This gives the model perfect foresight of all future inflows (further details in Chapter 5 and Appendix 2K). Carryover storage and groundwater operation will be influenced by this perfect foresight. Model results may therefore under-estimate scarcities and scarcity costs in the Unconstrained Alternative and under-estimate somewhat the value of system expansion. These effects are likely to be damped somewhat by the large amounts of carryover storage present in the Basin, in the form of groundwater (Appendix 2K).

COMPARISON OF MODEL RESULTS

A summary of the overall water use by sector appears in Table 2D-5. Both Base Case and Unconstrained Alternatives show small differences in the annual average percentage of surface water and groundwater use. The difference remains in water allocations. While pumping approximately the same amount of groundwater (in total), the Unconstrained Alternative prioritizes regions with lower pumping cost and high water values, resulting in reductions in operating costs and scarcity costs for both the urban and agricultural sectors. Since the other urban deliveries are fixed and always supplied, only economically represented urban demands for Fresno, Bakersfield, and Santa Barbara-San Luis Obispo are presented here (roughly 70% of the region’s urban demands). Compared to agricultural deliveries, urban deliveries saw greater changes in supply mix (groundwater pumping reduced by 5%) and an increase in total deliveries. Both results reflect the high value of water to urban demands.

Table 2D-5. Average Annual Water Use by Sector

	Base Case Policy		Unconstrained Policy	
	taf	Percentage	taf	Percentage
Agriculture				
Surface Water	4,608	49.6%	4,501	48.9%
Ground Water	4,676	50.4%	4,695	51.1%
Total Deliveries	**9,284**		**9,196**	
Urban[1]				
Surface Water	211	28.6%	280	35.9%
Ground Water	526	71.4%	499	64.1%
Total Deliveries	**737**		**779**	

[1] *Cities of Fresno, Bakersfield, Santa Barbara and San Luis Obispo*

Table 2D-6 presents the total annual scarcity and scarcity costs for the region. The agricultural sector has more water scarcity in the Unconstrained Alternative, although scarcity costs are lower. The unconstrained case reduces deliveries to low value demands to increase deliveries to areas with higher economic value, in particular to the Fresno urban area. The result is a higher volume of scarcity in the agricultural sector associated with an overall lower scarcity cost. A deeper analysis of this result is provided in the following sections. Some of the increased agricultural scarcity is artificial, due to the seasonal mismatch between boundary inflows and SWAP demands in the Unconstrained Alternative. The urban sector receives greater benefits from an Unconstrained Alternative over current policies (Base Case), with scarcities being reduced to zero.

Another important aspect is the operating cost changes resulting from changes in the operations under an ideal water market policy. Increase in the scarcity in CVPM regions 15, 16, and 19 is associated with a reduction in pumping and costs (due to reduced recharge). The opposite effect is seen in CVPM regions 18, 21, and the City of Fresno, where reductions in scarcity and changes in supply mix incur additional pumping costs (see Table 2D-7). Operating and scarcity costs are presented in more detail in Table 2D-8. It must be noted that operating benefits are overestimated somewhat since CALVIN pumping costs do not include dynamic variations in the water table that would tend to increase pumping cost as groundwater is drawn down.

Table 2D-6. Average Annual Scarcities and Scarcity Costs

	Total		Agriculture		Urban	
Policy	Scarcity (taf/yr)	Cost ($ millions/yr)	Scarcity (taf/yr)	Cost ($ millions/yr)	Scarcity (taf/yr)	Cost ($ millions/yr)
Base Case	274	37	232	19	42	18
Unconstrained	322	18	322	18	0	0

Table 2D-7. Operating Benefits From Changes in Groundwater Pumping

Region	Reduced Pumping (taf/yr)	Benefit ($ millions/yr)	Pumping Cost ($/af)
CVPM14	0	0	76.4
CVPM15	5.3	0.2	46.6
CVPM16	42.5	1.3	29.8
CVPM17	1.4	0	31.6
CVPM18	-13.4	-0.6	45.2
CVPM19	8.1	0.6	68.8
CVPM20	0	0	67.2
CVPM21	-63	-4.4	69.6
Fresno	-42	-3.4	80
Bakersfield	69	8.9	128
Total	**8.1**	**2.6**	

Table 2D-8a. Agricultural Operating and Scarcity Costs (Annual Averages)

	Base Case		Unconstrained Alternative		Change UC-BC
	$1000/yr	% Total	$1000/yr	% Total	$1000/yr
CVPM 14					
Surface water operating costs	25,760	31.7%	25,760	31.7%	0
Groundwater operating costs	55,438	68.3%	55,421	68.3%	-16
Scarcity costs	0	0.0%	0	0.0%	0
Total	81,198		81,181		-16
CVPM 15					
Surface water operating costs	4,640	7.1%	2,000	3.1%	-2,640
Groundwater operating costs	60,778	92.4%	60,529	92.5%	-249
Scarcity costs	352	0.5%	2,903	4.4%	+2,551
Total	65,769		65,432		-337
CVPM 16					
Surface water operating costs	0	0.0%	0	0.0%	0
Groundwater operating costs	1,675	100.0%	409	77.2%	-1,266
Scarcity costs	0	0.0%	121	22.8%	+121
Total	1,675		530		-1,145
CVPM 17					
Surface water operating costs	0	0.0%	0	0.0%	0
Groundwater operating costs	12,939	100.0%	12,894	97.3%	-45
Scarcity costs	0	0.0%	361	2.7%	+361
Total	12,939		13,255		+316
CVPM 18					
Surface water operating costs	0	0.0%	0	0.0%	0
Groundwater operating costs	44,991	70.6%	45,597	81.5%	+607
Scarcity costs	18,778	29.4%	10,367	18.5%	-8,411
Total	63,768		55,964		-7,804
CVPM 19					
Surface water operating costs	17,578	41.8%	14,175	34.9%	-3,403
Groundwater operating costs	24,514	58.2%	23,960	58.9%	-554
Scarcity costs	0	0.0%	2,510	6.2%	+2,510
Total	42,092		40,645		-1,447
CVPM 20					
Surface water operating costs	0	0.0%	0	0.0%	0
Groundwater operating costs	19,843	100.0%	19,843	100.0%	0
Scarcity costs	0	0.0%	0	0.0%	0
Total	19,843		19,846		0
CVPM21					
Surface water operating costs	12,045	24.5%	8,394	16.3%	-3,651
Groundwater operating costs	37,117	75.5%	41,529	80.9%	+4,412
Scarcity costs	0	0.0%	1,433	2.8%	+1,430
Total	49,162		51,353		+2,191

Note: Agricultural surface water operating costs are only conveyance pumping costs.
Groundwater operating costs are fixed head pumping costs.

Table 2D-8b. Urban and Total Operating and Scarcity Costs (Annual Averages)

	Base Case		Unconstrained Alternative		Change UC-BC
	$1000/yr	% Total	$1000/yr	% Total	$1000/yr
Fresno					
Surface water operating costs	0	0.0%	0	0.0%	0
Groundwater operating costs	27,035	60.5%	30,406	100.0%	+3,371
Scarcity costs	17,650	39.5%	0	0.0%	-17,650
Total	44,685		30,406		-14,279
Bakersfield					
Surface water operating costs	5,291	18.0%	10,388	40.4%	+5,097
Groundwater operating costs	24,153	82.0%	15,295	59.6%	-8,858
Scarcity costs	0	0.0%	0	0.0%	0
Total	29,443		25,683		-3,760
S. Barbara & San Luis Obispo					
Surface water operating costs	49,604	100.0%	49,604	100.0%	0
Groundwater operating costs	0	0.0%	0	0.0%	0
Scarcity costs	0	0.0%	0	0.0%	0
Total – Agriculture & Urban					
Surface water operating costs	114,918		110,321		-4,596
Groundwater operating costs	308,483		305,883		-2,599
Scarcity costs	36,779		17,698		-19,081
Total	460,180		433,903		-26,277

Note: Urban surface water operating costs include treatment, local distribution, and conveyance pumping costs. Groundwater operating costs are fixed head pumping costs.

Analysis of results for drought years under the Unconstrained Alternative allows assessment of scarcities in more extreme situations. For this study, the droughts of 1929 to 1934, 1976 to 1977, and 1987 to 1992 were considered. The results are shown in Tables 2D-9, 2D-10, and 2D-11. Comparison shows small increases in the scarcity level relative to the whole period average of 322 taf/year ($18 million in cost). CVPM regions 15, 18, and 21 have slightly higher costs for these periods. Although the values are small, they indicate that these regions are somewhat more vulnerable to drought impacts. In the case of CVPM region 18, the higher value of the crops in this region may be influencing this result.

Conjunctive use groundwater/surface water plays an important role in these results as detailed in the next sections.

Agricultural Supply Sources and Reliability

Agricultural demands are presented in Table 2D-2 with detailed supply sources in Table 2D-12. CVPM region 18 is key to these results. As illustrated in Figures 2D-2 and 2D-3, the Unconstrained Alternative increases the supply to CVPM region 18 and to the urban sector at the expense of other lower value agricultural demand areas. This provides an idea of the potential for intra-regional water transfers. As shown in Figure 2D-2, more than half of the re-allocated water goes to other agricultural regions (CVPM region 18 in particular).

Table 2D-9. Unconstrained Alternative Scarcity Levels During Drought Years

Region	1929-1934 Scarcity (taf/yr)	1976-1977 Scarcity (taf/yr)	1987-1992 Scarcity (taf/yr)
CVPM14	0	0	0
CVPM15	74	74	74
CVPM16	5	5	5
CVPM17	14	14	14
CVPM18	169	169	170
CVPM19	44	38	38
CVPM20	0	0	0
CVPM21	24	23	24
Fresno	0	0	0
Bakersfield	0	0	0
S. Barbara & San Luis Obispo	0	0	0
Total	330	322	326

Table 2D-10. Unconstrained Alternative Scarcity Costs During Drought Years

Region	1929-1934 Scarcity Costs ($1000/yr)	1976-1977 Scarcity Costs ($1000/yr)	1987-1992 Scarcity Costs ($1000/yr)
CVPM14	0	0	0
CVPM15	2,940	2,907	2,940
CVPM16	121	121	121
CVPM17	361	361	361
CVPM18	10,427	10,393	10,476
CVPM19	2,862	2,469	2,513
CVPM20	0	0	0
CVPM21	1,472	1,438	1,472
Fresno	0	0	0
Bakersfield	0	0	0
S. Barbara & San Luis Obispo	0	0	0
Total	18,182	17,690	17,883

Table 2D-11. Unconstrained Alternative Increase in Scarcity Costs During Drought Years[1]

Region	1929-1934 Drought (%)	1976-1977 Drought (%)	1987-1992 Drought (%)
CVPM14	0.0	0.0	0.0
CVPM15	1.3	0.2	1.3
CVPM16	0.0	0.0	0.0
CVPM17	0.0	0.1	0.1
CVPM18	0.6	0.2	1.1
CVPM19	0.0	0.0	0.0
CVPM20	0	0	0
CVPM21	2.7	0.3	2.7
Fresno	0	0	0
Bakersfield	0	0	0
S. Barbara & San Luis Obispo	0	0	0

