CHAPTER 8

PRELIMINARY CALVIN RESULTS

"The purpose of models is not to fit the data but to sharpen the questions."
Samuel Karlin, 11th R A Fisher Memorial Lecture, Royal Society 20, April 1983.

This chapter presents some preliminary CALVIN model results for Policy Option 1a (price allocation) as described in Chapter 7. Policy Option 1a represents the existing statewide physical system with 2020 levels of water demand. Water use and transfers are driven by their relative values and only inhibited by physical capacity constraints and environmental flow requirements. The results presented here are considered preliminary because the input data entered into the model probably contains some errors and discrepancies that have not yet been rectified. Once these errors have been corrected, Policy Option 1a will be used as a foundation for the development of policy and infrastructure alternatives as explained in the previous chapter.

Following a description of the model run and a review of the types of outputs from the CALVIN model, examples of the use of CALVIN results will be given for Southern California and the EBMUD system. The preliminary nature of this first run is then illustrated by storage and flow comparisons with DWRSIM and CVGSM.

These results should not be used to draw conclusions about the system performance under Policy 1a. They are being presented to demonstrate CALVIN's ability to measure the integrated economic and physical performance of California's statewide water system. In addition, their presentation illustrates the types of results that will be available to evaluate alternative policy options.

PRELIMINARY MODEL RUN DESCRIPTION

The Policy 1a preliminary model run incorporates CALVIN's entire statewide schematic and solves for water allocation decisions in every month from October 1921 to September 1993. For debugging purposes, CALVIN has been solved using two separate sub-models that represent, respectively, the portions of the state North and South of the Tehachipi Mountains. These two sub-models are related by a pre-processed California Aqueduct flow over the Tehachipi Mountains. Once debugging and error checking is complete, the two sub-models will be joined and a single system-wide model run. All nodes, links, and demands described in Chapter 6 are included along with their hydrologic inputs, physical and environmental constraints, operating costs, and economic water value functions.

While the schematic representation of the system has been well checked and is believed to be accurate, the numeric inputs have not yet been finalized for all elements of the system. The economic value functions for agricultural regions, the schematic representation of Southern California, hydrologic inputs in the Sacramento Valley and Southern California, and variable operating costs are still being modified. In addition, some data have not yet been checked for accuracy. Preliminary results suggest that the model has an excess of water in the Central Valley, most likely due to errors in input hydrology or agricultural demand data. Consequently, there are few water supply shortages and unrealistic increases in groundwater storage. This imbalance between hydrology and demand needs to be corrected before Policy Option 1a can be finalized and other alternative model runs developed.

OUTPUT AVAILABLE FROM CALVIN

Output available from CALVIN can be classified into two types: physical outputs, which describe monthly water allocations throughout the system over the analysis period, and economic outputs, which describe the economic value of these monthly allocation decisions. Much of this output is provided by HEC-PRM in DSS format. The pathname conventions for HEC-PRM DSS output are described in Appendix C. Other output is computed using post-processing tools as described below.

To understand the overall performance of the system from model outputs, time series of monthly allocations and economic values over the 72-year analysis period are examined as probability distributions using statistical analysis. Useful statistical results include exceedance and percentile plots of monthly and annual data for such things as deliveries, storage levels, flows, economic values, and so on.

Physical Outputs

The following physical information at node and link locations can be obtained from CALVIN output:

Flow

On every link in the system, CALVIN output provides a time series of monthly flow over the analysis period.

Storage and Evaporation

For every storage node, CALVIN output provides a time series of monthly storage levels and evaporation. Where no evaporation rate is defined, such as for groundwater storage nodes, evaporation output is not produced.

Deliveries and Shortages

For every agricultural and urban demand node, CALVIN produces a monthly time series of deliveries. Deliveries are allocated by CALVIN to maximize statewide economic benefits based on the value functions of water that have been input into the model. Deliveries are only restricted by physical and environmental constraints in Policy 1a. Each demand node has a unique set of monthly value functions for delivered water. These functions vary for urban and agricultural demand nodes and among individual nodes of each type throughout the system. Because of these differences, there can be significant differences in the level of allocations to urban and agricultural users and to different regions.

Post-processing tools have been developed to translate CALVIN monthly deliveries into equivalent monthly shortages for each demand node. Shortage is defined as the difference between the demand node's actual delivery and its maximum demand, when delivery is less than maximum demand in any month. The maximum demand delivery is derived from the economic value function as the point where marginal net benefits of additional water for the given month go to zero or, equivalently, total benefits of delivered water are maximized, net of operating costs and constraints.

Economic Outputs

The following economic outputs at node and link locations can be obtained from CALVIN:

<u>Marginal Willingness-To-Pay for Additional Water</u>

For each agricultural and urban demand node, a monthly time series of the marginal willingness-to-pay (WTP) for additional water is computed with post-processing tools. It is the slope of the economic value function or, equivalently, the price on the urban demand curve or the marginal value of water for agriculture, at the delivered quantity of water. If the delivered quantity corresponds to a corner point on the piece-wise linear value function, the marginal WTP is equal to the value of delivering the next additional unit of water. Thus, if the delivery equals the maximum demand, marginal WTP equals zero. Marginal WTP is an important barometer of the relative value of water at different demand nodes throughout the state.

<u>Cost of Shortage</u>

Post-processing tools are also used to compute the monthly cost of shortage events for each demand node. Shortage cost is equal to the value of maximum demand water deliveries minus the value of water actually delivered to that location in the model. By dividing this total cost by the amount of shortage, an average unit cost of shortage can be computed for each shortage event (i.e., each month when a shortage occurs) and for all shortages that occur over the 72-year period of analysis.

<u>Marginal Values of Water</u>

For every node in the system, CALVIN provides a monthly time series of the marginal value of water, defined as the net system-wide benefit in dollars of increasing the external inflow into the node by one unit (the PI_ORIG value for each node from raw HEC-PRM output). These marginal values can be interpreted as the net value, integrating costs and benefits across the system, of additional water supply at a given location.

<u>Shadow Values on Constraints</u>

Output generated by HEC-PRM includes shadow values (Lagrange multipliers) for every constrained link in the system at every time step. These shadow values indicate the net benefits of relaxing a constraint by one unit, integrated across the whole system network. A negative net benefit of increasing a constraint indicates that such action would produce net costs in the system. When a constraint is not binding, the shadow value is zero. For reservoirs and groundwater basins, shadow values are provided on the storage link that transfers stored water from one time step to the next. Shadow values can be used to evaluate the economic benefits of various changes to the physical or operating limits of the system without having to make another model run. For example, the net economic benefits of increasing a canal or a reservoir storage capacity by one unit, or the net economic costs of increasing minimum instream flow requirements by one unit, can be estimated for each time step.

WATER DELIVERY ECONOMICS FOR SELECTED REGIONS

When examined together, the outputs described above yield considerable insight into the operation of different regions within the context of the statewide system. Because there is excess water in the system in this preliminary run, water deliveries are unusually high and most areas of the state do not experience water supply shortages. Two exceptions are Southern California and East Bay Municipal Utility District (EBMUD) in the San Francisco Bay Area. Both are demand areas with somewhat limited physical access to the rest of the statewide system. Institutional access is not an issue in these model results because Policy 1a does not represent such operating restrictions, allowing only physical capacities and environmental requirements to restrict water movement. EBMUD's isolation is due to its reliance on a single source of water (the Mokelumne River) while Southern California’s is caused by the temporary separation of CALVIN into two sub-models at the Tehachapi Mountains. Shortages found in these two areas are not as large as those predicted in DWR's Bulletin 160-98 (DWR 1998a) for several reasons:

- Free market allocation of water in Policy 1a allows the maximum possible water transfers up to the limits of physical capacity and willingness-to-pay;
- Perfect foresight of CALVIN regarding the timing, duration, and magnitude of droughts;
- Optimized reservoir operations to maximize water supply benefits without having to follow operating rules or meet other purposes; and
- Excess water in the Central Valley (affecting EBMUD but not Southern California in this preliminary run since Southern California receives a fixed time series of California Aqueduct flows).

Despite these differences, the following delivery shortages demonstrate how CALVIN results can be analyzed and used to compare the performance of California’s water system under different alternatives.

Southern California

The analysis of Southern California focuses on two CALVIN demand nodes: "Imperial Valley" (IV-IID) agricultural demand and "Eastern and Western Metropolitan Water District" (E&W MWD) urban demand, with annual 2020 maximum demands of 2735 and 675 taf, respectively. Both nodes are supplied largely by the Colorado River. Water is conveyed from the Colorado River to IV-IID by the All American Canal and to E&W MWD by the Colorado River Aqueduct. In addition, IV-IID can be supplied by a very limited amount of groundwater pumping, while E&W MWD can be supplied with SWP water via the California Aqueduct and the Inland Feeder or from the Santa Ana Pipeline and related storage.

