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Southern California Water Markets: Potential and Limitations

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Abstract

This paper explores the potential and limitations for Southern California water markets using an economic-engineering network flow optimization model, CALVIN. CALVIN is used to estimate how a market would affect overall Southern California water use, to preliminarily assess the economic benefit of more flexible water allocation policies, and to explore the characteristics of an ideal market. Results from CALVIN suggest substantial economic and reliability benefits exist for implementing water market or other transfer mechanisms and these benefits could be achieved with relatively little reallocation of agricultural water. An ideal water market in Southern California would reduce more costly urban water shortages, reducing demand for increased imports from outside of Southern California. Additionally, substantial economic benefits could accrue from expanding some conveyance and storage facilities, particularly the Colorado River Aqueduct and conjunctive use storage capacity.

Introduction

In Southern California (California south of the Tehachapi Mountains), the combination of a limited water supply and a growth-oriented economy has helped create elaborate physical and institutional systems of water allocation and management with sustained water management controversies. Water managers increasingly look to water transfers and regulated forms of water marketing to improve reliability, quality, and costs (Holburt, et al. 1988; Vaux and Howitt 1984; Lund and Israel 1995). Metropolitan Water District of Southern California (MWD) (1997) and San Diego County Water Authority (SDCWA) (1997) both have identified water transfers as a source to augment water supplies. However, little economic and engineering analysis has examined the effects of a water market on the entire Southern California region. This paper presents modeling results that indicate the potential of water markets to economically improve water management in the region and reduce demands for additional water imports. Elaborations and limitations of these results also are presented.

Figure 1 shows the Southern California water infrastructure that imports up to 70% of the region's water supply (DWR 1998a). The Southern California region includes the Los Angeles and San Diego metropolitan areas, with a population of roughly 18 million people in its western portions, and major agricultural areas in the east. The western area of predominantly urban demands is supplied with water by a complex web of wholesale and retail water agencies. Of these, the wholesaler Metropolitan Water District of Southern California (MWD) is the largest (with 26 member agencies and roughly 120 sub-purveyors). Los Angeles, the major part of the Central MWD (CMWD) user area, has additional imported supplies from the Owens Valley and Mono Basin, via the Los Angeles Aqueduct. San Diego County Water Authority (SDCWA) is another major member agency of MWD with additional independent supplies. Antelope Valley (AV), Castaic Lake (Castaic), Mojave, San Bernardino Valley (SBV), and Coachella Valley (Coachella) are urban water users substantially outside the MWD supply system. All of these urban agencies have contracts to receive water from the State Water Project (SWP), which delivers water to Southern California from the Central Valley’s Sacramento-San Joaquin Delta. Major agricultural users include Imperial Irrigation District (IID), Coachella Valley Water District (CVWD), and Palo Verde Irrigation District (PVID), which are all located in eastern Southern California and draw supplies from the Colorado River (Newlin 2000; DWR 1989a).

The management of water within and for Southern California has a colorful history of enduring importance for the contemporary management of water within the region, as well as within California and the Colorado River Basin (Hundley 1992; Kahrl 1982, Blomquist 1992). Historically and presently, much water development in California and the Colorado River has been based on perceived needs to supply urban and agricultural activities in Southern California. Southern California water demands have generated controversy both locally and in water supplying regions throughout the West. Particular concern has resulted from perceptions and concerns for environmental impacts in the Sacramento-San Joaquin Delta, Mono Basin, and Owens Valley which export water to Southern California, as well as real and potential economic and social impacts on competing water users (mostly agricultural, but sometimes urban) in exporting regions and elsewhere. As urban demands have continued to grow, despite water conservation and recycling efforts, and traditional imports from the Colorado River and Mono Basin have been curtailed, water users from Southern California have sought expanded, higher quality, and more reliable water imports (MWD 1996; DWR 1998a). As the second most populous metropolitan region in the country, the supply of water to Southern California has considerable statewide, regional, and national importance, but is often seen as a threat to the environment and the water supplies of other water users.

In addition to the roughly 7 million acre-feet/year (maf/yr) of imported water indicated in Figure 1, Southern California relies on extensive local ground water supplies (1.7 maf/yr) and a limited amount of natural runoff (DWR 1998a). Of the numerous agencies that govern water for Southern California, Figure 1 lists the major agencies represented in this study. Represented agencies were chosen based on quantity of water imported from outside Southern California, water demand data availability, and level of autonomous water contracting activity.

Two terms used in this study merit clarification. First, an *ideal market* in Southern California is defined as a market without transaction costs or risks, where decision makers have perfect knowledge and foresight of hydrologic and economic information and only environmental and physical constraints prevent water deliveries. Theoretically, such economically ideal water management can arise from a variety of mechanisms (including various cooperative or centralized forms, or an economically-enlightened despot), but some form of market mechanism seems among the more likely approaches for approximating economically ideal operation and allocation. Second, *scarcity* is the degree to which water users would like to have more water delivered, and is intended here as a more precise and economically-based definition of shortage. Scarcity is defined here as the difference between maximum economic use (also called target use) and actual delivery, as illustrated in Figure 2. For agricultural users, maximum economic use is the maximum quantity demanded if price is zero and with no limitation on water availability. For urban users, maximum use is calculated as 10% greater than projected 2020 per-capita use (Jenkins and Lund 1999). *Scarcity cost*, then, is a measure of the economic loss that occurs to a user or group because water is not abundantly available, the area under the demand curve between delivery and maximum or target use (Figure 2). Of course, given that delivery systems incur some costs and there are often opportunity costs to water use, having some scarcity cost is optimal.

Modeling Approach

Howitt et al. (1999 and appendices) developed an economic optimization model, CALVIN, to highlight promising institutional and infrastructure water supply options for California. CALVIN combines year 2020 economic values of water use from agricultural and urban demand models (monthly-varying willingness to pay functions for water deliveries) with projected 2020 infrastructure, unit operating costs, and hydrologic information to suggest economically optimal water operations and allocations. The problem is formulated as a generalized network flow optimization and solved by the HEC-PRM reservoir optimization solver. HEC-PRM maximizes net piece-wise linear economic benefits from operation of a time series of hydrologic inputs through a network given physical infrastructure and other constraints on a monthly time-step (HEC 1993). The statewide CALVIN model includes all of California's inter-connected water system. The analysis in this paper is restricted to CALVIN's Southern California representation (Newlin 2000).

Representing California’s Water in CALVIN

In the CALVIN model, California's inter-tied system has been represented in a network diagram of the physical layout of canals, pipelines, reservoirs, aquifers, and demand locations, based on other modeling and technical studies by federal, state, and local agencies. Various arcs represent surface reservoirs and groundwater reservoirs, conveyance infrastructure, return flows, and water demand regions, with water loss coefficients representing consumptive use, reservoir evaporation, and other losses. CALVIN uses monthly hydrologic data from 1921 to 1993, including the three most severe droughts on record in California: 1928-1934, 1976-1977, and 1987-1992 (DWR 1998a).

Constraints to flows or deliveries are represented explicitly in CALVIN as maximum, minimum, or fixed flows. Infrastructure, environmental, earthquake water storage, and flood control constraints are always included. (With the exception of smaller local reservoirs represented as aggregated time-series of inflows in the model, Southern California's water supply system is affected little by flood control.) Institutional constraints vary between model runs. These details are fully described in Howitt, et al. (1999) and its appendices.