[1] *Increase relative to the whole 72-year annual average.*

Table 2D-12. Average Annual Agricultural Supplies by Source

	Base Case		Unconstrained	
Supply Source	taf/year	% Total Supply	taf/year	% Total supply
CVPM 14				
California Aqueduct	756.2	50.5%	755.8	50.5%
Mendota Pool	15.1	1.0%	14.8	1.0%
Groundwater	725.6	48.5%	725.4	48.5%
Total	**1497.0**		**1496.0**	
CVPM 15				
Kings River	394.4	20.9%	443.0	24.2%
Kaweah River	6.2	0.3%	10.2	0.6%
California Aqueduct	137.8	7.3%	31.1	1.7%
Mendota Pool	45.0	2.4%	43.9	2.4%
Groundwater	1304.3	69.1%	1298.9	71.1%
Total	**1887.7**		**1827.1**	
CVPM 16				
Friant Kern Canal	21.6	4.8%	11.3	2.5%
Kings River	368.9	81.7%	416.1	93.3%
San Joaquin River	5.0	1.1%	5.0	1.1%
Groundwater	56.2	12.4%	13.7	3.1%
Total	**451.7**		**446.1**	
CVPM 17				
Kings River	310.7	40.9%	331.2	44.4%
Friant Kern Canal	38.7	5.1%	7.0	0.9%
Groundwater	409.5	54.0%	408.0	54.7%
Total	**758.9**		**746.2**	
CVPM 18				
Kaweah River	314.5	16.2%	275.0	13.8%
Tule River	36.3	1.9%	81.4	4.1%
Friant Kern Canal	591.8	30.5%	626.5	31.5%
Groundwater	995.4	51.4%	1008.8	50.7%
Total	**1938.0**		**1991.7**	
CVPM 19				
Friant Kern Canal	13.1	1.4%	9.6	1.0%
Kern River	64.9	6.8%	139.3	15.2%
California Aqueduct	522.2	54.6%	421.1	45.9%
Groundwater	356.3	37.2%	348.3	37.9%
Total	**956.6**		**918.3**	
CVPM 20				
Friant Kern Canal	230.2	36.4%	169.8	26.9%
Kern River	106.9	16.9%	167.2	26.4%
Groundwater	295.3	46.7%	295.3	46.7%
Total	**632.3**		**632.3**	
CVPM 21				
Friant Kern Canal	102.1	8.8%	78.2	6.9%
Cross Valley Canal	75.4	6.5%	125.7	11.0%
Kern River	168.7	14.5%	214.4	18.8%
California Aqueduct	282.5	24.3%	123.7	10.9%
Groundwater	533.3	45.9%	596.7	52.4%
Total	**1162.0**		**1138.7**	

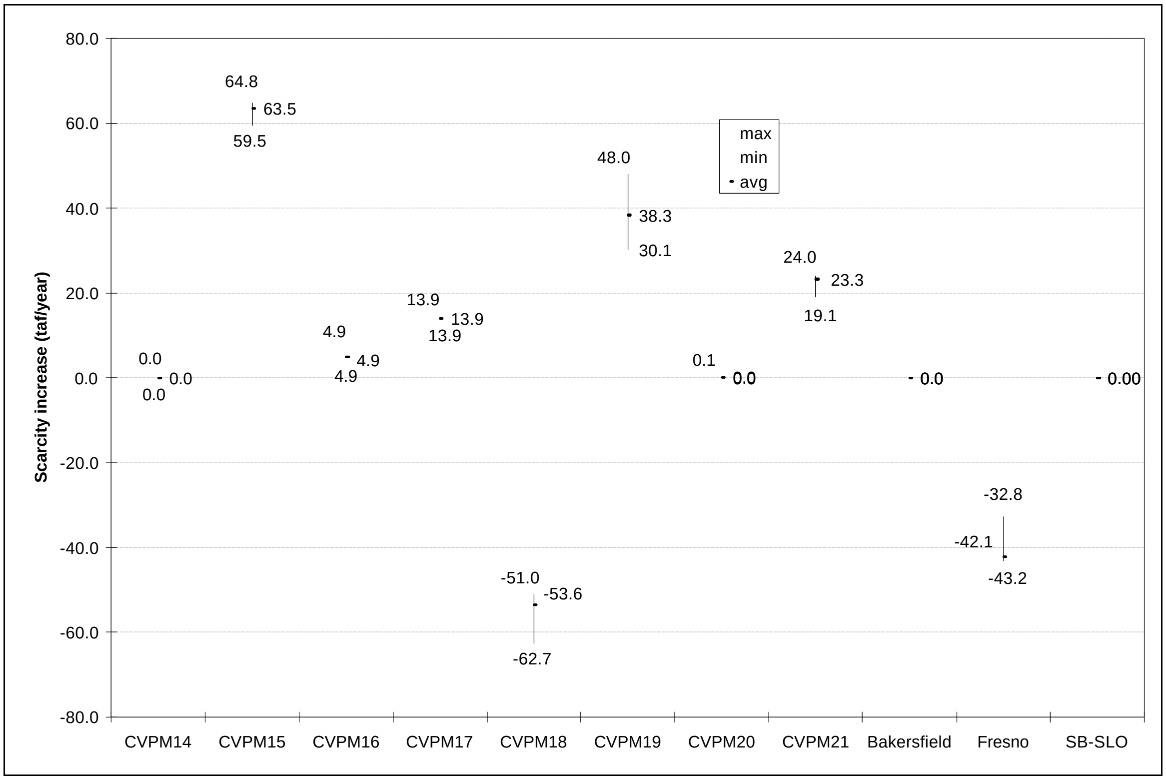

Figure 2D-2. Average Annual Scarcity Increase By Demand Region

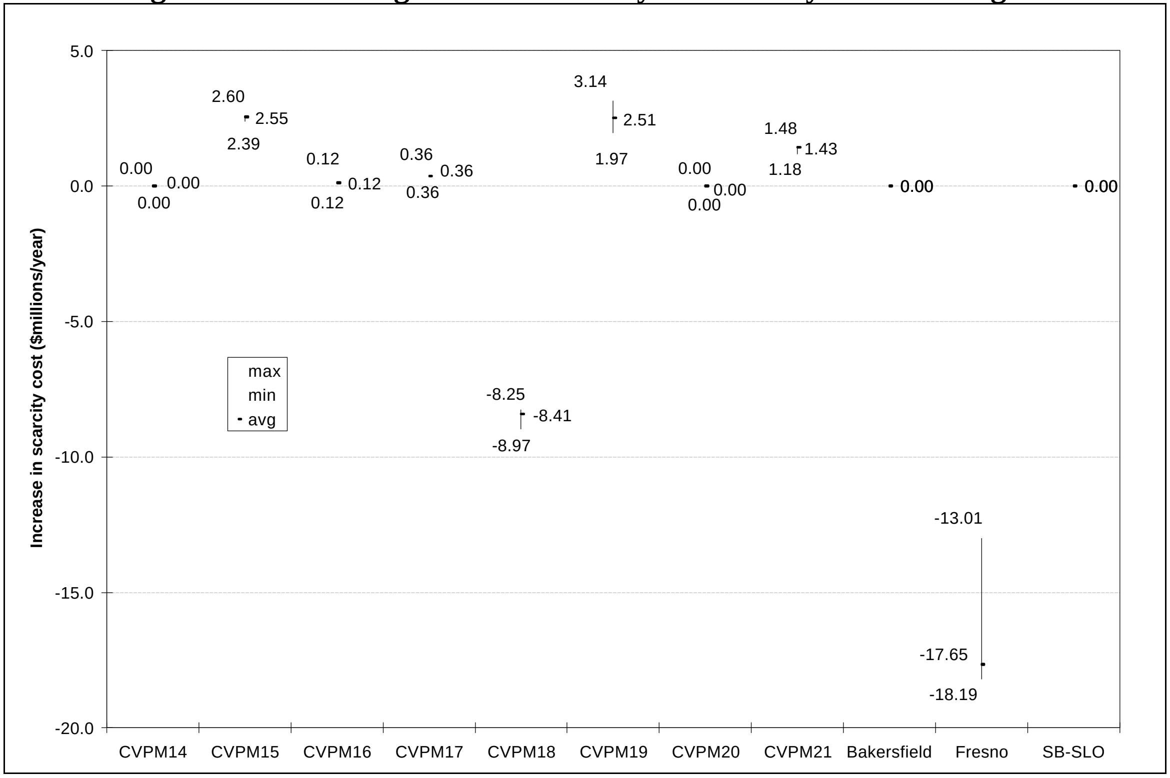

Figure 2D-3. Average Annual Scarcity Cost Increase By Demand Region

A conclusion of this analysis is that the ideal water market policy can lead to an overall regional benefit, mostly to higher value demand areas. For example, in CVPM region 18, a 24% reduction in scarcity (on average) with an Unconstrained Alternative economic re-allocation of water corresponds to a 45% reduction in scarcity costs. The analysis of changes in the scarcities and costs shows that the water use benefits are not shared proportionally among the agricultural regions. CVPM regions 15, 16, 17, 19, and 21 experience increases in scarcity costs, some of which are due to the artificial reduction in water availability in the Unconstrained Alternative over the Base Case from limitations in the CALVIN model. Purchase or rent payments may be necessary to compensate these users.

Figure 2D-4 shows the difference in deliveries between the Base Case and Unconstrained Alternative for agricultural users. Because inter-annual variability in demand is not considered in the Unconstrained Case, its delivery line is flat, in contrast with Base Case deliveries, where inter-annual variability is taken into account. Under this limitation only a comparison on an annual average basis is possible. For the Base Case, annual average deliveries represent 97.6 % of annual average demands, while in the Unconstrained Case the proportion is 96.7 %. Although small, these figures indicate the agricultural sector loses some reliability due to water transferred to the urban sector and lost water in the Unconstrained Alternative.

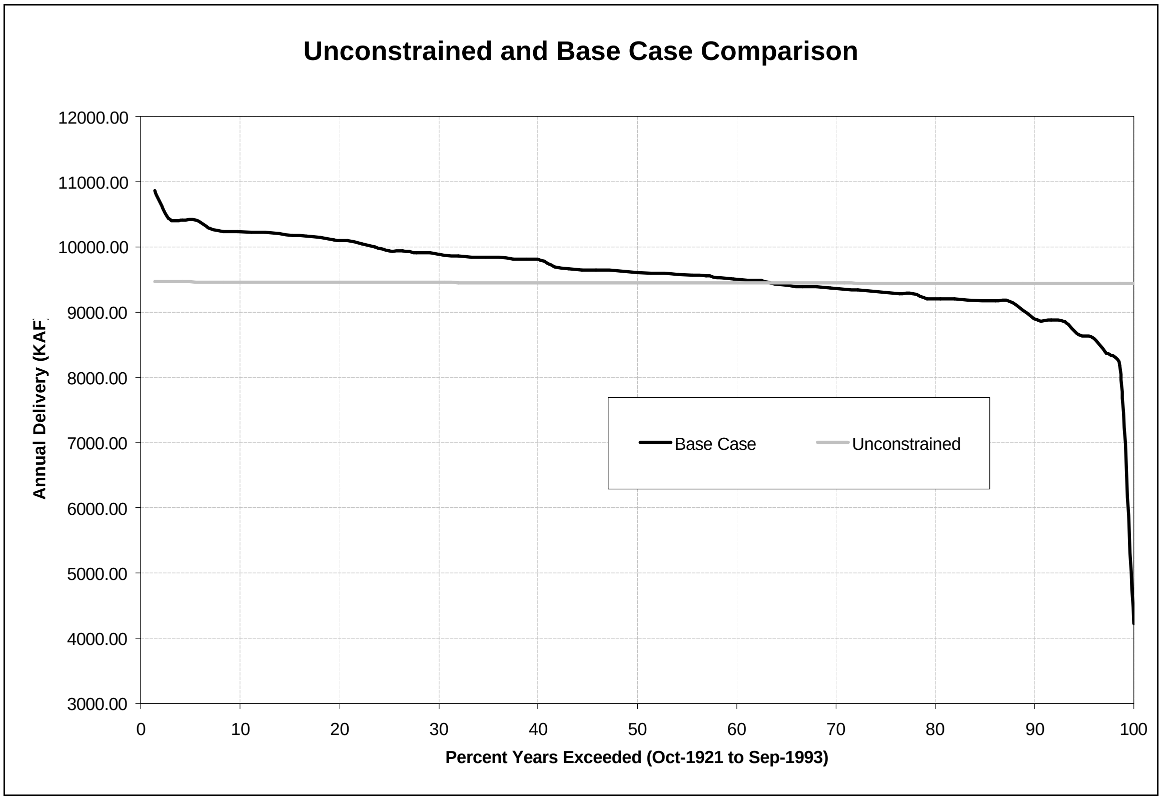

Figure 2D-4. Annual Agriculture Supply Reliability

Urban Supply Sources and Reliability

The urban sector gets a high benefit in the Unconstrained Alternative. Without constraints to force Fresno demand to share groundwater with CVPM region 16, Fresno is able to pump enough groundwater to meet 100% of its demand in the Unconstrained Alternative, in contrast with 88.9% of demand in the Base Case. This scarcity reduction produces a net benefit of $14.3 million/year (after accounting for the increased groundwater pumping cost) (Figure 2D-3).