Figure 8-1 shows probabilities of exceedance for annual deliveries to IV-IID and E&W MWD for the 72-year period of analysis. Annual deliveries to IV-IID are always at or below 90% of its annual maximum demand and drop below 90% in 29% of all years or about three out of every ten years. E&W MWD maximum demand is fully satisfied in about 47% of all years. The minimum annual delivery to the Imperial Valley is about 86% of its maximum demand, while that of E&W MWD is about 93% of its maximum demand. The monthly minimums are lower.

Figure 8-2 shows a time series of the annual deliveries to E&W MWD. Frequent shortages are distributed throughout the period of analysis from October 1921 to September 1993 with the largest occurring in 1960-61 and in 1990-92. Both of these periods involve significant droughts. The remainder of this analysis will focus on the 1960-61 time period.

Figure 8-3 shows monthly shortages and marginal WTP for additional water at E&W MWD from February 1958 to February 1963. E&W MWD experienced shortages during the summers of 1959 through 1962 with the largest occurring in 1960 and 1961. No shortages were experienced during the winter seasons. Values of additional water (marginal WTP) during the drought increase from $0/af in the summer of 1958 to about $800/af in 1959 and peak at about $1200/af in the summers of 1960 and 1961.

E&W MWD shortages (53% of years) result from a combination of capacity constraints on the Colorado River Aqueduct and San Diego Canal (CALVIN link C140 to Lake Skinner), along with limited storage in Lake Skinner. Lake Skinner storage is constrained at the beginning and end of each E&W MWD1959-62 summer shortage but available during shortage months as illustrated by the pattern of shadow values in Figure 8-4 on Lake Skinner storage capacity. Non-zero shadow values indicate infrastructure is at capacity and provide an estimate of the net operating benefits of increasing that capacity for water supply. Figure 8-4 also shows that the San Diego Canal is at capacity (has a positive shadow value) during shortage months so no extra SWP or Colorado River water can get through, Lake Skinner is low, and shortage persists. Lake Skinner storage and San Diego Canal capacities have shadow values that directly reflect E&W MWD's marginal WTP for more water, minus their respective operating costs.

Figure 8-5 shows the same information as Figure 8-3 for IV-IID. The Imperial Valley experiences shortages (less than ideal deliveries) during every month of the 72-year analysis period as a consequence of the Colorado River 4.4 plan implementation (CALVIN restricts Colorado River water to 4.4 maf per year). During the 1959 through 1962 period in Figure 8-3, IV-IID shortages experienced in summer months are much larger in magnitude than those experienced in winter months. This occurs because IV-IID has much higher maximum demands in summer than in winter months. However, on a percentage basis, shortages are greater during winter months. While summer month deliveries typically equal about 90% of maximum demand, during the winter months of 1960 through 1962 only about 80% of the maximum demand is delivered. These results are reflected in IV-IID's marginal WTP for water, which increases from about $88/af in summer to about $114/af in the winter seasons of 1960 through 1962. IV-IID's situation in the drought of 1960-62 differs from that of E&W MWD in that the largest shortage costs and greatest willingness-to-pay for more water occur during winter months rather than summer months.

Comparing marginal WTP provides a good indication of the relative value of additional water deliveries to each demand area. The large difference in marginal WTP of IV-IID and E&W MWD during the summer months from 1959 through 1962 indicates that, if infrastructure capacity were available, CALVIN would allocate less Colorado River water to the Imperial Valley and reallocate that water to E&W MWD. In this case, the Colorado River Aqueduct is operating at full capacity, preventing such a reallocation of water. In other words, E&W MWD would buy water from IV-IID if it were possible and cost-effective to convey it. Figure 8-6 shows the monthly shadow values on the Colorado River Aqueduct capacity constraint. This

