SOUTHERN CALIFORNIA WATER MARKETS: POTENTIAL AND LIMITATIONS

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Tienen un amigo bueno en La Republica Dominica,

Brad

ABSTRACT

Water marketing in Southern California has been increasingly sought to augment water supply for both urban and agricultural agencies, although it has yet to become a wide spread mechanism of water allocation. This thesis explores the potential and limitations for Southern California water markets using an economic-engineering network flow optimization model, CALVIN. CALVIN is used to compare the economic benefits of an ideal water market and recently employed allocation policies. Results from CALVIN suggest substantial economic benefits could be gained with relatively small quantities of reallocation of agricultural water. An ideal market in Southern California also would reduce pressure to increase imports from the State Water Project and the Colorado River as higher valued urban water shortages are decreased. Results highlight where and when additional water transfers would be economically beneficial. Additionally, the CALVIN results provide the user's willingness to pay to expand facilities and achieve economic benefits even beyond those achieved in an ideal market.

I. INTRODUCTION

In Southern California, the combination of a limited water supply and a growth-oriented economy has helped create elaborate physical and institutional systems of water allocation. Water managers increasingly favor water transfers and regulated forms of water marketing as methods of water allocation, although numerous obstacles have restricted water marketing in this region. This thesis explores the physical, environmental, and institutional constraints and potential for Southern California water markets. In this chapter, water marketing is formally defined, followed by an explanation of the study region, the decision-makers involved, and the approach used to analyze water marketing scenarios. Chapter 2 provides a description of Southern California's physical infrastructure and reviews the institutional constraints to Southern California water markets. Chapter 3 describes the CALVIN model, the model representation of Southern California, and the limitations of this approach. Results of the modeling effort are shown in Chapter 4. Conclusion and limitations are presented in Chapter 5.

Defining Water Marketing

Historical development, finance, and operations of water supplies have resulted in countless conflicts over water allocation procedures, cost allocation, and physical solutions to water resource problems (See Howitt et al. 1999). Market solutions to these problems have been offered and increasingly sought to augment water supplies. In theory, allowing a market to allocate supplies achieves the most efficient allocation of a resource, subject to several theoretical conditions. An *ideal market* is defined here as a market where buyers and sellers have perfect knowledge, there exists the ability to transfer rights inexpensively and reliably without any policy constraints other than environmental requirements, and all resource allocation is subject to the current projected infrastructure for the year 2020.

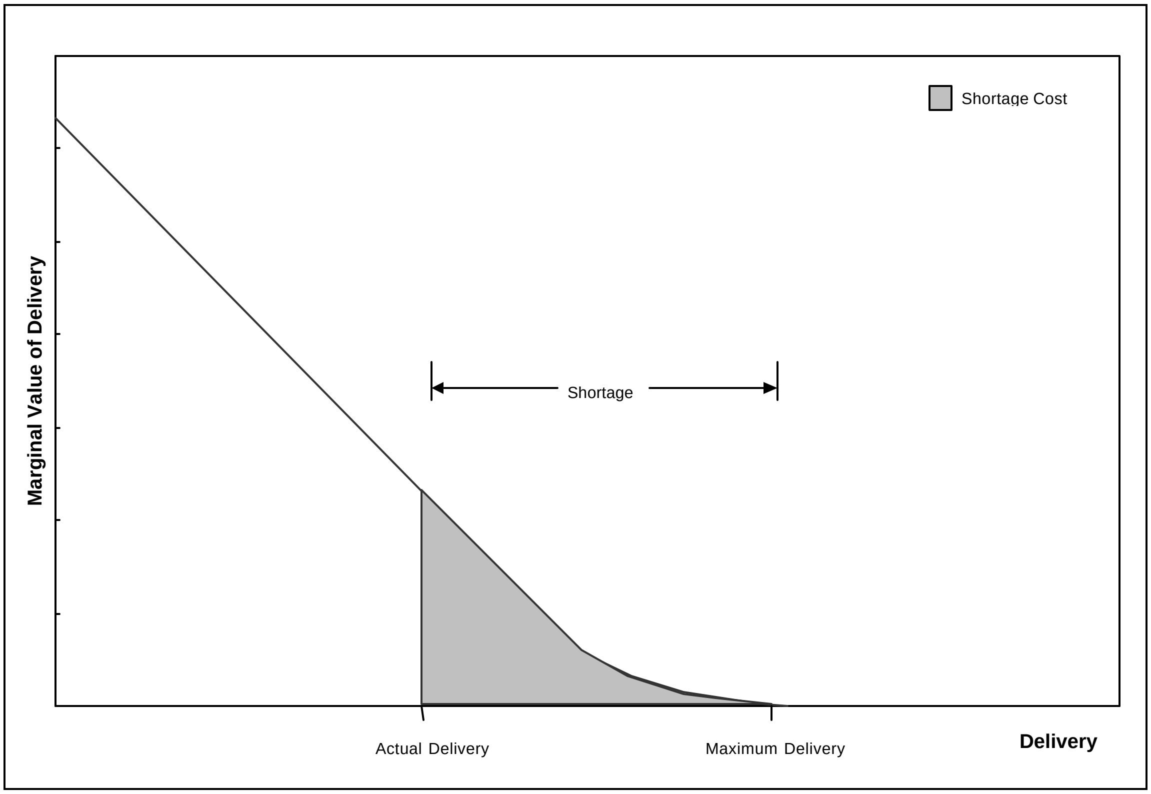
Water transfers are defined here as in MacDonnell (1990) and Lund et al. (1992): "the voluntary permanent or temporary change in existing purpose and/or place of use of water under an established legal right or entitlement". *Water marketing* is a transfer involving a financial transaction. Although water wheeling and exchanges may not be water marketing by this definition, such non-market water transfers can and ultimately will be important elements of future water marketing transactions. Water marketing agreements may often need to incorporate exchanges and water banking without a change in ownership to circumvent legal obstacles and third party impacts. Market and non-market water transfers occur in several forms as summarized in Table I-1.

Further terms used in this thesis that merit clarification are shortage and shortage costs. *Shortage* is defined as the discrepancy between maximum demand at zero price and actual delivery. *Shortage cost*, a function of shortage, is the area under demand curve between demand at actual deliveries and the maximum demand at zero price (see Figure I-1.)

Southern California Water Supply

Southern California's economy would be the tenth largest in the world as an independent nation (Hundley 1992; LAEDC 1997). The region depends greatly on imports of water from other sources to meet its 10 maf/yr demand (DWR 1998a). Extensive literature documents Southern California’s historical efforts to expand its water supplies (Karhl 1982, Reisner 1986, Hundley 1992). Figure I-2 shows this study area, describes the decision-makers involved, and lists the results of Southern California's water expansion efforts

Figure I-1. Definition of Shortage and Shortage Costs



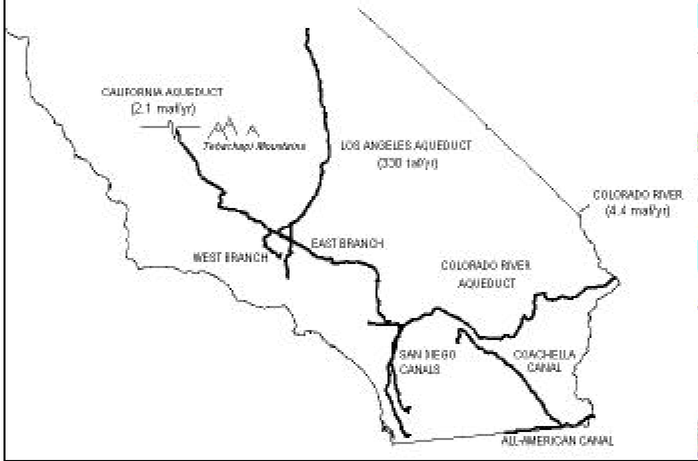
In addition to the reliance on imported water, Southern California relies on extensive ground water supplies (1.2 maf) and a limited amount of natural runoff (DWR 1998a). As Southern California began to grow more rapidly in the early twentieth century, this natural runoff was adequate to meet local needs, but was not conducive to sustaining levels of economic growth sought by business and community leaders (Gottlieb and FitzSimmons 1992). As Southern California's economy and population have grown, water transfers and water marketing have begun to play an integral role in major region water plans (SDCWA 1997; MWD 1997).

Table I-1. Taxonomy of Water Transfers

Type	Description
Permanent Transfers	*Permanent transfer of water right from one user to another.* Often, these are incorporated with lease back arrangements during wet years, when supplies are more plentiful. Permanent trading of water rights may best accommodate favorable shifts in water demand (Howitt 1998).
Spot Markets	*Typically classified by single year short-term transfers or water rights leases.* Bidding processes often establish these markets, although they recently have resulted from multi-party negotiations. Spot Markets have historically been viewed by California's water managers as a source of supply with higher risk (Howitt et al., 1999).
Water Banks	*A regulated and centralized form of market where third party impacts and transaction risks are reduced.* Water banks have been employed in both the 1976-1977 and 1987-1992 droughts.
Contingent Transfers/Dry-Year Options	*Occur under agreements to transfer water contingent to a specified event.* They may be activated for numerous reasons: drought, water supply interruption due to earthquakes, flooding, contamination, or mechanical failure of a conveyance system.
Conservation, Reclamation, and Surplus Transfers	*Using water transfers in combination with a conserved water source.* Water utilities have employed such practices involving their retail customers on a small scale (Lund 1992). Transfer water under these arrangements comes from the water saved from the use of BMP's such as installation of low flush toilets and xeriscaping (DWR 1994).
Water wheeling and Exchanges	*Water sold from one water district to another can be "wheeled" via conveyance and storage facilities owned by water agencies*. Exchanges usually entail exchanging equal amounts of water for different purposes. Wheeling can benefit operational, storage, water quality, seasonal, and environmental concerns.
Water Quality Transfers and Exchanges	*Exchange of higher quality water to a region or contractor requiring it*. An example could include an exchange where an agricultural contractor uses urban gray water while the urban contractor uses the agricultural contractor's water right to higher quality water

Source: Howitt et al. (1999), Lund et al. (1992)

Figure I-2. Southern California Study Area



Water Users Included in Study:
- Antelope Valley (AV)
- Castaic Lake urban area (Castaic)
- Central MWD of Southern California (CMWD)
- Coachella Valley urban area (Coachella)
- Coachella Valley Water District (CVWD)
- Eastern and Western MWD (EW MWD)
- Imperial Irrigation District (IID)
- Mojave urban area (Mojave)
- Palo Verde Irrigation District (PVID)
- San Bernardino Valley urban area (SBV)
- San Diego County Water Authority (SDCWA)

Adapted from DWR 1998a

Southern California Water: The decision-makers

Numerous agencies and districts govern water for Southern California. Figure I-1 highlights the inventory of the water users included in this thesis. Agencies are included based on quantity of water imported from outside Southern California, water demand data availability, and level of autonomous water contracting activity. Although the City of Los Angeles (LADWP) and the San Diego Water Authority (SDCWA) are member agencies of MWD, imports from the Owens Valley and recent independent dealings with IID merit separate inclusion of LADWP and SDCWA. All other users import large amounts of water either from the State Water Project (SWP) or the Colorado River.

Analysis of Southern California Water Marketing

To investigate the potential of water marketing and other innovative water allocation and financing methods, Howitt et al.(1999) developed a statewide economic optimization model, CALVIN. Using hydrology from 1921 to 1993, CALVIN allocates water to urban and agricultural demand regions based on economic value functions subject to physical, environmental, and policy constraints. A regional version of CALVIN will be used to analyze the potential of Southern California water markets. The modeling effort focuses on the following questions:

1. What is the economic value of an ideal market in Southern California from a statewide perspective? A regional perspective? A water users perspective?

2. What characteristics would an ideal market have in terms of the quantities, frequency, and priority of water transfers?

3. What are the economic and reliability costs of current policies? What are the most limiting constraints preventing an ideal market?

4. What kind of operational flexibility and infrastructure expansion would be economically attractive even in the presence of an ideal market?

II. INFRASTRUCTURE AND INSTITUTIONAL FRAMEWORK

Consideration of Southern California water markets, as discussed in this chapter, involves a vast water delivery infrastructure and a complex web of institutional arrangements that determine where and when the water is delivered. Further discussed are obstacles that have historically and could potentially inhibit water markets, a brief summary of solutions to these obstacles, and current Southern California water market activity.

Many Southern Californian urban and agricultural water agencies were created to build, maintain, and operate the large water import systems. The City of Los Angeles began these permanent interbasin transfers with the completion of the Los Angeles Aqueduct in 1913. In 1928, MWD was formed to deliver water to Southern California from the Colorado River Aqueduct. In 1972 the State of California complemented these efforts by delivering water via the SWP to MWD, and later to Castaic Lake, San Bernardino Valley, CVWD, Mojave and Antelope Valley. Southern California agriculture also relies heavily on the Colorado River via the All American and Coachella Canals (see Figure I-1).

Imported Water Supplies and Groundwater

Southern California's major imported water supplies are summarized in Figure I-1. These conveyance facilities route water to local distribution systems and several surface water and groundwater reservoirs summarized in Table II-1. In addition to the physical limitations of these conveyance and storage facilities, the institutional framework surrounding each imported source affects operating policy.

State Water Project

SWP operating policy has recently been reworked in terms of water allocation method and will likely be affected by decisions made in the ongoing CALFED process concerning the Sacramento-San Joaquin Delta (Delta). Before 1994, SWP water contractors used distinct methods of water allocation depending on whether the water use was for agriculture or municipal and industrial (M&I) use. Maximum allocation was based on Table A entitlements, or the initial amount contracted for; the SWP contracted out 4.23 maf/yr (See Table II-2).

Table II-1. Southern California Reservoirs Included in CALVIN

Surface Water Reservoirs			
CALVIN name	Description	Minimum Capacity (taf)	Maximum Capacity (taf)
SR-25	Silverwood Lake	44	73
SR-27	Lake Perris	31	127
SR-28	Pyramid Lake	95	170
SR-29	Castaic Lake	294	324
SR-CR3[a]	Colorado River Storage	0	4,440
SR-ER	Eastside Reservoir (Lake Domenigoni)	400	800
SR-GL	Grant Lake	5	48
SR-LA	Aggregate Los Angeles Reservoir	10	103
SR-LC	Long Valley Reservoir (Lake Crowley)	18	183
SR-LM	Lake Mathews of MWDSC	79	182
SR-LSK	Lake Skinner	34	44
Groundwater Basins			
Basin	Designated Area	Capacity (taf)	Monthly Infow (taf)
GW-AV	Antelope Valley	57,000	4.1
GW-CH	Coachella Valley	10,000	11.6
GW-MJ	Mojave Valley	8,800	5.9
GW-MWD[b]	MWD conjunctive use capacity	1,450	--
GW-OW	Owens Valley/ Mono Basin	38,000	12.9

[a] *In different modeling runs, the capacity of this reservoir varies as explained in later sections*

[b] *MWD's local groundwater operation is integrated into its local inflow time series*

Contractors were to submit requests every December, which would be approved by DWR staff. If the total amount requested exceeded the amount available, DWR would initiate Article 18(f), which dictated SWP shortage policy. Agricultural contractors would receive the first shortages up to 50% of their allocation, and not to exceed a total of 100% in seven consecutive years. M&I contractors would receive shortages only after the agricultural shortages, where each contractor would receive water in direct proportion to their Table A allocation. As a result of the SWP shortage policy and urban contractor desires for increased water supply reliability and stronger SWP financial structure, SWP contractors sought changes in SWP operations.

Table II-2. 1999 SWP Southern California Water Allocation

Contracting Agency	taf				
	Maximum Table A Entitlement	1999 Table A Entitlement	Initial Request	Initial Approved Allocation	Final Approved Allocation
North-of-Tehachapi contractors[a]	1,708	1,598	1,597	877	1,599
AVEK WA	138	138	138	76	138
CLWA	54	54	54	30	54
CVWD	23	23	23	13	23
MWD	2,012	2,012	1,380	1,106	1,180
MWA	51	76	20	20	20
SBVMWD	103	103	103	56	103
VCFCWCD	20	20	10	10	5
Other So.CA SWP contractors	110	95	92	51	92
Totals	4,218	4,119	3,418	2,240	3,214

Notes:
[a] *Includes Santa Barbara County Flood Control and Water Conservation District*

Source: DWR (1999)

Monterey Agreement

Drought conditions between 1987 and 1992 created disillusionment with SWP drought allocations. Several agricultural contractors were bitter over severe shortages in 1991 and many urban contractors sought greater water supply reliability from a system that was delivering much less than its contractual guarantee-- an average of 2.3 maf as of 1993 (Bucher, 1996; DWR Bulletin 132-95). Without the construction of the Peripheral

Canal and Los Banos Grandes reservoir, facilities not likely to be completed anytime soon, the SWP would not reach its full contracted deliveries. With these problems in mind, DWR and representatives from urban and agricultural water contractors convened in December of 1994 in Monterey to amend the original SWP contracts. Following is a summary the Monterey Agreement:

1. §18(a) was effectively removed, so all contractors receive shortages proportional to their Table A entitlement.
2. Agricultural contractors must relinquish 130 taf of annual entitlement to urban contractors on a willing buyer-willing seller basis.
3. Kern Water Bank property was transferred to KCWA and Dudley Ridge Water District in return for 45 taf of annual entitlement relinquished to the SWP.
4. SWP contractors and DWR are to develop financial programs related to payment of debt service on bonds to: (i) bring the obligations of the parties in line with current market and regulatory circumstances facing SWP, DWR, and contractors; (ii) ensure continuing financial viability of the SWP and improve security for bond holders; and (iii) provide for more efficient use of project water and facilities.
5. Concepts of surplus, wet weather, and make-up water are replaced with interruptible water service.
6. Operations of Perris and Castaic Reservoir will be altered to better conform to the needs of local water supply facilities. Agencies affected include MWD, CLWA, SGPWA, and SGBMWD.
7. Contractors gained the ability to store SWP water outside a Contractor’s service area.
8. Transfer of non-SWP water is now allowed via SWP facilities
9. Creation of an annual “turnback” pool, an internal SWP mechanism where unused water supplies can be purchased by other contractors at a set price or may be sold to non-SWP contractors. Contractors that participate in the pool are prohibited from storing SWP water outside their service area.

The Monterey Agreement made several comprehensive changes to the SWP water allocation system for the contractors who agreed to it. Agricultural contractors were no longer faced with automatic shortages, and in return urban contractors were provided greater assurance in terms of water supply reliability and financial security. Fundamental to the Monterey negotiations, however, was a reduced SWP yield due to incomplete components dependent on a Delta fix.

The Delta

Both major state and federal water projects (the SWP and Central Valley Project, respectively) depend on pumping large amounts of water from the Sacramento-San Joaquin Delta. Water export from the Delta now depends on the ongoing CALFED planning process and numerous water quality and quantity decrees mandating specific levels of water quantity and quality for the Delta and water exported to the SWP and CVP. As specific directives from the CALFED planning process remain uncertain, the water supply reliability of the SWP source is also uncertain. This study represents SWP water deliveries as a single inflow source from north of the Tehachapi mountains. The derivation of the SWP inflow is discussed in Chapter 3.

Article 19 of the original SWP contracts states that DWR shall deliver water that does not exceed an average of 220 mg/l in TDS over any 10 year period, although current salinity levels average 325 mg/l for West Branch deliveries and 250 mg/l for East Branch deliveries (DWR 1965; MWD and USBR 1998). Salinity damage caused by low quality imports could cost up to $95 million/yr to customers (MWD and USBR 1998). These costs include higher costs attributed to CRA deliveries, as discussed later. SWP water alone is estimated to have a $76/af cost attributable to average SWP salinity levels of 250 mg/l (assuming a $0.51/af per 1 mg/l over 100 mg/l TDS; See Howitt et al. 1999, Appendix G).

Los Angeles Aqueduct

With the prophetic words "there it is, take it," William Muholland seemingly guaranteed the City of Los Angeles an uninterrupted water supply. With restrictions on withdrawals in the Mono Basin and mitigation on Owens Lake, however, LAA deliveries have been substantially reduced.

Mono Basin

In 1970, a second barrel was added to the Los Angeles Aqueduct, increasing its intake capacity to 760 cfs or 550 taf/yr (DWR, 1998). As a result of the enhanced conveyance facilities, drought year diversions greatly decreased the natural flow from four creeks that naturally flow into Mono Lake. Resulting decreased lake levels endangered water fowl by exposing their nesting grounds to predators, increased salinity threatened Mono Lake biota, and fisheries in the four tributaries nearly disappeared (Vorster, 1983). Litigation over the Mono Basin's public value concluded in 1993 placing severe restrictions on LAA diversions from the Mono Basin. The specifics of these diversion constraints are discussed in Chapter 3.