Table 2D-13. Urban Annual Average Supplies by Source

	Base Case Policy			Unconstrained Policy		
Supply Source	taf/year	% Supply	% Demand	taf/year	% Supply	% Demand
Fresno						
Surface water	0	0		0	0	
Groundwater	338	100%		380	100%	
Total	338		88.9%	380		100%
S. Barbara & San Luis Obispo						
SWP Imports	56	40%		56	40%	
Local Supplies	83	60%		83	60%	
Total	139		100%	139		100%
Bakersfield						
Surface water	72	27.6%		141	54.2%	
Groundwater	188	72.3%		119	45.8%	
Total	260		100%	260		100%

Bakersfield, in contrast, reduces its use of more expensive groundwater from 71.8% in the Base Case to 45.5% in the Unconstrained Alternative, a reduction of 69 taf/year of groundwater that is replaced by increased use of surface supplies (SWP imports or exchanges) (see Table 2D-13). The benefits of reduced ground water pumping costs are diminished by increased surface water treatment costs. Given a pumping cost of $128/af, and a treatment cost of $40/af, the net benefit in reduced operating costs is approximately $6.0 million/year. Overall, urban water supply reliability rises from approximately 93% in the Base to 100% in the Unconstrained Case (Figure 2D-5).

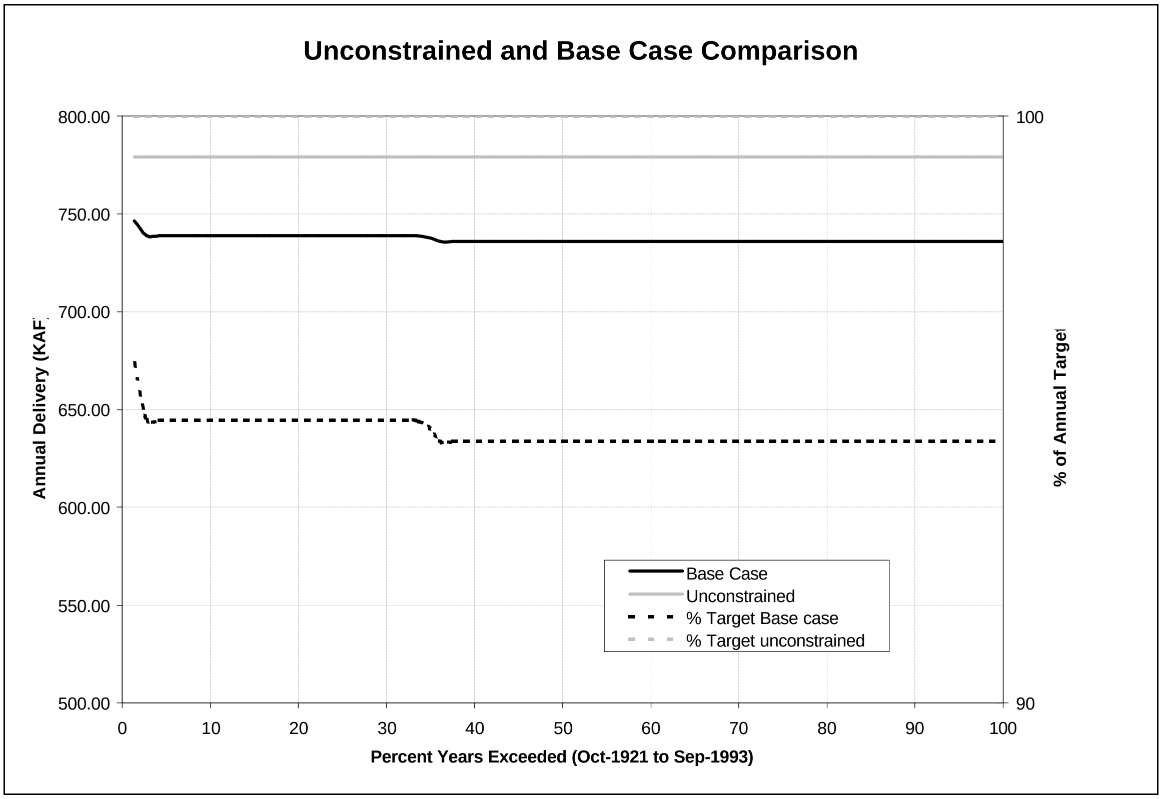

Figure 2D-5. Annual Urban Supply Reliability

Changes in Deliveries and Scarcity Costs

Figure 2D-2 shows the range of changes in annual deliveries to each demand region between the Base Case and Unconstrained Alternative. A positive value indicates an Unconstrained Alternative-induced reduction in deliveries (increase in scarcity); a negative amount indicates an Unconstrained Alternative increase in deliveries (reduction in scarcity). Water transfers to CVPM region 18 result in a reduction of its scarcity cost of approximately $8.4 million per year. In contrast, the other agricultural regions experience increased scarcity costs.

Although some of these increased costs are due to transfers to the urban sector, the seasonal mismatch between Base Case inflows into Region 4 and the SWAP agricultural demands result in an artificial reduction in available water in the Unconstrained Alternative amounting to 184 taf/year of California Aqueduct supply, 108 taf/year of Friant-Kern Canal supply, and 10 taf/year of Mendota Pool deliveries. These reductions in supply are most likely responsible for almost all of the increase in agricultural sector scarcities. The 184 taf/year “lost” California Aqueduct deliveries could supply the Unconstrained Alternative scarcities in CVPM regions 15, 19, and 21 (135 taf/year) while the 108 taf/year “lost” Friant-Kern Canal deliveries represent 57.6% of the Unconstrained Alternative scarcities in CVPM regions 16, 17, 18, and 20 (188 taf/year). The Unconstrained Alternative re-operation of the system is mostly driven by the need to replace these lost Base Case supplies (302 taf/yr) rather than by the small Base Case urban scarcity (42 taf/yr).

ENVIRONMENTAL WATER DEMANDS

Kern NWR refuge received 11.2 taf/year under current operations for level 2 refuge demands. Under the Unconstrained Alternative it is interesting to analyze the opportunity cost of this water to agricultural and urban users in Region 4. This can be done by looking at the marginal costs (benefits) resulting from delivering one more (less) taf of water to Kern NWR. On a monthly basis, these opportunity costs are presented in Table 2D-14, averaged for the 72 years. Peak values occur in May and June, falling to $1.2 /af in November and December, when there is excess water in Region 4 (partly caused by limitations in the Unconstrained CALVIN model).

Table 2D-14. Opportunity Costs of Refuge Deliveries ($/af)

Month	Average Marginal Cost	Maximum Marginal Cost	Standard Deviation
September	59.5	64.0	16.3
October	52.6	85.7	25.0
November	1.2	85.7	10.1
December	1.2	85.7	10.1
January	3.5	84.7	17.1
February	20.6	84.7	30.7
March	63.6	84.7	3.6
April	62.1	63.0	7.4
May	64.0	64.0	0.1
June	64.0	64.0	0.0
July	63.0	63.0	0.0
August	63.0	63.0	0.0

The inter-annual variability (standard deviation) over the 72 years of the marginal costs of increased refuge deliveries shows zero variability in the dry season months of June, July, and August. Refuge water opportunity costs for these months remains nearly constant at $63/af across all years.

On average, the cost to increase the environmental supply is approximately $43/af. As expected, the cost increases as water availability drops in drought years. Figures 2D-8 and 2D-9 show marginal costs approaching $86/af in some months during the 76-77 and 87-92 droughts.

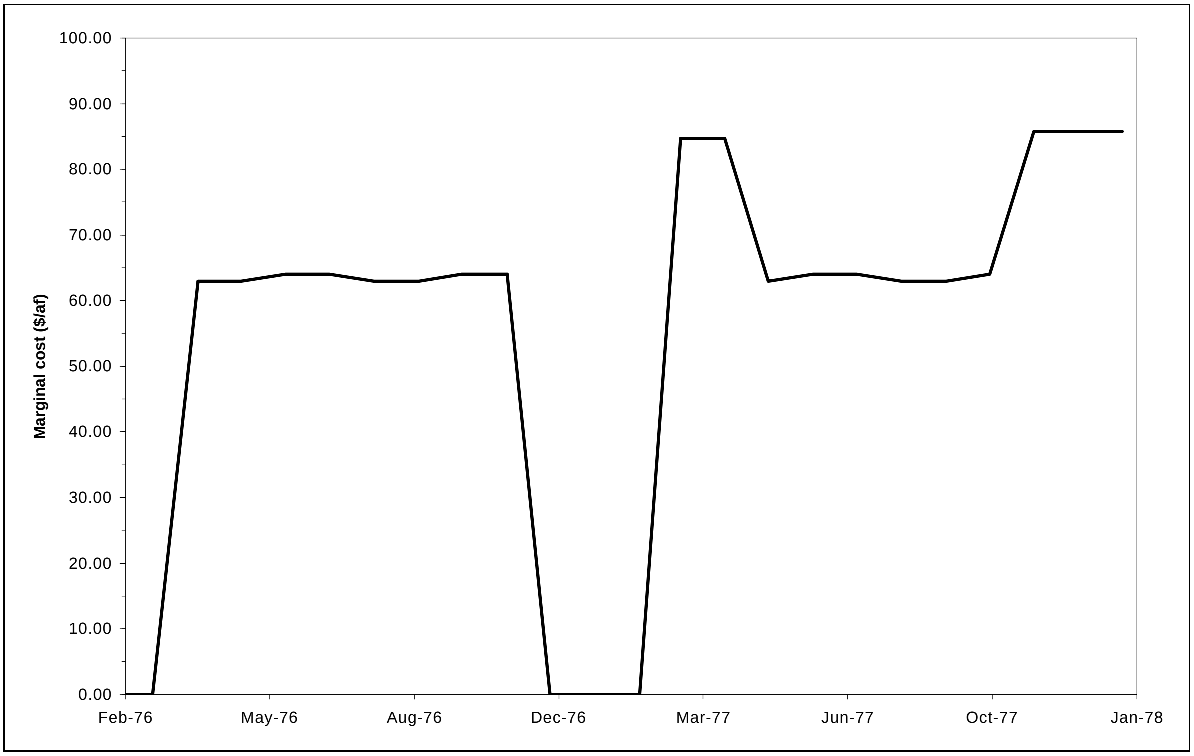

Figure 2D-8. Opportunity Cost of Environmental Water in the 1976-77 Drought ($/af)