Figure 8-1. Southern California Deliveries
Annual Probability of Exceedence

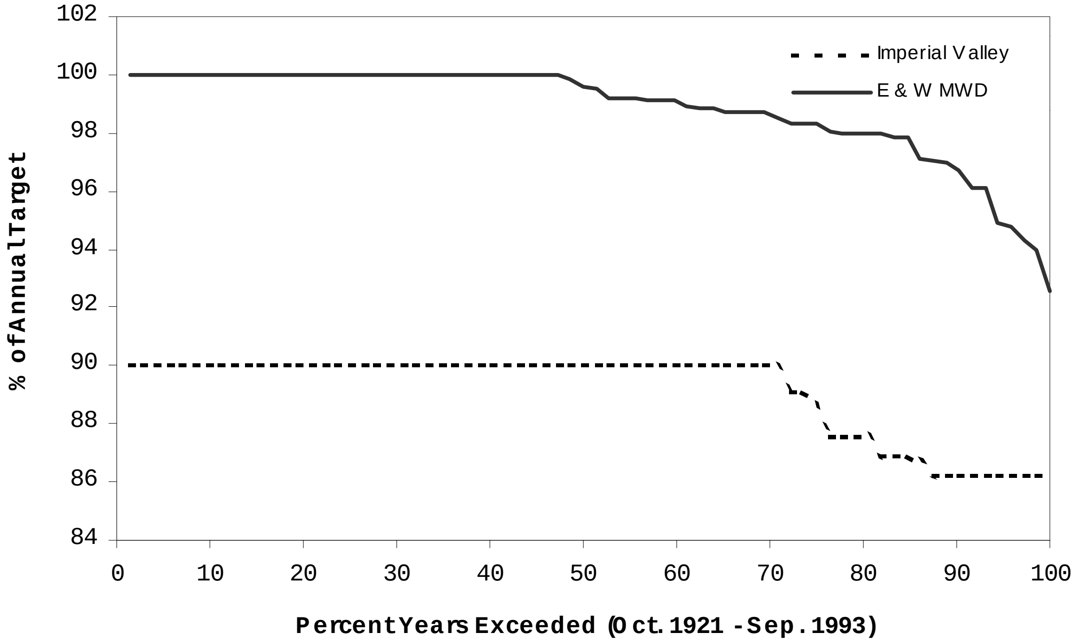


Figure 8-2. E & W MWD Deliveries
Plot of Total Annual Time Series

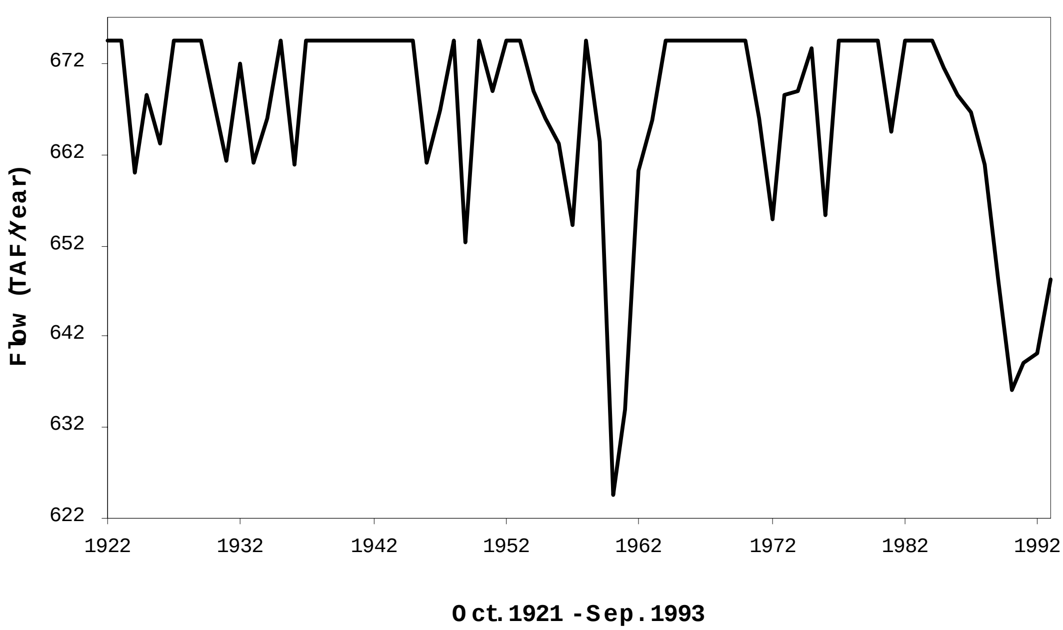


Figure 8-3. E & W MWD Deliveries
Plot of Monthly Time Series

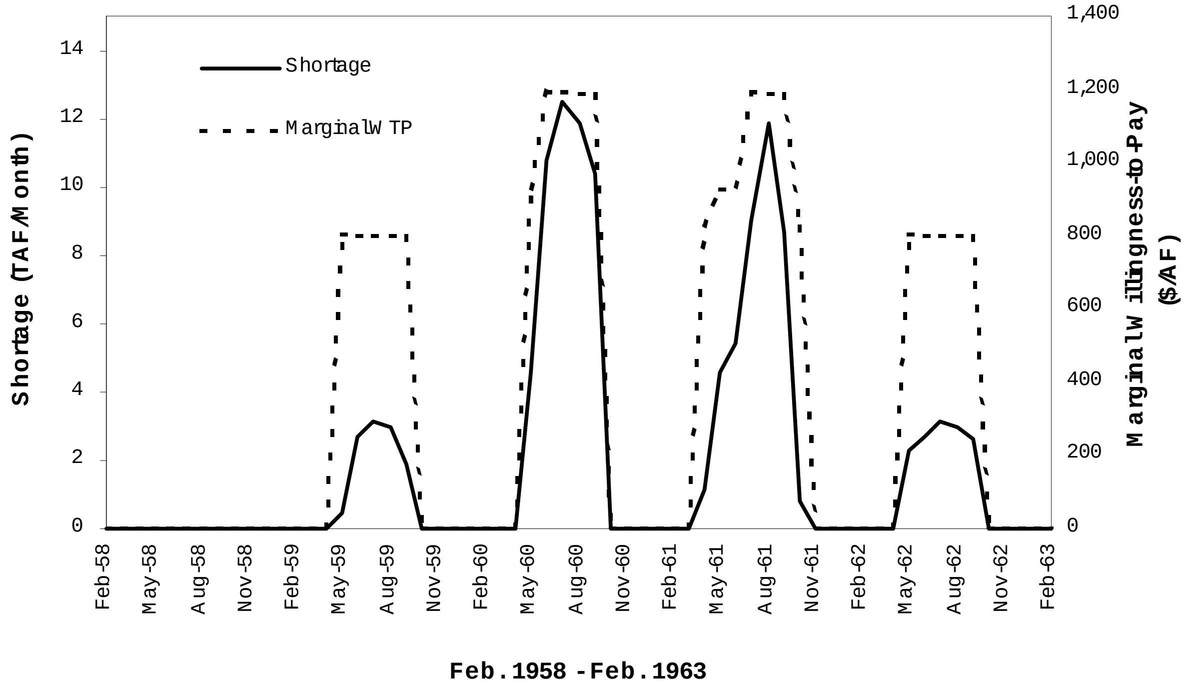


Figure 8-4. San Diego Canal and Lake Skinner Shadow Values
Plot of Monthly Time Series

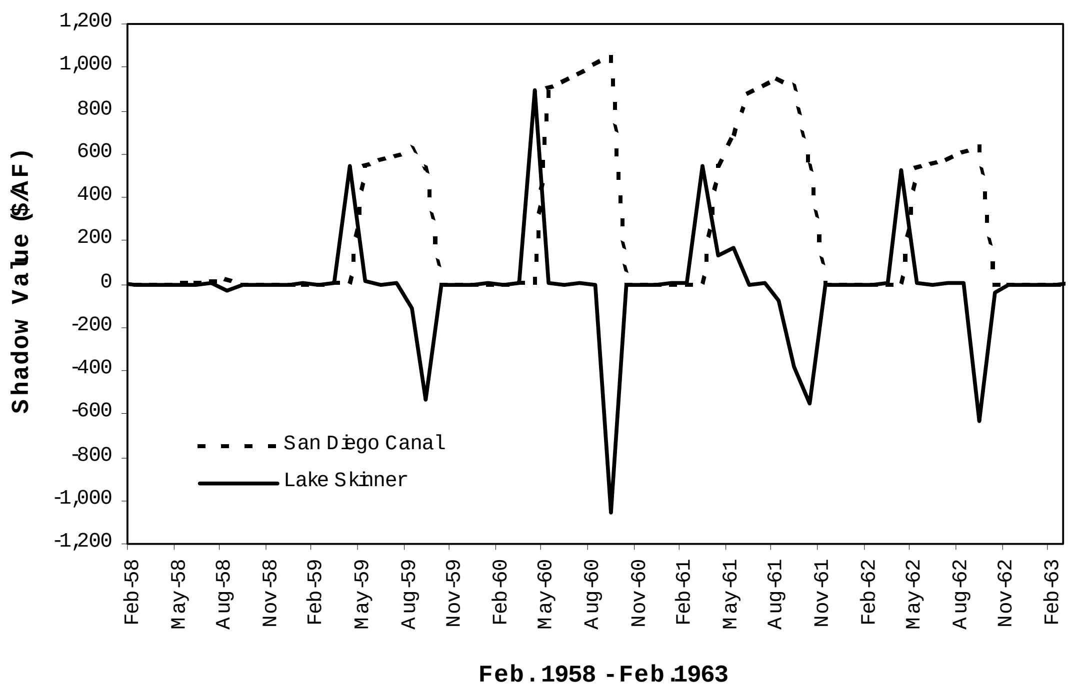


Figure 8-5. Imperial Valley Deliveries
Plot of Monthly Time Series

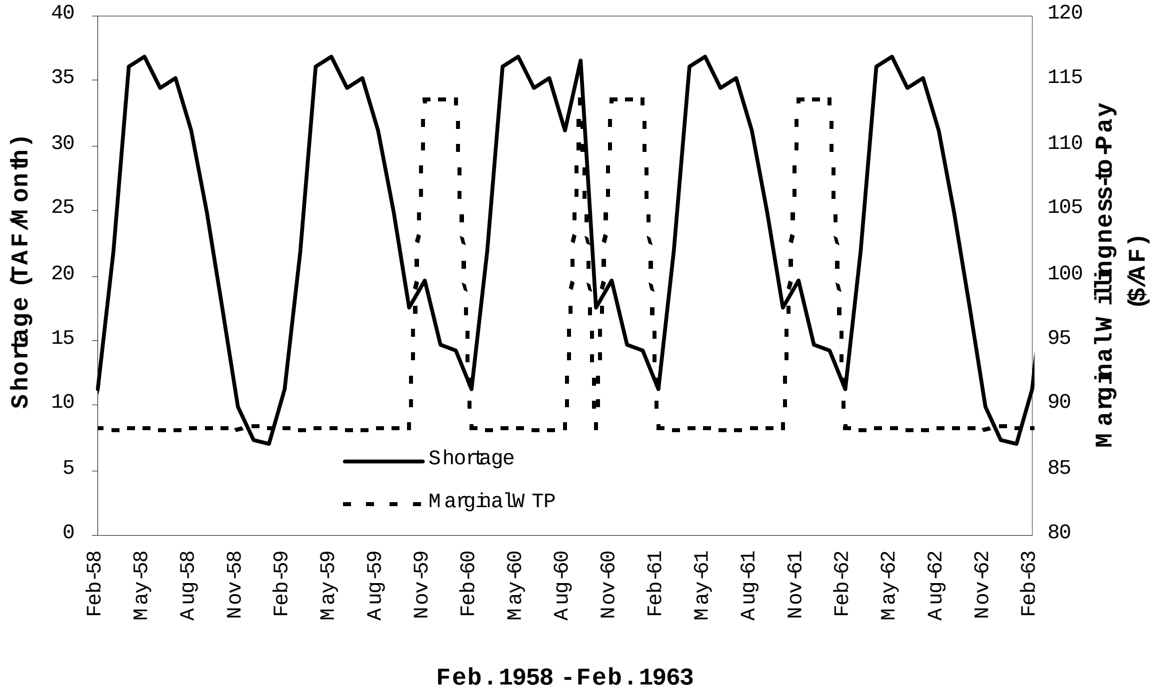
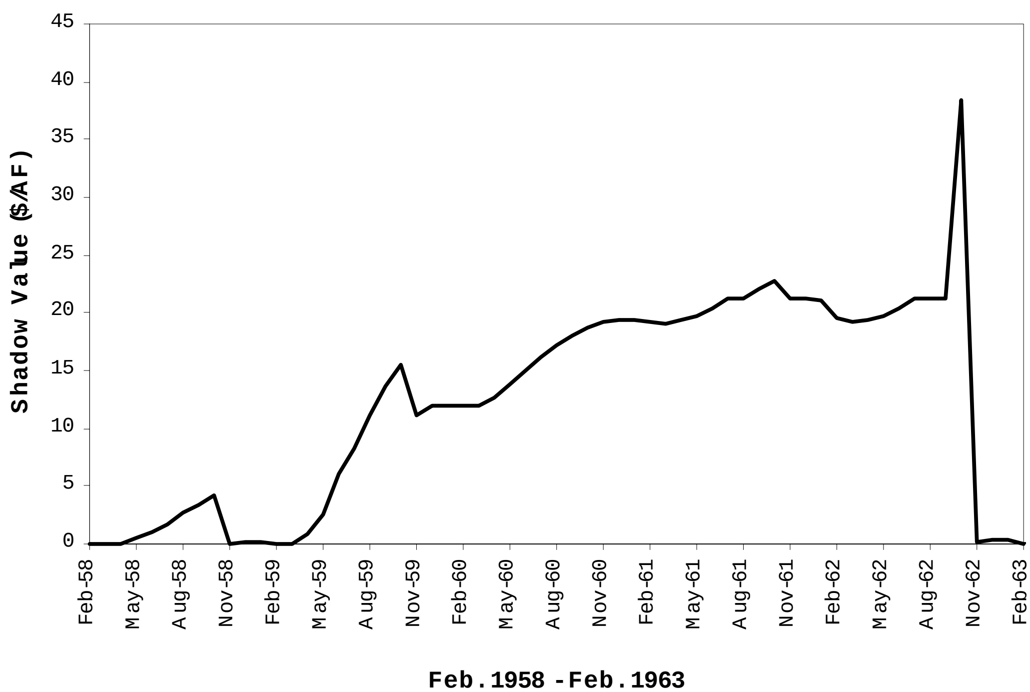