Owens Lake

Groundwater pumping in the Owens Valley also was affected by the increase of LAA capacity. Groundwater overdraft in the Owens Valley and the lack of releases to the dry Owens Lake bed resulted in severe dust storms as winds would spread the dry alkaline soils of the lake bed throughout the Valley, causing some of the nation's worst air pollution. Recent litigation also mandated ground water pumping limits and specific mitigation measures for air pollution abatement. The specific amount of water required for Owens Lake is discussed further in Chapter 3.

Colorado River: the AAC and the CRA

Southern California’s third source of water, the Colorado River, remains one of its most contentious. Current Colorado River issues include complications of the ‘Law of the River’, a body of law severely limiting California's allocation, and the quality of Colorado River water.

Law of the River

Colorado River water is first allocated according to the 1922 Colorado River compact in which the projected 15 maf/yr of flow would be equally divided between upper basin and lower basin states. California rights to the river, as a member of the lower basin, were further defined in *Arizona v. California et al.* (1964) [376 U.S. 340]. According to *Arizona*, California is limited to 4.4 maf/yr plus one-half of surplus flows when declared by the Secretary of the Interior.

California’s 4.4 maf limitation began with its passage of the California Limitation Act of 1929, but the remaining water in the lower basin was not being put to beneficial use and California was able to use an average of much more than 4.4 maf/yr (See Table II-3).

With the completion of the Central Arizona Project and immense growth in Southern Nevada, California’s 4.4 maf limitation is slowly becoming a reality. Allocation between California’s Colorado users then comes into question as summarized in Table II-4. The first 3.85 maf of Colorado River water is allocated to agricultural uses and the remaining 0.55 maf belongs to MWD. If the 4.4 plan were implemented according to the seven party agreement, MWD would be the first to lose the surplus, since part of its allocation is beyond the 4.4 maf limitation. Urban shortages would likely occur in this scenario if water is allocated by strict priority, with the most economically valuable user's incurring the most severe shortages. Current water transfer arrangements between IID, MWD, and SDCWA have altered this water allocation by giving the urban water users up to 300 taf of conserved IID water (DWR 1998a).

Table II-3. History of the Law of the River

Document	Date	Comments
Colorado River Compact	1922	Equitable apportionment of 15 maf between lower and upper basin states (7.5 maf each); lower states allowed to increase consumptive use by 1 maf annually
Boulder Canyon Project Act	1928	Authorized constuction of Hoover Dam, AAC, and the Coachella Canal; provided users of Colorado River water must enter into contract with USBR
California Limitation Act	1929	Limits California's use of water to 4.4 maf plus one-half of any surplus
Seven Party Agreement	1931	Agreement among Southern California water users to recommend to the Secretary of the Interior on intrastate water allocation (See Table II-4)
U.S. - Mexican Treaty	1944	Guarantees Mexico 1.5 maf plus 0.2 maf during surplus years
Arizona v. California et al.	1964	Apportions water from mainstream Colorado River among lower division states; when 7.5 maf is available 2.8 maf is apportioned to Arizona, 4.4 maf to California, and 0.3 maf to Nevada
Colorao River Basin Project Act	1968	Requires Secretary of the Interior to prepare long range operating criteria for major Colorado River reservoirs
Arizona v. California et al.	1979	Quantifies Colorado mainstream present perfected rights in the lower basin
4.4 Plan	future	Allocates water among California's users given a 4.4 maf Colorado River Allocation

Source: DWR 1998

Agricultural Colorado River water deliveries come through stream diversions (PVID), the All American Canal (AAC; owned by the USBR), and the Coachella Canal (CVWD). Urban water deliveries come through the CRA, which is capable of delivering MWD fourth and fifth water delivery allocations (1,300 taf), even though a 4.4 limitation could limit these deliveries to 550 taf.

Table II-4. Colorado River Allocation

Party		Amount
Upper Basin States		
Wyoming, Utah, Colorado, New Mexico, small portion of Arizona		7,500 taf
Lower Basin States[a]		
Arizona		2,800 taf
California[b]		4,400 taf
Priority 1 Palo Verde ID (based on area of 104,500 acres)	Total for First 3 priorities: 3,850 taf	
Priority 2 Land in California's Yuma Project (not to exceed 25,000 acres)		
Priority 3 IID and lands served from AAC in Imperial and Coachella Valleys, and PVID for 16,000 acres on Lower Palo Verde Mesa		
Priority 4 MWD for a coastal plain of Southern California	550 taf	
Priority 5 MWD and City and County of San Diego	662 taf	
Priority 6 IID and lands served from AAC in Imperial and Coachella Valleys, and PVID for 16,000 acres on Lower Palo Verde Mesa	300 taf	
Priority 7 All remaining water for agriculturual use in California's Colorado River basin		
Total California allocation: 5,362 taf		
Nevada		300 taf
Republic of Mexico[c]		1,500 taf

Notes:

[a] California and Arizona split surplus flow equally when declared by the Secretary

[b] Present perfected rights exist for the Chemehevi, Yuma, Colorado River, and Fort Mojave Indian Reservations ranging from 11 to 52 taf. Additional presented perfected rights exist for, in order of priority, PVID (220 taf), IID (2,600 taf) and the Yuma Project (38 taf). These rights recieve priority when the lower basin allocation is less than 7.5 maf

[c] Mexico also recieves an additional 200 taf during surplus years

Source: DWR 1998a, Littleworth and Garner 1995

Water Quality Concerns

Water quality is an additional Colorado River issue, especially the high TDS levels characteristic of CRA and AAC water (747 mg/l and 879 mg/l respectively; MWD and USBR 1998). In addition to blending efforts for reducing TDS levels, MWD has historically received SWP water in exchange for relinquishing CRA water to DWA and CVWD. CRA water is estimated to have a \$136/af cost attributable to average CRA salinity levels of 700 mg/l (assuming a \$0.68/af per 1 mg/l over 100 mg/l TDS; MWD and USBR 1998).

Groundwater

Table II-1 indicates significant groundwater inflows and storage capacity, although much of the potential is limited by legal and institutional arrangements. Legal and institutional aspects of Southern California groundwater are discussed in detail in Blomquist (1992). Regarding groundwater, this study considers mostly conjunctive use opportunity provided by Southern California groundwater basins. Problems associated with overdraft and water quality, though extensive throughout Southern California, are simplified in this study (See Gottlieb and FitzSimmons 1992; DWR 1998a). For MWD specifically, a large percentage of local ground water interaction is aggregated into the local inflows based on the assumption that this ground water is allocated within district limits according to its best economic use. Additionally, MWD and the Southern Nevada Water Authority have contracted with Central Arizona Water Conservation District for ground water storage of up to 300 taf of unused Colorado River supplies. MWD is allowed to withdrawal up to 15 taf/month when the Secretary declares surplus conditions on the Colorado River. MWD would receive the stored water via an exchange for Arizona receiving less water from the Central Arizona Project

Obstacles to Water Markets

Use of CALVIN without considering current projected operations represents an ideal Southern California water market. As explained in following chapters, this modeling approach gives water users perfect knowledge of the historical hydrology, flexible use of the physical infrastructure, and no institutional restrictions outside of environmental requirements. Despite the economic benefits of water marketing as indicated by using CALVIN, several theoretical and practical obstacles exist that prevent such activity on a larger scale. Following is description of some of these obstacles and some solutions proposed in the literature.

Economics

Many of California's water managers agree that water marketing may provide substantial economic benefits and more efficient water usage. Because of this and the lack of other alternatives for meeting growing demands economically, transfers are becoming ubiquitous in many long range plans (MWD 1997; SDCWA 1997). Yet, numerous impediments have prevented widespread use of water markets. Between 1982 and 1996, only 1700 taf of water transfers occurred in California, and all of those were spot transfers (DWR 1996). Reluctance to rely on market solutions for water supply problems could result from both third party impacts and the inherent risk associated with market implementation (Lund 1993). Evaluating these impacts is crucial in determining the efficient amount of an individual transfer. Conditions and third party impacts preventing water markets include recent favorable hydrologic conditions (no serious drought has occurred since the 1987-1992 water years), water conservation measures applied to existing systems during the drought, and a general political resistance to change in the absence of crisis. Inherent or perceived risk in water marketing further reflects unresolved problems with water marketing theory.

In theory, a pure market can become reality only if four criteria should be achieved: 1) water property rights must be well defined, 2) there must be many buyers and sellers, 3) resources must be easily transferable, and 4) good information must be acquired (Brajer et al. 1989).

Many of these rights are poorly defined. Additionally, the vast majority of water in California is allocated based on applied rather than consumptive use, thus creating the difficulty in separating “real” from “paper” water.

An additional difficulty in implementing long-term transfers is the distinction between real and paper water (Lund et al. 1992). Contract negotiations result in the transfer of specific quantities of water (paper water), while the amount of water applied on farmland or necessary for the benefit of fish and wildlife (real water) may not be easily quantified. Contracts may also specify an amount of water from a surface source or ground water source, thereby neglecting the interdependence of the two. Conveyance losses resulting from seepage, leakage, or evaporation also become difficult to quantify in a contract where negotiations may span many different spatial and temporal hydrologic conditions.

Monopsonistic (few buyers) and monopolistic (few sellers) behavior often characterizes water markets, where excess water is owned by few users or excess water is only purchased by a few users. For example, Kern County Water Agency and MWD together are entitled to over 75 percent of the entire SWP supply. Marketing by one of these *two* agencies will likely alter market conditions. Transferability of water in California is easy in theory and often difficult in practice. Use of the California's extensive infrastructure is often costly or infeasible. Water transfers may become infeasible when conveyance capacity is fully used, environmental concerns are raised, and/or parties external to the financial transaction object through political or legal means.

Without a central agency behaving as DWR did in the drought water banks, market information about potential buyers and sellers may often be difficult to obtain. This problem was perhaps more significant before California instituted the drought water banks, where numerous water agencies began to rethink previous conceptions about water marketing.

To evaluate water markets, six criteria for evaluating resource allocation are presented in Saliba (1987) and Lund et al. (1992). Briefly these criteria are:

1. Does the market provide greater flexibility in meeting demands?
2. Can water marketing allow water users to be secure in their tenure of water use?
3. Is the user confronting the real opportunity cost of water?
4. Is the market outcome predictable on a regular basis?
5. According to public perception, is the market allocation fair and equitable?
6. Are public values reflected in market outcome?

The authors conclude that water marketing can fulfill these criteria with careful consideration of the arguments against water marketing. One of the main obstacles in market implementation is the uncertainty associated with effect of parties external to the buyer and sellers: third party impacts or externalities.

Third Party Impacts and Externalities

Third party impacts and externalities occur when a good is traded between parties and individuals not involved in the trade are harmed or benefited as a result of the transaction. Water transfers potentially affect urban, agricultural, and environmental water sectors. Effects for urban users include every possible loss associated with a lost water right: revenue lost due to reduced water-dependent industry, possible dependence on another inferior water source, and subsequent economic losses resulting from decreased economic productivity.

Externalities associated with agricultural water damages include the damage associated with lost water rights. Some California history demonstrates the long-term damage associated with permanent agriculture to urban transfers, most notably in the Owens Valley. Much of the literature considers the externalities associated with agriculture a greater threat since most water marketing has emphasized agriculture to urban transfers or transfers from low value agriculture to high value agriculture (Michelson and Young 1993; Reisner 1992; Dinar 1991; Howe 1990; Vaux and Howitt 1984). Institutional provisions in any water marketing scheme should ensure that a broader view of equity is considered by water buyers and sellers, or at least some regulatory entity.

A key tenet of water marketing is flexibility-- allowing water users to augment their water supply *when* they need to, using the bargaining process to achieve their goals. Timing, however, is also crucial to environmental uses of water for salmon runs, water quality, and recreation. Instream uses often conflict with other water demands and greatly concern the environmental community. Environmental uses such as fishing, recreational boating, and habitat area are not traditionally perceived as having an economic value comparable to that of irrigation, urban water use, or hydropower. Although efforts have been made to place dollar value on environmental entities (Colby 1990), the water industry has been hesitant to use these values in making instream flow allocation. Public opposition may outweigh any measure of economic benefits to a decision-maker and inclusion of existence values, or non-use values, makes these quantities especially difficult to estimate.

Transaction Costs and Risks

The negotiating and administrative costs and perceived risks in developing a water transfer plan also can inhibit water transfers. Archibald et al. (1998) aggregate transaction costs into two categories: administrative induced costs and policy induced costs. Administrative costs include gathering appropriate information and negotiation. Policy induced costs result from the implementation strategies advocated by decision-makers, including the legality of transfers, agency approval process, and possibly adjustment of costs to account for third party impacts and litigation. Economic theory suggests excessive transaction costs hinder market efficiency. Evidence from Colorado, New Mexico, and Utah over the 1975 to 1984 time period suggests that current state policies do not overburden markets, but some suggest costs may be too low (Colby 1990).

Transaction costs may become excessive in specific instances, often dependent on the political feasibility of a transfer. MacDonnell (1990) found significantly higher transaction costs for agricultural to urban water transfers. In Colorado, where transfers out of agriculture account for 80 percent of water transfer applications, 60 percent of all transfers were protested and took an average of 21 months for the State to approve. In contrast, only 30 to 40 percent of transfers in New Mexico and Utah are out of agriculture, and protests were less frequent. In New Mexico and Utah, only 5 and 15 percent of transfers were protested, respectively; while the average time of State approval was 6 and 9 months, respectively.

In addition to hesitancy caused by high transaction costs, many elements of water marketing are perceived as excessively risky. From this perspective, Lund (1993) suggests that reluctance is a function of the probability of failure as much of the actual transaction costs. Therefore, reluctance to seek a water transfer diminishes as the probability of a successful transfer increases. Increasing the probability of successful water transfers involves gaining experience in addition to assuring the rights of water rights holders, providing firm legal guidelines for management of third party impacts, and providing firmer legal guidelines for the water transfer approval process.

Solutions to the Difficulties in Implementing Water Markets

To solve the problems preventing market implementation, numerous solutions have been proposed in terms of economic and legislative action. Briefly, some of these suggestions include:

1. Water transfer laws should be streamlined—Current laws designed to protect third parties often inhibit possibly beneficial water transfers. Reisner (1992) suggests state water codes should be revised to protect against *substantial* injury rather than *any* injury as currently applied.

2. Third party protections—Several mechanisms have been suggested for limiting third party impacts including (Western Water Committee 1992; CAN 1992; Lund 1992):

    - monetary taxing on transfers to compensate third parties,
    - requiring additional water for instream flow in every marketing transaction,
    - state compensation for those economically harmed by water transfer exportations,
    - requiring explicit regulatory approval of transfers (in addition to mandated environmental and contractual requirements),
    - requiring formal monitoring of third party impacts of transfers, and
    - public review of water transfer proposals.

3. Strengthen property rights and water accounting for area of origin and area of storage users.

4. Area of Origin protections should be reviewed and modified to meet the needs of exporters. Reisner (1992) and Western Water Committee (1992) warn of the danger in neglecting area origin concerns, but also suggest care should be taken that impact analysis of area origin protection is not prohibitive.

5. Instream flow measures should be strengthened and possibly added to markets. Gray (1989) notes the apparent failure of the appropriative rights system to recognize instream flows as a beneficial use. The ability of environmental interests to secure these instream flows in a market system necessitates their classification as a beneficial use. Some advocate allowing these uses to be marketed along with urban and agricultural water rights under constrained conditions, thus privatizing instream flows (Willis 1998; Anderson 1997; Griffin 1993).

6. Public trust doctrine considerations must be accommodated by state water transfer laws and policies. By invoking the public trust doctrine to protect the Mono Basin in *National Audobon Society vs. Superior Court of Alpine County* and subsequently enforcing it with SWRCB Decision 1631, California has necessitated the valuation of public trust in many water allocation decisions. Transfers should account for the impact and implication on public trust values. Reisner (1992) suggests public interest determinations, although some find such methods too cumbersome and the public trust doctrine too vague in influencing transfer legislation (Anderson 1997).

Current Status of Water Marketing in Southern California

Several examples of water marketing exist within Southern California. Following is a summary of the water programs identified as water market transactions (DWR 1998a).

MWD and IID

Under the provisions of this agreement, MWD pays IID $92 million in capital costs, $3 million in annual O&M costs, and $23 million in liability and indirect costs for implementing a water conservation program in the IID service area. In return, MWD receives up to 100,000 af/yr in of IID’s annual Colorado River entitlement (Reisner 1992). The contract has recently been extended to year 2033 (DWR 1998a).

Semitropic Water Storage District (SWSD)

SWSD has developed a conjunctive use water banking program capable of storing up to 1 million af and producing up to 223 taf/yr when requested. In addition to 350 taf provided to MWD, Santa Clara Valley Water District (SCVWD; 350 taf), Alameda County Water District (50 taf), and Alameda County Water Agency, Zone 7 (Zone 7; 43 taf) have invested in the SWSD program. This leaves 200 taf of marketable water available for $175/af for recharge and extraction. Banking partners may contract with SWSD to deliver their SWP water or other water supplies to the California Aqueduct for in-lieu-groundwater recharge. At a contractor's request, water could be extracted and delivered to the Aqueduct or pumped by SWSD farmers in exchange for SWP entitlement deliveries, possibly a promising alternative for Southern California water users.

CVPIA Authorization for Water Transfers

Federal efforts to support water marketing under the CVPIA have yet to produce any transferred water. Only one contract had been signed as of 1996, between MWD and Areias Ranch, a large agricultural operator and member of the Central California Irrigation District. This contract, however, has been intensely disputed and has yet to deliver water to MWD.

Arizona Water Banking Authority (AWBA)

Authorized in 1996 by the Arizona legislature, the AWBA is allowed to purchase surplus Colorado River water for storage in ground water to meet future needs. As previously mentioned, MWD has purchased water from Arizona, but not yet through the AWBA. Future interstate water banking could lead to an increased Colorado River yield of up to 100 taf/yr when activated.

CVP Interim Water Aquisition Program

Fish and wildlife requirements have been augmented by an temporary CVP program meant to help the USBR fulfill Section 4306(b) of the CVPIA. In 1995-97, 281 taf of water were purchased from CVP users. Water from this program benefited wildlife refuges in the Sacramento and San Joaquin Valleys, spawning conditions for spring-run chinook salmon and steel head trout on Battle Creek, and instream flow requirements on the Stanislaus, Tuolumne, and Merced Rivers.

Monterey Agreement Transfers

Of the 130 taf of SWP annual entitlement allocated for permanent sale to urban contractors. Permanent Monterey Agreement transfers are outlined in Table II-5.

Table II-5. Monterey Agreement Agricultural Relinquishment

Approved Transfers	Quantity (taf)
Mojave WA	25
Castaic Lake WA	41
Palmdale WD	4
Alameda County FC&WCD Zone 7	22
Transfers in negotiation	
Solano County WA	5.8
Castaic Lake WA	19.5
Napa FC&WCD	3.4
Alameda County FC&WCD Zone 7	9.3

source: Quan 2000

PVID to MWD

In addition to the conservation arrangement with IID, MWD has investigated land fallowing programs with the Palo Verde Irrigation District. MWD paid PVID irrigators $1,240 per fallowed acre, allowing MWD to purchase water at about $135/af. DWR (1998a) estimates up to 100 kaf of water from land fallowing arrangements from southern agricultural regions could be provided to southern urban areas.

IID to SDCWA

IID also has contracted with the San Diego County Water Authority in another water conservation agreement, although details of this agreement is still being negotiated. If the agreement proceeds as executed on April 28, 1998, SDCWA will annually receive up to 200 taf for the next 75 years (SDCWA 1999).