Economic Demands, Costs, and Inputs

CALVIN prescribes operations and allocations based on economic value functions derived for urban and agricultural demands. Howitt et al. (1999 and appendices) present detailed descriptions of the urban and agricultural models of economic water demand, so the present discussion is limited to Southern California's demand regions. Agricultural water demands in this study include Imperial Irrigation District (IID), Palo Verde Irrigation District (PVID), and Coachella Valley Water District (CVWD). SWAP, a quadratic-programming-based economic model of agricultural production, simulates an agricultural area's choice of crop, planted area, and investment in irrigation to maximize farm profit, limited by water, land, technical, and market constraints (Howitt et al. 1999, Appendix A). For this study of Southern California, SWAP is not available for each area. Instead, monthly economic demand curves from a SWAP application in the Southern San Joaquin Valley are interpolated and combined with Southern California agricultural land use patterns (DWR 1998b) to create piece-wise linear economic value functions for agricultural deliveries in Southern California (Newlin 2000).

Urban water demands are modeled with bounded piece-wise linear economic value functions. Smaller agencies have been aggregated into water demands and value functions of one or more of the agencies appearing in Figure 1. MWD is split into three demand areas: Central MWD, Eastern and Western MWD, and SDCWA. Inter-annual shifts in urban economic demands for water, due to weather, are based on information provided by MWD. Urban demands include residential, commercial, industrial, and public (government) water use sectors. Monthly-varying per-capita 1995 economic demands (e.g., demand curves) are scaled to projected 2020 population levels for each area. The per-capita economic demands are derived from published price elasticities of demand, observed retail prices (in 1995 dollars), and observed residential water usage (Howitt et al. 1999 Appendix B). These implicitly reflect consumer behavior (including conservation) and economic values in the context of water price and availability. These demand curves are integrated to provide economic willingness to pay functions used in CALVIN. In light of the high willingness-to-pay for residential water use near 1995 quantities, upper bounds are added to residential demand to prevent per-capita use from exceeding projected 2020 levels by more than 10%. Industrial water use value functions are 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 Southern Coastal area of California for 2020 projected levels of industrial water usage (Jenkins and Lund 1999).

Variable economic costs are represented throughout the supply system as described in Howitt et al. (1999 and Appendix G). Fixed-head pumping costs exist for groundwater and surface conveyance. Fixed-head hydropower benefits are represented for Mono Basin, Owens Valley, and several other locations. Urban water quality and local distribution costs appear on the major links feeding the large metropolitan region. Water quality costs represent consumer and treatment costs arising from total dissolved solids and disinfection byproduct precursors in each water source (MWD-USBR 1998; CALFED 1999, as described in Howitt et al. 1999 and Appendix G).

Model Alternatives

CALVIN model outputs include: regional and agency economic benefits, deliveries, storages and flows, and shadow and marginal values (Lagrange multipliers). Shadow and marginal values are by-products of the optimization algorithm and provide useful sensitivity analysis regarding the economic effects of small changes in capacity and water availability at any location in the system for each time-step. Four CALVIN model runs are used to analyze Southern California water marketing and transfers. Two subsets of runs describe the modeling strategy: 1) no allocation or operation policy rules internal to the region except for environmental flows and emergency earthquake storage constraints and 2) policy constrained runs with pre-allocated deliveries representing current water allocation policies (See Table 1). While all four runs are presented here, the majority of focus is on Runs A and B. Runs C and D were performed to evaluate performance and operations without 1.45 maf of proposed additional MWD conjunctive use groundwater capacity (MWD 1996).

Runs A and B: Base Case

Run A shows, at one extreme, the maximum economic value of institutional changes in water allocations and operations. Operations and allocations prescribed in Run A have the sole objective of maximizing regional economic benefit minus operating costs over the modeled hydrologic period subject to only water availability, physical infrastructure capacity, earthquake water storage, and environmental requirements (Newlin 2000). These operations are prescribed without any current water rights or operating rules. Run B adds the existing legal and operational constraints on water allocations and operations as represented by DWRSIM (a State Water Project (SWP) simulation model) and the 4.4 maf Colorado River allocation (the 'Law of the River') to Run A. DWRSIM allocates SWP water according to each user's contractual entitlements (MWD, Mojave, Antelope Valley, Castaic, Coachella, and San Bernardino Valley). The Law of the River representation assumes 3.55 maf of Colorado River water is allocated to agriculture (CVWD, PVID, and IID) and 0.85 maf is allocated to urban (MWD and SDCWA) regions (DWR 1998a). Comparison of Runs A and B illustrates an ideal market’s effects on total water use and the economic and reliability costs of current operating and allocation policies.

Runs C and D: No Additional MWD Groundwater Capacity

The operation of conjunctive use groundwater storage capacity in Southern California is somewhat controversial among local agencies (Blomquist 1992). Initial model results indicated a preference for using additional MWD conjunctive use facilities (GW-MWD) over Diamond Valley Lake (DVL), an off-stream storage facility in the Eastern portion of MWD, on the basis of lower estimated operating costs and better access to water supplies. However, access to groundwater storage space has encountered political difficulties. DVL is operated differently, according to the model, without GW-MWD and has very different associated shadow values, illustrating the importance of additional groundwater storage capacity within MWD’s service area (Newlin 2000).

Model Results

What would be the benefit of an ideal water market in Southern California? The economic value of an ideal market or other form of economically-optimal operation and allocation (without transaction costs or risks) is explored from statewide, regional, and agency perspectives. 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 and patterns of water imports, CALVIN derives the marginal willingness to pay (shadow value) for increasing deliveries from each import source (Figure 3). Under current management (Run B) Southern California values additional SWP water the most. This occurs because Mojave, Antelope Valley, and Castaic are relatively isolated, importing only SWP water, and experience severe shortages. Los Angeles Aqueduct (LAA) and Colorado River water supplies follow in marginal economic value, with magnitudes 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 maximum marginal willingness to pay for SWP and LAA water reaches extreme magnitudes, reflecting small industrial shortages in Central MWD.

In contrast, an ideal market, as represented in Runs A and C, reduces the marginal willingness to pay for both SWP and Colorado River waters. Additional Colorado River water generates far fewer benefits in both these runs since the Colorado River Aqueduct (CRA), the only link between Colorado River water and urban regions, already operates at full capacity. (The value of expanding CRA capacity is examined later.) LAA water has the highest value, reflecting better water quality and higher hydropower benefits (Newlin 2000). (Though not explored here, the economic willingness-to-pay for additional water at each demand area can indicate the value of water recycling or conservation at these locations. Clearly the base case, without additional imports or intra-region transfers, has a much greater economic benefit for additional local water conservation, wastewater recycling, and perhaps desalination activity.)

Economic Value to the Southern California Region

Table 2 shows the average annual scarcity and scarcity costs for different alternatives, combining both urban and agricultural demands. Total scarcity is greater with current operating policies (Runs B and D), indicating ideal markets would substantially reduce the overall scarcity quantity and costs. An ideal market reduces scarcity by an average of 120 thousand acre-feet/year (taf/yr) or 13% below current projected scarcity (Run B). Less scarcity occurs in economically ideal operations because of the greater re-use potential and lower loss rates associated with urban demands (that see less scarcity in an ideal market) and from greater flexibility in infrastructure operations. An ideal market or other economically-ideal re-allocation of water for Southern California would lead to the transfer of a modest amount of water from agricultural to urban demands (460 taf/yr), a 13% reduction in region-wide scarcity, and an 81% reduction in region-wide scarcity costs (mostly from water reallocation).