Figure 8-6. Colorado River Aqueduct Shadow Values
Plot of Monthly Time Series



plot shows rising shadow values from April 1959 through October 1962. Non-zero shadow values indicate the aqueduct is at capacity and provide an estimate of the net operating benefits of increasing capacity for water supply.

Marginal values of water at different locations also can yield insight into the operation of the system. Figure 8-7 shows marginal values of increasing inflow by 1 af/month into the Colorado River (at node SR-CR), the Owens Valley (at node SR-LC), and the California Aqueduct (at node D865) from October 1957 through April 1963. In all months, the value of additional water is highest for the California Aqueduct and lowest for the Colorado River. The value of additional Colorado River water is constrained, by fully utilized Colorado River Aqueduct capacity, to supply only IV-IID's shortage. Consequently, the marginal value of additional Colorado River water is approximately equal to IV-IID's positive marginal willingness-to-pay for additional water throughout the 72 years of analysis due to implementation of the 4.4 plan.

Values of additional water from the other two sources in Figure 8-7 are limited by capacity constraints (see Figure 8-4) on the San Diego Canal and at Lake Skinner that block additional deliveries to E&W MWD during the drought. The increased values of California Aqueduct and Owens Valley water in Figure 8-7 during the 1960-62 drought are much smaller, around $50/af, than E&W MWD's marginal WTP of $800-$1100/af. Owens Valley can only supply Central MWD via the Los Angeles Aqueduct and the Long and Owens Valley agricultural nodes, all of which always receive their maximum demands. Likewise, additional SWP water can only serve to offset the use of other urban water supplies (e.g., Colorado River water, groundwater, reclaimed water, or stored water) in areas such as Central and San Diego MWD which all receive their full maximum demands. By increasing delivery to Central MWD from the Owens River, or to Central, E&W, or San Diego MWD from the California Aqueduct, deliveries from the Colorado River Aqueduct to MWD are offset. This frees up more Colorado River water to go to unmet IV-IID demands or possibly to offset the use of more expensive urban water supplies in the Colorado River Region, such as recycling. The increased values of SWP and Owens water from the summer of 1959 through the Fall of 1962 in Figure 8-7 largely reflect IV-IID's marginal WTP for additional water less any net operating costs of such substitutions of MWD water supply. Net operating cost differences in this preliminary model run include, among other things, an avoided salinity damage cost of $136/af associated with Colorado River water (see Appendix G).

EBMUD System

EBMUD's sole source of supply is the Mokelumne River Aqueduct, through which water is conveyed from Pardee Reservoir on the Mokelumne River. Two options for augmenting EBMUD's supply have been represented in CALVIN as links with zero capacity, thereby generating time series of shadow values to assess the possible economic benefits of their construction. These are an extension of the Folsom South Canal to connect with the Mokelumne River Aqueduct (CALVIN link C173 to C39) and a local connection with the Contra Costa Water District (CCWD) (CALVIN link C71 to C201) to allow a transfer of water to EBMUD.

Figure 8-8 shows the annual probability of exceedance for deliveries to EBMUD. EBMUD receives its full 2020 maximum demand of 305 taf in 94% of all years. The maximum annual shortage experienced by EBMUD is about 7%. Figure 8-9 shows EBMUD's monthly shortages and marginal WTP for additional water from January 1975 through January 1979. EBMUD

Figure 8-7. Marginal Value of Additional Inflow
Plot of Monthly Time Series

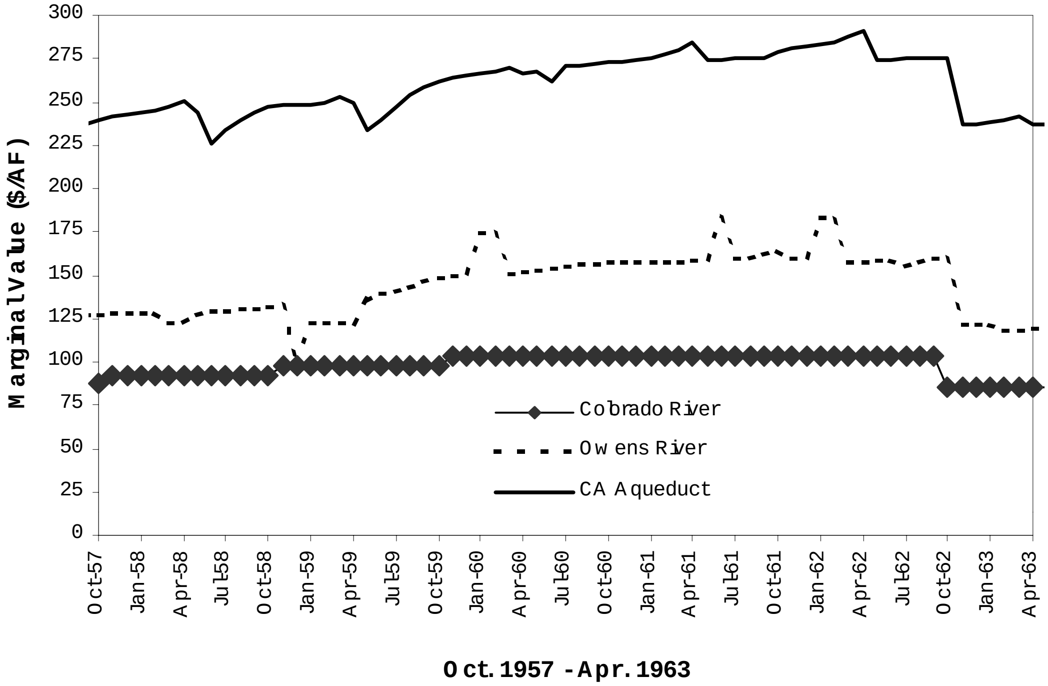
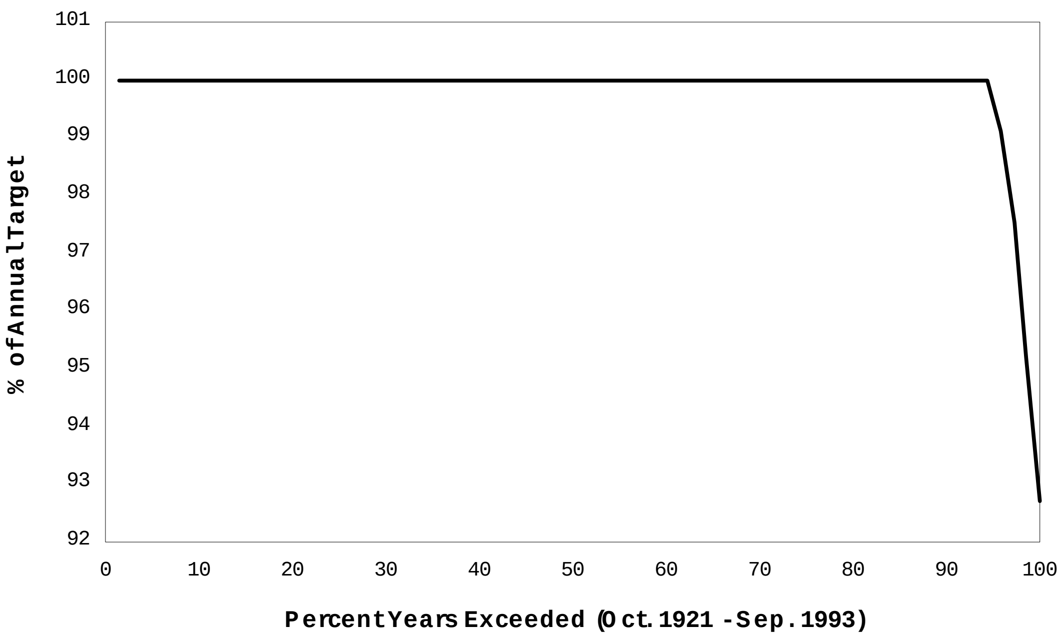


Figure 8-8. EBMUD Deliveries
Annual Probability of Exceedence



experienced continuous shortage starting in February 1976 and ending in November 1977. Summer months had the largest shortages, with those in the summer of 1977 slightly higher than those in the summer of 1976. Marginal WTP increases from $0/af during the non-short months to $800-$1200/af during the peak of the drought.