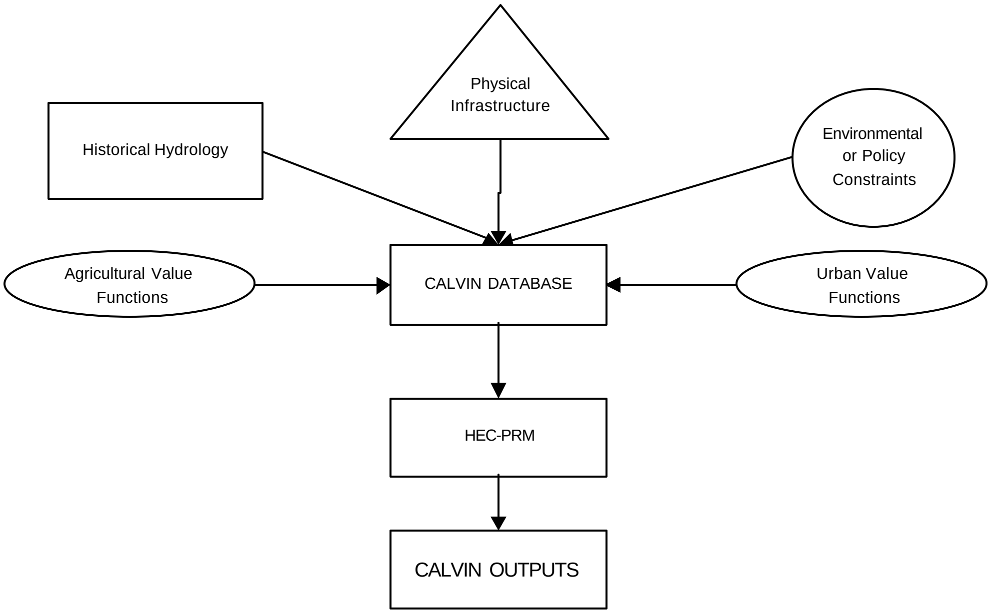
III. MODELING APPROACH

Howitt et al. (1999) develop an economic optimization model, CALVIN, to highlight promising institutional and infrastructure options for all of California. To examine Southern California water marketing scenarios, a regional version of CALVIN is developed. Following is a description of CALVIN and its application to Southern California.

CALVIN: A Statewide economic optimization model

CALVIN incorporates economic inputs from an agricultural and urban demand model with infrastructure and hydrologic information, and then determines an economically optimal water allocation using the HEC-PRM reservoir optimization solver (see Figure II-1). HEC-PRM, a network flow optimization model, maximizes economic benefits using hydrologic inputs and a given physical infrastructure to deliver water to users with economic value functions.

Figure III-1. CALVIN Data Flow Chart

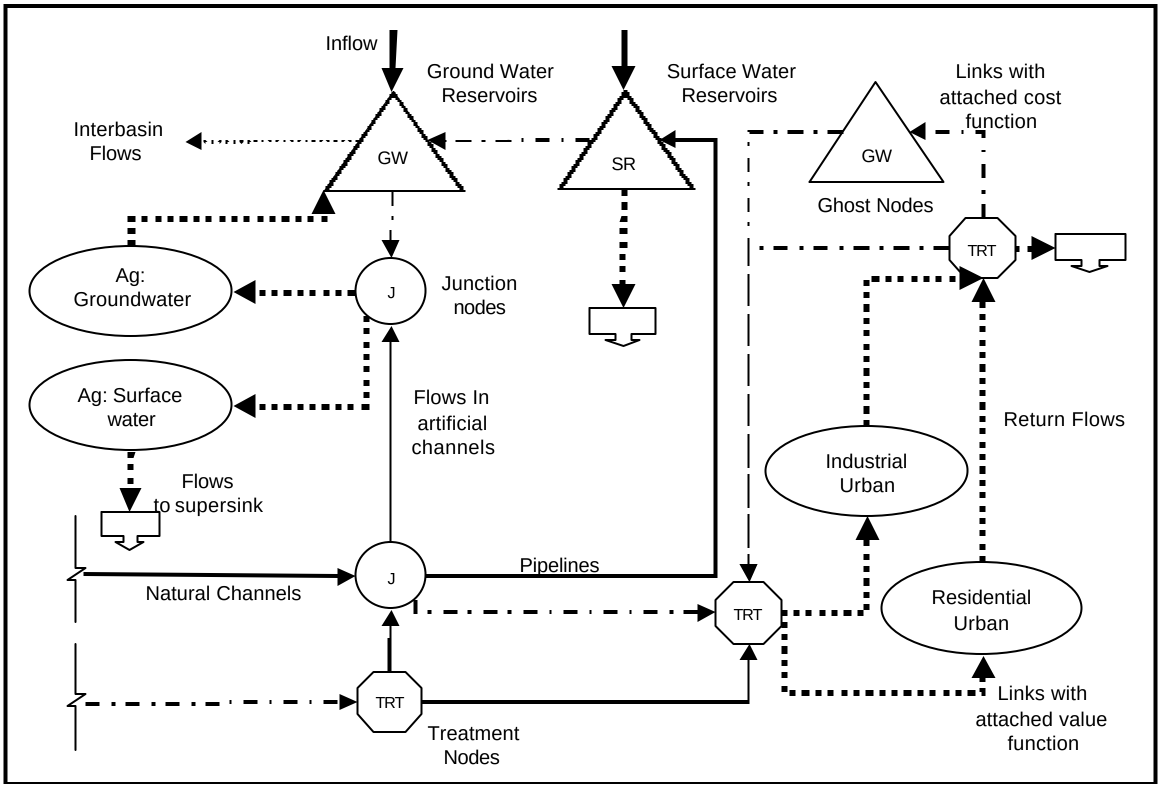


CALVIN's scope in Howitt et al. (1999) includes all of California's inter-connected water system. This analysis focuses on CALVIN's Southern California representation using HEC-PRM to perform market and capacity expansion analyses. Other applications using HEC-PRM have been successfully applied to the Missouri River, Columbia River, Central and South Florida, Tahoe-Truckee, and Alamo Reservoir systems for flood control, hydropower, multipurpose, and water allocation optimization (USACE 1991a, 1991b, 1991c, 1992, 1994a, 1994b, 1995, 1996, 1998a, 1998b, 1998c; Lund et al., 1996; Israel, 1996).

Representing California Water in CALVIN

California's inter-tied system has been represented in a network flow diagram. CALVIN represents the system based on the physical layout of canals, pipelines, and reservoirs, evolving from several other modeling efforts by federal, state, and local agencies. Each element on the schematic diagram represents a part of this physical layout. Several elements are used to represent storage, conveyance, and consumptive regions as shown in Figure III-2. Figure III-3 is a full diagram for Southern California.

Figure III-2. Example Schematic Diagram for CALVIN



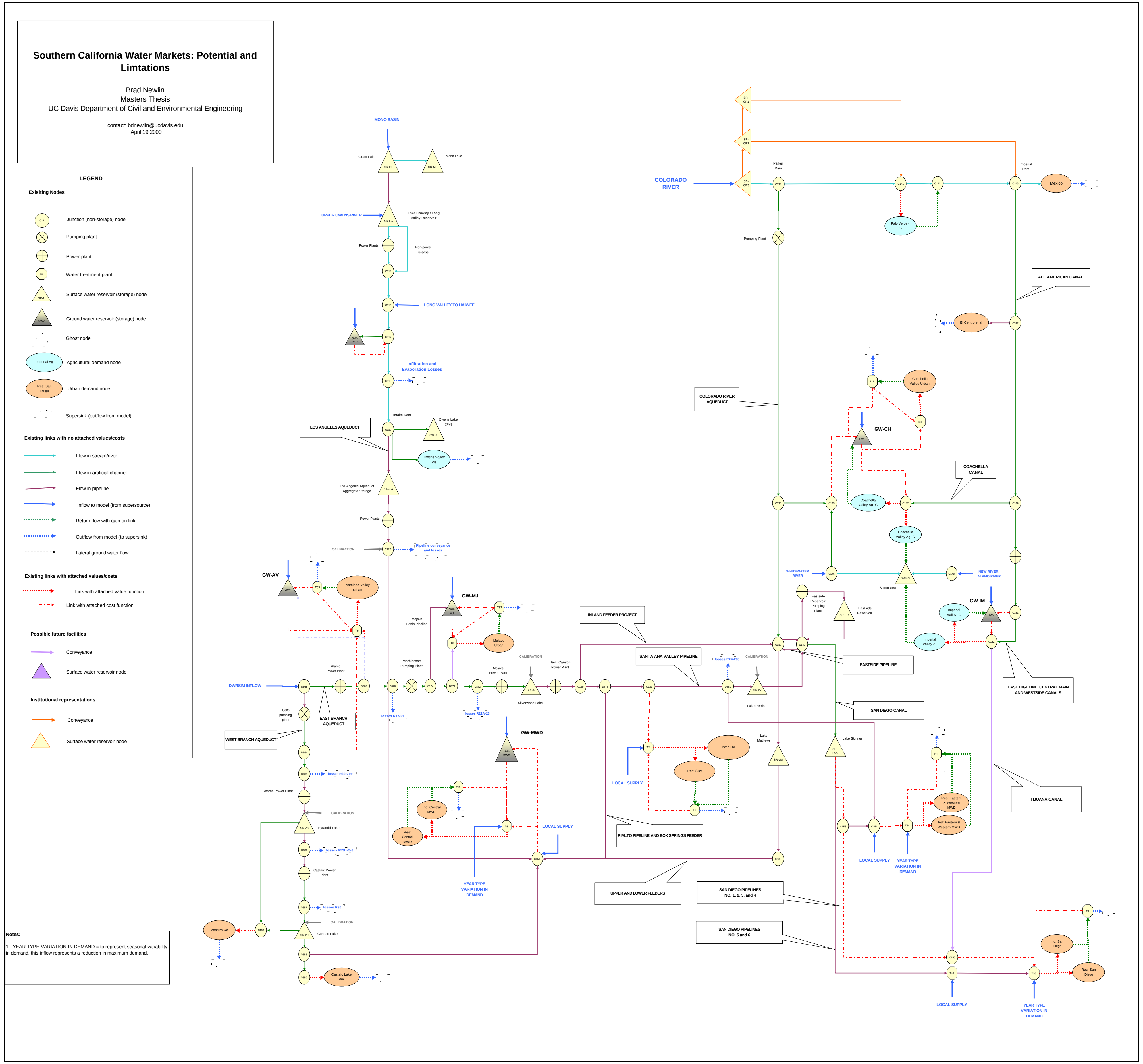
Storage Nodes

Storage nodes represent both surface and groundwater storage within CALVIN. Each storage node may have any number of inflows and outflows, and may be constrained by maximum and minimum storage, inflows, outflows, and mass balance requirements. 16 surface water storage nodes are included in the Southern California CALVIN representation.

Junction Nodes

Junction nodes represent locations of confluence or distribution and are constrained only by mass balance requirements. Junction nodes may be pumping plants, diversion points, confluences, or forks in pipelines, channels, and rivers.

Figure III-3. Southern California CALVIN Schematic



Southern California Water Markets: Potential and Limtations

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April 19 2000

LEGEND

Exisiting Nodes

C11	Junction (non-storage) node
⊗	Pumping plant
⊕	Power plant
T18	Water treatment plant
SR-1	Surface water reservoir (storage) node
GW-1	Ground water reservoir (storage) node
	Ghost node
Imperial Ag	Agricultural demand node
Res: San Diego	Urban demand node
	Supersink (outflow from model)

Existing links with no attached values/costs

→	Flow in stream/river
→	Flow in artificial channel
→	Flow in pipeline
→	Inflow to model (from supersource)
⋯▶	Return flow with gain on link
⋯▶	Outflow from model (to supersink)
⋯▶	Lateral ground water flow

Existing links with attached values/costs

⋯▶	Link with attached value function
-·-▶	Link with attached cost function

Possible future facilities

→	Conveyance
▲	Surface water reservoir node

Institutional representations

→	Conveyance
△	Surface water reservoir node

Notes:

1. YEAR TYPE VARIATION IN DEMAND = to represent seasonal variability in demand, this inflow represents a reduction in maximum demand.

Demands

Demands may receive one inflow and release one outflow, or return flow. Two types of return flow included in CALVIN are surface return flows and ground water return flows (see Figure III-2). Return flows are typically fractions of water deliveries reflecting consumptive losses. This allows for modeling of conjunctive use within the model.

Links

Links may represent a river, artificial channel, or pipeline and are constrained by minimum and maximum flows. Costs for pumping, treatment, and delivery are placed on the arcs entering demands or on other links, as appropriate.

Hydrology Inputs

CALVIN uses monthly data from 1921 to 1993 for both surface and groundwater inflows. The 1921-1993 time period includes the three most severe droughts on record in California: 1928-1934, 1976-1977, and 1987-1992 (DWR 1998A). Table III-2 reflects the severity of these droughts for Southern California water supply sources.

Table III-2. Severity of Extreme Droughts in the Southern California

Drought Period	Colorado River[b]		Feather River[c]		LAA Inflow[d]	
	maf/yr	% of avg	maf/yr	% of avg	maf/yr	% of avg
1929-1934	13.5	93	2.2	57	0.39	71
1976-1977	7.8	54	1.3	34	0.33	59
1987-1992	10.8	75	2.0	52	0.36	66

Notes:
[a] *Averages for 1922 - 1993 water years*
[b] *Source: Fulp 2000*
[c] *Source: DWRSIM 514a*
[d] *Source: LADWP 1998*

Surface Water Representation

Model inflows for this CALVIN analysis include a single source entering just north of the Tehachapi mountains to represent SWP supplies, a single source from the Colorado River entering at Parker Dam on the California-Arizona border, water from the Owens River basin and local surface water supplies. For inflow from the SWP, DWRSIM output from run 514 was used as the inflow for water north of the Tehachapi Mountains. This run assumes SWP water is not supplemented by any additional conveyance or storage facilities in the Sacramento-San Joaquin Delta.

For Colorado River hydrology, an annual 4.4 maf inflow enters California and is distributed throughout the year from an imaginary reservoir. CALVIN prescribes withdrawals and the reservoir must be empty at the end of every year. The initial run represents this reservoir with a capacity of 4.4 maf for all months except September, when the reservoir is required to be empty. Fulp (2000) estimates California is estimated to use 4.7 maf during surplus years on the Colorado River.

As recommended by Hasencamp (1998), the inflows from the Owens and Mono Basins have been aggregated into four different inflows along four distinct regions in the South Lahontan region (See Table III-3).

Table III-3. Summary of LAA Hydrology

Region	Mean Inflow (taf/yr)[a]
Mono Basin	123
Long Valley (Grant Lake to Long Valley)	109
Long Valley to Tinemaha reservoirs	198
Tinemaha to Haiwee reservoirs	103

Source: Miller 1999

Instream flow requirements and the need to maintain a specified Mono Lake elevation limit Mono Basin diversions to an estimated 31 taf/yr (Howitt et al., Appendix F; DWR 1998A). Data was provided by LADWP for the 1934 to 1993 water years only, so some linear regressions were needed to extend the data until the 1922 water year to be consistent with other CALVIN model input.

All local water runoff and local ground water is aggregated according to demand areas and groundwater nodes (Howitt et al. 1999, Appendix I). Local water supplies for MWD was provided by Upadhyay (1999). MWD local supply includes groundwater operations available for conjunctive use operations.

Groundwater Representation

CALVIN explicitly includes dynamic operation of groundwater storage nodes as surface water reservoirs. Southern California groundwater is separated into 9 basins. Similar to surface water storage nodes, the ground water storage nodes each have specified capacities, initial volumes, usable storage, and ending volumes. HEC-PRM uses similar constraints to impose monthly minimum and maximum pumping limits on pumping links to groundwater storage, and allows for a simple representation of local inflows (including percolation from local runoff, precipitation, and streams). An important exclusion from the local inflows is percolation from agricultural surface water and artificial recharge—values that CALVIN determines via its network flow optimization.

Another important distinction are costs assigned to links that withdraw (pumping costs) and recharge from the ground water basin. These costs have developed from local agency publications and water master reports. An average pumping cost of $ 0.20 per acre-foot per foot of head was derived from various sources (Howitt et al. 1999, Appendix J: Groundwater).

Constraint Inputs on Flows and Storage

Constraints to water deliveries are explicitly represented in CALVIN as maximum, minimum, or fixed flows on particular links. Infrastructure and environmental constraints are always included. Institutional constraints vary between model runs.

Infrastructure Constraints

Constraints within HEC-PRM allow CALVIN to place maximum storage levels to represent dam safety or flood control levels; minimum storage levels for reservoirs with emergency storage (whether for drought or seismic emergencies); and estimated monthly evaporation losses.

Environmental Constraints

Although CALVIN has no explicit environmental value functions, environmental restrictions such as minimum instream flow requirements are represented explicitly. CALVIN's environmental restrictions exist as flow constraints and annual deliveries. The only environmental constraints explicitly included in this Southern California analysis concern the Mono Basin and Owens Valley.

According to SWRCB Decision 1631, minimum instream flow requirements are placed on Mono Lake inflows from Walker, Parker, Lee Vining, and Rush Creeks. These requirements are aggregated with the hydrology input for the entire basin. Minimum instream flow requirements limit LA diversions from the Mono Basin to an average of 45 taf/yr.

In addition to the minimum instream flow requirement provided by Decision 1631, Mono Lake also is constrained to maintain a minimum storage level corresponding to 6,391 ft above msl every end of March. Decision 1631 allows for limited diversions from the basin once this elevation has been attained. Since this study uses a planning horizon of year 2020, the initial storage of Mono Lake is assumed to correspond to 6,391 feet.

Further south in the Owen Lake area, a fixed annual diversion of 51 taf is used to mitigate dusts from the dry Owens Lake bed. According to GBUPCD (1998), the City of LA may choose any combination of three alternatives for air pollution control: 1) shallow flooding, 2) vegetation, and 3) gravel. Ono (1999) suggests this fixed diversion might be as low as 40 taf/yr, depending on measures chosen by the City of Los Angeles.

Institutional Constraints

Without any internal policy or operating rules, CALVIN represents ideal market water allocations and operations, limited only by the current physical infrastructure and environmental constraints. Constraining CALVIN to current operating policies also provides useful information. For every month that a constraint limits a model run, a corresponding shadow value, or Lagrange multiplier, is calculated. This is the economic value of loosening the constraint by one acre-foot/month. Thus, the willingness-to-pay for changing current operating policies may be derived and explored with CALVIN model runs.

Each of the three imported sources of water is allocated by different policies. The City of Los Angeles solely operates the LAA, subject only to physical and environmental constraints. Operation of the SWP involves a contractual relationship between the State of California and particular SWP contractors-- dictated by the Monterey Agreement, the initial SWP contracts, and subsequent amendments. The Seven Party Agreement controls the allocation of Colorado River water. Several other modeling efforts have accounted for the different operating policies of each source, which may be used as flow constraints in CALVIN.

LAA

Few, if any, public models of the LAA correspond with CALVIN data requirements. Data provided by Upadhyay (1998) reflects LAA operation used in MWD planning studies, and is used in this analysis as the assumed operation criteria for the LAA. Current LAA operations are represented only as an inflow into MWD; reservoir operations and aqueduct flows are constrained to simulate these operations. Ideal market LAA operations are represented by a system of links, junction, and storage nodes in a similar manner as the rest of Southern California; reservoir operations and aqueduct flows are optimized with the rest of the system.

Colorado River

For the Colorado River seven party agreement, three virtual reservoirs are used to mimic the different tiers of priorities. Each reservoir is delivered their annual allocation based on the 4.4 agreement at the beginning of each year, assuming that the IID-to-MWD and IID-to-SDCWA transfers are in effect (300 taf annually). Withdrawals depend on contractor demands, and each annual allotment must be depleted by the end of the year.

SWP

SWP water deliveries are allocated based on DWRSIM Run 514. DWRSIM allocation is based upon Table A entitlements, rules agreed to in the Monterey Agreement, and a few individual exchange agreements for each contractor. Most transfers from the 130 taf agricultural relinquishment via the Monterey Agreement are not included since most of these transactions occurred after the simulation was developed. Table II-5 specifies which transfers are (25 taf to MWA) and are not included (105 taf).

Economic Demands and Inputs

CALVIN prescribes operations and allocations based on value functions derived for urban and agricultural demands. Howitt et al. (1999) present a detailed description of the urban and agricultural demand models, so the present discussion is limited Southern California demand regions.

Southern California Agriculture

Agricultural water demands in this thesis include IID, PVID, and CVWD. In developing these functions, SWAP, an economic agricultural production model, simulates an agricultural region's choice of crop, planted area, and investment in irrigation to maximize profit, limited by water, land, technical, and market constraints (Howitt et al., 1999 Appendix A).

For this study of Southern California, SWAP is not directly used for each region. Instead the marginal value of water is extrapolated from a SWAP application in the Southern San Joaquin Valley and combined with land use patterns described in DWR (1998b).

Owens Valley agricultural water demands are modeled as fixed annual deliveries using 2020 land use projections and the corresponding consumptive water requirements for each crop (a diversion of 124 taf/yr) using similar land use patterns in DWR (1998b).

Southern California Urban Regions

Urban water demands for MWD, MWA, AVEK, SDCWA, Castaic, Coachella Valley, and SBVMWD are modeled with economic value functions. Data availability was the biggest influence in determining demand node aggregation. MWD is split into three demand regions: Central MWD, Eastern and Western MWD, and SDCWA. Table III-4 represents which MWD members are included in the Central MWD demand region.