Ideal market allocations or transfers, as represented in the Southern California CALVIN model, substantially reduce scarcity and scarcity costs and therefore net regional water demand. Ideal market or transfer 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 result from reduced diversions through the All American Canal). Higher allocation to urban areas allows greater re-use opportunities since more return flows are directed towards usable groundwater storage. Additionally, CALVIN's perfect foresight (a limitation currently being addressed) allows storage space to be allocated with perfect knowledge of upcoming droughts, reducing spills and perfectly hedging storage use. This increases the modeled benefits above what would actually be possible. Thus, the $1.2 billion/yr benefit derived from employing an ideal market is an upper bound on what could actually be achieved with realistic hydrologic forecasts.

Quantifying the effects of perfect foresight is difficult for a large-scale model. However, the importance of perfect foresight for this system is probably limited because Colorado River supplies are highly reliable given their enormous storage, most reallocations occur consistently in all years (through the CRA), and the water supply system is highly intertied with relatively little spill or flood potential. Thus, the influence of perfect foresight on model results is likely to be predominantly for drought years. On this basis, our experienced speculation is that perhaps 10% or less of the reduction in scarcity costs is due to perfect foresight. Some quantitative reasoning supports this estimate. The effects of perfect foresight probably occur predominantly during the major droughts, about 20% of the hydrologic years modeled (typically those with the highest transfer benefits). If annual benefits of transfers are clipped at the median level ($1.1 billion/year), disregarding benefits above the median in any year, a 14% reduction in overall water transfer benefits results. This should be a clear upper bound on the effects of perfect foresight. Clipping annual benefits less severely at the 70th percentile ($1.25 billion/yr) or 80th percentile ($1.45 billion/yr) levels reduces overall transfer benefits by roughly 9% and 5%, respectively.

Figure 4 demonstrates the effect of economically-based water transfers on scarcities, particularly scarcities of great magnitude. In the ideal market (Run A), fewer scarce periods occur, creating significant benefits over current allocation policies (Run B). Extreme scarcities are reduced in severity by more than 360 taf/yr in an ideal market.

Figure 5 shows the economic differences between current operating policies and an economically-based water allocation. This difference is the benefit of increased flexibility for Southern California water allocation. An annual benefit of over $1.1 billion/yr is gained with an ideal market in typical years, since some urban agencies experience scarcity in all years under current projected operations. This benefit increases dramatically in drought conditions to almost $2 billion/year. Moreover, the increased urban water supply under ideal market conditions allows urban users to employ their storage capacity more aggressively (with less hedging) to dampen 'peaks' of scarcity during drought that have more severe economic consequences.

Also revealed in Figure 5 is the benefit of MWD’s proposed conjunctive use capacity (Runs C and D compared with runs A and B, respectively). With the 1.45 maf of additional storage provided by GW-MWD, drought year scarcity is substantially reduced. CALVIN recommends incurring additional minor scarcity costs in normal years just before a large drought by storing water in GW-MWD to reduce subsequent drought year scarcity. However, the great improvement of Runs A and C compared with Runs B and D shows that the ability to flexibly reallocate water provides far greater benefits than the additional 1.45 maf of groundwater storage.

Economic Value to Southern California Water Users

Comparing the economic costs of current policies to an ideal market highlights the economic virtues of water transfers between water users. Although the aggregate Southern California region gains significantly from operating as a market, the water use benefits are not shared equally among economic sectors. Pragmatically, substantial transfer payments probably would be needed. Agricultural water users lose reliability and incur more water scarcity costs with economic water allocations, while urban water users gain reliability and incur fewer shortage costs (see Table 3). 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. Agricultural users, who receive constant annual deliveries based only on the constant 4.4 maf Colorado River allocation, relinquish about 13% of their water under an ideal market (from 97% to 84% of full annual delivery in an ideal market). However, even with ideal market allocations, urban users incur more than five times the scarcity costs of agricultural users. Externalities and third party impacts incurred by this kind of economic transformation are outside the scope of CALVIN, but should be considered in long-term planning.

To understand the characteristics of an ideal water market within Southern California, scarcities in Runs A and B are compared for each demand. Additionally, each water user's scarcity costs and marginal value of additional water under current projected policies provide some insights into the economic priority of different water transfers.

Scarcity for Each Local Demand

Figure 6 provides estimates of changes in annual deliveries to each demand region in an ideal market. A positive amount indicates an ideal market-induced increase in deliveries; a negative amount indicates a reduction in deliveries. In an ideal market, some urban water users show much more variation in deliveries between wet, average, and critical years, pointing to the value of short-term dry-year water transfers. For example, Central MWD receives a minimum scarcity reduction of up to 100 taf in all years (indicating the desirability of permanent transfers of this amount) and a maximum scarcity reduction of 243 taf in extreme drought conditions (indicating desirability for spot-market or dry-year option transfers for the difference). Both long-term and short-term water transfers also are recommended for Antelope Valley, Castaic, EW MWD, Mojave, and SDCWA. Coachella does not demonstrate this variation, suggesting a benefit to permanent or long-term transfers.

Although Central MWD receives the largest water transfers in Figure 6, other districts see more economic benefit from water transfers. Water users with smaller demands may have a greater willingness-to-pay for water depending on the shape of their demand curve and the quantity of scarcity relative to their overall demand. Figure 7 demonstrates that Castaic currently incurs the largest scarcity costs, particularly since recent transfers (under the Monterey Agreement) are not reflected in the current policy allocations to Castaic (Runs B and D). Under current project operating and allocation policies, Castaic scarcity averages 83 taf/year with an average scarcity cost of $508 million/year, demonstrating potential eagerness to acquire additional water. Indeed, Castaic and Mojave are finalizing acquisition of significant additional water imports under a transfer from Central Valley SWP agricultural contractors.

The most economically 'desperate' water users are, in order of average scarcity cost reduction, Castaic, Coachella, Mojave, Antelope Valley, Central MWD, EW MWD, and SDCWA. San Bernardino incurs negligible scarcity costs due to a sufficient SWP supply under current projected operating policies. Agricultural users incur additional scarcity costs, suggesting a possible starting point for transfer negotiations.

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 by outside regulators. Reallocation of SWP entitlements recently initiated under the Monterey Agreement illustrates how institutional policies can change (DWR 1998a).

Values in this section reflect scarcity costs to MWD urban users (Central, Eastern and Western, and SDCWA). Much higher marginal water values are associated with 2020 scarcity for the smaller fast growing urban areas of Castaic, Coachella, Antelope, and Mojave under the current policies represented in Run B. These very high values are uncertain and likely to diminish somewhat as new transfers are finalized.

Institutional Constraints

Shadow values for changing the Law of the River (governing Colorado River water allocations) (DWR 1998a) are derived from the policy constrained base case, Run B. Most urban water users almost always have a high marginal benefit for increased water above the current projected policy allocations. The typical pattern follows that in Figure 8, the shadow values for increasing urban water allocation in the Law of the River: 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 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 is more urban scarcity.