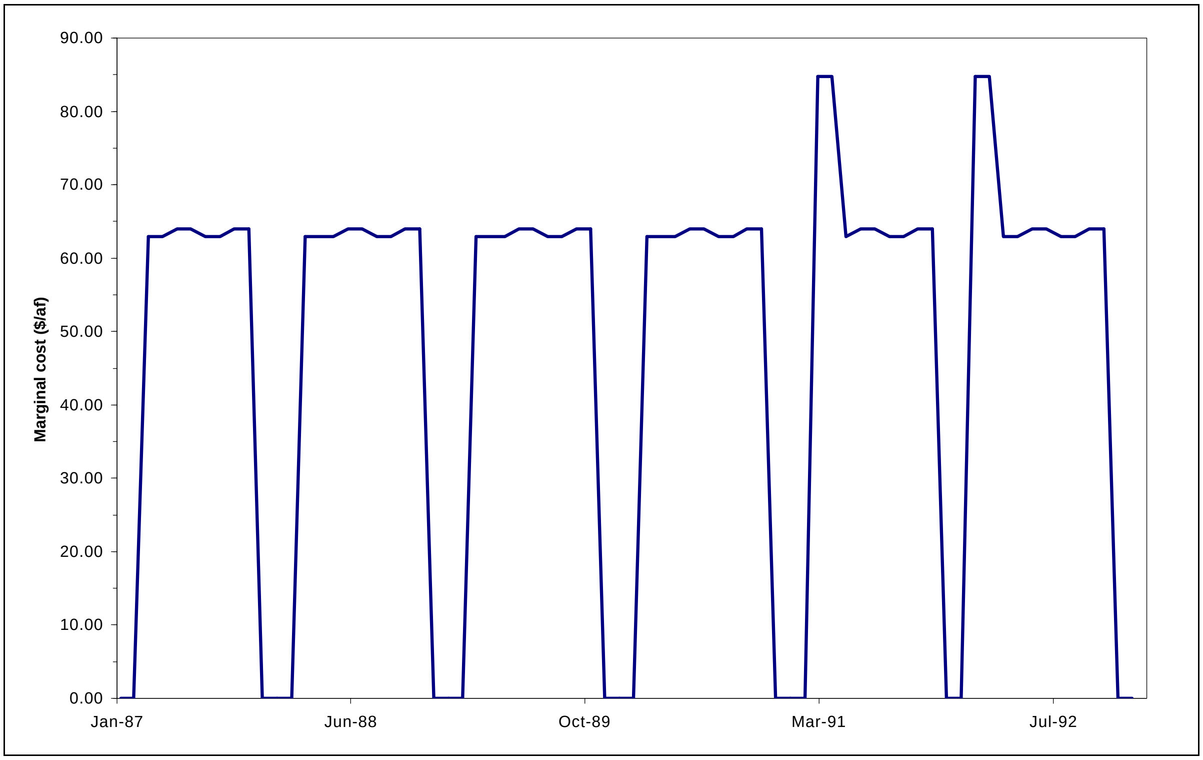

Figure 2D-9. Opportunity Cost of Environmental Water in the 87-92 Drought ($/af)

Demand for Inter-Regional Transfers

Water exports and imports to and from adjacent regions are another important aspect of water management. Although the Unconstrained Alternative holds all boundary flows between Region 4 and its neighboring Regions 3 and 5 fixed at Base Case levels, the likely direction of inter-regional flows and changes in regional benefits under an Unconstrained Alternative can be assessed. Tables 2D-16 and 2D-17 compare the net value of an additional unit of water at the boundaries of adjacent regions under the Unconstrained Case. CALVIN calculates these values as the Lagrange multipliers (shadow values) on the fixed boundary flows in and out of the region. Comparing the shadow value (net willingness-to-pay) of one extra unit of inflow water to the shadow value of one extra unit of outflow water in the adjacent region permits an evaluation of the water value to each region and the potential for inter-regional water transfers under an Unconstrained Alternative. Tulare Basin is south of Region 3 (San Joaquin and Bay Area) and north of Region 5 (Southern California).

As shown, additional water transfers from Region 3 to Region 4 beyond the Base Case would result in significant marginal benefits for all boundary inflows. It is important to note that the values in Table 2D-16 are averages for the 72-year sequence. In wet months when there is no Region 4 scarcity, additional inflows on the California aqueduct raise pumping cost to move this excess to Region 5 resulting in negative values (costs) for additional water.

Table 2D-16. Unconstrained Net Willingness-To-Pay (WTP) for Additional Inflows ($/af)

Inflow to Region 4	Region 4 WTP	Region 3 WTP
Millerton Lake diversion to Friant-Kern Canal	43.7	13.2
San Luis Unit/California Aqueduct	43.5*	23.1*
San Joaquin River riparian diversions to CVPM Region 16	52.5	8.5
Mendota Pool deliveries to CVPM region 15	42.7*	8.2*
Mendota Pool deliveries to CVPM region 14	43.5*	

Notes:

** Region 3 and 4 WTP do not consider the costs of Banks and Tracy Pumping plants ($22/af), and Region 4 San Luis Unit/California Aquieduct WTP also does not consider Dos Amigos Pumping plant costs ($11/af). These pumping conveyance costs would decrease both regions' net willingness-to-pay marginal values.*

Table 2D-17. Unconstrained Net WTP for Additional Outflows ($/af)

Outflow from Region 4	Region 4 WTP	Region 3 WTP	Region 5 WTP
Fresno urban return flow to San Joaquin R.	52.5	11.6	-
St. James/ N. Kings River to Mendota Pool	47.7	8.5	-
California Aqueduct to Region 5	70.8*	-	329

Notes:

** Region 4 WTP does not consider the cost of Banks and Dos Amigos pumping plants. These pumping conveyance costs would decrease Region 4's net WTP for California Aqueduct outflows.*

Tables 2D-16 and 2D-17 show that transfers from Region 3 will result in positive net benefits given the higher WTP for all boundary inflows in Region 4. Compared to Region 5, both Regions 3 and 4 have lower WTP and transfers from these two regions through the California Aqueduct to Region 5 are likely to result in positive economic benefits.

Examination of the detailed monthly WTP values for the flows reported in Tables 2D-16 and 2D-17 indicates that water transfers are actually likely to flow in both directions across Region

4's boundaries. In wet months, Region 3 shows higher WTP for boundary flows than Region 4, despite the average WTP value being higher in Region 4. Statistics on the difference in WTP between Region 4 and Region 3 are shown in Figure 2D-10. Positive values indicate higher Region 4 WTP and negative values indicates higher Region 3 WTP. The negative minimums indicate that temporary transfers to Region 3 in wet months may be possible when there is excess water available in the Tulare Basin region. Looking at the frequency distribution of the WTP difference between the Tulare and San Joaquin regions, approximately 30% of the time transfers to Region 3 are more beneficial (Table 2D-18).

Table 2D-18. Distribution of WTP Differences Between Regions 3 and 4

Boundary	Region 4 WTP higher - % Time	Region 3 WTP higher - % Time	Difference very small[a] - % Time
Millerton Lake diversion to Friant Kern Canal	68%	31%	1%
San Luis Unit/California Aqueduct	68%	38%	0%
San Joaquin R. riparian diversion to CVPM 16	70%	11%	19%
Mendota Pool deliveries to CVPM 15	67%	13%	21%
Mendota Pool deliveries to CVPM 14	68%	12%	20%
Notes: [a] Differences ranging from 0 to 1 $/af			

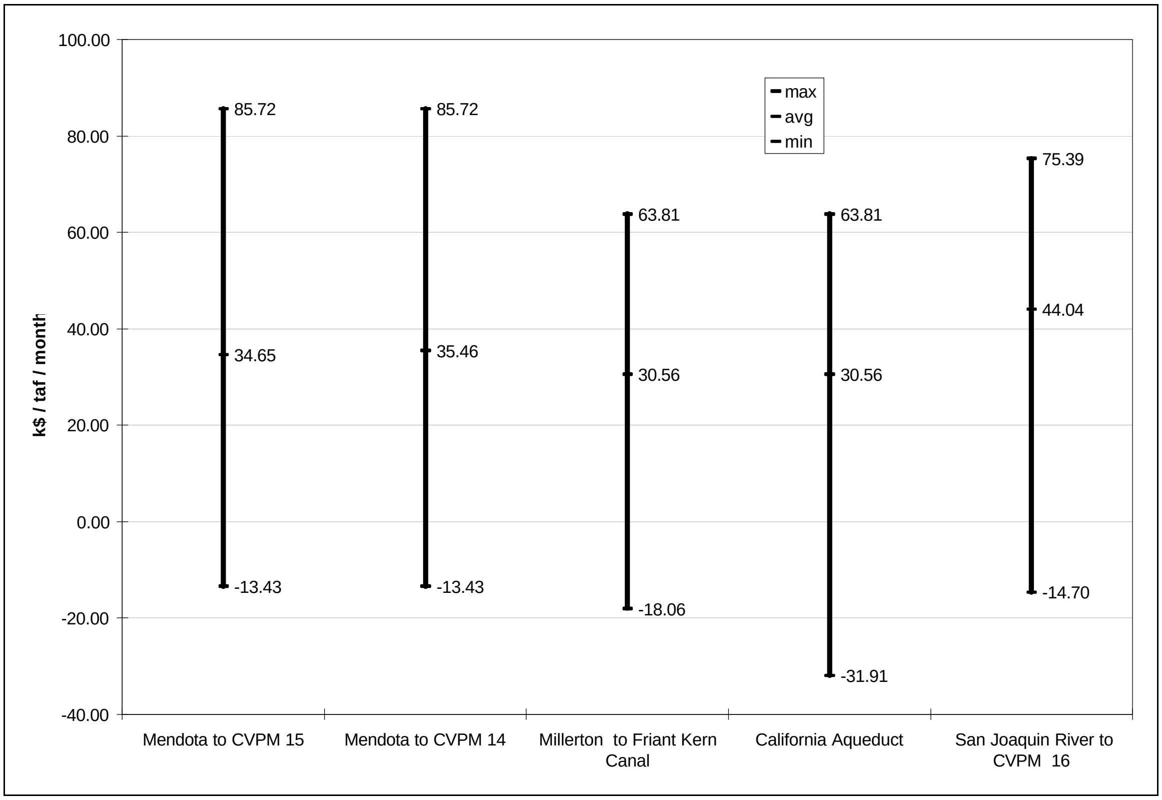

Figure 2D-10. Difference in WTP for Water Transfers Between Region 4 and 3

Users Willingness-to-Pay for Additional Water

Under the Unconstrained Alternative it is possible to evaluate the benefits of additional supplies to different users from the "dual values" reported in CALVIN at each node. The dual values for each of the CVPM regions show that agricultural users can be grouped based on their willingness to pay for additional water from different sources, as presented in Table 2D-19. These values are driven by the operating costs of alternative supplies and users' marginal values for additional water. Differences in willingness-to-pay across these groups can arise because of capacity constraints that prevent equal sharing of a common water supply or differences in conveyance losses. CVPM regions 14 and 19 are supplied mostly by the California Aqueduct; CVPM regions 18 and 20, by the Friant-Kern Canal; CVPM regions 15, 16, and 17, by the Kings River; and CVPM region 21 by California Aqueduct and Kern river.