Table III-4. MWD Member Districts Represented in Central MWD Node

Calleguas MWD	City of Fullerton	City of Santa Monica
Central Basin MWD	City of Glendale	City of Torrance
Coastal MWD	City of Long Beach	Foothill MWD
Chino Basin MWD	City of Los Angeles	Las Virgenes MWD
City of Anaheim	City of Pasadena	MWD of Orange County
City of Beverly Hills	City of San Fernando	Three Valley MWD
City of Burbank	City of San Marino	Upper San Gabriel Valley MWD
City of Compton	City of Santa Ana	West Basin MWD

Due to limited data availability and relatively small populations, Ventura County and the El Centro urban areas are modeled as fixed monthly deliveries. As reflected in the schematic, most urban regions are separated into industrial and residential demands. Residential demands include residential, commercial, and public (government) water use sectors. The target demands are based on the 2020 projected population levels and per capita use factors.

Residential water use values are based on monthly residential water demand functions derived from published price elasticities of demand, observed retail prices (in 1995 dollars), and observed residential water usage (Howitt et al. 1999 Appendix B). Industrial water use values are derived from survey data on the value of production lost in different industries in California under hypothetical shortages (CUWA, 1991). Industrial value functions are constructed from these production values for each month and county in the Bay and Southern Coastal areas of California for 2020 projected levels of industrial water usage (Jenkins et al. 1999).

CALVIN Model Use and Outputs

What model outputs are available from CALVIN and how can they be used? This section describes the model alternatives in this thesis and the CALVIN outputs used to evaluate them. Outputs include: regional economic benefits, deliveries and shortages, sensitivity analysis and marginal valuation, and storage and flow comparisons.

Alternative Comparison

Four model runs are used to analyze Southern California water marketing with CALVIN. Two subsets of runs describe the modeling strategy here: 1) no policy rules and 2) policy constrained runs (See Table III-5).

Table III-5. Modeling Runs Using Southern California CALVIN model

	Base Case: Under 4.4 Plan	No MWD ground water
No Policy Rules: 'Ideal Market'	Run A	Run C
Policy Constrained: Current Operations	Run B	Run D

Although four runs are used in the following analysis, the majority of focus is on Runs A and B. Runs C-D were performed to evaluate specific facilities beyond the Base Case.

<u>Runs A and B: Base Case</u>

Run A reveals physical, institutional, and environmental constraints to an ideal water market in Southern California. Operations and allocations prescribed in Run A have the sole objective of maximizing regional economic benefit subject to water availability, physical infrastructure, and environmental requirements. These operations are prescribed without any current water rights or operating rules. Run B adds the existing legal and operating policy constraints to the Run A case so current management practices may be evaluated. Comparison of Run A and Run B sheds light on an ideal market's effect on total water demand and the economic and reliability costs of current operating policies.

Runs C and D: No MWD Groundwater Capacity

Initial model results indicated a preference of using GW-MWD versus the Eastside Reservoir, solely based on estimated operating costs. Additionally, the ability of MWD to use the groundwater storage space indicated in MWD (1997) has come in to question due to various political difficulties. The use of the Eastside Reservoir without GW-MWD demonstrates the importance of such capacity to Southern California and the associated shadow values.

Calvin Model Outputs

Regional Economic Benefits

CALVIN maximizes regional economic benefit by recommending water allocation and operation decisions which provide the most economic value over all water demands. Given the storage levels and flows for each schematic element, regional and local economic benefits can be compared for the various model runs. Such comparisons can indicate where market results are desirable or where market constraints are needed.

Deliveries and Shortages

Direct CALVIN output includes "optimal" flows for every link throughout the entire time period. Lund and Ferreira (1996) discuss the development and testing of operating rules using output from HEC-PRM, techniques applicable to CALVIN output.

Also apparent in CALVIN output is the quantity of shortages (from desired deliveries) for a given scenario. Shortages will be minimized according to temporal distribution of the economic values for each demand node. This analysis may also shed light on when market oriented policies are necessary or attractive.

Sensitivity Analysis and Marginal Valuation

A fundamental result from the network flow optimization is the marginal economic value of changing a constraint placed on a link or storage node. Two distinct types of marginal values are calculated: 1) the shadow price on link capacity constraints (storage or conveyance capacities, minimum instream flows, or minimum deliveries) and 2) the marginal value of additional water at each node in the system. These values, generated at each model time step, provide an explicit sensitivity analysis as output. Suppose a pipeline has a capacity of 10 taf/month, yet the economically desired delivery at the end of the pipeline is 20 taf/month; thus, the pipeline's capacity is limiting, preventing additional economic benefit. When the network flow algorithm is executed, such binding constraints are complemented by a dual cost or marginal value-- the economic benefit of increasing the limiting capacity by one unit. Thus, CALVIN is able to identify which storage and conveyance facilities might be attractive to expand and places an economic value on their marginal expansion.

Economic Value of New Facilities

Two approaches used in the analysis can provide economic indicators for the value of new facilities. Implicitly, the presence of a shadow value suggests the economic value of new facilities in terms of the value of marginal capacity expansion.

An explicit method for estimating the value of capacity expansion is adding a link between two regions with zero capacity. CALVIN then calculates the shadow value in light of any operating costs that might be attributed to such a facility. For this Southern California analysis, new explicit facilities include the Tijuana Canal, surface water transfers from Arizona, ground water recharge potential to Antelope Valley, surface water delivery to the Mojave Urban region, and recycled water for all three MWD regions.

Storage and Flow Comparison

For calibration and analytical purposes, CALVIN model output is compared to a specific DWRSIM model simulation (DWRSIM 514). In Run B, most of the Southern California system is constrained and calibrated to match DWRSIM values. Calibration of inflows and outflows are used to account for model variation in accounting for evaporation and operational losses (approximately 30 taf/yr). Run A is then implemented with the calibration inflows and outflows but without any policy constraints. Run A results are then compared with DWRSIM output to ensure reasonable behavior is occurring. Since CALVIN uses the same monthly time step and contains much of the same information as DWRSIM, these comparisons are relatively convenient.

Limitations of approach

In interpreting these model results, the limitations of this approach and the input data should be carefully considered-- as with any modeling effort. Several limitations of this model and modeling approach should always bear on interpretation of CALVIN results (Howitt et al. 1999).

Limited ability to represent water quality

Given the inherent relationship between water quality and quantity, CALVIN's limited representation of water quality is a serious limitation. Water quality is represented in CALVIN by using various consumer treatment costs to represent different water quality levels. The process of blending, where a water user may blend lower quality supplies with higher quality supplies to meet the necessary standards, is difficult to represent since blending requires a set fraction of water from different sources. Applying water quality costs to represent various levels of water qualities as currently done in CALVIN results in maximization of the cheapest source regardless of blending potential. Unfortunately, explicit blending constraints are beyond the CALVIN and HEC-PRM network flow programming formulation.

Environmental values modeled as constraints

No explicit economic value functions for environmental needs are included since few, if any, credible state-wide estimations of environmental cost functions exist. While dollar values have been assigned to specific environmental benefits through contingent valuation techniques, these numbers have yet to be developed to levels comparable to agriculture and urban water demands (Colby, 1990). Implicit valuation of environmental constraints can be derived from the sensitivity analysis when such constraints are binding, but these values only reflect the economic opportunity costs to urban and agricultural water users.

Limitations of input data

One of the most common problems in modeling efforts is the availability of reliable data, and it certainly applies in this situation. While the CALVIN project is fortunate enough to benefit from data collection efforts of several other modeling efforts (DWRSIM and several local sources), CALVIN also inherits all of the limitations of these data.

Additional simplifications are necessary to model non-linear physical constraints, such as reservoir release capacities. Potentially substantial simplifications are necessary to include these in our initial analyses. For example, the East Side Reservoir currently being constructed by MWD has a maximum outlet capacity of 2800 cubic feet per second when the reservoir is at full elevation. CALVIN only uses a maximum single value of 2800, even though it may be much less when the reservoir surface elevation is lower.

Network flow optimization limitations

Several limitations are inherent with the linear network flow optimization used by HEC-PRM. For one, optimization models usually require a high degree of aggregation to minimize data requirements and difficulties in heuristic representation. As previously mentioned, linearization of often non-linear phenomena results in inaccuracies that may sometime be significant. Unfortunately, it is not computationally feasible or possible to calibrate such an extensive non-linear optimization model at this time.

Another limitation of the network flow programming approach is the perfect foresight that the model uses to make its decisions. A standard run of CALVIN solves the entire 1921 to 1993 time period at once, allowing the model to determine what benefits or costs will be incurred in the future for a current flow or storage allocation. This problem can be partially solved by decreasing the span of the time to a more appropriate time period for planning studies, i.e., running CALVIN in smaller time periods. For example, some hydrological conditions may be reasonably predicted one, two, or three months ahead in arid regions, so CALVIN could be run with 3 months of input at a time. This approach eliminates the advantages of using a long time series, such as the analysis performed by Lund and Ferreira (1996), but may be more appropriate for some applications. However, the use of perfect foresight may not be as critical in regions such as Southern California where most reservoirs do not have large flood pools. The influence of perfect foresight in CALVIN output merits further investigation.

Groundwater simplified

Modeling groundwater reservoirs in a similar manner as surface water reservoirs neglects the complex relationships of aquifer discharge/recharge relationships and interbasin groundwater flows. Additionally, many of the groundwater basin operations have been aggregated into local supplies under operating criteria designated by other modeling efforts, mostly from MWD.

Primitive representation of urban water shortage costs

Given the extremely heterogeneous characteristics of California urban areas, segmenting water demands into residential or industrial sectors offers a crude approximation of the many different sectors that actually exist. Difficulty was found in extrapolating demand functions beyond observed price and use levels. Also, little consensus exists on how to best represent factors of California's economic demand for urban water, such as the appropriate price-elasticity of demand.

Hydropower not included in the initial analysis

Although a crucial part of the California water economy, hydropower analysis is excluded from CALVIN. Future applications may be directed towards the inclusion of hydropower analysis. Only fixed-head hydropower costs are included for Southern California (for pumping and power plants).

IV. MODEL RESULTS

"Don't throw away the old bucket until you know whether the new one holds water."
-Swedish Proverb

If an ideal water market were established in Southern California what would be the benefit? Economic benefits (one aspect to be considered in water resources planning) can be examined with CALVIN. Results from the four model runs are presented in this chapter. Questions posed in the introduction serve as the framework. The economic value of an ideal market is first explored from statewide, regional, and agency perspectives. The economic and reliability costs of current policies are then discussed, specifically SWP operations, the Law of the River, and environmental constraints. In conclusion, the economic values of additional operational flexibility and water infrastructure expansion are explored.

Economic value of an ideal market

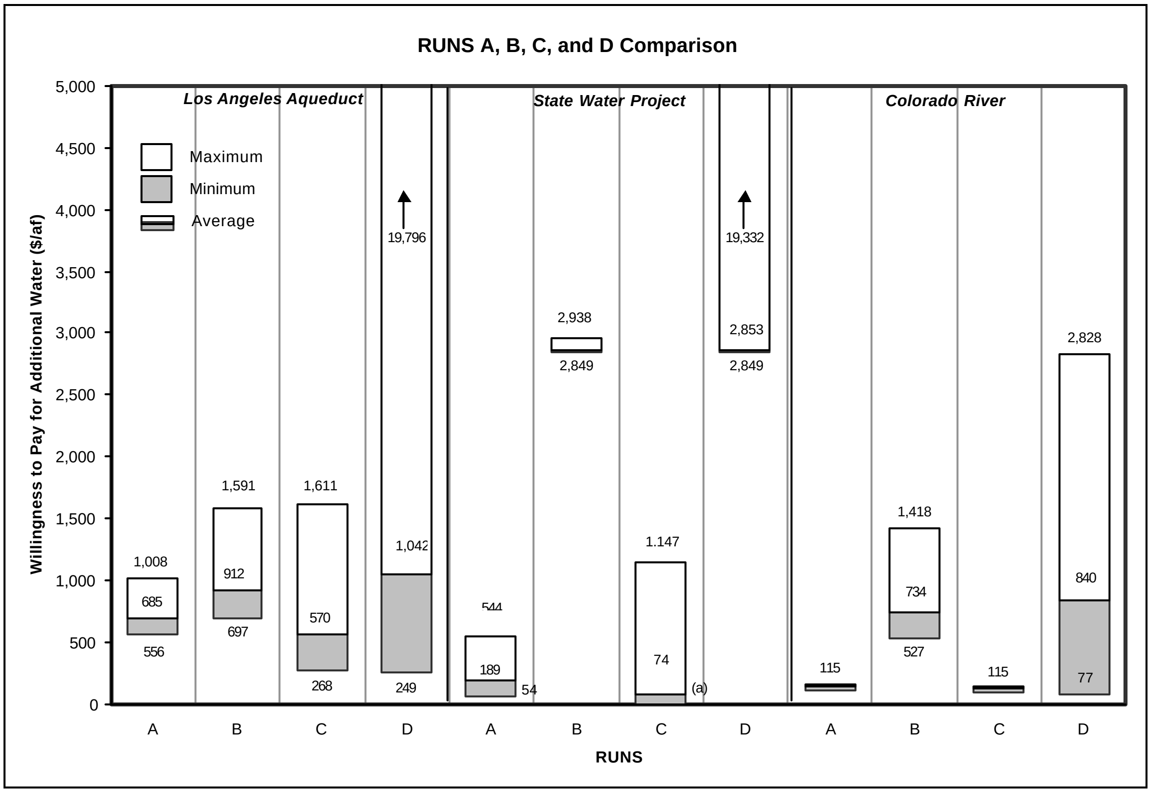
Three perspectives can be used to describe the economic value of an ideal market: statewide, the entire Southern California region, and particular local Southern California water agencies. Further analysis provides insight on the characteristics of this market such as the frequency and type of water transfers.

Statewide Implications for an Ideal Southern California Water Market

For current levels of northern and central Californian water imports, CALVIN derives the willingness to pay for increasing deliveries from each source (see Figure IV-1). Under current management (Run B) Southern California desires SWP water the most since Mojave and Antelope Valley, who only import SWP water, accumulate severe shortages. LAA and Colorado River water follows in priority with a magnitude similar to the marginal willingness to pay of Central MWD and Eastern and Western MWD, respectively. When GW-MWD is removed in Run D, the marginal willingness to pay for SWP and LAA water reaches extremely high magnitudes, reflecting very small and rare industrial shortages in Central MWD.

In contrast, an ideal market, as represented in Runs A and C, reduces the marginal demand for both the SWP and Colorado River. Additional Colorado River water generates only minimal benefits in this run since the CRA, the only link between Colorado River water and urban regions, is at full capacity. LAA water is given the highest value, reflecting its lower water quality costs and higher hydropower benefits.

Figure IV-1. Willingness to Pay for Additional Water



(a) a negative value of -$234/af is incurred during wet years, since an increase in SWP supply would be more expensive than using other sources

Economic Value to the Southern California Region

Table IV-1 shows the annual average shortage results for different alternatives. Shortages in current operating policies (Runs B and D) are greater, indicating ideal free markets would substantially reduce overall shortage quantity and costs. An ideal market reduces shortages by an average of 118 taf/yr or 13% of current shortages. The non-linear relationship between shortage and shortage cost is reflected in the Table IV-1. A 13% reduction in shortage, with an ideal market allocation of water, leads to an 81% reduction in shortage costs for Run A. The transfer of a small amount of water may have a more significant economic effect. Fewer shortages occur in an ideal market because of the relative efficiencies of urban and agricultural return flows and the assumed flexibility and foresight in infrastructure operations.

Table IV-1. Shortage and Shortage Costs In Different Scenarios

Run	Description	Total Annual Average			
		Shortage (taf)	% change from current policies	Cost ($ million)[c]	% change from current policies
A	Ideal Market with GW-MWD	823	-13	294	-81
B	Current Operations with GW-MWD	940	0	1506	0
C	Ideal Market without GW-MWD	854	-9	355	-76
D	Current operations without GW-MWD	965	3	1601	6

A free market allocation, as represented in the Southern California CALVIN model, substantially reduces shortages and therefore net regional demand. Free market conditions should be more efficient for several reasons. Less water is allocated to agricultural regions resulting in less operational loss of Colorado River water (about 30 taf/yr less evaporation, seepage, and other losses occur from reduced All American Canal diversions). Higher allocation to urban areas allows greater re-use opportunities since many return flows are directed towards usable groundwater basins. Additionally, CALVIN's perfect foresight allows storage space to be allocated with perfect knowledge of upcoming droughts (reducing spills and making fuller use of storage during droughts). For increased economic benefits, CALVIN uses its perfect foresight to hedge storage deliveries to prevent more severe shortages and deliver water to contractors that induce higher shortage costs. Thus, the $1.2 billion/yr, 120 taf/yr benefit derived from employing an ideal market (Shortage costs of Run B - Shortage costs of Run A) is an upper bound.

Figure IV-2 demonstrates the effect of allowing economically-based water transfers on shortages, particularly shortages of high magnitude. In the ideal market (Run A), fewer shortages occur, creating significant benefits over current operating policies (Run B). Extreme shortages are reduced in severity by more than 360 taf/yr in an ideal market.

Figure IV-2. Southern California Delivery and Reliability

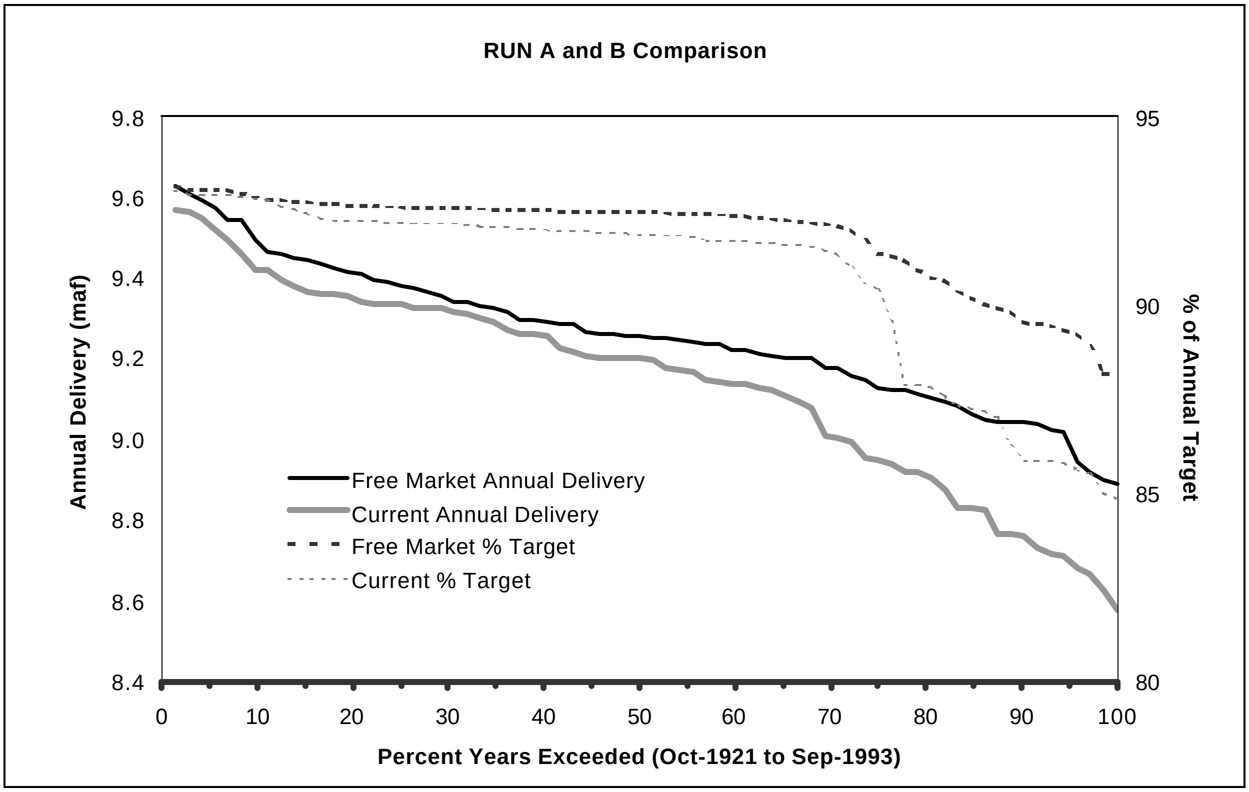
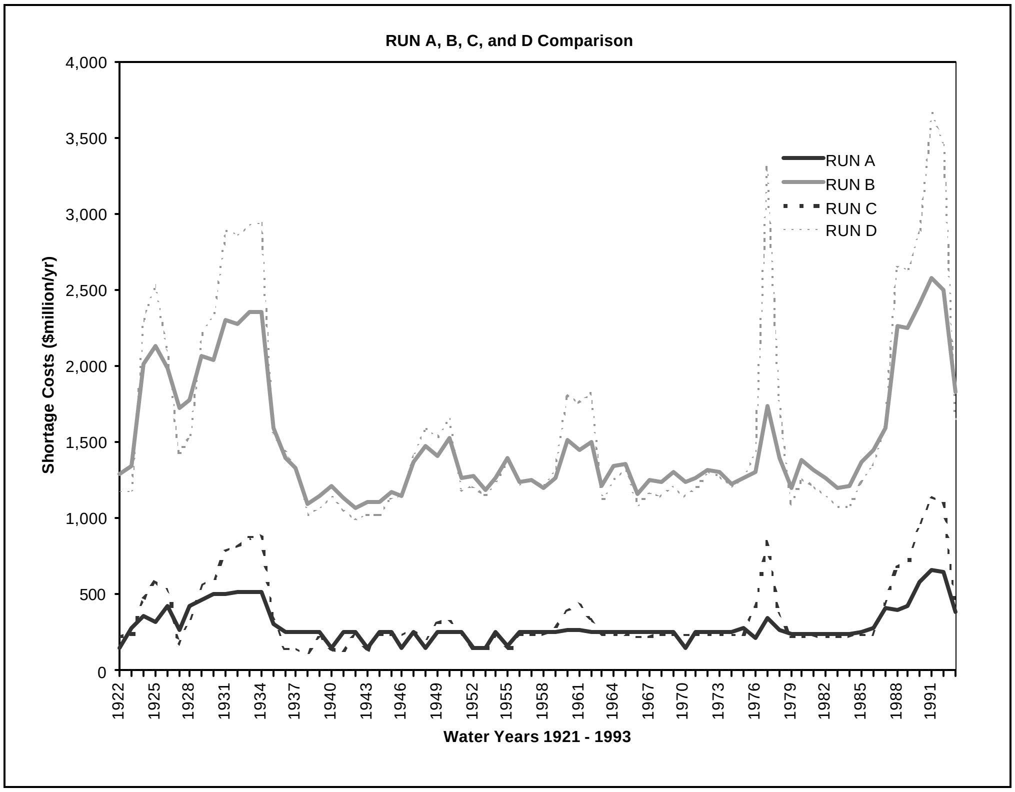


Figure IV-3 shows the economic differences between current operating policies and an economically-based water allocation. Quantified, this difference is the benefit of increased flexibility for Southern California water allocation, as shown in Figure IV-3. A consistent annual benefit of over $1.2 billion/yr is gained in normal year operations, but this benefit increases dramatically in drought conditions (to almost $2 billion/year). Since current operating policies create annual shortages in some urban regions, an average year annual benefit is accrued by reducing urban shortages in an ideal market. Moreover, the increased urban water supply under free market conditions allows urban water users to use their storage capacity more aggressively to dampen the 'peak' drought shortages that have more severe economic consequences.