Shadow values for changing California's Colorado River use from a 4.4 maf/year total have direct implications for Colorado River water transfers since this water is either allocated to urban users via the CRA or to agricultural contractors. Urban (MWD and SDCWA) scarcity is a major factor in these shadow values. Figure 8 indicates a delivery increase of one acre-foot of Colorado River water to agricultural regions costs Southern California urban water users up to $1,338 during the 1987-1992 drought and $643 on average These values arise because MWD is willing to pay up to $1,338/af for a transfer from the agricultural regions or out-of-state Colorado River users during extreme drought years and an average of $643/af over all years, over and above MWD's marginal delivery and treatment costs. Since IID has a slightly higher willingness to pay for water than PVID, a slight cost is incurred from allocating additional Colorado River water to PVID. These results demonstrate substantial economic value to allowing water transfers to modify within-California allocations of Colorado River water irrespective of transfer mechanism.

Environmental

Environmental shadow values were calculated for the Mono Basin, Owens Lake bed dust mitigation, and reduced export from the Delta or Central Valley. Required flows for dust suppression to the old Owens Lake bed and instream flows in the Mono Basin reduce water availability from the Los Angeles Aqueduct. Reduced exports from the Sacramento-San Joaquin Delta or Central Valley would reduce SWP supplies to Southern California. For the Mono Lake and Owens Valley constraints, Southern California water users would incur substantial costs if environmental flows were raised by one acre-foot (averaging $1,023/af and a maximum of $1,723/af), as shown in Figure 9. For the marginal decreases in Delta exports (SWP imports), Southern California water users incur costs varying with MWD scarcity patterns (averaging $189/af with a maximum of $544/af).

Of the two Mono Basin constraints (lake level and minimum instream flows) only the minimum instream flows limit water flowing to Los Angeles, assuming initial Mono Lake storage is at or above required minimum elevations. Shadow values for the minimum instream flows reflect the considerable scarcity costs occurring in Central MWD, lost hydropower benefits (estimated at $298/af between the Mono Basin and Los Angeles), and higher costs of lower quality substitute water from the SWP. Figure 9 indicates the shadow value reaches zero in some periods, reflecting extremely wet years when the Mono Basin diversion capacity is limiting (400 cfs).

The costs of increasing Owens Lake dust mitigation deliveries roughly mimic the pattern of Mono Lake inflows, but are slightly lower reflecting the additional hydropower benefits of Mono Basin diversions. Drought year reductions in mitigation deliveries or substitution of less water intensive mitigation measures could create significant benefits on the order of $700 to $1,100 per acre foot reduction. Shadow values for the Mono and Owens environmental flows have statewide planning importance, representing the economic value of using additional LAA water to reduce Central MWD dependence on more SWP deliveries, which depend on exports from the Sacramento-San Joaquin Delta, another environmentally sensitive area.

Operational Flexibility and Economic Value of Infrastructure Expansion

To increase the economic benefits from an ideal market, CALVIN results recommend increased operational flexibility for surface water and groundwater storage. For additional economic benefits beyond the ideal market scenario, CALVIN provides the economic values for incremental expansion of facilities from shadow values on capacity constraints, discussed in this section.

Operational Flexibility

Since surface water storage in Southern California is currently heavily constrained by emergency storage requirements (mostly for earthquakes), operations between Run A and Run B differ only moderately (less than 300 taf/month). With perfect foresight and purely economic objectives, CALVIN is probably more aggressive than most water managers (the Run B lower limit is seldom as low as CALVIN's). Also, because MWD facility operations (aside from capacities) were unavailable for the policy-constrained cases (Run B and D), MWD storage and conveyance operations are optimized for all four cases. More significant differences between Run A and Run B occur with groundwater storage operations, where CALVIN prescribes more aggressive withdrawal and recharge operations. Aggressive pumping occurs during the 1929-34 drought period while aggressive recharge corresponds to preparation for the 1976-77 and 1987-92 droughts. Groundwater and MWD facilities reduce the scarcity costs and shadow values for the short drought (1976-77), but are unable to compensate as much for long droughts (1929-34 and 1987-92).

Storage Capacity Expansion

CALVIN only recommends surface water storage capacity expansion for drought periods under an ideal market scenario. The value for increasing Southern California surface water storage averages only $13/af-year, with values as high as $225/af in drought years. (Given CALVIN's perfect foresight, these are lower bounds. Inflow uncertainty typically raises the value of keeping additional water in storage.) LAA storage facilities have the highest expected benefit since they can store the cheapest water in terms of water quality costs and hydropower benefits.

Shadow values for additional MWD groundwater storage capacity (GW-MWD) mimic the DVL with higher magnitudes, due to differences in operating costs. With the presence of GW-MWD, shadow values for any increased storage capacity are minimal (usually below $100/af). Under an ideal market, the average annual value of increasing storage capacity in GW-MWD is $21/af in Run A and $146/af in Run C (at a 3% real interest rate and very long life spans, these become present economic values of $700/af and $4,870/af, respectively). The value in Run C is the value to Southern California water users for any MWD conjunctive use ability.

Conveyance Capacity Expansion

Most canal capacities in the Southern California system did not have high shadow values (>$100/af-month) under an ideal market scenario. The only facility with significant shadow values in terms of expected and present value is the Colorado River Aqueduct (CRA). CRA water is delivered to the Coachella Valley urban area and all of MWD (Central, Eastern and Western MWD, and SCDWA). Figure 10 shows the shadow values associated with the CRA operating under an ideal market.

For the majority of the 72 year hydrologic period, the net benefit of expanding the CRA is $300/af. In the '87-'92 drought, however, shadow values increase to $700/af-yr. Scarcity of up to 62 taf occurs during drought, incurring residential scarcity costs throughout MWD. The economic value of increasing the capacity of the CRA has an average annual value of $398/af-yr and a present value of $13,300/af-yr, at a 3% real interest rate and very long life span.

More direct conveyance between the Colorado River and the SDCWA (via the All American Canal), a “Tijuana Canal,” has been contemplated as an alternative delivery route for Colorado River water to SDCWA. Since the route would divert Colorado River water at a more southern point than the CRA, this diversion’s salinity will be significantly higher, with an additional water quality cost estimated at $79/af (Newlin 2000). The shadow values for a small Tijuana Canal (Figure 10) parallel CRA shadow costs, with the difference from water quality costs ($178/af for the CRA versus $257/af for a Tijuana Canal). The Tijuana canal would provide moderate marginal benefits outside of drought periods and much larger economic benefits during droughts, with an average annual benefit of $318/af.

Conclusions and Future Improvements

Considering the limitations of this modeling approach and water marketing, the following conclusions can be made from the CALVIN results for Southern California. In the future, more specific and reliable information can be derived with improvements to the CALVIN approach.

Conclusions

1. Substantial economic benefits could be derived from a water market within Southern California. These benefits average as high as $1.2 billion/year. Even with recent additional water imports, these benefits could average as high as $700 million/year.

2. Several promising long and short-term water transfer opportunities exist within Southern California. The most promising Southern California transfers remain from agricultural regions on the Colorado River to urban regions nearer the coast.

3. An ideal water market or other efficient form of transfers greatly reduces Southern California’s willingness to pay for importing additional water. Ideal market transfers lower the marginal value of imports differently, depending on source quality, costs, and internal distribution constraints. Reductions in the marginal economic value of additional imported water with an ideal market or other similar water management improvements, compared with projected current policies, average 25% for LAA water, 97% for SWP water, and 84% for Colorado River water, though willingness to pay for additional water remains significant in all cases.

4. Small reallocations of water, represented as market outcomes in this paper, can substantially reduce regional shortage costs. An ideal southern California water market decreases average agricultural deliveries by 460 taf/yr (a 13% reduction), but decreases region-wide average annual scarcity costs by 81%. These are upper bound estimates for the value of an ideal market.