The first group with the higher WTP (CVPM regions 15, 16 and 17) is prevented from receiving more water through the Friant-Kern canal due to conveyance constraints (Table 2D-22) causing their WTP to be higher than in CVPM regions 18 and 20, which are also mostly supplied by Friant-Kern Canal water. Increasing the Friant-Kern Canal diversion capacities to CVPM regions 15, 16, and 17 would likely equalize their WTP with CVPM regions 18 and 20.

CVPM region 21 is constrained for getting additional supply from the Friant-Kern Canal (Table 2D-22) and from the Kern River. The diversion facility that supplies CVPM region 21 with Kern River water has a marginal benefit of expansion of $0.74/af per month.

Although the California Aqueduct capacity is never binding in Region 4, differences in conveyance losses and/or alternative water costs may explain differences in WTP between CVPM regions 14 and 19, and CVPM regions 15 and 21. CVPM regions 14 and 19 have a loss factor of approximately 1%, while CVPM regions 15 and 19 have loss factors of 15% and 5%, respectively. Reuse rates on deliveries also could affect willingness to pay, but in this case there is no significant differences between CVPM regions 14, 19, 15, and 21.

Table 2D-19. Users' WTP for Additional Supplies Under the Unconstrained Alternative

Region	WTP Dry Months ($/af)	WTP All Months ($/af)	Common Major Surface Supply Source	% Supply Provided by Source
CVPM14	63.4	43.7	California Aqueduct	50.5
CVPM19	63.2	43.3		45.9
CVPM15	74.6	50.4	Kings River	24.2
CVPM16	75.2	52.5		93.3
CVPM17	78.8	55.0		44.4
CVPM18	71.4	47.3	Friant-Kern Canal	31.5
CVPM20	70.2	48.5		26.9
CVPM21	65.9	45.2	Kern River California Aqueduct	18.8 10.9

There are some small marginal values for expanding diversion capacity from the Kern River to CVPM regions 20 and 21 but not frequent enough to explain the difference in their WTP with CVPM region 19. Again, the difference in conveyance losses is the most significant factor explaining the situation. CVPM region 20 has higher losses (11%) and also higher WTP, while CVPM 21 presents the second higher loss rate (5%).

The value of additional water in the Base Case is driven by Fresno scarcity, since this urban demand has a fairly high value for more water. It is willing to pay an average of $359 for an additional acre-foot supplied. In the Unconstrained Alternative, urban scarcities are eliminated. A more economically efficient allocation of water leads to reductions in scarcities, scarcity costs, and reduced potential for water conflicts with adjacent regions. It does this, despite over 300 taf/yr reduced water availability over the Base Case.

POTENTIAL FOR FACILITY AND MANAGEMENT CHANGES

Results of the Tulare Basin CALVIN model suggest several areas for water facility and management changes. These are detailed below for facility expansion, surface storage operations, groundwater storage operations, conjunctive use operations, cooperative operations, and water transfers.

Promising Areas for Facility Expansion

Increasing the capacity of the system to store and convey water can help reduce scarcities and reduce operating costs. An important analysis to guide capacity expansion decisions is assessment of the benefits of an additional unit of capacity, as indicated by Lagrange multiplier values. These are non-zero when a constraint is binding, giving the increase in the value of the objective function for a unit increase in capacity. For example, shadow values on the upper bound storage constraints on each of the four reservoirs in Tulare Basin indicate the benefits of increasing their storage capacity by 1 af, as shown in Table 2D-20.

Table 2D-20. Marginal Values of Additional Storage Capacity

Reservoir	Annual Expected Benefit ($/af capacity)
Pine Flat (Kings R.)	1.8
Lake Isabella (Kern R.)	3.6
Lake Kaweah (Kaweah R.)	55.6
Lake Success (Tule R.)	48.2

Lake Kaweah and Lake Success show the highest benefits. Both these reservoirs are considerably smaller than Pine Flat and Lake Isabella. Comparing mean reservoir inflow to conservation storage capacity allows further evaluation of the potential value of increased storage as shown in Table 2D-21.

Table 2D-21. Ratio of Conservation Storage Capacity to Mean Annual Inflow

Reservoir	Mean Inflow (taf/yr)	Conservation Storage (taf)	Ratio (S/I)
Pine Flat (Kings R.)	1,594	840	0.53
Lake Isabella (Kern R.)	684	364	0.53
Lake Kaweah (Kaweah R.)	416	68	0.16
Lake Success (Tule R.)	132	45	0.34

Tables 2D-20 and 2D-21 show that Lake Kaweah not only presents the highest benefit ($55.6/year per af), but also has the largest potential for expansion. Present conservation storage capacity in Lake Kaweah represents only 16% of the mean annual inflow. CVPM region 18, with 14% of supplies from the Kaweah River, plays an important role in the storage value estimates. Most of the benefits of Lake Kaweah expansion probably come from reducing remaining scarcities in CVPM region 18.

Lake Success is the second highest in benefits and expansion potential. Other ways to augment water supply storage capacity in these reservoirs include decreasing flood control space. This analysis does not compare the benefits of changing flood control operations with the benefits of physical expansion and does not indicate which would be preferable.

The California Aqueduct does not have any binding capacity constraints in the Unconstrained Alternative (marginal values along the aqueduct are zero). The same result was found for pumping facilities at Buena Vista, Wheeler Ridge, Christman, and Edmonston. The Friant-Kern Canal had some very small benefits to increasing the capacity of diversion facilities to CVPM agricultural regions 15, 16, 17, 19, and 21. These values are presented in Table 2D-22.

Table 2D-22. Marginal Values of Additional Conveyance Capacity

Conveyance Structure	Annual Expected Benefit ($ per af/month)
Friant diversion to CVPM15	1.0
Friant diversion to CVPM16	1.5
Friant diversion to CVPM17	1.5
Friant diversion to CVPM19	1.4
Friant diversion to CVPM21	1.4

Groundwater storage and pumping capacities do not limit groundwater supplies to any of the demand areas in the Unconstrained Alternative. Thus, there is no value to increasing pumping capacities in Region 4. Since the end-of-period storage in the Unconstrained Alternative was constrained to match the Base Case level, it is interesting to access how Tulare Basin would react to a relaxation in this constraint. Table 2D-23 presents the net benefits of reducing the ending storage constraint by one af. Positive values indicate that the system will be better off (benefits) if more groundwater could be pumped (lower end-of period storage compared to the Base Case). Negative values indicate that further groundwater pumping is unnecessary and would incur net costs to the region. As expected, basins with higher pumping costs and less or no scarcity would benefit from reduced pumping. Westlands Water District (CVPM region 14) has no scarcity in the Unconstrained Alternative and the highest pumping cost, resulting in a net cost of $11.8/af of additional pumping. On the other hand, CVPM regions with some scarcity and lower pumping costs, such as CVPM 15, 16, 17, and 18, would gain net benefits of up to $47/af if more pumping were allowed.

Table 2D-23. Marginal Values of Increasing Long-Term Groundwater Depletion

Groundwater Basin	Groundwater Pumping Cost ($/af)	Marginal Benefit of Lowering Ending Storage Constraint ($/af)
CVPM 14	76.4	-11.8
CVPM 15	46.6	29.4
CVPM 16	29.8	45.6
CVPM 17	31.6	47.3
CVPM 18	45.2	27.5
CVPM 19	68.8	-4.2
CVPM 20	67.2	4.7
CVPM 21	69.6	-2.3

Surface Storage Operations

The four major reservoirs in the Tulare Basin have important flood control purposes that limit their operation for inter-annual storage. Three other factors influence CALVIN's optimized reservoir operations: conjunctive use, evaporation, and perfect foresight. Perfect knowledge of future reservoir inflows allows CALVIN to optimally hedge and reduce carryover storage in anticipation of heavy winter inflows. Availability of large volumes of stored groundwater and widespread use of pumping also reduce the need for reservoir carryover storage (as well as the importance of perfect foresight in CALVIN operations – see Appendix 2K). CALVIN also tends to keep reservoirs drawn down to limit evaporation losses in dry periods. Figure 2D-10 compares the total surface storage in the Base Case and Unconstrained Alternatives, beginning in 1958 shortly after the reservoirs started operation. These three effects can be seen in the less risk averse operation under the Unconstrained Alternative. The reservoirs are more frequently drained to lower levels with unconstrained operations.