The benefit of using conjunctive use capacity in MWD is also revealed in Figure IV-3 (Runs C and D). With the 1.45 maf of additional storage provided by GW-MWD, drought year shortages are reduced substantially in an economically induced hedging rule; CALVIN recommends incurring additional minor shortage costs in average years by storing water in GW-MWD to reduce the magnitude of drought year shortages.

Figure IV-3. Shortage Costs for All of Southern California



Economic Value to Southern California Water Users

Comparing the economic costs of current policies to an ideal market highlights the economic virtues of more frequent water transfers between water users. Although the aggregate Southern California region gains significant benefits from operating as a free market, the water use benefits is not shared proportionally among economic sectors. Substantial transfer payments would be needed. Agricultural water users lose reliability and incur more water shortage costs in a free market system while urban water users gain reliability and incur far fewer shortage costs (see Table IV-2). Urban water users almost always receive 95% of their target demands in an ideal market while current polices never meet 90% of urban target demands (see Figure IV-4). Agricultural users, who receive constant annual deliveries since their allocation is based only on the constant 4.4 maf Colorado River allocation, voluntarily relinquish about 13% of their water use in an ideal market scenario (97% to 84%; see Figure IV-5). External and third party costs from the economic sector transformation shown in Figures IV-4 and IV-5 are outside the scope of CALVIN, but should be considered in long-term planning.

Table IV-2. Average Shortages and Shortage Costs in Each Economic Sector

Run	Agriculture			Urban		
	Shortage (taf/yr)	% Annual Shortage	Cost ($million/yr)	Shortage (taf/yr)	% Annual Shortage	Cost ($million/yr)
A	575	16	48	248	4	246
B	115	3	9	825	13	1,497
C	553	15	45	302	5	311
D	115	3	9	849	13	1,591

Figure IV-4. Southern California Urban Delivery and Reliability

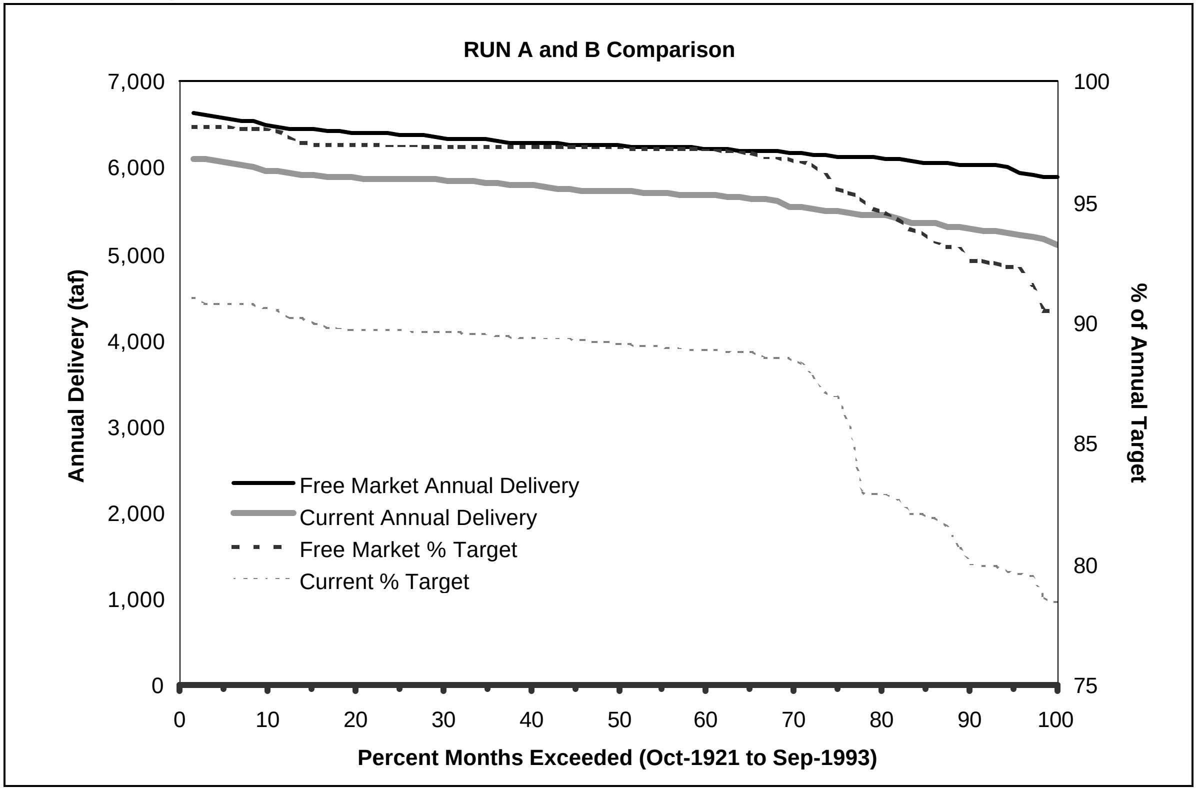
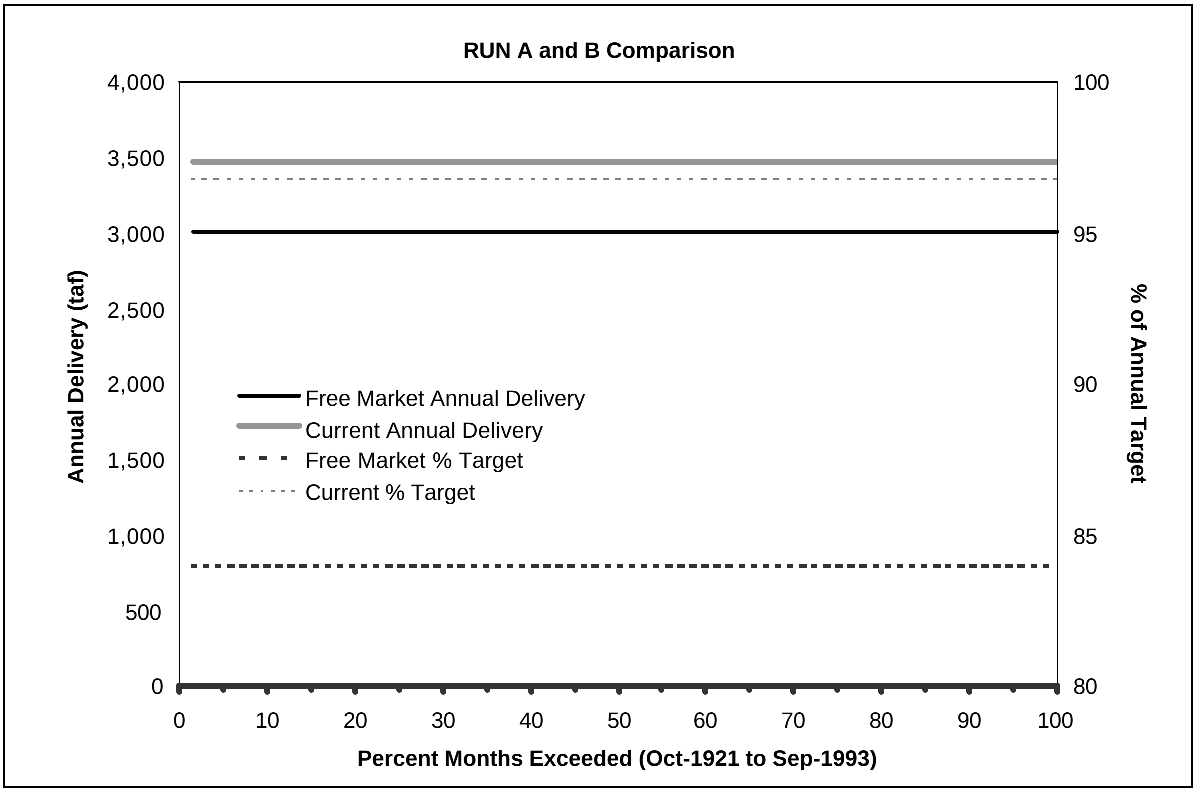


Figure IV-5. Southern California Agricultural Delivery and Reliablity



To understand the characteristics of an ideal water market within Southern California, shortages in Runs A and B for are compared for each user. Additionally, each water user's shortage cost and set of shadow values of current policies highlights the priority of these water transfers.

Shortages of Each Local Demand

Table IV-3 and Figure IV-6 provide estimates of changes in water delivered for each demand region in an ideal market. The change in water use is not a water transfer but rather the reduction or increase in deliveries into the demand region at its delivery point. A positive amount indicates a free market gain in deliveries; a negative amount indicates a free market reduction in deliveries.

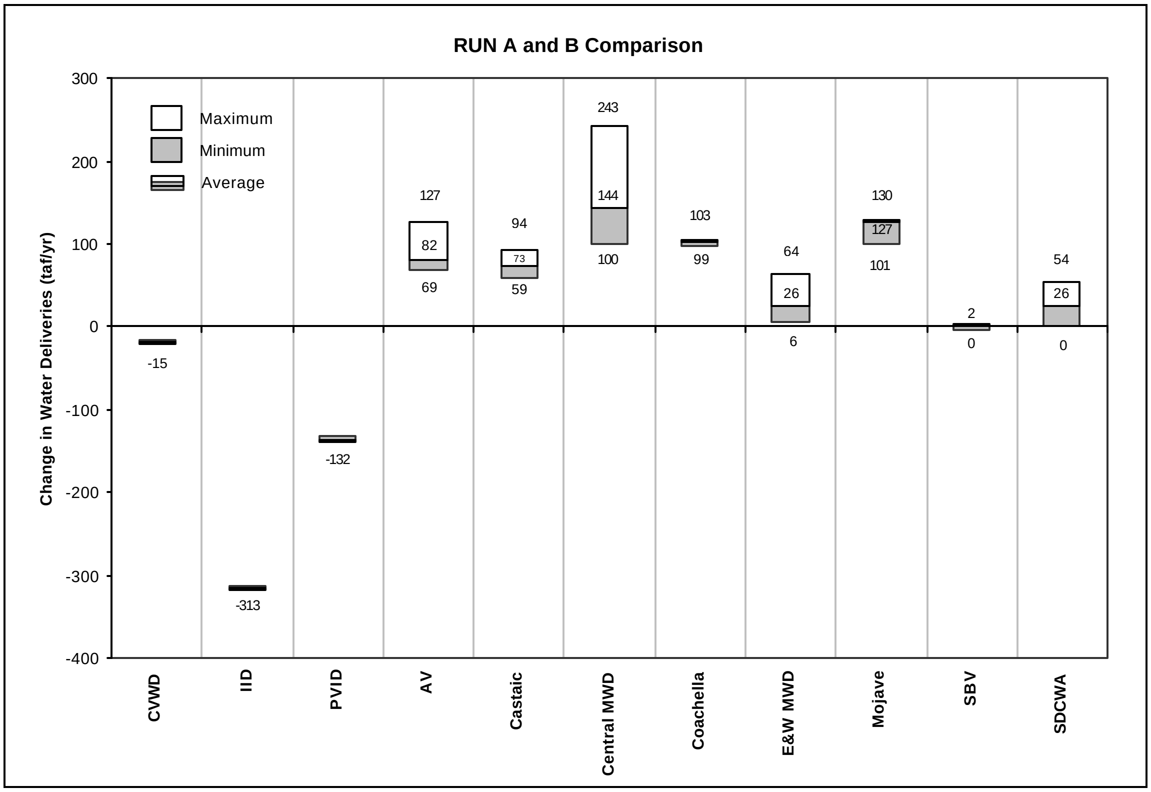
Table IV-3. Change in Water Deliveries by Employing an Ideal Market[a,b]

Demand Region	Run A Shortages		Run B Shortages		Change in Deliveries	
	Average	Maximum	Average	Maximum	Average	Maximum
Agriculture						
CVWD	31	31	46	46	-15	-15
IID	84	84	397	397	-313	-313
PVID	0	0	132	132	-132	-132
Agriculture subtotal	575	575	115	115	-460	-460
Urban						
Antelope Valley	10	16	91	142	82	127
Castaic	11	19	83	113	73	94
Central MWD	54	317	198	560	144	243
Coachella	151	161	253	264	101	103
EW MWD	8	42	34	106	26	64
Mojave	0	0	127	130	127	130
SBV	4	27	4	30	0	2
SCDWA	9	54	35	107	26	54
Urban subtotal	247	635	825	1453	578	817
Total SC region	823	1211	940	1568	118	357

Notes:
[a] *all units in taf*
[b] *values may not add up due exactly due to rounding errors*

In an ideal market, some urban water users typically show much more variation in water deliveries between average years and critical years, showing the value of short-term dry-year water transfers. For example, Central MWD receives a maximum shortage reduction of up to 100 taf in extreme drought conditions. Short-term water transfers also are recommended for Antelope Valley, EW MWD, Mojave, and SDCWA. Castaic (without the newest Monterey Agreement transfers) and Coachella do not demonstrate this variation, suggesting more benefit from long-term transfers.

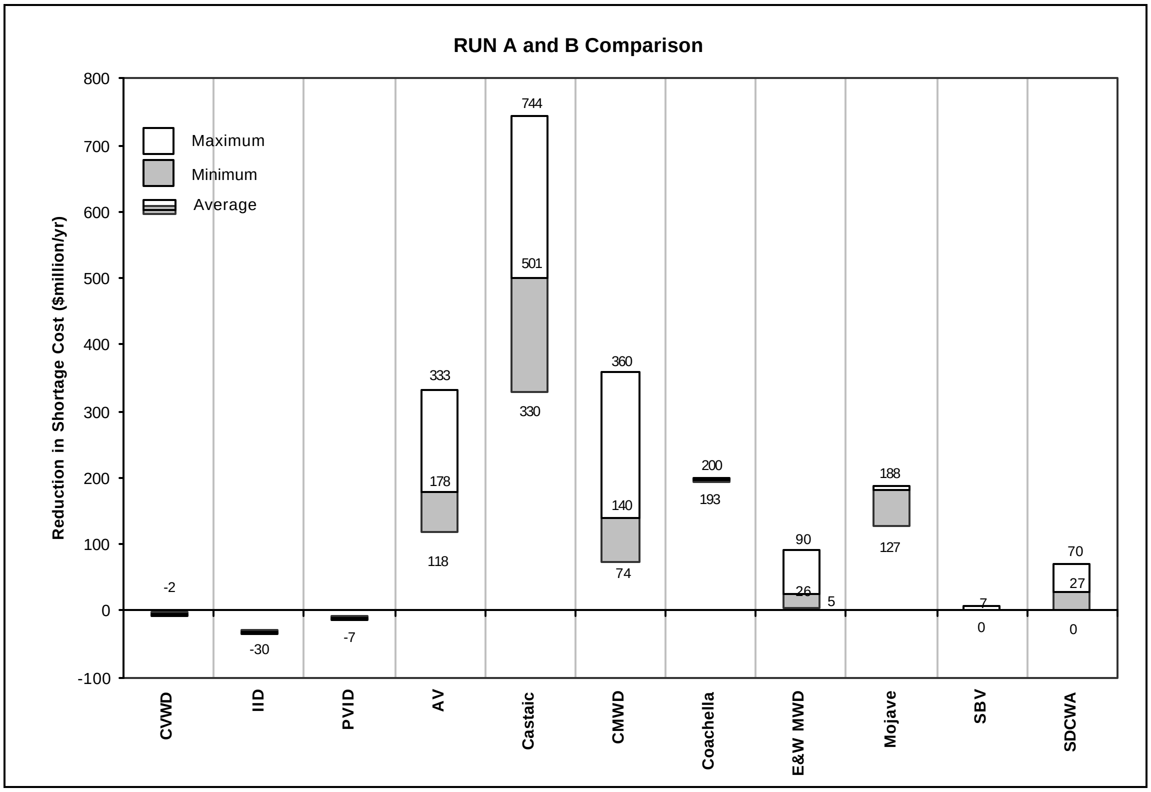
Figure IV-6. Change in Water Deliveries with an Ideal Market



Although Central MWD receives the largest water transfers in Figure IV-6, little information is provided on the priority of water transfers. Water users with smaller demands may benefit more from additional water, depending on the slope of their demand curve and the quantity of shortage relative to their overall demand. Figure IV-7 demonstrates that Castaic currently incurs the largest shortage costs (approximately 30% of total Southern California shortage cost), particularly since the most recent Monterey Agreement transfers are not reflected-- transfers that will reduce Castaic shortage and shortage costs. Moreover, there exists a $200 million/yr reduction in Castaic shortage costs in critical years. The most 'desperate' (in an economic sense) water users are then, in order of priority Central MWD, Antelope Valley, Coachella, Mojave, EW MWD, and SDCWA; San Bernardino incurs negligible shortage costs, possibly due to a sufficient

SWP supply. Agriculture users incur additional shortage costs, suggesting a possible starting point for transfer price negotiations.

Figure IV-7. Reduction in Water User Shortage Costs with an Ideal Market



The economic value of making small changes in current policies are examined in the next section, providing further characterization of an ideal market by highlighting priorities and the economic pressures to trade water.

Economic and Reliability Costs of Current Policies

This section distinguishes between institutional policies and environmental flow requirements. Institutional constraints are created *by* water users for both historical and legal reasons and could conceivably change for the water users' benefit, while environmental constraints are largely imposed on water users and are less likely to change.

Institutional Constraints

Shadow values for SWP allocation (the Monterey Agreement and MWD-CVWD exchange) and the Law of the River are derived from Run B, the policy constrained base case. Most urban water users almost always have a high marginal benefit for increased water above the policy allocations. The typical pattern follows that in Figure IV-8, the shadow values for Monterey Agreement-based SWP deliveries to MWD: high shadow values in the three drought periods, with smaller but still significant shadow values in non-drought years. Smaller shadow values typically appear in the 1976-77 drought since unconstrained MWD storage capacity is better able to compensate for short-term droughts. The shadow values in Run B are typically much greater than in Run A since there are more urban shortages.