5. Groundwater conjunctive use capability is critical to supplying urban water demands in Southern California. The MWD program for 1.45 maf of additional local conjunctive use groundwater storage has an average value of approximately $95 million/year under current operations and allocations and $65 million/year with an ideal water market. (Both estimates are lower bounds, due to the model's perfect foresight.)
6. Other factors need to be carefully considered for Southern California water markets. Much of the recommended water transfer activity involves agriculture to urban water transfers. Positive and negative third-party impacts, externalities, and transaction costs, not accounted for in this modeling effort, should be considered in long term planning decisions.
7. Even a simple deterministic optimization model can provide insights and preliminary values for changes in Southern California water management, whether such management takes market or non-market forms.

Improvements

Several limitations of the general CALVIN approach are inherent in these results, including perfect foresight and demand uncertainties (Howitt et al 1999). Additionally, several improvements could be made to the specific Southern California representation to more accurately represent current operating policies. These include: a more detailed MWD representation that would allow for additional analysis of market potentials within the MWD service area; examination of Southern California in the context of the statewide CALVIN model to examine water transfer possibilities between Northern and Southern California; extension of SWAP to Southern California for a more accurate agricultural representation; and better Colorado River representation so more intricacies of the Law of the River and Colorado River surpluses could be included.

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Figure 1. Southern California Water System and Water Users