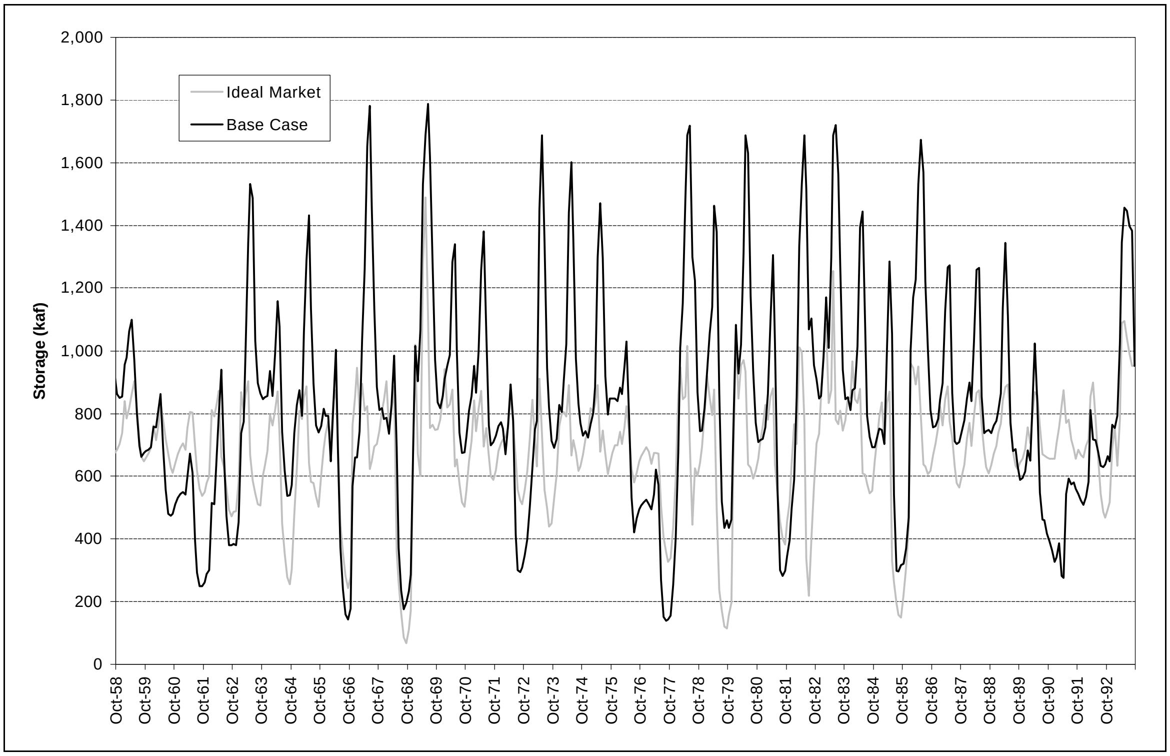

Figure 2D-10. Tulare Basin Combined Surface Storage Operations

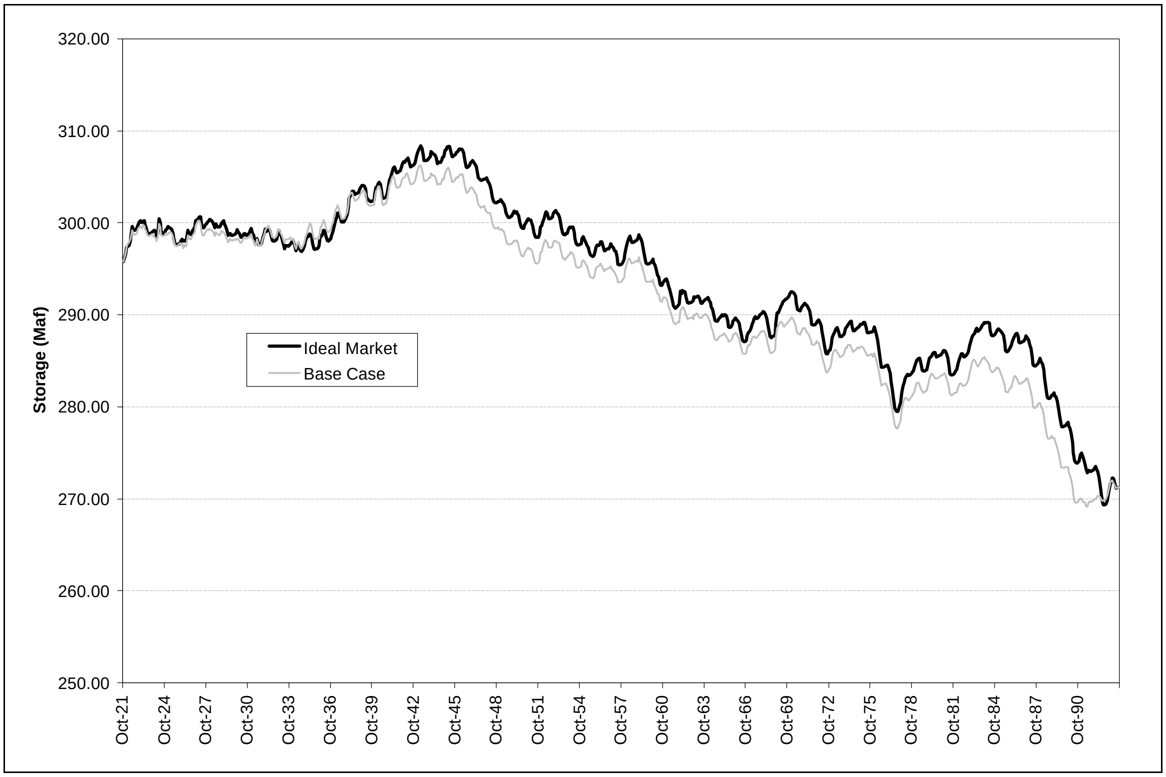

Figure 2D-11. Tulare Basin Groundwater Storage

Groundwater Storage Operations

The relatively large storage capacity of the groundwater system provides much greater potential to adjust to dry and wet periods. Because of weaknesses in the CVGSM data for the Tulare Basin (see Appendix 2I: Base Case Details, and Chapter 5), storage operations before and after the construction of the four surface reservoirs (beginning in 1953) are not comparable.

Groundwater operations in both the Unconstrained Alternative and Base Case are very similar, with an increasing small difference in total storage over time (until the last year) in the Unconstrained Alternative. Since Tulare Basin relies on significant lower cost surface water supplies, CALVIN tries to minimize more expensive groundwater pumping during wet years to reduce costs whenever possible (although in a fairly limited way, due to the end-of period groundwater storage constraint), and conserve groundwater for drier years. The lack of inter-annual variation in SWAP demands and the absence of seasonal variation in agricultural efficiencies contribute to the reduced amplitude in the pumping pattern. Similarity between the Base Case and Unconstrained pattern would suggest that Tulare Basin conjunctive operations are already close to optimal, given the current (Base Case) level of long-term groundwater depletion.

Conjunctive Use Operations

The availability of such a large quantity of groundwater allows significant flexibility in system operations, which is fully exploited in the Unconstrained Alternative. The two main objectives driving operations are to minimize operating costs while maximizing revenue from crop production.

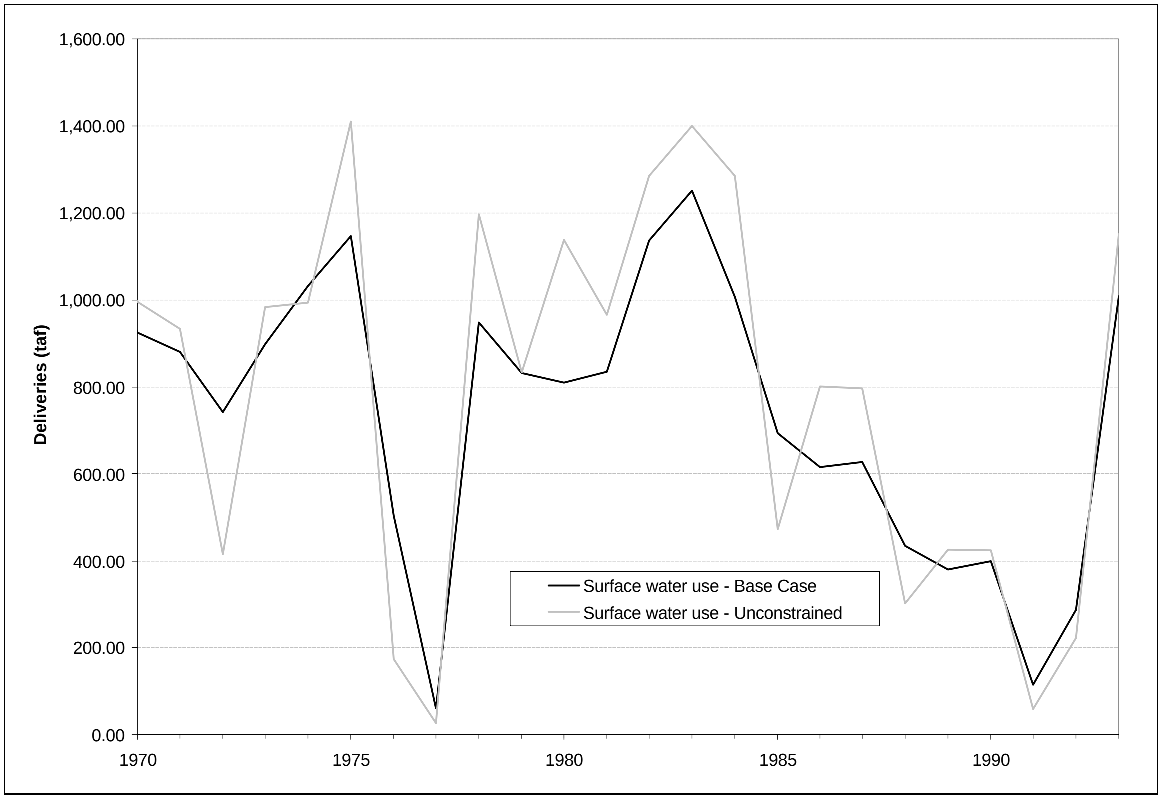

Figure 2D-12. CVPM Region 14 Annual Surface Water Use: 76-77 and 1987-92 Droughts