Deliveries to MWD via the West Branch (Figure IV-8) correspond to the Central MWD willingness to pay (minus the treatment, distribution, and SWP operational costs). For this representation, West Branch deliveries are slightly preferred due to lower operating costs. This observation neglects the benefits of blending SWP deliveries with more saline supplies.

For the equitable shortage method in the Monterey Agreements, consistent shortages among SWP contractors heavily influence shadow values (see Table IV-4). Persistent shortages among Mojave and Antelope Valley result in fairly constant economic values for increased deliveries. Results for MWD West Branch and CVWD-MWD Exchange deliveries demonstrate the shadow values typical for DWRSIM-simulated deliveries.

Figure IV-8. Marginal Value of SWP West Branch Deliveries to Central MWD

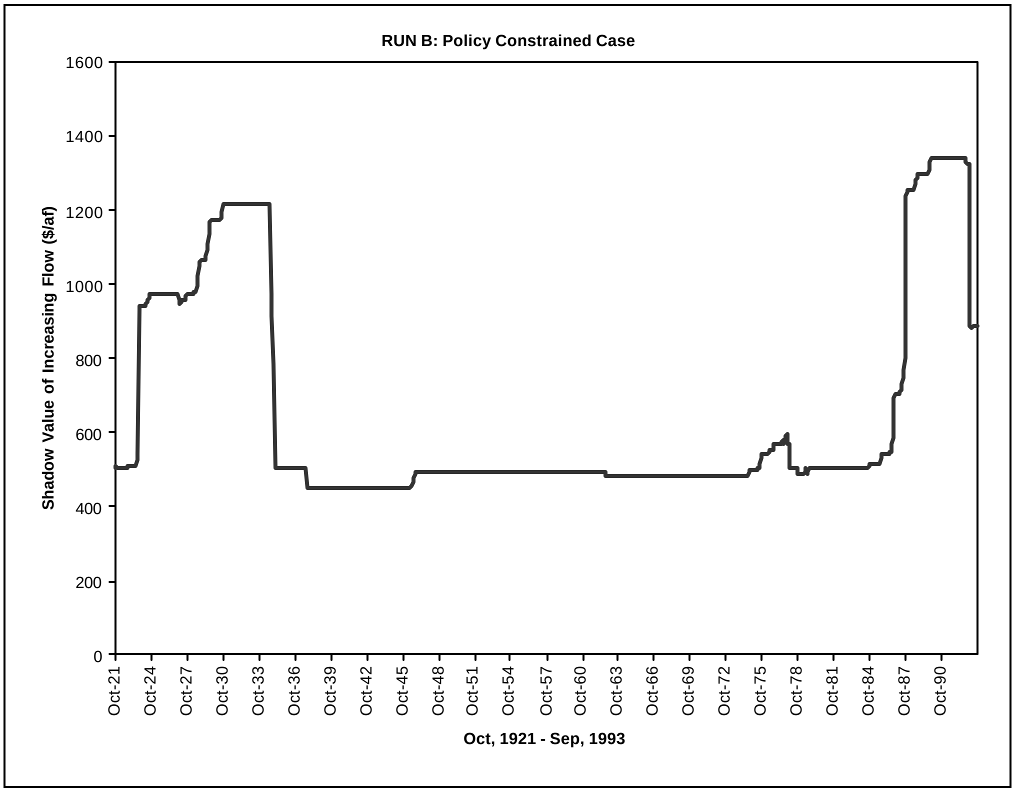


Table IV-4. RUN B Shadow Values for SWP Deliveries

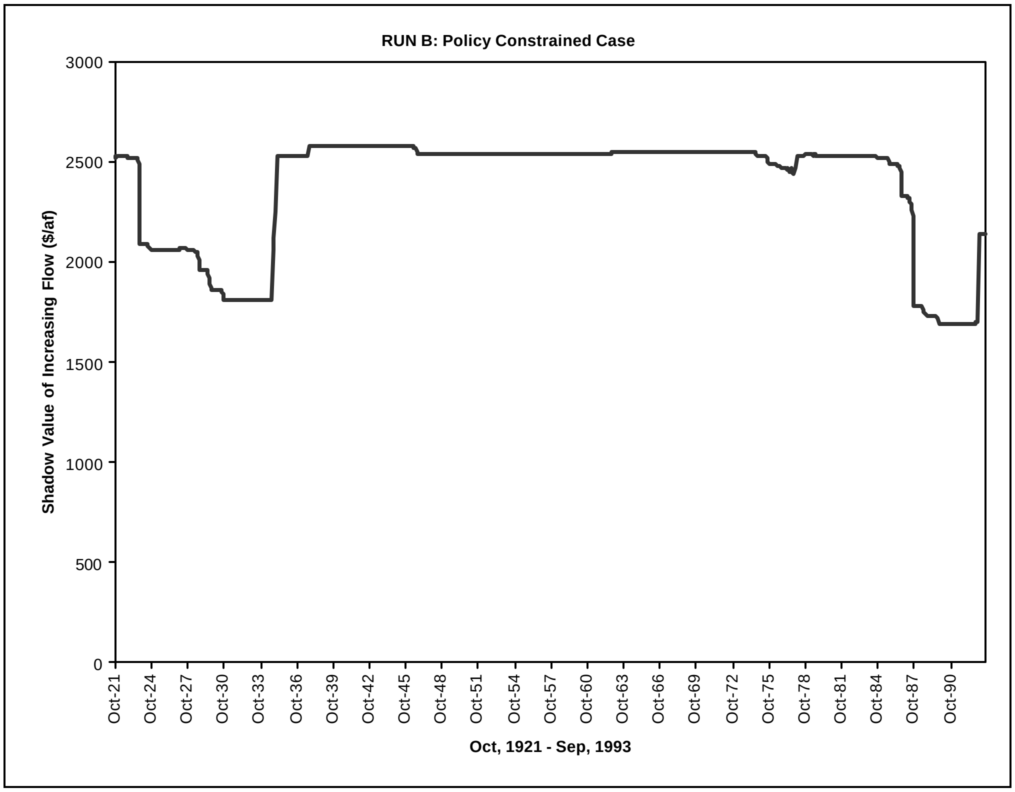
	Max ($/af)	Min ($/af)	Average ($/af)
SWP East Branch			
Mojave Urban	3,205	3,205	3,209
San Bernardino Valley	2,819	0	135
Antelope Valley	2,785	2,692	2,699
South of Silverwood[a]	1,304	0	627
SWP West Branch			
Antelope Valley	2,755	1,694	2,372
MWD West Branch	1,342	448	663
Other			
CVWD-MWD Exchange	2,585	1,694	2,372

Notes:
[a] *South of Silverwood Storage includes MWD east branch deliveries, SGVMWD and SGPWA water deliveries*

Table IV-4 provides further information on the priority of the recommended change in water use. Since the marginal values are a function of each contractor's willingness to pay, an ideal market permits trading so that these values become equal. Thus, an ideal market would provide additional SWP water to Mojave, Antelope Valley, and MWD on a long-term basis in order of priority (since their marginal values are fairly constant). Additional short-term water supplies should be delivered to San Bernardino Valley and MWD (since their shadow costs have higher short-term peaks). The additional SWP water to these regions would come from sources north of the Tehachapi Mountains or additional CRA water since agricultural users in Run B have only a small marginal willingness to pay value (less than $20/af). In an ideal market each water user's marginal willingness to pay would likely be substantially closer, but are impossible to equalize due to capacity constraints.

Coachella illustrates the dynamic relationship between water users. Figure IV-9, the shadow values for increasing CRA exchange deliveries, demonstrates that although Southern California always benefits from increased deliveries to Coachella, these benefits *decrease* during drought seasons. The benefit of delivering additional CRA water to Coachella decreases as the willingness to pay increases in other urban regions such as Central, Eastern and Western MWD and SDCWA. Given Coachella's shortages are a function mainly of recharge capacity and the storage availability, flexibility might be sought in the CVWD-MWD exchange to decrease the shadow values of other Southern Californian urban users. The results suggest it might be valuable for MWD, the other CRA urban water user, to help CVWD increase their recharge capacity to reduce their shortages and to help use their storage for dry year replenishment.

Figure IV-9. Shadow Value of CVWD-MWD Exchange Delivery from the CRA

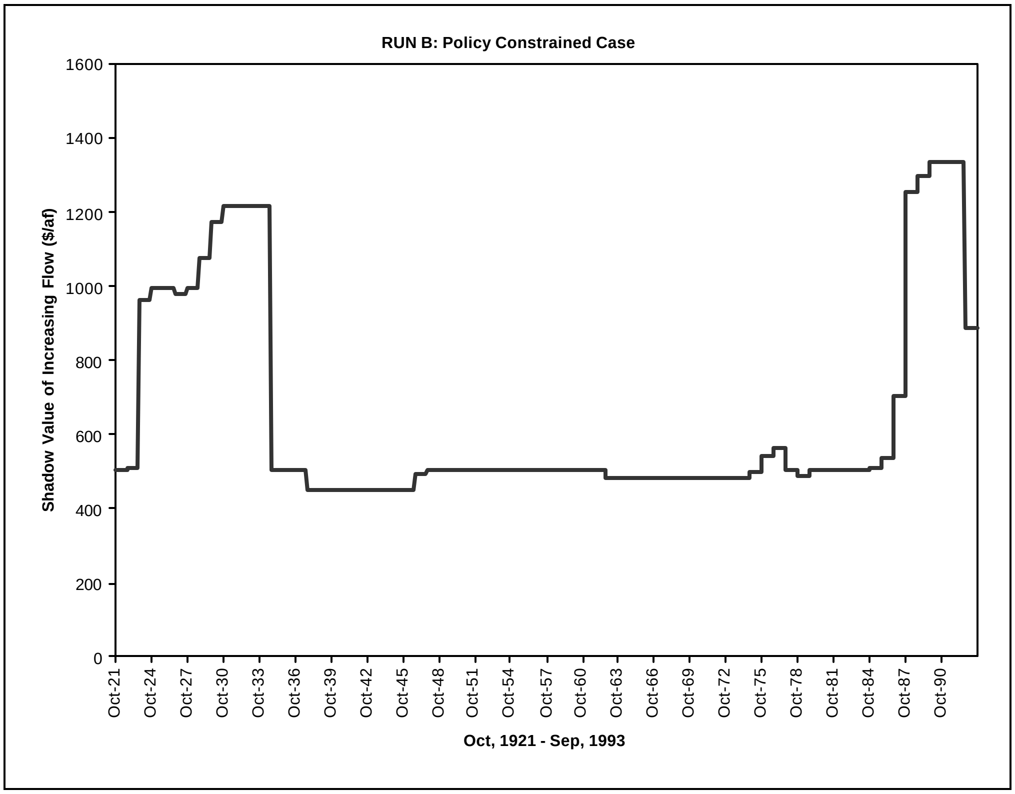


Capacity shadow values for the current 4.4 Plan have direct implications for water transfers since water is either allocated to the CRA or to agricultural contractors. MWD shortages are a major factor in these costs. Coachella does not influence these costs since the CVWD-MWD exchange is limited by a fixed DWRSIM time-series (see Figure IV-9). With the current CALVIN configuration and according to the values depicted in Table IV-5 and Figure IV-10, a delivery increase of one acre-foot to agricultural regions costs Southern California water users up to $1,338/af during the 1987-1992 drought and $643 on average. Conversely, MWD is willing to pay up to $1,338 for a one acre-foot water transfer from the agricultural region in extreme drought years and an average of $643/af. Since IID has a slightly higher willingness to pay for CRA water that PVID, a slight cost is incurred from allocating additional water to PVID ($12/af). Thus, there exists substantial economic value to allowing water transfers to modify within-California allocations of Colorado River water.

Table IV-5. Colorado River Agricultural Allocation Shadow Costs

	Min ($/af)	Max ($/af)	Average ($/af)
3.55 maf Agricultural Allocation	447	1338	654
PVID Allocation	12	12	12

Figure IV-10. Shadow Costs for Law of the River



Environmental

Environmental shadow values are calculated for the Mono Basin, Owens Lake bed dust mitigation, and as earlier discussed, the value of additional export from the Delta or the Central Valley. Table IV-6 provides these shadow value results. For the Mono Lake and Owens Valley constraints, Southern California water users incur greater costs if the constraints were raised by one acre-foot. For the marginal value of increased Delta outflow, Southern California water users incur varying benefits also dependent on MWD shortage patterns.

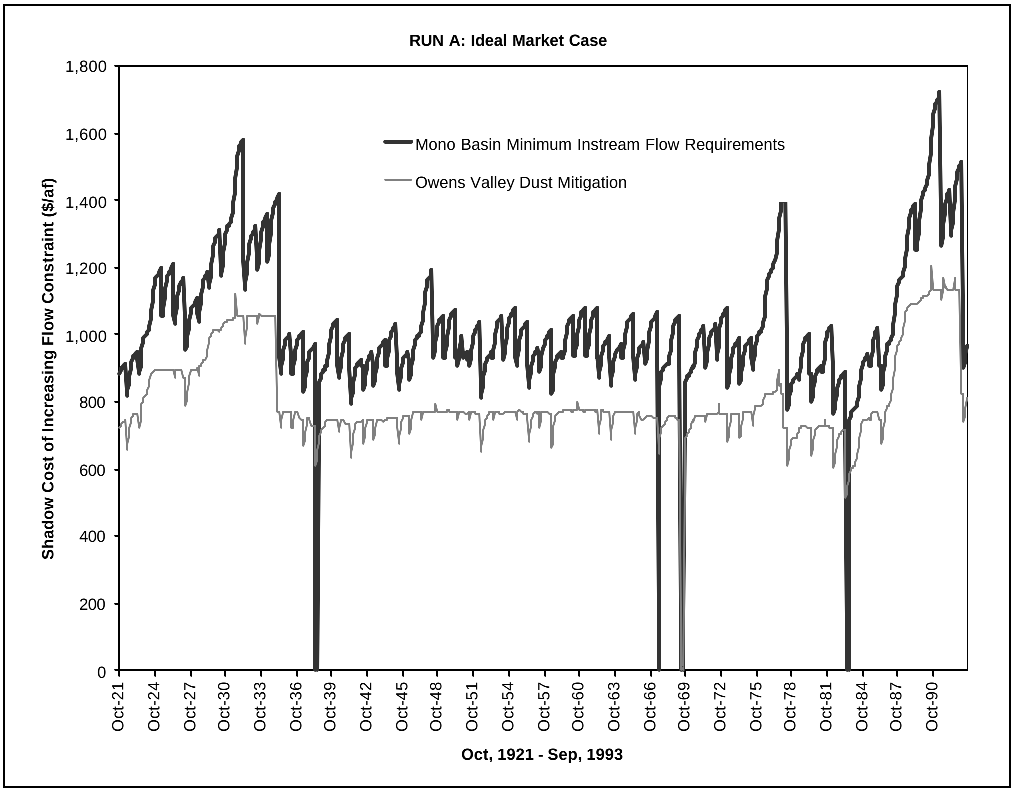
Table IV-6. Shadow and Marginal Values for Environmental Constraints with an Ideal Market

	Max ($/af)	Min ($/af)	Average ($/af)
Shadow Costs			
Mono Lake Minimum Inflow	1,723	0	1023
Owens Lake Dust Mitigation	1,203	0	806
Marginal Value of Additional Inflow			
Delta	544	54	189

Of the two Mono Lake constraints, the lake level and minimum instream flows, only the minimum instream flows limit water from flowing to Los Angeles, assuming the lake initial storage level is at or above Decision 1631-based minimum elevations. Shadow values for the minimum instream flows reflect the considerable shortage costs occurring in Central MWD and the lost hydropower benefits from not diverting water through the Mono Craters tunnel (an estimated $298/af hydropower benefit accrues between the Mono Basin and the City of Los Angeles). Figure IV-11 indicates the shadow value reaches zero in some years reflecting extremely wet years when the limiting constraint becomes the Mono Craters diversion capacity (400 cfs). Shadow value for this incidental infrastructure expansion is significant (up to $800/yr per af /yr) since the ability to capture additional LAA water reduces Central MWD dependence on more expensive SWP deliveries and produces additional hydropower.

The pattern in Figure IV-11 does not match the shortage pattern exactly since it is a function of the IFIM based-Decision 1631 flow regime. Varying flow constraints based on dry, wet, and normal Mono basin hydrology alter the cost incurred from marginally increasing the environmental flow constraint.

Figure IV-11. Environmental Flow Shadow Costs



The costs of increasing Owens Valley dust mitigation deliveries roughly mimic the pattern of Mono Lake inflows with slightly lower magnitudes reflecting the additional hydropower benefits of Mono Basin diversions. If LADWP could exercise discretion in dust mitigation measures by using less water intensive mitigation measures, such high shadow costs suggest a drought contigent policy might be adopted. Particularly, drought year reductions in mitigation deliveries could create significant benefits.

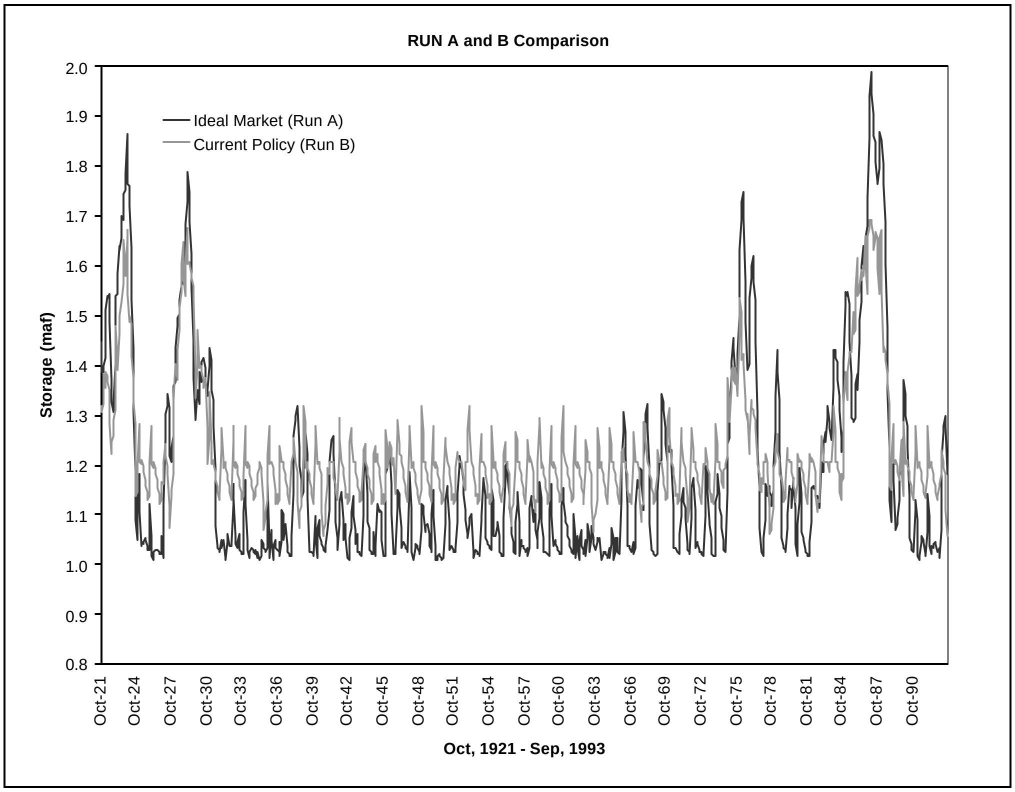
Operational Flexibility and Economic Value of Infrastructure Expansion

To acquire the economic benefits promised from an ideal market, CALVIN recommends increased operational flexibility for surface water and groundwater storage. To acquire additional economic benefits beyond the ideal market scenario, CALVIN provides the economic values for incremental expansion of facilities.

Operational Flexibility

By using perfect foresight and economic benefit maximization, CALVIN allows more flexible operations to increase the value of an ideal market. Figure IV-13 portrays the difference in operation between surface water storage in Run A and B. Since surface water storage in Southern California is heavily constrained by emergency storage requirements (0.98 maf is dedicated to dead pool and emergency storage), the operations between Run A and Run B differ only moderately (less than 300 taf/month). With perfect foresight, CALVIN is less risk averse than water managers would be (notice the Run B lower limit is seldom as low as CALVIN's). The pattern of Run B does not vary significantly with Run A, particularly since MWD-owned facilities are optimized in both cases.