The impact of the drought also is seen in the storage levels and storage capacity shadow values for Pardee Reservoir in Figure 8-10. Pardee Reservoir is full in January 1976, just before the first EBMUD shortage occurs. By the end of the drought, in November 1977, the water level has been drawn down to the dead storage level. CALVIN uses perfect foresight of the drought to operate the reservoir most efficiently by perfectly hedging and cutting back deliveries just enough during the drought to minimize the costs of shortages. There is no unnecessary hedging to guard against high flows before the drought nor against continued low flows after the drought, as there would be in a simulation model or in a real-world situation.

The value of increasing Pardee Reservoir capacity is measured by the shadow values in Figure 8-10. In January 1976, the shadow value is $1200/af, reflecting the net marginal benefit of increasing storage capacity by a small amount. In December 1977, the shadow value is -$800/af, indicating that increasing the dead storage volume by one acre-foot during that month would incur a net cost of $800. This result is equivalent to a net benefit of $800 from decreasing the dead storage volume by one acre-foot, as might occur from using a pump to access dead storage. This range of $800-$1200/af for additional storage capacity during the drought is comparable to the range seen for EBMUD’s marginal WTP for additional water during the drought. In fact, the marginal value of increased reservoir storage capacity is directly driven by marginal WTP for additional water at the demand node served by or benefiting from that capacity.

The shadow values of new supply links to EBMUD also depend on EBMUD’s marginal WTP. Figure 8-11 shows the shadow values of the proposed CCWD connection and Folsom South Canal extension. For each of these options, the value of construction is approximately $1100/af from February 1976 to November 1977, a value which is comparable to the shadow values seen for Pardee Reservoir capacity and to EBMUD’s marginal WTP values.

During the years before and after the drought the shadow value on the CCWD connection is about $45/af higher that on the Folsom South Canal extension. This value is approximately equal to the difference in unit pumping costs between the Contra Costa and Walnut Creek Pumping Plants. EBMUD is only able to convey about 312.5 cfs by gravity through the Mokelumne River Aqueduct. The Walnut Creek Pumping Plant must pump any additional amount. Because it is $45/af cheaper to pump water from the Old River via the Contra Costa Pumping Plant, construction of the CCWD connection would produce net benefits of $45/af during non-drought years when EBMUD’s delivery exceeds 312.5 cfs. This result does not properly account for water treatment and salinity impact operating cost differences between the quality of water from CCWD and the Folsom South Canal which have not been represented in this preliminary run. During drought years, the delivery to EBMUD is less than 312.5 cfs. Therefore, the Walnut Creek Pumping Plant is not used and the shadow values on the construction of the two proposed facilities are very similar.

Environmental minimum flow constraints can be important during periods of water shortage. However, the economic value of changing these flows in such an interconnected network as

Figure 8-9. EBMUD Deliveries
Plot of Monthly Time Series

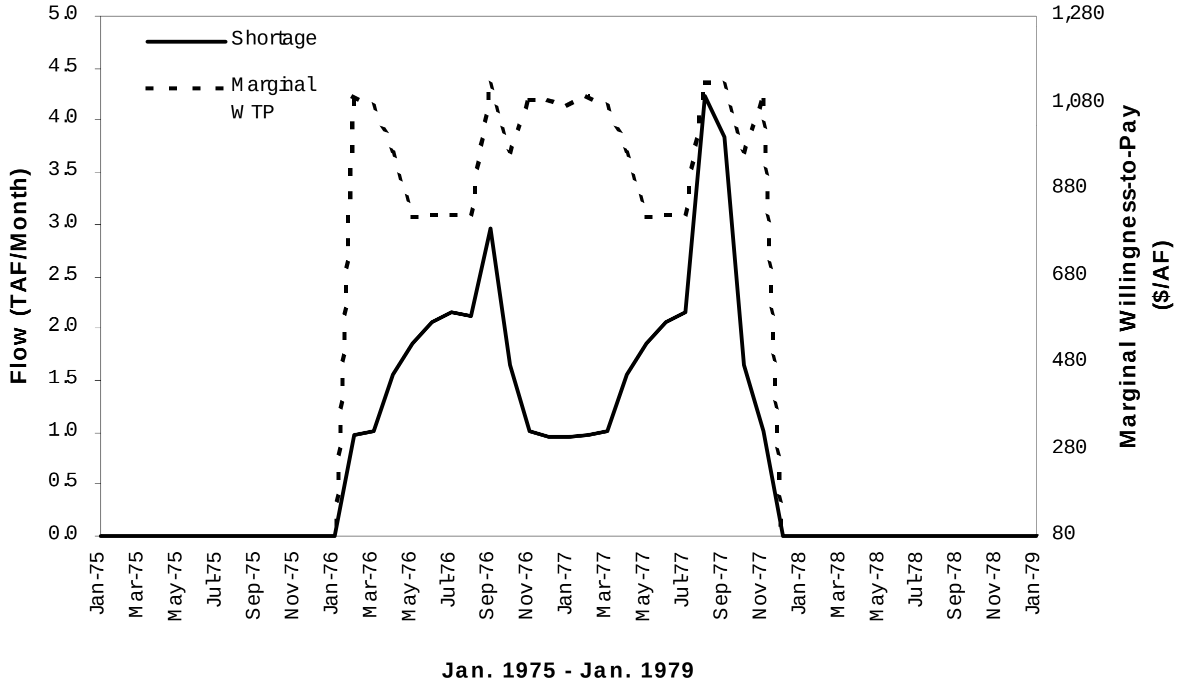
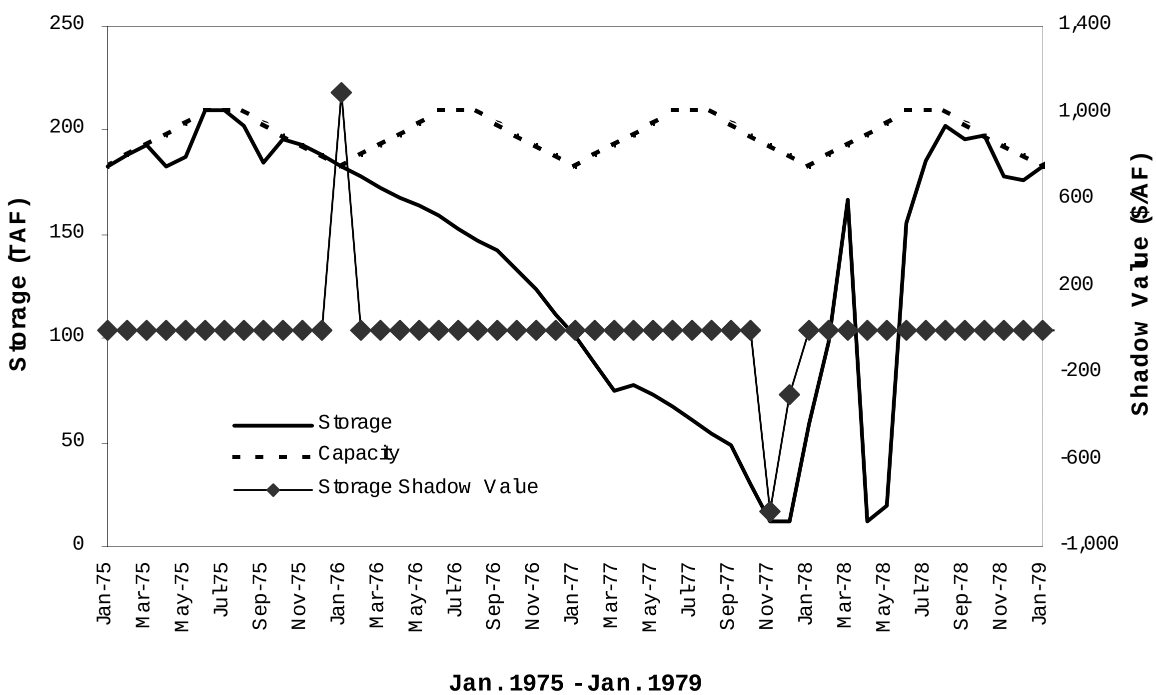


Figure 8-10. Pardee Reservoir
Plot of Monthly Time Series



California's water system is very difficult to predict without a fully integrated analysis. The next set of results illustrate the complicated interaction between economic tradeoffs, infrastructure capacity, and hydrology that are involved in determining water values, including environmental flows, at different times and places in California's system.