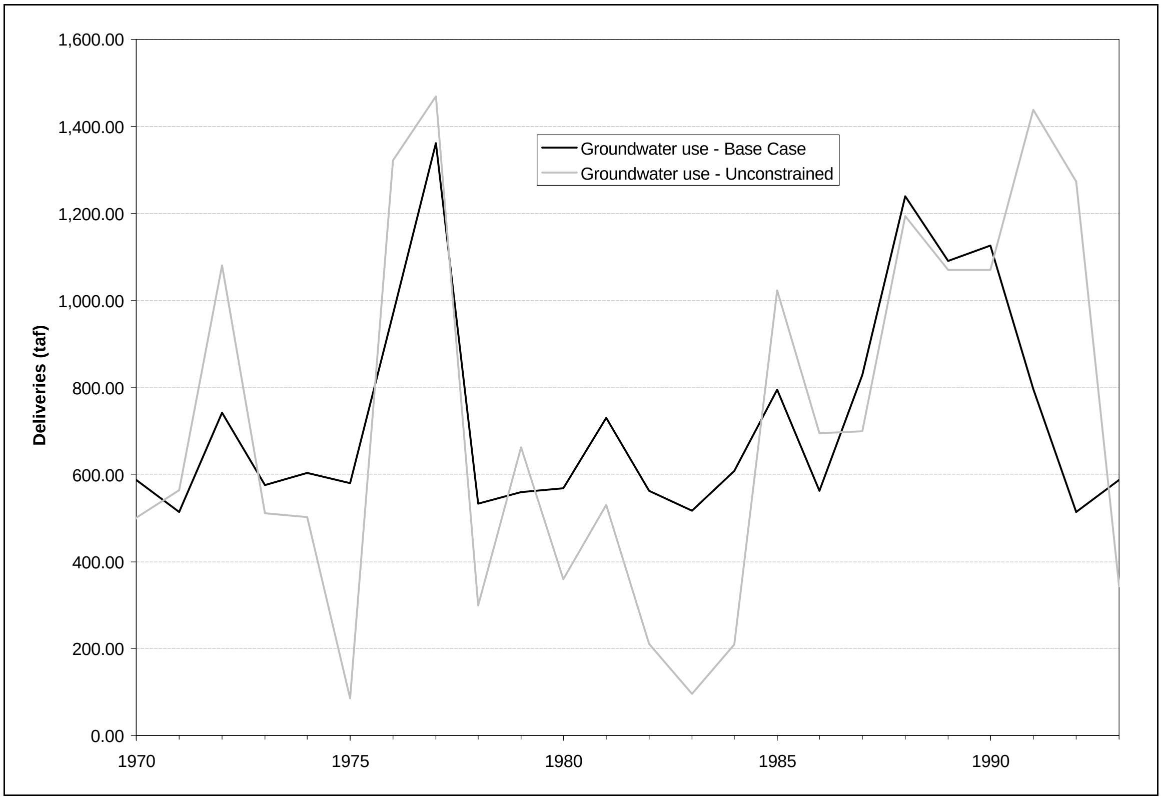

Figure 2D-13. CVPM Region 14 Annual Groundwater Use: 76-77 and 87-92 Droughts

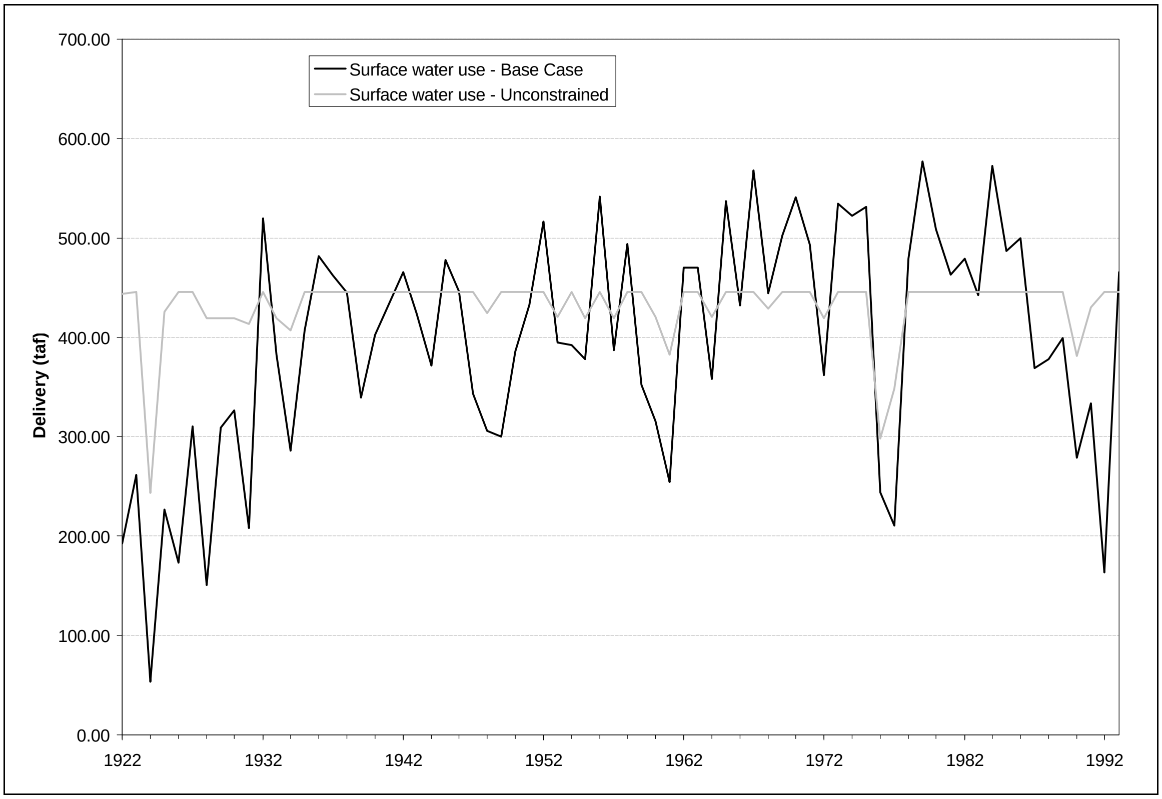

Figure 2D-14. CVPM Region 16 Annual Surface Water Use: 1922-1993

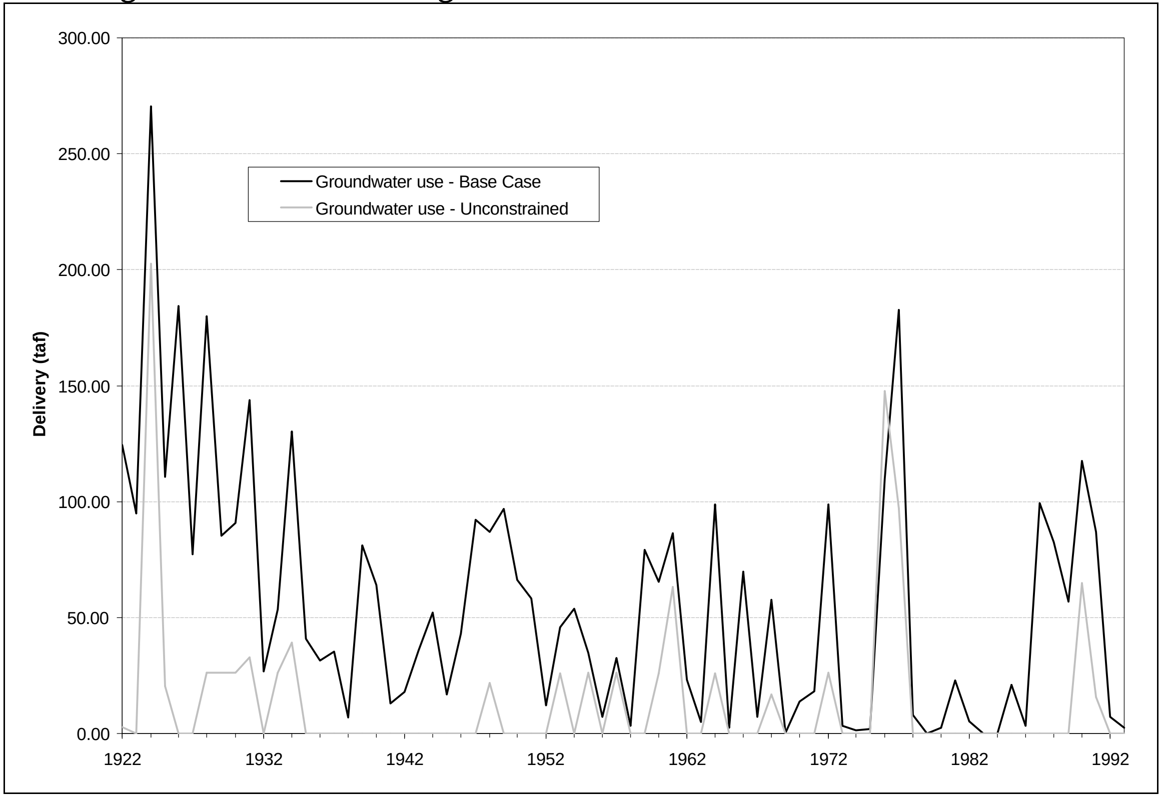

Figure 2D-15. CVPM Region 16 Annual Groundwater Use: 1922-1993

The important result in conjunctive use operations is the ability to reduce groundwater pumping during wet years, and keep the water stored for use in the dry years, reducing overall scarcity costs. Figures 2D-12 and 2D-13 give some insight into the situation. For CVPM region 14, it is possible to see less use of surface water during drought periods for the Unconstrained Alternative, contrasting with higher use in wet years. Figure 2D-13 depicts the opposite situation for groundwater operations: higher groundwater pumping in drought periods for the Unconstrained Alternative and more limited use in wet years.

CVPM region 16 presents a more extreme but similar situation in Figures 2D-14 and 2D-15. Groundwater storage is being depleted by Fresno demands at a much greater rate in the Unconstrained Alternative, leaving less groundwater for CVPM 16. Under the Unconstrained Alternative conjunctive use operations maximize surface water deliveries to CVPM 16 whenever possible, while reserving groundwater use to replace reduced surface water supplied in drought periods (1976-77 and 1987-92) only.

Through the region-wide coordinated operation of both surface imports and local reservoirs, somewhat greater conjunctive use of groundwater and surface water is possible in the Tulare Region, allowing for an additional 42 taf/yr in urban deliveries and nearly 212 taf/yr in additional agricultural deliveries over the Base Case (accounting for artificially lost supplies), for a total of 254 taf/yr in new supply by re-operating the system.

Cooperative Operations

More flexible use of water is also possible through the cooperative operation of the available infrastructure. Significant changes were found in the diversions of water from the reservoirs, the Friant-Kern Canal, and the California Aqueduct, under the Unconstrained Alternative. Changes in operation towards more cooperative use supports greater conjunctive use of surface and groundwater supplies, resulting in economic benefits from reduced scarcity costs. The effects of cooperative operations tend to involve exchanges of water between CVPM regions through the complex network of canals, reservoirs, rivers, and diversion structures that exists among agricultural users in the Tulare Basin, making its analysis a complex task. Some examples of cooperative exchanges are presented in this section. Tables 2D-24 and 2D-25 present some changes in the operation of the reservoirs and conveyance structures from the Base to the Unconstrained Case.

Table 2D-24. Changes in Reservoir Operations

Reservoir / River	Region	Base Case		Unconstrained Alternative		Change (UC-BC)
		Delivery (taf/yr)	% Supply	Delivery (taf/yr)	% Supply	(taf/yr)
Pine Flat / Kings River	CVPM15	394.4	20.9%	443.0	24.2%	48.6
	CVPM16	368.9	81.7%	416.1	93.3%	47.2
	CVPM17	310.7	40.9%	331.2	44.4%	20.5
Kaweah / Kaweah River	CVPM15	6.2	0.3%	10.2	0.6%	4.0
	CVPM18	314.5	16.2%	275.0	13.8%	-39.5
Success / Tule River	CVPM18	36.3	1.9%	81.4	4.1%	45.1
Isabella / Kern River	CVPM19	64.9	6.8%	139.3	11.8%	74.4
	CVPM20	106.9	16.9%	167.2	26.4%	60.3
	CVPM21	168.7	14.5%	214.4	18.8%	45.8

Table 2D-25. Changes in Conveyance Operations

Facility	Region	Base Case		Unconstrained Alternative		Change
		Delivery (taf/yr)	% CVPM Supply[1]	Delivery (taf/yr)	% CVPM Supply[1]	(taf/yr)
California Aqueduct	CVPM14	756.2	50.5%	755.8	50.5%	-0.4
	CVPM15	137.8	7.3%	31.1	1.7%	-106.7
	CVPM19	522.2	54.6%	421.1	45.9%	-101.1
	CVPM21	357.9	30.8%	249.4	21.9%	-108.5
	Bakersfield	71.8	27.6%	141.0	54.1%	69.2
	Total	1845.9		1598.4		-247.5
Friant Kern Canal	CVPM16	21.6	4.8%	11.3	2.5%	-10.3
	CVPM17	38.7	5.1%	7.0	0.9%	-31.7
	CVPM18	591.8	30.5%	626.5	31.5%	34.7
	CVPM19	13.1	1.4%	9.6	1.0%	-3.6
	CVPM20	230.2	36.4%	169.8	26.9%	-60.4
	CVPM21	102.1	8.8%	78.2	6.9%	-23.9
	Total	997.5		902.4		-95.2

[1] Percentages are for the CVPM region's total supply.

Lake Success (Tule River)

CVPM region 18 scarcities were reduced, in part, with increased diversions from the Tule River (Lake Success). This operation of Lake Success is important since it prevents CVPM region 18 from taking more Friant-Kern water and causing a greater impact on CVPM regions 16, 17, 18, 20, and 21. As seen on Tables 2D-23 and 2D-24, CVPM region 18 receives a greater increase in supply from the Tule River than from the Friant-Kern Canal.

Pine Flat (Kings River)

Pine Flat is operated to increase diversions to CVPM regions 15, 16, and 17 and reduce their scarcity costs. CVPM region 15 increases diversions from the Kings River (Pine Flat) to replace reduction in California Aqueduct supplies. CVPM region 16 must replace groundwater supplies employed by Fresno (to reduce its high Base Case scarcity costs), Friant-Kern Canal supplies used by CVPM region 18, and Base Case winter deliveries "unavailable" in the Unconstrained Alternative. CVPM region 17 also replaces lost Friant-Kern supplies with Kings River water.

Lake Isabella (Kern River)

The operation of Isabella under the Unconstrained Alternative significantly increases supply to CVPM regions 19, 20 and 21, all of which reduce their diversions from the California Aqueduct and Friant-Kern Canal. CVPM region 20 reduces its diversion from the Friant-Kern Canal and replaces it with water from Kern River, maintaining the same level of overall supply as in the Base Case (no scarcity). CVPM region 19 substantially reduces use of the California Aqueduct, in addition to a small reduction in Friant-Kern Canal supply. Part of this water is replaced by Kern River supply, but the overall result is an increase in scarcity relative to the Base Case. CVPM region 21 faces the same situation as CVPM region 19, with a slightly higher reduction in Friant-Kern Canal supply. However, CVPM region 21 increases its groundwater supply, ending up with a smaller scarcity than CVPM region 19 in the Unconstrained Alternative.