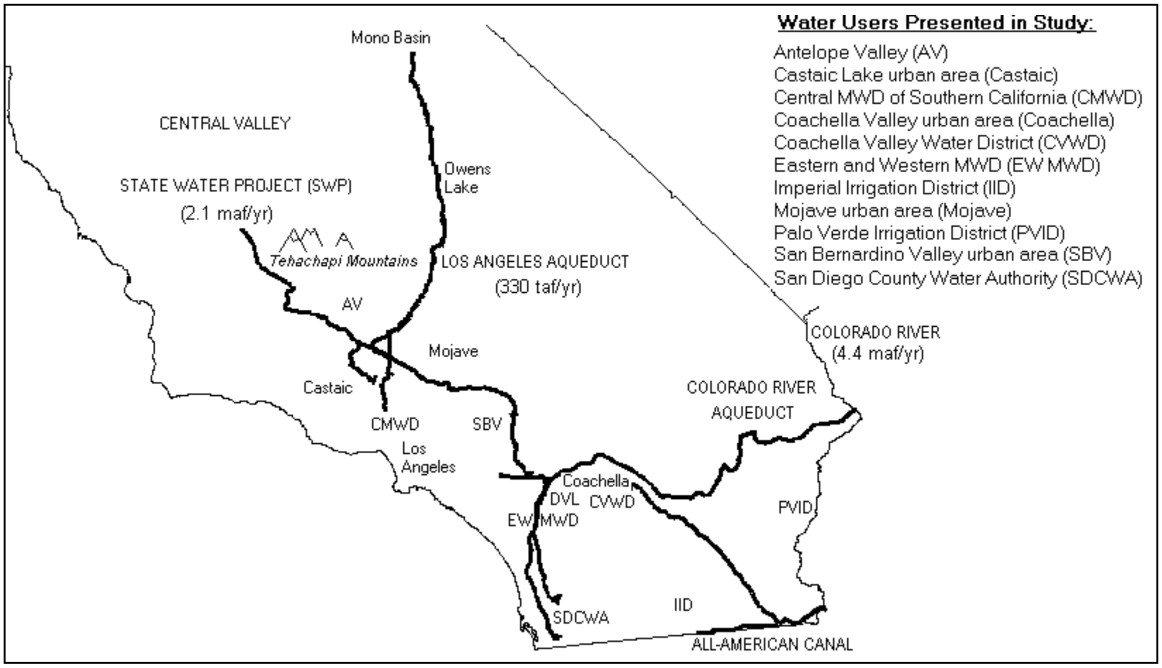

Figure 2: Definitions of Scarcity and Scarcity Cost for Economic Demands

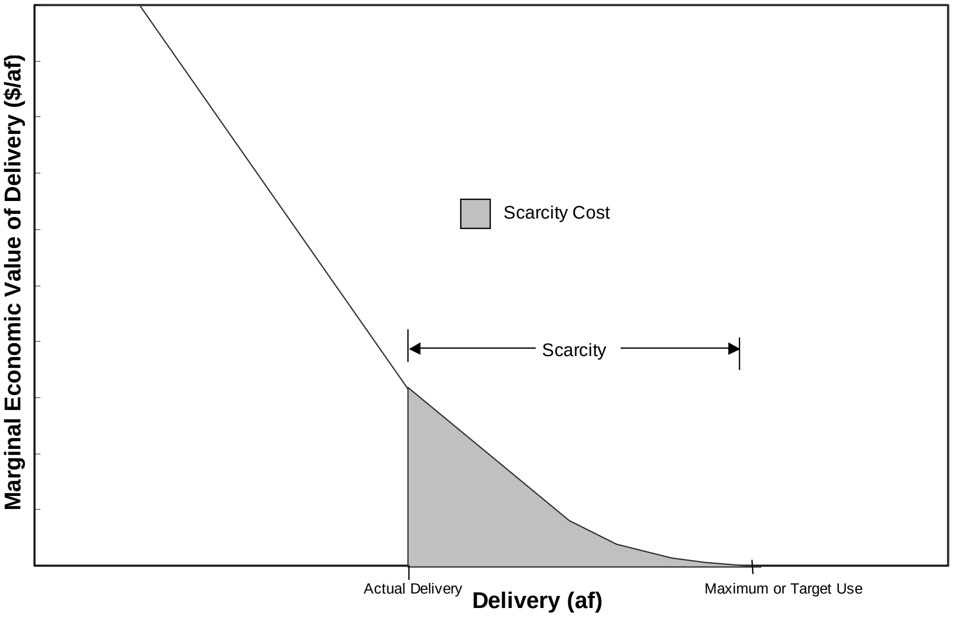

Figure 3. Preliminary Marginal Willingness-to-Pay for Imports

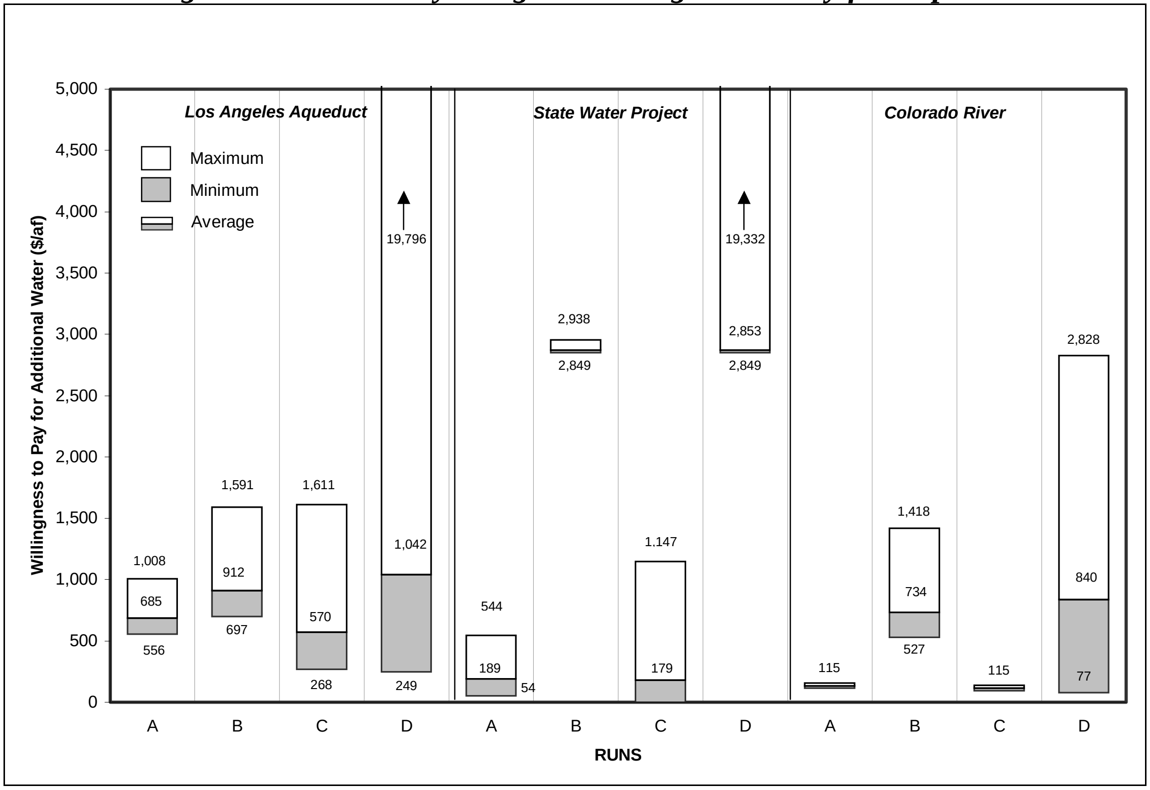

Figure 4. Southern California Delivery Reliabilities

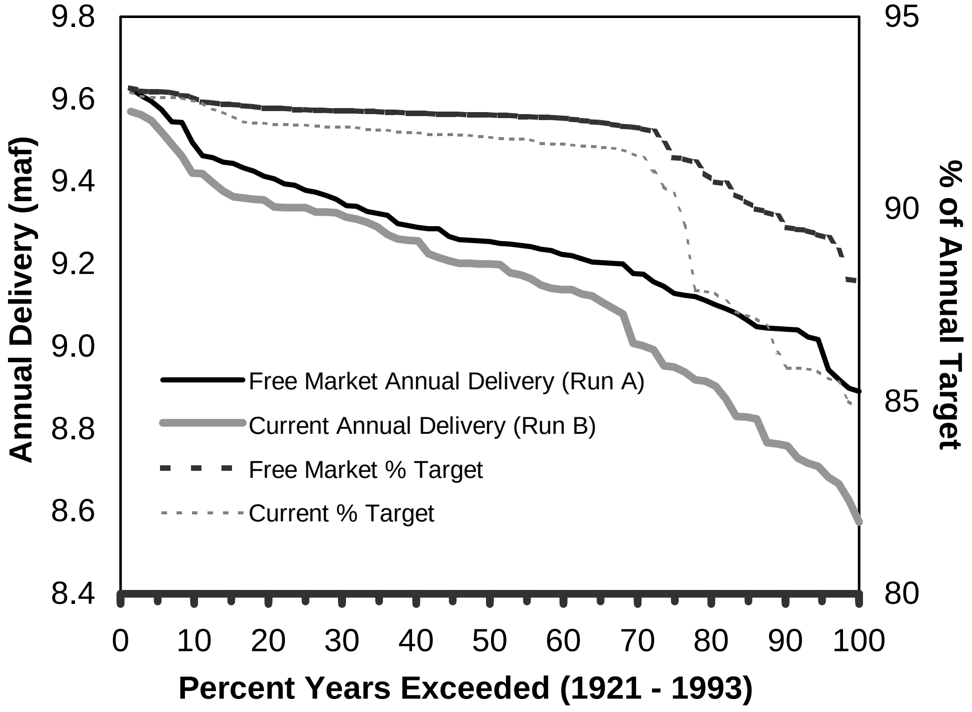