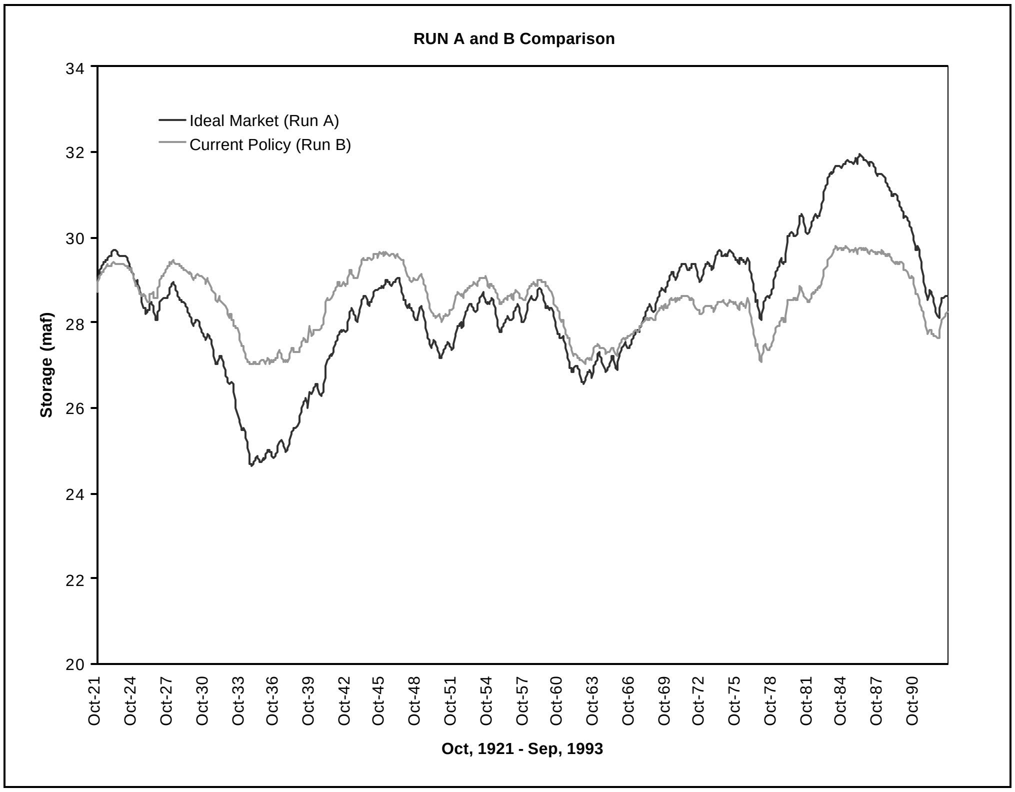
Figure IV-13. Southern California Total Monthly Surface Water Storage



Note: not including LAA facilities

More significant differences between Run A and Run B occur with groundwater storage operations where CALVIN prescribes more aggressive withdrawal in the beginning of the time period and more aggressive recharge towards the end of the time period (see Figure IV-14). The aggressive pumping corresponds to the 1929-34 drought period while the aggressive recharge corresponds to preparation for the 1976-77 and 1987-92 drought periods. The storage magnitudes in Figure IV-13 and IV-14 reflect the importance of Southern California groundwater management, particularly in drought periods.

Figure IV-14. Southern California Total Monthly Groundwater Storage



Note: not including LAA facilities

The lack of institutional constraints for groundwater and MWD facilities reduce the shortage costs and shadow values for the short-term drought (1976-77), but are unable to compensate as much for the long term-droughts (1929-34; 1987-92). Operations in Figures IV-13 and IV-14 show CALVIN's use this storage capacity to reduce the effect of these drought conditions.

Storage Capacity Expansion

CALVIN only recommends surface water storage capacity expansion for drought years. The total expected value for increasing Southern California surface water storage in any year averages only $13/af, with values as high as $225/af in drought years (given CALVIN's perfect foresight, these are lower bounds). Table IV-7 displays the expected and present value of expanding each surface water storage facility. LAA facilities have the highest expected value since they can store the cheapest water in terms of water quality costs and additional storage in Grant Lake may help prevent non-power producing spills in the Owens Valley gorge. Since the LAA system is the only location of major spills in Southern California, its expected value of storage expansion should be the highest. Present values for these unit comparisons allow comparison with construction costs.

Table IV-7. Annual Expected and Present Value of Storage Capacity Expansion

Reservoir	Expected Value ($/af)	Present Value (i = 3%) ($/af)	Present Value (i = 5%) ($/af)
Castaic Lake	11.4	379	228
Eastside Reservoir	4.9	162	97
Grant Lake	253.2	8440	5064
LAA Aggregate Storage	207.8	6928	4157
Lake Crowley	188.8	6295	3777
Lake Mathews	4.0	133	80
Lake Perris	6.2	205	123
Lake Skinner	4.7	156	94
Pyramid Lake	9.1	303	182
Silverwood Lake	14.7	489	294

For reservoirs with emergency storage, the value of being able to use emergency storage pool can be higher than those displayed in Table IV-8. Table IV-8 also shows the expected value of using these emergency pools for dry year water supply.

Table IV-8. Annual Expected Emergency Storage Withdrawal

Reservoir	Expected Value ($/af)
Castaic Lake	20.9
Eastside Reservoir	24.7
Lake Mathews	77.1
Lake Perris	35.0
Lake Skinner	119.4
Pyramid Lake	24.8
Silverwood	26.3

Results for Silverwood Lake on the SWP East Branch provides typical patterns while results for the Eastside reservoir demonstrate the importance of the MWD storage facilities.

Silverwood Lake: SR-25

Figure IV-15 shows shadow values on storage capacity for Silverwood Lake, demonstrating typical patterns and magnitudes for all of Southern California storage facilities. The three drought periods are shown to generate both the highest negative and positive shadow values. The magnitudes of these shadow cost represent MWD shortage costs minus SWP water quality and operational costs.

Figure IV-15. Silverwood Lake Shadow Values

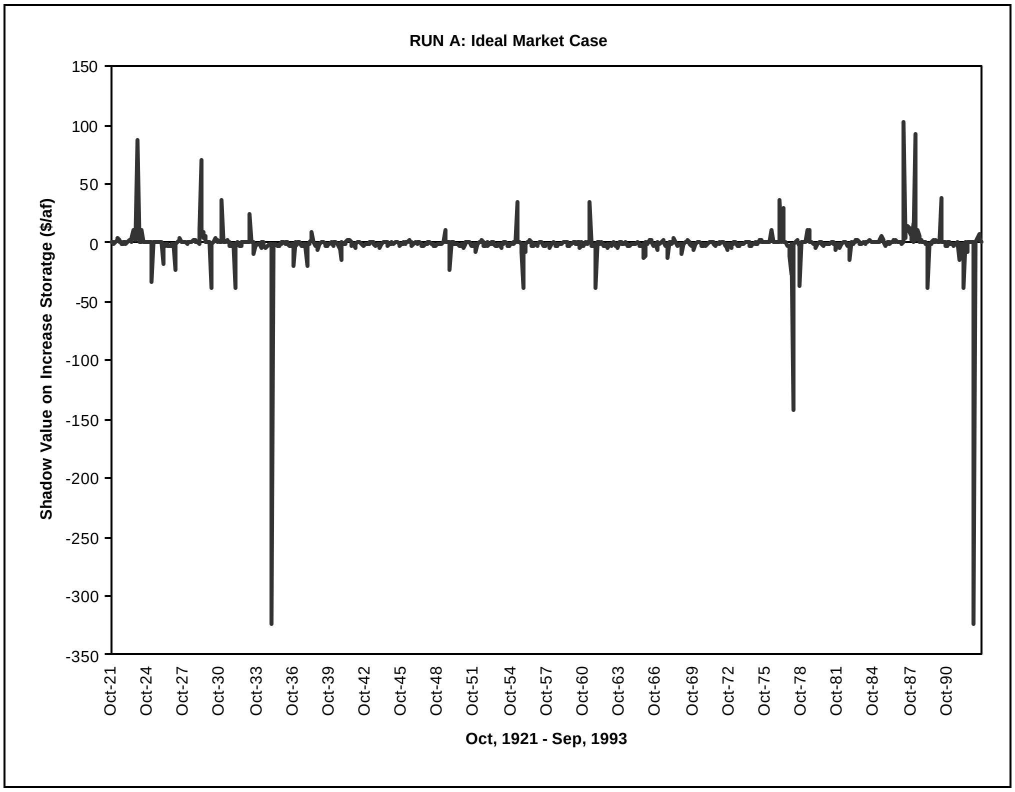
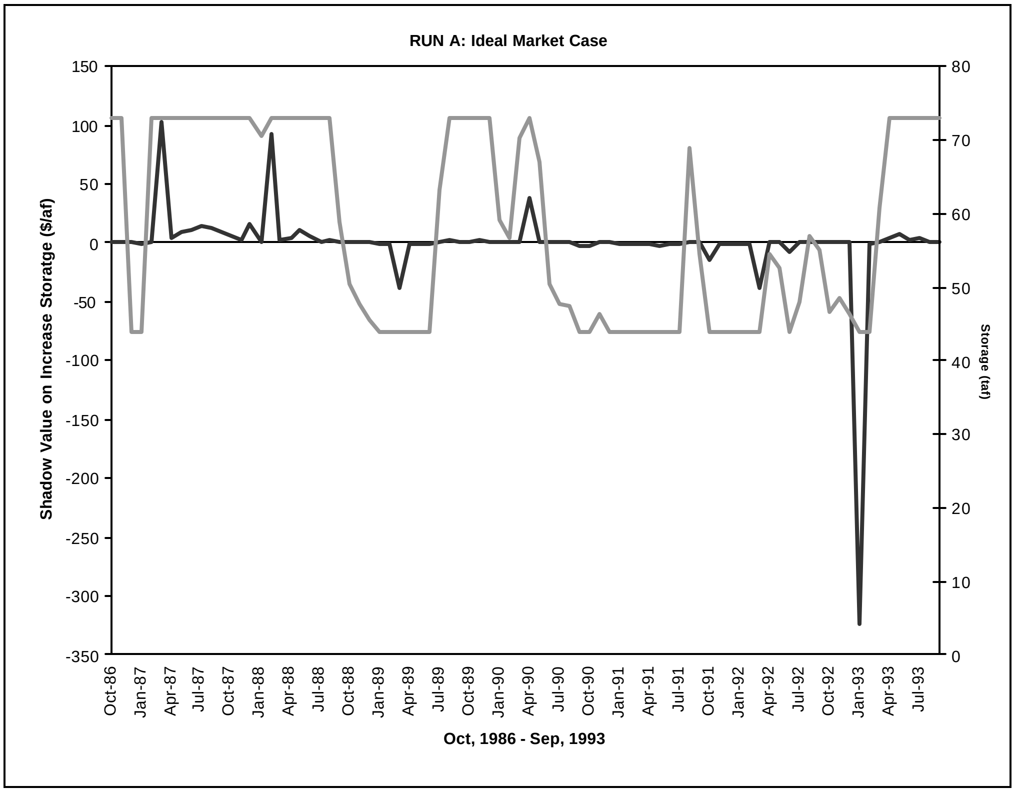


Figure IV-16 explains why the shadow values become negative. Silverwood is a reservoir with 73 taf storage capacity and an emergency storage pool of 44 taf. With perfect foresight, CALVIN stores as much water as possible for the oncoming drought. Since water is available to store before the drought, $110/af of benefit exists to expand the upper storage limit of Silverwood lake by one acre-foot. Towards the end of the drought in 1992 as Silverwood Lake reaches the bottom of its usable storage pool, drawing from the emergency storage by one acre-foot would prevent $320/af of cost.

Figure IV-16. Silverwood Lake Storage and Shadow Values



Eastside Reservoir: SR-ER

Results from the Eastside reservoir provide further evidence that surface water storage in the base case does not greatly limit an ideal market. As an off-stream reservoir, the Eastside is the only surface water reservoir with an operating cost ($21.25/af for pumping). Storage in the Eastside Reservoir, unlike the majority of the other facilities in Southern California, is used only prior to drought periods and remains empty the majority of the time (see Figure IV-17). Shadow values to expand the Eastside Reservoir during drought periods are fairly significant despite the infrequent storage-- reflecting CALVIN's preference to use less expensive CRA water rather than the SWP. When MWD conjunctive use ability is eliminated in Run C, the use of SR-ER storage space and the pressure to increase the capacity on the Eastside increases and becomes more desirable throughout the historic time period (see Figure IV-17). Use of GW-MWD appears more attractive than the Eastside Reservoir to CALVIN because the current CALVIN representation stores relatively inexpensive LAA water in GW-MWD while storage in the Eastside Reservoir incurs costs for pumping and for storing more expensive CRA and SWP water.

Under the policy constraints to Run B, SWP facilities are constrained to a fixed monthly operation, CRA facilities are constrained to a set annual operation, but internal MWD facilities are left to be optimized given current operations. Under this scenario, it is intuitive that MWD would operate their facilities differently given the opportunity to operate within an ideal market. Figure IV-18 highlights the differences of optimal operation of the Eastside Reservoir operation under ideal market conditions and current projected policy scenarios. Although shadow values vary considerably for this scenario, storage for MWD facilities does not deviate tremendously from ideal market conditions since flow quantities do not vary tremendously. Use of the Eastside Reservoir depends more on the existence of other MWD storage facilities; when GW-MWD is removed in Run C, the Eastside Reservoir is used much more consistently.

Figure IV-17. Eastside Reservoir Monthly Storage

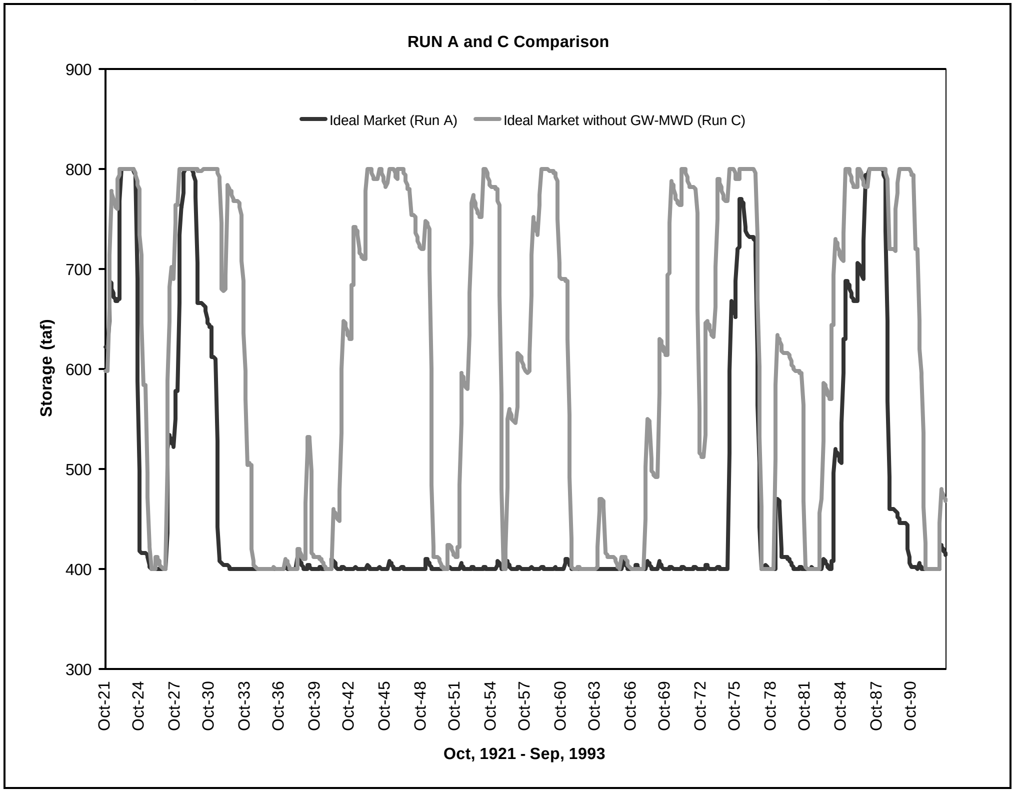
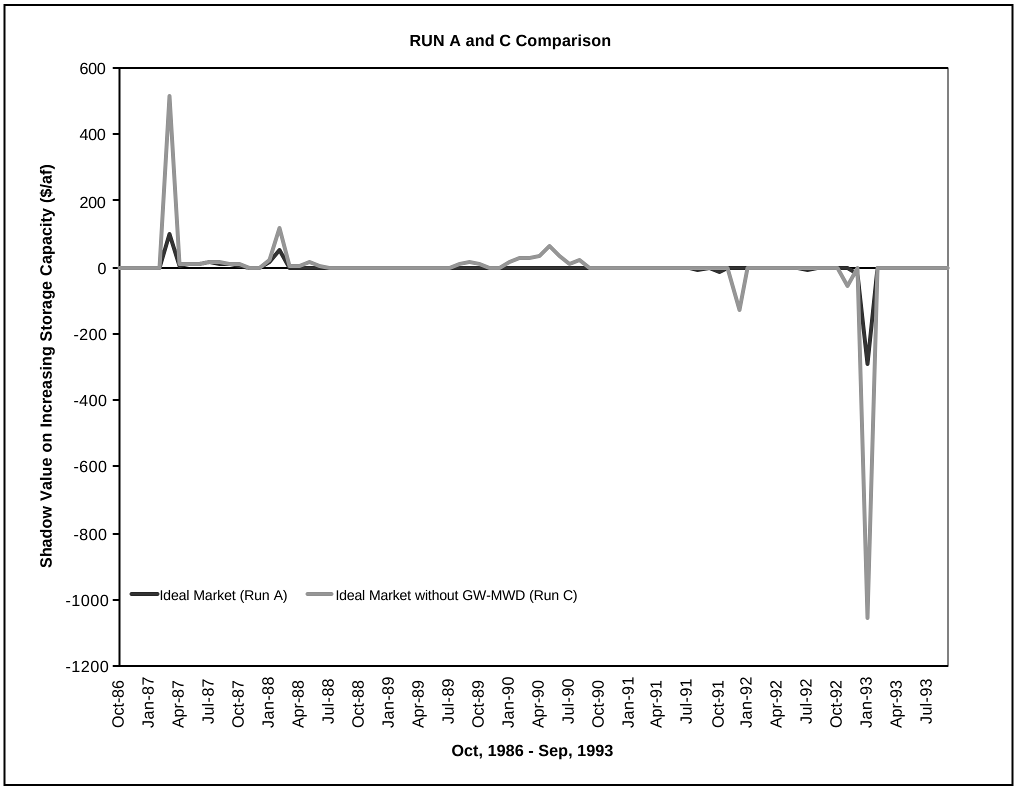


Figure IV-18. Eastside Reservoir Shadow Values



Groundwater storage capacity, per se, almost never binds with the exception of MWD conjunctive use capacity. GW-MWD plays a crucial role in MWD water supply while the most pressing recharge capacity is in the Coachella groundwater basin.

GW-MWD

Shadow values for GW-MWD mimic the Eastside Reservoir with slightly higher magnitudes since the operating cost is slightly less. With the presence of GW-MWD, shadow values for increased storage are minimal (usually below $100/af). Shortage costs during drought periods, however, increase from about 21% during average years to more than doubling during the '76-77 drought (see Table IV-9). MWD, as an aggregate agency, bears the majority of these costs since the resulting shortages occur in Central MWD, EW MWD, and SCDWA. The annual expected value of increasing storage in GW-MWD is $21/af in Run A and $146/af in Run C (a present of value of $685/af and $4,862/af, respectively, with an interest rate of 3%). The value in Run C is the value to Southern California water users for any MWD conjunctive use ability.