Reductions in available California Aqueduct and Friant-Kern imports for agriculture under the Unconstrained Alternative from the mismatch between Base Case deliveries and SWAP demands are partially made up by significant reservoir re-operations. Specifically, Pine Flat and Lake Isabelle are re-operated in the Unconstrained Alternative to produce nearly 300 taf/yr, on average, of additional agricultural deliveries.

Some of the reduction in diversions from the California Aqueduct produces water to supply the city of Bakersfield, replacing groundwater pumping and reducing its overall operating costs.

Water Transfers

Water transfers within the region (intra-regional transfers) and among neighboring regions (inter-regional transfers) can provide efficient solutions to some scarcity problems. In the Unconstrained Alternative, CALVIN uses intra-regional transfers and exchanges, given available supplies and the value of water demands, to minimize the total costs (operating and scarcity) for the Tulare Basin Region. Comparing results to the Base Case, it is possible to evaluate the gains with this management technique.

Costs and Benefits of Inter-Regional Transfers

Results in Tables 2D-16, 2D-17, and 2D-18 point to the potential value of different types of water transfers between CALVIN regions if a larger-scale or statewide water market were operated. *Temporary or seasonal* transfers are mainly due to differences in the availability of surplus water in a given region. Comparing shadow values at the Tulare Basin boundary with the San Joaquin and South Bay Region it is possible to see that although on average a transfer from the San Joaquin Region to Tulare Basin would result in positive gains, *during wet months* the direction of transfers would be reversed, resulting in positive gains from transfer to the San Joaquin and South Bay Region.

Permanent transfers or long-term leases are likely if the benefits are unlikely to change between years or seasons. If the receiving region's willingness-to-pay is sufficiently and consistently high, permanent transfers might be negotiated. This seems to be the case for transfer from Tulare Basin to Region 5 (Southern California). The average shadow value for additional California Aqueduct water in Region 5 is $329/af, well above the $70.8/af willingness-to-pay for such water in Tulare Basin.

Costs and Benefits of Intra-Regional Transfers

Conjunctive use possibilities and minimizing the region's scarcity costs are driving the potential for water transfers and exchanges within Tulare Basin as CALVIN seeks to jointly minimize operating costs and maximize economic return from the water used.

The main potential lies in transfers from the agriculture sector to the urban sector and among agricultural users. CVPM region 16 transfers 42.3 taf/year (on average) of its groundwater pumping to the city of Fresno, increasing CVPM region 16's scarcity costs by approximately $0.12 million/year while reducing Fresno's by $17.65 million/year. The small impact on CVPM 16 is due to its ability to acquire substitute surface water supplies in the region through additional transfers from lower value agricultural users.

Another beneficial transfer is an exchange between CVPM region 21 and the city of Bakersfield. Under the Unconstrained Alternative, Bakersfield reduces its groundwater pumping by 69 taf/year replacing it with cheaper surface water for a net operating cost reduction of approximately $6.0 million/year.

Transfers among agricultural regions are also significant under the Unconstrained Alternative, but are more complex to track. As an overall result, the benefits of these potential transfers come from large scarcity cost reductions in higher value CVPM regions with small scarcity cost increases in several lower value CVPM regions. Some possibilities are discussed below.

The high value CVPM region 18 reduces its scarcity by an additional 34.7 taf/year, with additional Friant-Kern Canal water transferred from CVPM regions 16, 17, 19, and 20 (see Table 2D-25). It is interesting that CVPM region 20 has no scarcity, despite this loss of Friant-Kern water, because it succeeds in replacing all of the lost supply with additional Kern River deliveries.

Transfers from CVPM region 17 to CVPM region 15 are possible to partially compensate for supply reductions imposed on CVPM 15 by lost Base Case California Aqueduct deliveries. To equalize the dual costs between these two regions, CVPM region 17 receives a smaller share of Kings River water, allowing CVPM region 15 to increase its share. Table 2D-26 summarizes the overall results.

Table 2D-26. Overall Economic Benefits from Intra-Regional Transfers

Benefit Category	Benefit Value ($\$10^6$/yr)	Users Affected
Scarcity Cost Reductions	26.1	City of Fresno and CVPM 18
Scarcity Cost Increases	-7.0	CVPM 15, 16, 17,19, and 21
Groundwater Pumping Cost Reductions	11.0	City of Bakersfield, CVPM 15, 16, 17, and 19
Groundwater Pumping Cost Increases	-8.4	CVPM 18, 21, and City of Fresno
Surface Water Treatment Cost Increases	-2.8	City of Bakersfield
Surface Water Pumping Cost Reductions[1]	9.7	CVPM 15, 19, and 21
Surface Water Pumping Cost Increases[1]	-2.3	Cities of Bakersfield, Santa Barbara and San Luis Obispo
Overall Balance	**26.3**	

[1] *California Aqueduct and Mendota pool diversions*

REGIONAL ECONOMICS

Impacts of operational changes under an unconstrained alterative are further evaluated using the SWAP model.

Table 2D-27. SWAP Post-Processed Regional Economic Impacts

	Base Case	Unconstrained Alternative	Change (BC - UC)	% change
Calculated Irrigation efficiency	-	-	-	1.0%
Calculated Crop areas (1,000 acres)	2958	2955	3	0.09%
Gross Revenue ($millions)	4484	4477	7	0.15%
Net Revenue ($millions)	2008	2005	3	0.14%

The agricultural regional economic impacts assessed by SWAP show in what the reduction of water supply to the agricultural sector translates into. The changes are rather small, as depicted in table 2D-27, and the increase in water supplies to some high crop value regions, such as CVPM region 18, may help to overcome the overall loss and contribute to a lower regional economic impact. Further detail in this analysis is presented in Appendices A, 2J, and 2L.

It is possible to conclude that the operation of the system under an Unconstrained Alternative can lead to significant economic benefits. This more flexible alternative allows intense conjunctive and cooperative use operations, allocating water in a more efficient manner. Such efficiency is reflected in a supply reliability increase for agricultural and urban sectors, reduced drought economic impacts, and maximized economic return for each acre-foot of water used.

LIMITATIONS

Several factors still pose difficulties and some uncertainties for the analysis and interpretation of the Tulare Basin results. The behavior of some components of the system is not yet fully known (and consequently are modeled approximately), although this may not change the nature of the overall results presented here. For instance, the pattern of scarcity re-allocation, from CVPM region 18 in the Base Case, to other agricultural regions in the unconstrained case, and from Fresno urban users to agricultural users, should be a reliable indication of how scarcity would be optimally allocated. The following caveats are discussed as they highlight some desirable improvements.

Mismatch Between SWAP Demands and Base Case Tulare Basin Imports

SWAP monthly demands do not match the seasonal timing of region boundary inflows causing unmatched supply being discarded to Southern California and other sinks in the region (St. James Bypass/Fresno Slough, terminus of Friant-Kern Canal and Coastal Aqueduct, etc.). This limitation reduces the amount of water available to Tulare Basin in the Unconstrained Alternative by more than 300 taf/year over the Base Case and is driving much of the water re-allocations and re-operations in the model's solution. This limitation leads to artificially created scarcities and scarcity costs in the Unconstrained Alternative, requiring caution when comparing it to the Base Case. At this point, more sophisticated and improved representation of SWAP monthly demands as well as inter-annual variation representation is required to mitigate the problem.

CVGSM Data

Perhaps the most fundamental limitation faced in modeling Tulare Basin is the lack of consistent and accurate data on the hydrologic inputs, Base Case diversions, agricultural operations, and reservoir operations. The calibration process was based on the CVGSM NAA model results, which relied on historic gage measurements for estimating diversions, and a mixture of unimpaired and impaired hydrology for representing reservoir releases on most of the local rivers. We are particularly concerned with representations in the Westlands Water District and Kern County area, which are relatively satisfied in the model, but in fact have demonstrated considerable economic demand and willingness-to-pay for additional water.

Surface Water Return Flows from Agriculture Regions

In some agricultural regions, the reuse of return flows from upstream farms is common. Information on when and how much water is reused is not always available or consistent. As discussed in Chapter 3 and Appendix 2H, the solution adopted in the calibration process was to allow water to be added to local rivers at “calibration” nodes to compensate for any distortions caused by in-accurate estimates of the volume and location of surface return flows.

Agricultural On-Farm Efficiencies

Agricultural on-farm efficiencies might be too high, so that not enough groundwater recharge occurs in CALVIN. Problems with the groundwater calibration in the Tulare Basin Region are discussed more fully in Chapter 3 and Appendix 2H.

Groundwater Recharge

A common practice of agricultural districts in this region is the use of the surplus surface water to recharge groundwater. There is a significant amount of agricultural surface water deliveries in the Tulare Basin that is recharged, more than 350 TAF/yr on average for Friant-Kern water users (see Appendices 2H and 2I, Calibration and Base Case Details). The CVGSM NAA model does not distinguish these deliveries from applied water demands. Since SWAP demands were adjusted to match CVGSM NAA deliveries, CALVIN perceives less groundwater recharge than may actually exist. The consequence is potentially greater groundwater storage depletion in both the Base Case and Unconstrained Alternative.

Of all the regions modeled in CALVIN, the Tulare Basin is clearly the one with the greatest data difficulties, despite being one of the most important for understanding California’s water management statewide. While some useful general conclusions can be made, substantial effort is needed to reconcile surface water operations, groundwater, return flow, and water demand data for this region.

REGIONAL WATER MANAGEMENT IMPLICATIONS

For the Tulare Basin, groundwater storage is generally maintained at higher levels in the Unconstrained Case while overall pumping increases slightly due to the greater amount of agricultural recharge resulting from increased applied water. This builds up “strategic” reserves of groundwater that increase supply reliability in extreme droughts. Groundwater pumping is avoided during wet periods of surplus surface supply and increased during droughts.

Intra-regional transfers and improved operations may result in an average of $26.3 million/year in net economic benefits. Although the greatest volume of transfers is among agricultural users, most of the economic benefits arise from the smaller volume agriculture-to-urban transfers within the region. Transfers among agricultural regions produce benefits from reduced operating costs and increased value of agricultural production.

These benefits can be achieved with no structural changes in the existent infrastructure, although there is potential for expansion of Lake Kaweah and Lake Success. At the margin, increase in these reservoirs' capacity may result in up to $55.6/yr of benefits per additional acre-foot of storage capacity under ideal water market conditions.

As mentioned, inter-regional imports from the San Joaquin and South Bay (Region 3) are possible since Tulare Basin Region users are willing to pay up to $52.5 per each additional af of imported water. Compared to a marginal willingness-to-pay in Region 3 of $8.5/af for this exported water, the overall net benefit would be approximately $44/af of additional water transferred to Tulare Basin beyond the Base Case. The implementation of some mechanism to compensate exporter regions and third parties is needed, both for intra-regional and inter-regional transfers.

The opportunity cost of environmental flows is high, as expected in a region with such levels of scarcities and economic values as Tulare Basin. Each acre-foot diverted to Kern NWR under ideal water market conditions has an average cost to the region's agricultural and urban users of up to $64/af in the agricultural demand months, with peaks of up to $85 in drought years.

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