Figure 8-12 shows the shadow value for the Mokelumne River minimum flow constraint (on CALVIN link D517 to D514) during the drought years. In most months, the minimum flow shadow value equals zero, but is negative, showing a net cost to increasing instream flows during some winter season months of the drought. Increasing the minimum flow during such months produces additional costs of shortage upstream that out-weigh benefits of water supply downstream by $7/af. This cost is unexpectedly small compared to the marginal WTP of EBMUD for additional upstream diversions at Pardee. In fact, increasing the minimum environmental flow at this location only impacts the upstream diversions to CVPM agricultural region 8 since no downstream releases from Pardee Reservoir are made during the drought. Reduced Mokelumne River diversions to CVPM region 8 force agricultural users at this location to pump groundwater (not used in this run) at a cost of $12.50/af to make up for reduced Mokelumne diversions. However, because instream flow requirements during summer months are more than adequately supplied by agricultural return flows from CVPM region 8, increased upstream pumping costs are only incurred during the winter low agricultural demand months of the drought. These upstream pumping costs are then offset by any downstream benefits of having more Mokelumne water flow into the Delta. Such downstream benefits would include the avoided costs of any agricultural groundwater pumping offset by greater diversions from the Sacramento River above the Delta or by more in-Delta withdrawals that could occur because of increased Delta inflow from the Mokelumne. Apparently, these avoided groundwater pumping costs on other inflow systems to the Delta amount to about $5/af, the difference between CVPM region 8's groundwater pumping cost and the shadow cost of increased Mokelumne instream flows.

STORAGE AND FLOW COMPARISONS

In this section, results generated by CALVIN are compared to those of DWRSIM and CVGSM to indicate their reasonability. While this provides a general feeling of modeling accuracy, CALVIN's results should not expected to correspond exactly with those of DWRSIM or CVGSM. CALVIN is a prescriptive model that operates the system with perfect foresight to maximize the net economic benefits of water allocation over the entire state. Descriptive models such as DWRSIM and CVGSM, on the other hand, attempt to simulate the actual operation of the system following allocation rules. In addition, CALVIN integrates large portions of the state's water system that are not represented in DWRSIM or CVGSM (e.g., Tulare Basin, Southern California, etc.). The operation of these other regions may be very different in CALVIN than they are assumed to be (through the pre-processing of model inputs) by CVGSM and DWRSIM. Furthermore, the excess water problem in the current model run is also likely to cause differences with DWRSIM and CVGSM results. Comparisons of monthly time series of storage levels in selected storage nodes and of flow in selected links are presented and discussed next.

Figure 8-11. Proposed Facility Shadow Values
Plot of Monthly Time Series

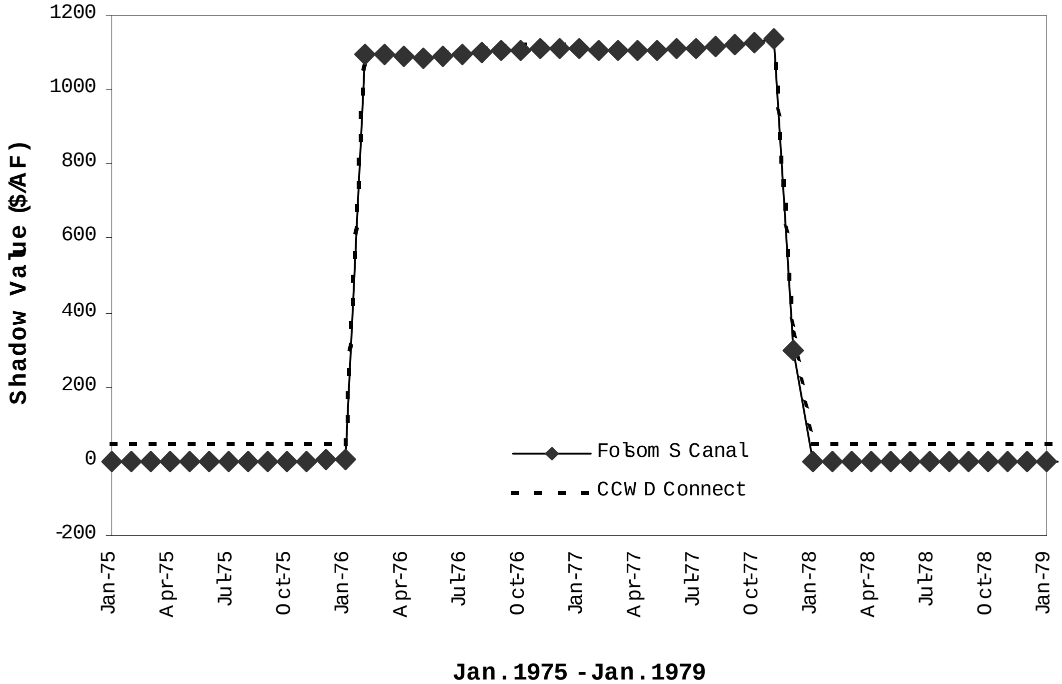
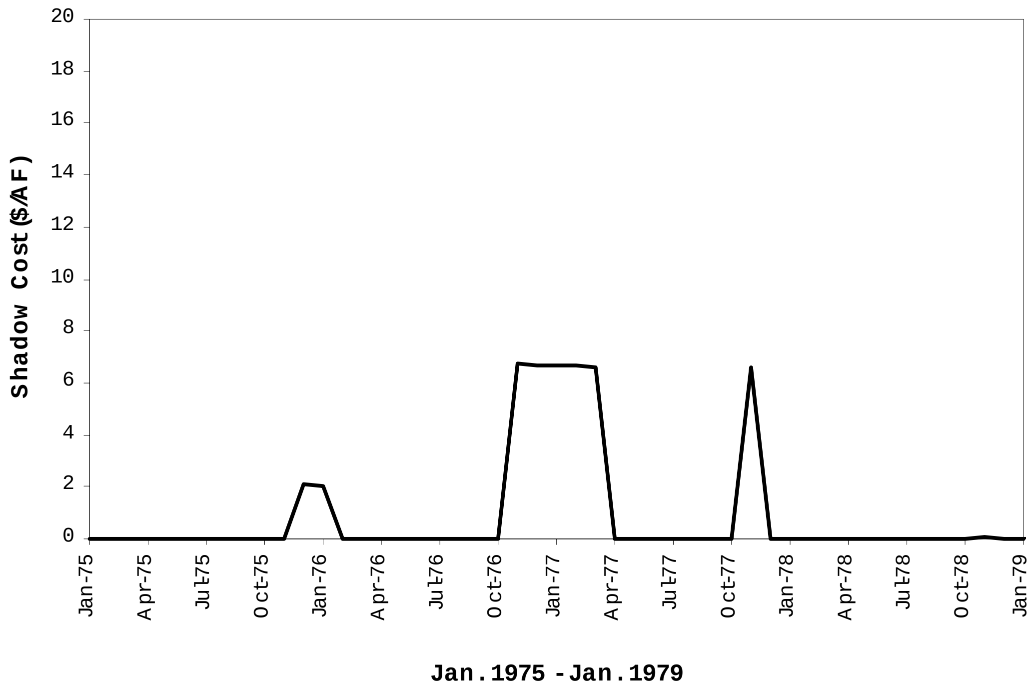


Figure 8-12. Mokelumne River Minimum Flow Shadow Cost
Plot of Monthly Time Series



Surface Water Storage

In this preliminary CALVIN run, monthly storage levels in several reservoirs match fairly well with those of DWRSIM. Clair Engle Lake is an example of one such reservoir, as seen in Figure 8-13. The two models show similar periods of low storage and comparable low storage levels. However, during normal years, CALVIN seems to prescribe much smaller fluctuations in storage than DWRSIM.

Some reservoirs show very poor matches. Lake Oroville, for example, is operated much differently by CALVIN than by DWRSIM as seen in Figure 8-14. As with Clair Engle Lake, CALVIN prescribes smaller fluctuations in storage than DWRSIM. DWRSIM draws down Lake Oroville to much lower levels than CALVIN and hits dead storage much more often. Full storage levels also generally occur in different periods.

One important difference in the way CALVIN operates reservoirs, beyond general differences in modeling approach (perfect foresight plus optimization), is that hydropower is neither modeled nor considered in CALVIN, nor are other reservoir purposes such as flood control and recreation. Hydropower in particular can cause significant changes to the way multi-reservoir systems are operated and may account for some differences in storage levels between CALVIN and DWRSIM.