Table IV-9. Role of GW-MWD in Ideal Market Shortage Costs

Time Period	Annual Average Shortage Cost		% Increase
	With ($ million)	Without ($ million)	
1922-1993	294	355	21
1929-34	504	752	49
1976-77	344	848	146
1987-92	502	776	54

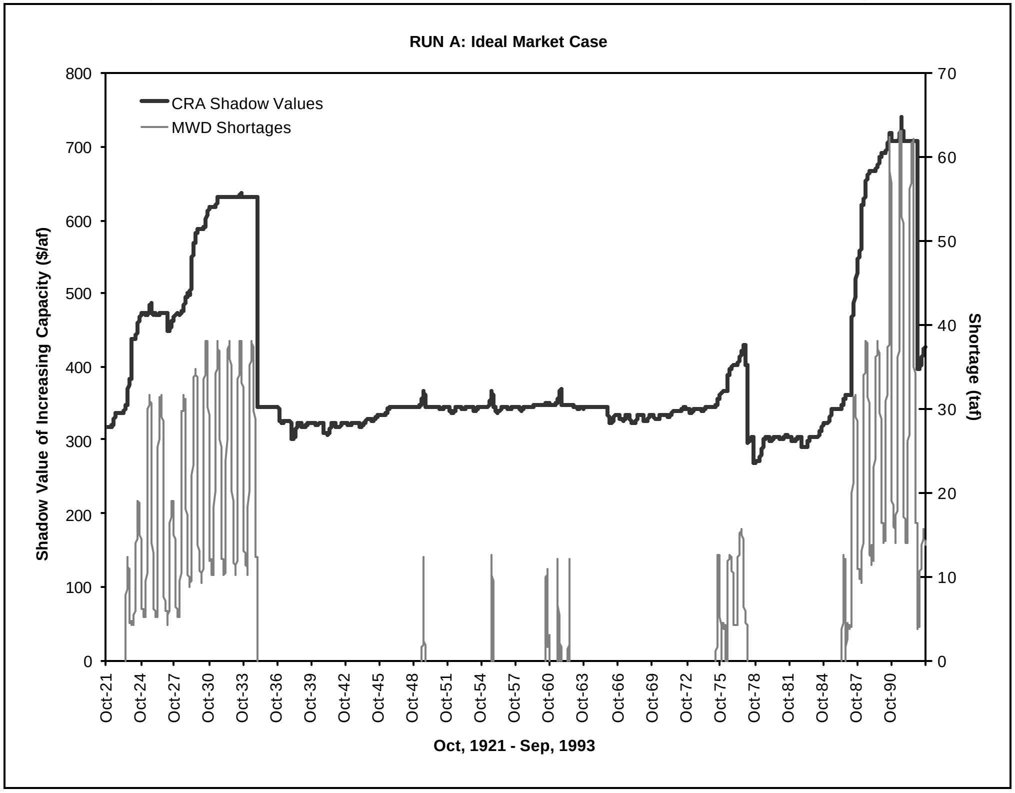
Coachella

Recharge and pumping capacity shadow values typically correspond to the shortage costs of the closest demand region or the costs of an alternative source. For example, the current CALVIN-represented Coachella Urban region consistently has an infrastructure-induced shortage of about 12 taf/month and a corresponding marginal willingness to pay around $3000/af. The shadow values for increasing the recharge from the CRA and pumping capacity to the Coachella Urban region are up to $2860/yr per af/yr and $3043/yr per af/yr, respectively (with very little variation). The discrepancy in value equals the cost of Coachella water recycling efforts-- the source used in lieu of groundwater for Coachella.

Conveyance Capacity Expansion

Most canal capacities in the Southern California system did not result in high shadow values (>$100/af-month). The only facility showing significant shadow values in terms of expected and present value is the CRA. CRA water is delivered to the Coachella Valley urban area and MWD-- Central, Eastern and Western MWD, and SCDWA. Figure IV-19 reflects the shadow values associated with the CRA and its relationship to CMWD shortages. For the majority of the 72 year time period, little pressure exists to expand the CRA. In the 1987 to 1991 drought period, however, shadow values increase up to $700/yr per af/yr. Shortages of up to 62 taf occur during these droughts incurring shortage costs in all of the MWD residential regions. Shadow values for increasing the capacity of the CRA result in an expected value of $398/yr per af/yr and present values between $13,250/yr per af/yr and $7,950/yr per af/yr, with interest rates of 3% and 5%, respectively.

Figure IV-19. CRA Shadow Values and MWD Shortages



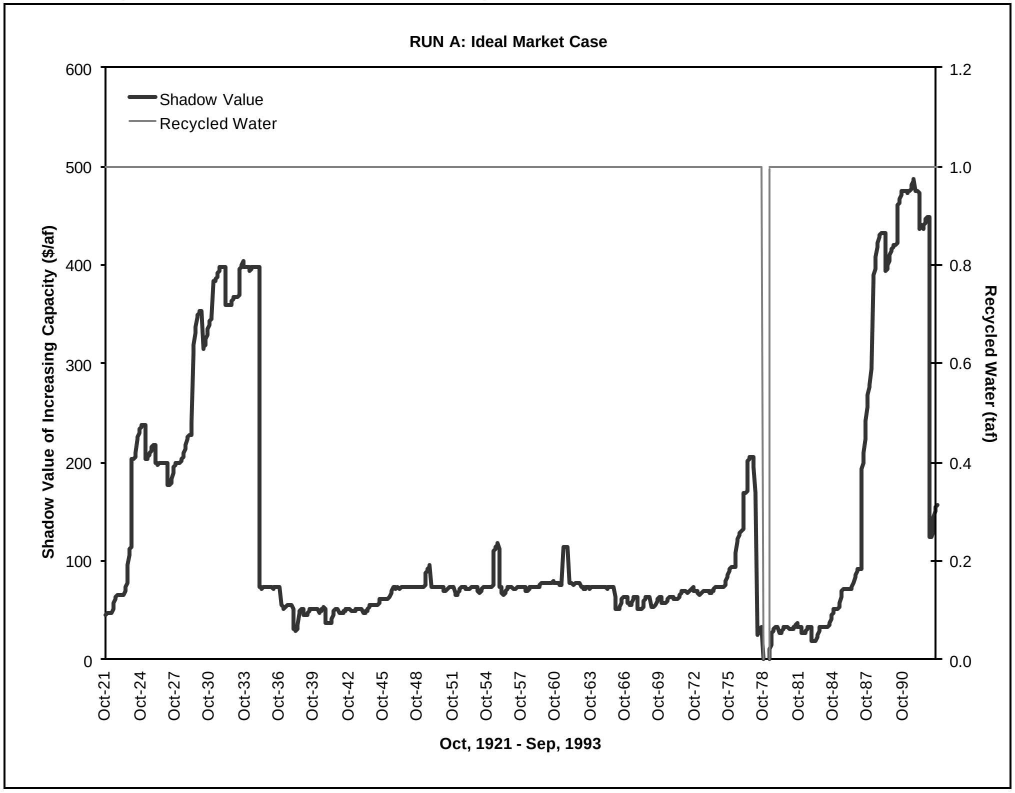
Recycling Facility Expansion

Since high costs are attributed to water recycling projects, increasing the capacity of most of the water recycling facilities does not appear to be beneficial for the majority of years with the exception of Antelope Valley (see Table IV-10). The other recycling facility shadow values are analogous to Figure IV-20: low benefits are accrued in non-drought years while more significant benefits accrue during drought periods.

Table IV-10. CALVIN Representation of Water Recycling Facilities

Recycled Water Facility	Operational Costs ($/af)	Capacity (taf/month)	Maximum Shadow Value ($/af)	Expected Shadow Value ($/yr per af/yr)
Antelope Valley	350	0.5	565	459.7
Central MWD	850	0.0	258	29.6
Coachella	350	1.3	0	0
Eastern and Western MWD	850	0.0	295	32.4
Mojave	350	0.5	0	0
San Bernardino Valley	350	1.0	487	129.6
SDCWA	850	0.0	276	29.7

Figure IV-20. SBV Recycling Facility Shadow Value and Use



New Facilities

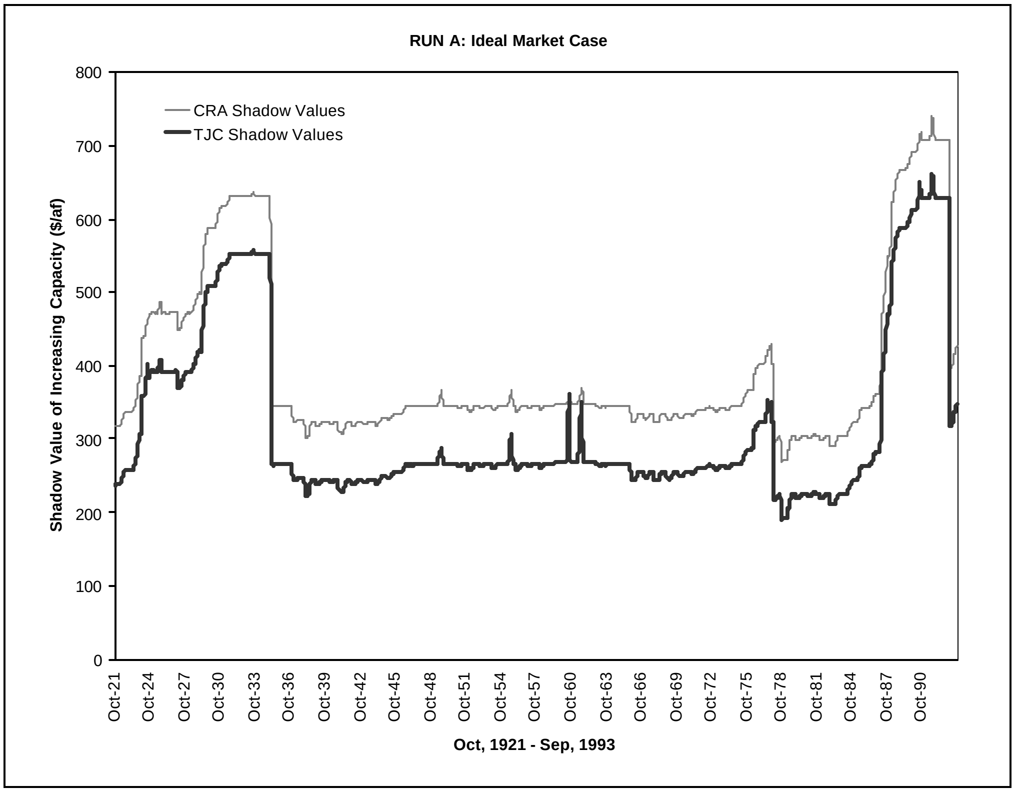
CALVIN also can provide an explicit valuation of new facilities. For this analysis, a possible Tijuana Canal and an Antelope Valley conjunctive use facility are explicitly included.

Tijuana Canal

A connection between the All American Canal and the SDCWA has been contemplated as an alternative delivery route for CRA water to SDCWA. Since the canal withdrawals from the Colorado River at a more southern point than the CRA, its TDS levels will likely be significantly higher. An assumed TDS level of 879 mg/l is assumed in CALVIN, corresponding to an estimated water quality cost of $257/af (USBR and MWD 1995).

Figure IV-21 presents the Tijuana Canal shadow values. The relationship parallels that of the CRA shadow cost, with the difference being the difference in operating and water quality costs ($178 for the CRA versus $257 for the Tijuana Canal). The Tijuana canal would provide moderate marginal benefits outside of drought periods and much larger economic benefit during droughts. Use of the Tijuana Canal provides an annual expected value of $318/yr per af/yr.

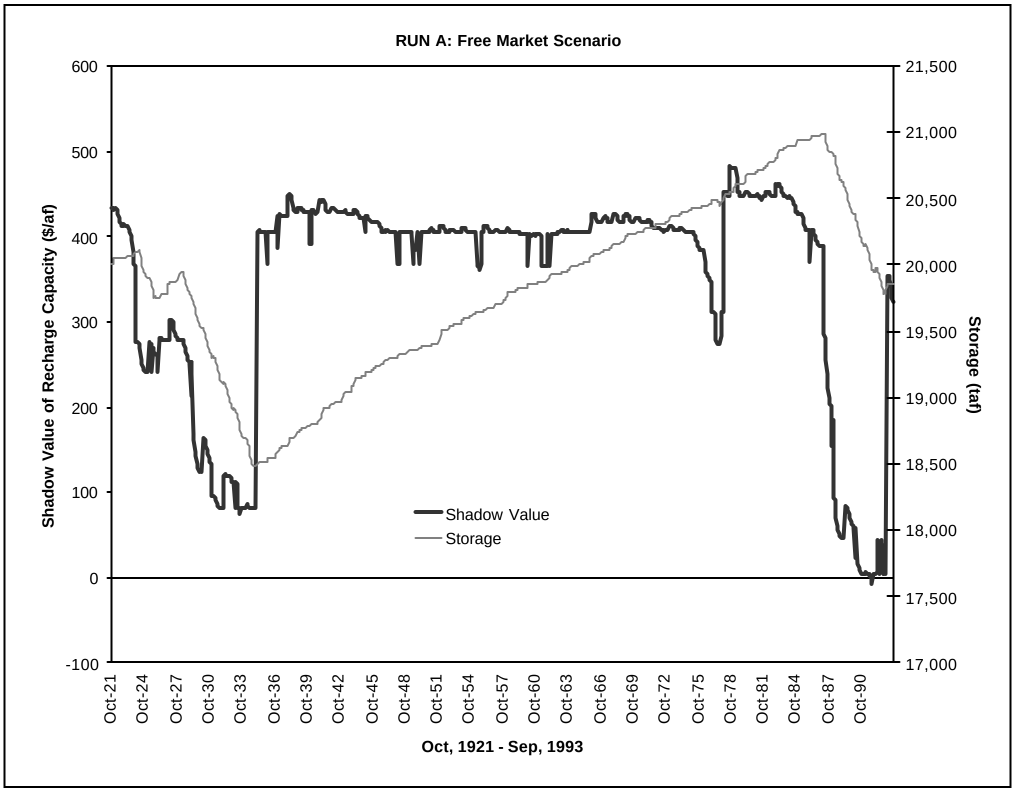
Figure IV-21. Tijuana Canal and CRA Shadow Values



Antelope Valley Conjunctive Use

Recharge capacity from the California Aqueduct for Antelope Valley is a potential conjunctive use facility. Without any SWP recharge capacity, CALVIN recommends the groundwater basin be recharged consistently until drought conditions occur (see Figure IV-22). Since shortages occur throughout Southern California during the three drought periods, little benefit would result from recharging water during droughts. However, recharging additional SWP deliveries during non-drought years would augment Antelope Valley supplies during drought years. The shadow value for these non-drought year deliveries reflects the reduced shortage cost in Antelope Valley and the value throughout Southern California or Antelope Valley reducing SWP use during drought periods minus the operational cost for pumping SWP water over the Tehachapi mountains.

Figure IV-22. Antelope Valley SWP Conjunctive Use Recharge Potential



The following chapter discusses the conclusions and policy implications of these model results.

V. CONCLUSIONS AND FUTURE IMPROVEMENTS

Considering the limitations of this modeling approach and water marketing, the following conclusions can be made. Additionally, more specific and reliable information can be derived with improvements to the CALVIN approach.

Conclusions

Potentially substantial economic benefits could be derived from an ideal market within Southern California. From the statewide perspective, instituting an ideal water market reduces Southern Californian reliance on imported water supplies, particularly the SWP and Colorado River. The Southern California region would reduce its average annual shortage by 118 taf and shortage cost by over $1.2 billion, increasing to as much as 360 taf and $1.94 billion in the most extreme drought year. Most of these benefits would accrue to urban water users, particularly Castaic, Central MWD, and Antelope Valley.

Several promising long and short-term water transfer opportunities exist within Southern California. Virtually all urban water users would benefit from long term water transfers (varying from 150 taf for Central MWD to 27 taf for SDCWA). In addition, Central MWD, Antelope Valley, EW MWD, and SDCWA would benefit from short-term water transfers to augment drought year supplies. Castaic, Central MWD, Antelope Valley, Coachella, Mojave, EW MWD, and SDCWA would benefit the most from increased drought year water supplies, in order of priority. Consequently, during the development of this thesis, Castaic became the largest purchaser of the 130 taf Monterey Agreement agricultural SWP relinquishment. Most of these transfers come from a 460 taf/yr Colorado River transfer from agricultural users (about a 13% reduction in their supplies).

An ideal market reduces reliance on imported sources. Since some water users depend solely on local supplies and SWP imports (particularly Castaic, Antelope Valley, and Mojave), an ideal market would substantially reduce dependence on SWP water by increasing SWP deliveries to these contractors; consequently this transaction reduces SWP delivery and increases Colorado River deliveries to MWD. With the CRA at full capacity, less economic incentive would exist to increase Colorado River deliveries in an ideal market. Thus, the marginal willingness to pay for additional SWP and Colorado River water is substantially reduced.

Small changes in allocation substantially reduce shortage costs. In terms of total Southern California water supply, relatively small amounts of water would be conserved in an ideal market with current facilities. An average annual 120 taf shortage reduction occurs, corresponding to a 13% savings in total water use relative to current operating policies. The 13% reduction in shortage with an ideal market reallocation, however, corresponds to an 81% reduction in shortage costs reflecting the transfer of water from lower valued to higher valued uses.

MWD's conjunctive use ability is critical. From the results in Runs C and D, it is apparent the 1.45 maf of conjunctive use capacity identified in MWD (1997) is critical to alleviate shortage and reduce shortage costs. Without GW-MWD, average annual shortage costs increased by 21%, while shortage costs during long and short-term droughts increased by 49 and 146%, respectively. Without MWD conjunctive use capacity, the Eastside Reservoir assumes a much greater role in reducing MWD shortages. With MWD conjunctive use capacity, the use of Eastside Reservoir is somewhat limited.

Substantial marginal benefits would be gained from expanding some Southern California water facilities. In addition to GW-MWD, limited benefits would be gained from increasing surface water storage capacity. More useful for improving Southern California's water supply would be expanding capacity to deliver Colorado River water to the South Coast region (either by expanding the Colorado River Aqueduct or the construction of the Tijuana Canal). Other facility expansions that might induce significant economic benefits include Antelope Valley conjunctive use and water recycling facilities.

In light of the potential for Southern California water markets several other factors need to carefully considered. Much of the water transfer activity suggested by this modeling effort involved agriculture to urban water transfers. Positive and negative third-party impacts, externalities, and transaction costs are not accounted for in this modeling effort but should be considered in long term planning decisions.

Improvements

Several limitations to the general CALVIN approach are listed in Chapter IV. Additionally, several improvements could be made to the specific Southern California representation to more accurately represent current operating policies.

More Detailed MWD representation

Currently disaggregated into three demand areas many of the local operations are included as local inflows based on an MWD-assumed operation. Increasing the complexity of the MWD system may highlight additional operation alternatives helpful to the entire Southern California region, particularly since MWD accounts for such a large portion of the Southern California demand.

Within the current representation, a more detailed current Policy Constrained scenario might introduce priorities to each region predicated on the policy in the MWD Drought Water Management Plan. Such analysis might provide additional insight on the benefits of Tijuana Canal for SDCWA.

Addition of Northern Californian Representation to CALVIN

Considering the benefit of additional SWP inflow, interaction of north-of-the Tehachapis demand regions should highlight where such water might come from in addition to observing the optimum water allocation from a broader perspective. Variability in SWP water quality is likely to be important.

Extension of SWAP to Southern California

Current results are limited by the extrapolation procedure of SWAP from the Central Valley to Southern California agricultural regions. A more accurate representation would provide better estimates of marginal values and the optimum level of increased flexibility.

Better Colorado River Representation

Time Series for TDS Level variation and surplus flows for the Colorado River are provided by other modeling efforts and might help explore further Colorado River operational flexibility including the need for increased storage and a more accurate estimate of the shadow values for additional Colorado water.

Evaluation of Perfect Foresight

CALVIN results, as presented in this thesis, allow water user's to optimize facilities with perfect hydrological knowledge. Further research should explicitly evaluate the role perfect foresight plays in CALVIN output.

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APPENDIX: ACRONYMS

ACWD	Alameda County Water District
ACFCWCD	Alameda County Flood Control and Water Conservation District
af	acre-foot/acre-feet
AVEK WA	Antelope Valley East Kern Water Agency
AWBA	Arizona Water Banking Authority
CALFED	State (CAL) and federal (FED) agencies participating in the Bay-Delta Accord
CALVIN	California Value Integration Model
CCWD	Contra Costa Water District
CLWA	Castaic Lake Water Agency
CRA	Colorado River Aqueduct
CUWA	California Urban Water Agencies
CVP	Central Valley Project
CVPIA	Federal Central Valley Project Improvement Act of 1992
CVPM	Central Valley Production Model
CVWD	Coachella Valley Water District
DWA	Desert Water Agency
DWB	DWR's Drought Water Bank
DWR	California Department of Water Resources
DWRSIM	DWR's operations model for the SWP/CVP system
E&W MWD	Eastern and Western Metropolitan Water District
FC&WCD	flood control and water conservation district
HEC	Hydrologic Engineering Center of the USACE
HEC-PRM	HEC's Prescriptive Reservoir Model

IFIM	Instream Flow Incremental Methodology
IID	Imperial Irrigation District
LAA	Los Angeles Aqueduct
maf	million acre-feet
MWA	Mojave Water Agency
MWD	Metropolitan Water District of Southern California
M&I	Municipal and Industrial
NGA	Federal Natrual Gas Act of 1938
O&M	Operations and Maintenance
PROSIM	USBR's operations model for the CVP/SWP
PVID	Palos Verde Irrigation District
SCVWD	Santa Clara Valley Water District
SCWA	Solano County Water Agency
SDCWA	San Diego County Water Authority
SWAP	State-Wide Agricultural Production Model
SWP	State Water Project
SWRCB	State Water Resources Control Board
SWSD	Semitropic Water Storage District
taf	thousand acre-feet
TDS	total dissolved solids
UCD	University of California at Davis
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
WA	water agency

WD	water district
WSD	water storage district
Zone 7	Zone 7 of Alameda County FC&WCD