Figure 5. Scarcity Costs for the Southern California Region

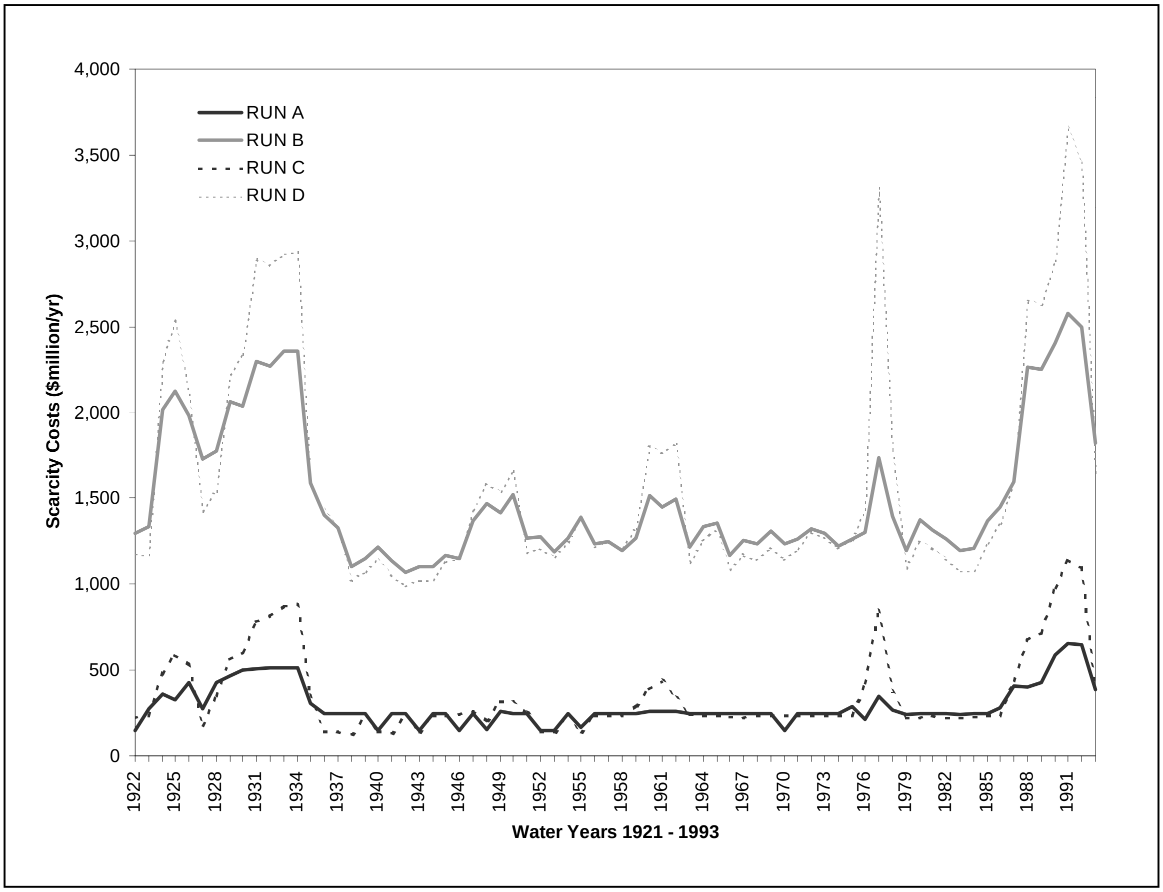

Figure 6. Change in Annual Water Deliveries In an Ideal Market

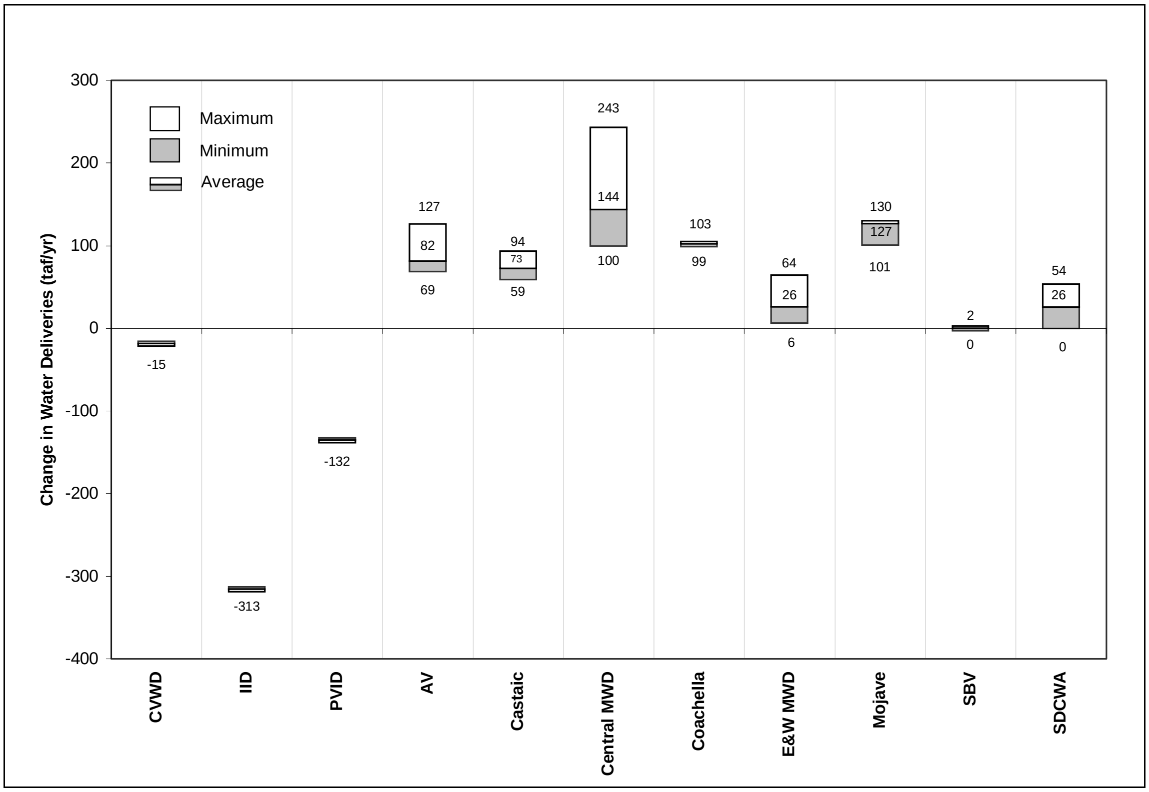

Figure 7. Reduction in Annual Scarcity Costs with an Ideal Water Market

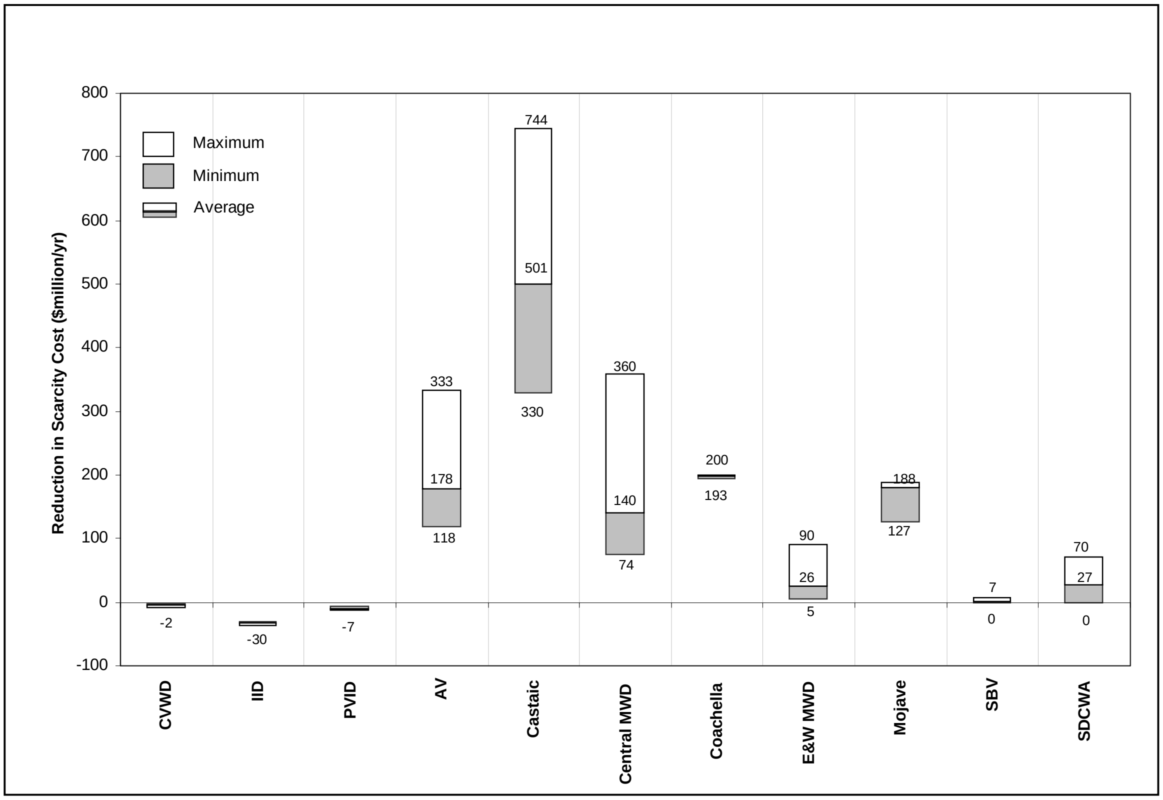

Figure 8. Shadow Values for Increasing Urban Deliveries above the Law of the River