Groundwater Storage

In this preliminary CALVIN run, several of the Central Valley groundwater basins show a steady increase in storage levels over the 72-year analysis period. Figure 8-15 compares monthly storage levels in the groundwater basin for region 14 of the Central Valley Production Model (CVPM 14). While CVGSM groundwater storage in CVPM 14 remains at around 50 maf, CALVIN storage increases from about 50 maf in 1921 to about 140 maf in 1993. On average, approximately 5 maf is added to total Central Valley groundwater storage each year in CALVIN. In contrast, CVGSM groundwater basins in the Central Valley all show nearly constant storage levels. CALVIN's increasing groundwater storage is related to the problem of excess water in the system and is likely caused by error in input data on hydrology or demands.

Storage in some CALVIN groundwater basins remain relatively constant and appear to operate similarly to CVGSM. One such basin is that of CVPM 18 as seen in Figure 8-16. Both CVGSM and CALVIN maintain storage levels of about 40 maf throughout the 72-year period of analysis.

Flow

As with storage, CALVIN's flow results prove a good match with DWRSIM in some locations but not in others. An example of a location with a good match is the Sacramento River inflow into the Sacramento-San Joaquin Delta (CALVIN node D503 or DWRSIM node 503). The time series of flow for the first 10 years of analysis are compared in Figure 8-17. Very similar flow results occur in both CALVIN and DWRSIM. The high and low flows mostly coincide temporally, although CALVIN's high flows appear to be somewhat higher than those of DWRSIM.

A flow with a very poor match between CALVIN and DWRSIM is the release into the California Aqueduct from Banks Pumping Plant, shown for the first 10 years of analysis in Figure 8-18.