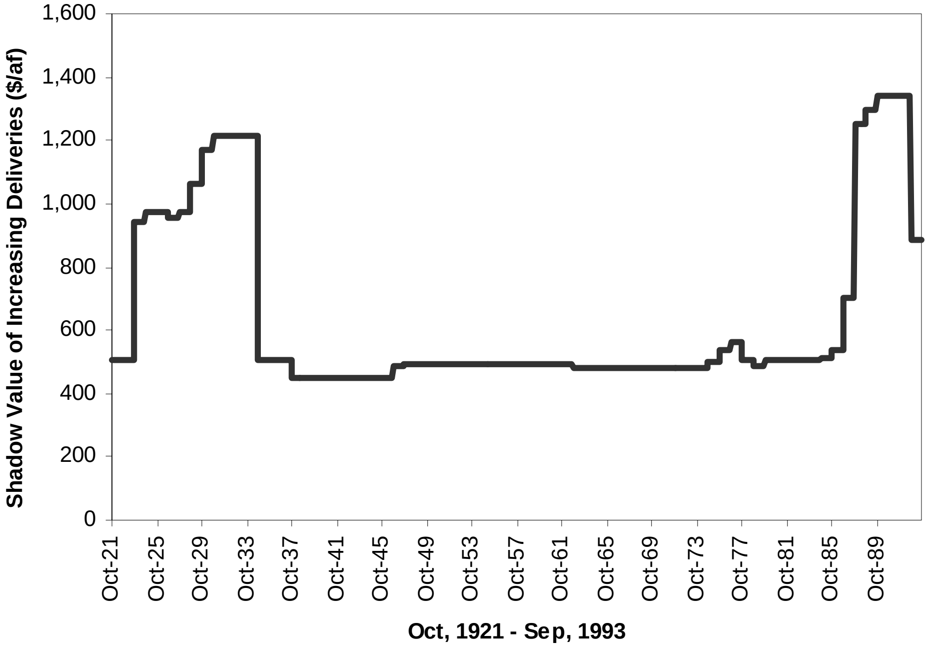

Figure 9. Environmental Flow Shadow Costs in Run B

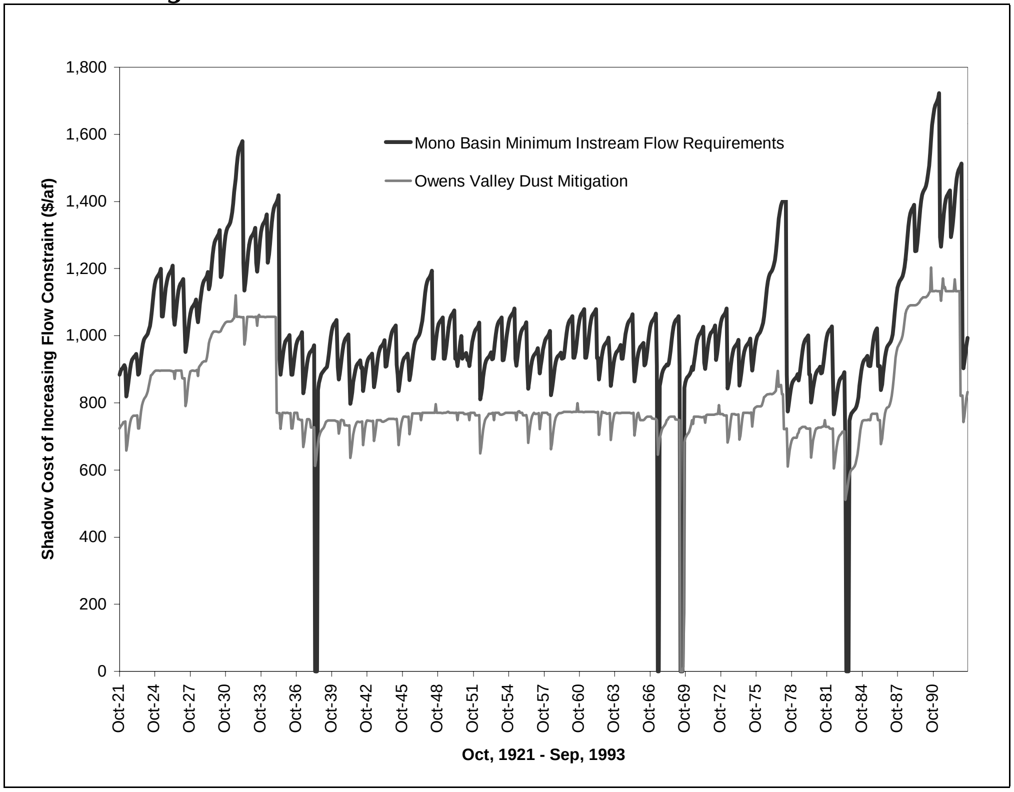

Figure 10. Tijuana Canal and Colorado River Aqueduct Capacity Shadow Values

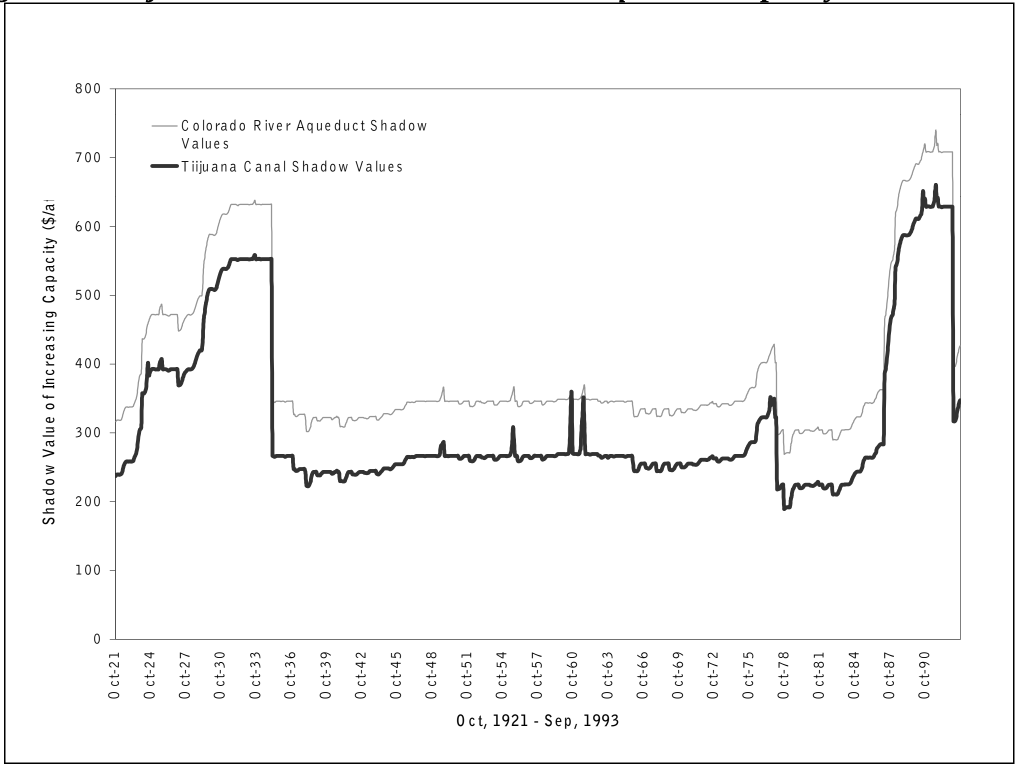

Table 1. Modeling Runs Using Southern California CALVIN model

	With additional MWD Conjunctive Use	Without additional MWD Conjunctive Use
No Policy Rules: 'Free Market'	Run A	Run C
Policy Constrained: Current Operations	Run B	Run D

Table 2. Total Urban and Agricultural Scarcity and Scarcity Costs

Run	Description	Total Annual Average			
		Scarcity (taf)	Change from current policies	Cost ($ million)	Change from current policies
A	Ideal Market with GW-MWD	823	-13%	294	-81%
B	Current Operations with GW-MWD	944	0	1509	0
C	Ideal Market without GW-MWD	855	-9%	356	-76%
D	Current operations without GW-MWD	968	3%	1604	6%

Table 3. Average Annual Scarcity and Scarcity Costs in Each Economic Sector

Run	Agriculture			Urban		
	Scarcity (taf)	% Scarcity	Cost ($million)	Scarcity (taf)	% Scarcity	Cost ($million)
A	575	16	48	247	4	246
B	115	3	9	829	13	1,501
C	553	15	45	302	5	311
D	115	3	9	853	13	1,596