Figure 8-13. Clair Engle Lake Storage
Plot of Monthly Time Series

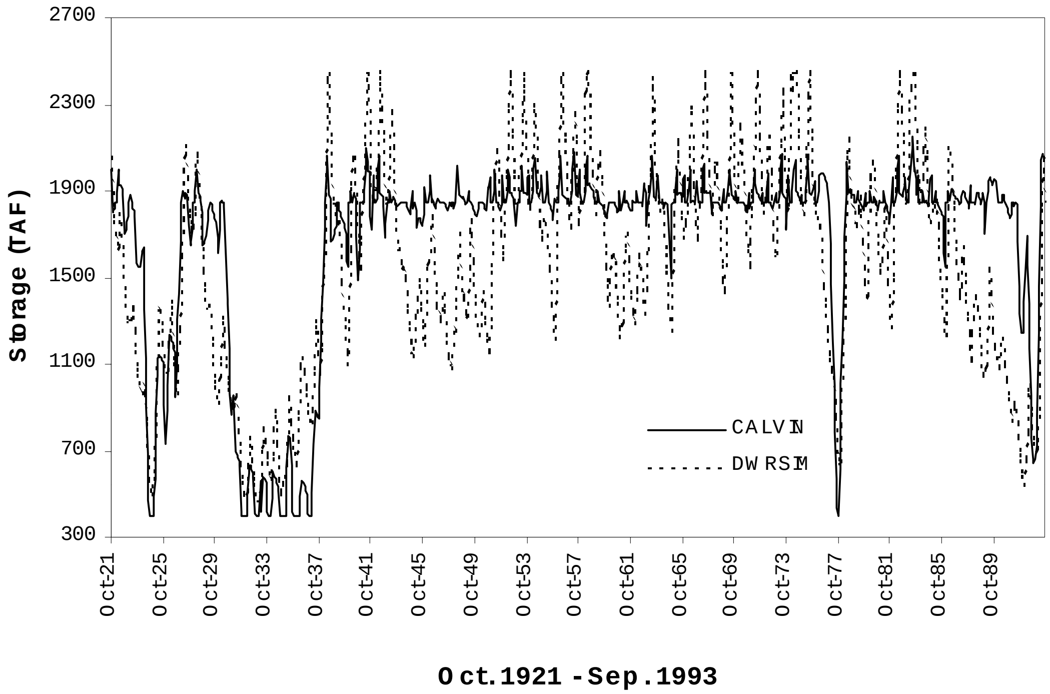


Figure 8-14. Lake Oroville Storage
Plot of Monthly Time Series

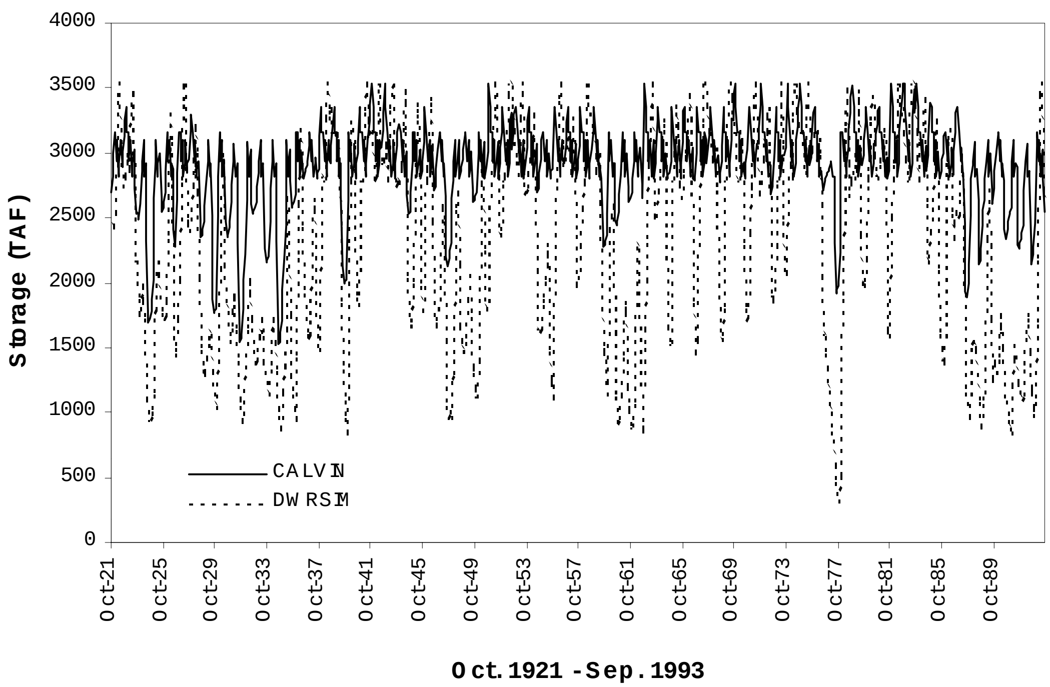


Figure 8-15. Groundwater Storage in CVPM 14
Plot of Monthly Time Series

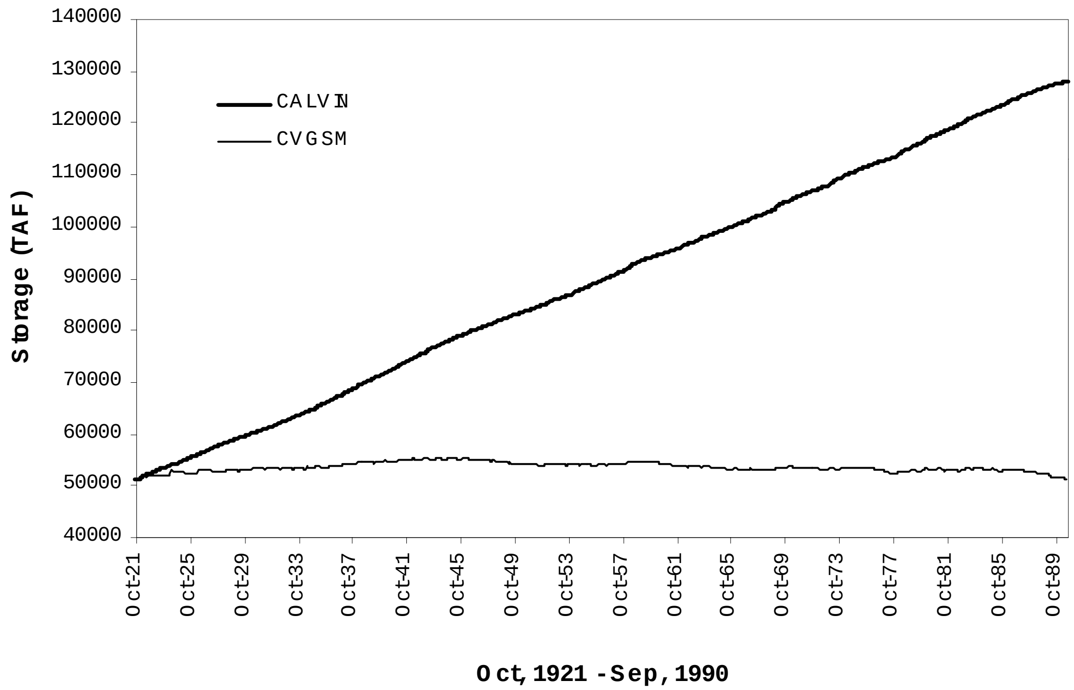


Figure 8-16. Groundwater Storage in CVPM 18
Plot of Monthly Time Series

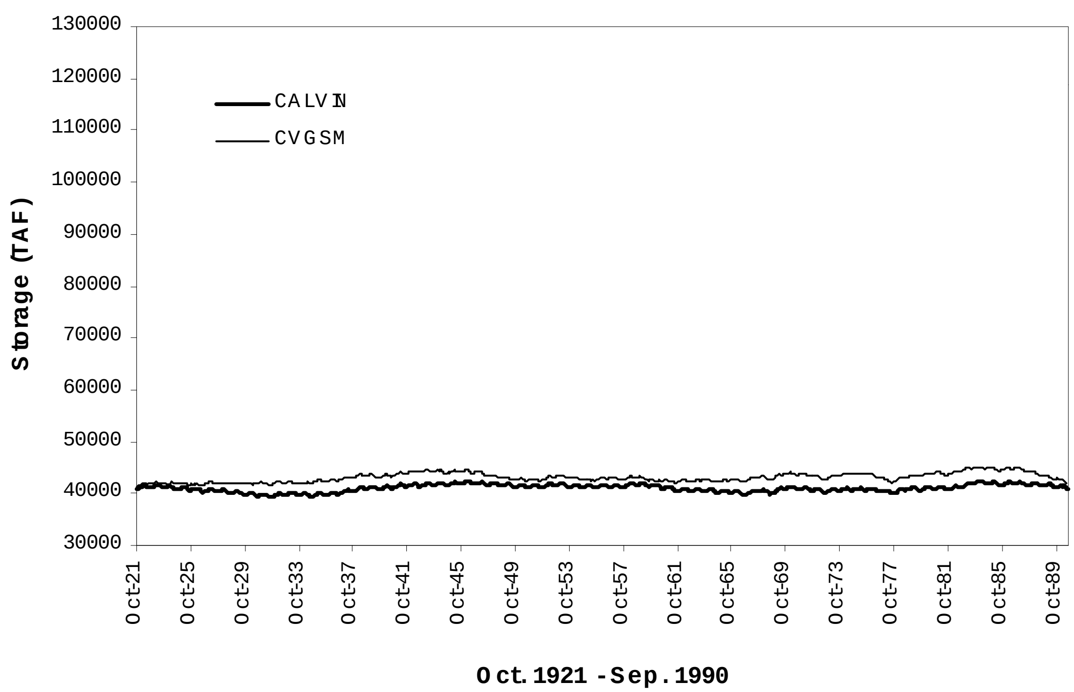


Figure 8-17. Sacramento River Flow
Plot of Monthly Time Series

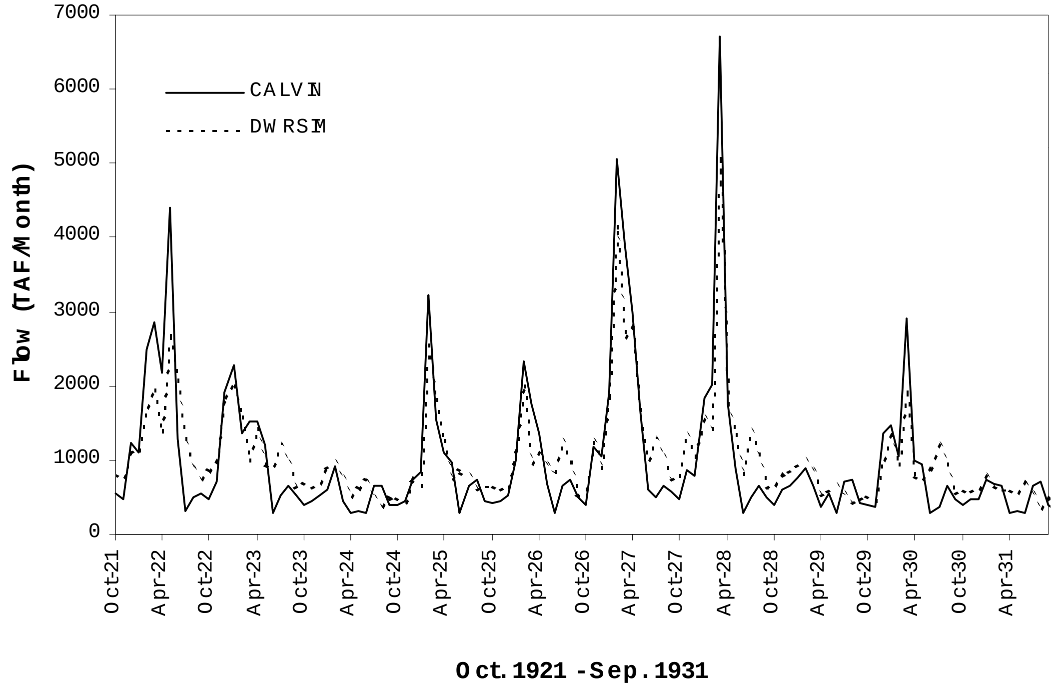
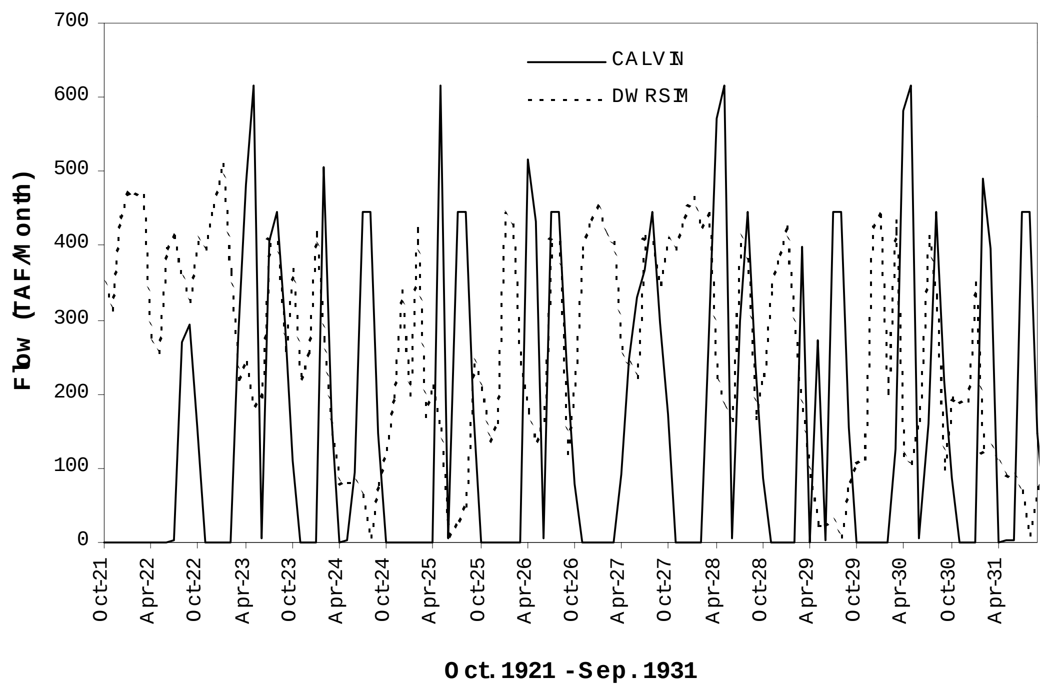


Figure 8-18. California Aqueduct Flow
Plot of Monthly Time Series



Although average annual flows for the two models at this location are similar, there is poor monthly temporal correlation; neither high nor low flows occur at the same time.

USES OF RESULTS

CALVIN's results are most useful when used to compare two or more alternatives to evaluate water allocation and economic changes caused by modifications in the infrastructure or operating policies. A single model run, however, can yield a number of useful results. Of particular interest are the following economic values, each of which is unique to CALVIN's modeling approach:

- net benefits from expansion of storage or conveyance facility capacity;
- net benefits of an additional unit of water at each node in the system; and
- net costs of increasing environmental flow requirements.

It is also possible to develop new reservoir operating rules from a single model run. Each of these contributions is discussed below.

Economic Value of Additional Water

For each demand node, the marginal willingness-to-pay for additional water in each time step can be derived from the economic value functions and water deliveries for that node. By comparing these values across nodes and regions, the relative value of additional supply to each region can be estimated. The marginal WTP provides an indication of how much each demand area would be willing to pay to obtain water supply from new facilities. Also available is the value of additional inflow at each node in the system. These values indicate the relative value of water at different locations.

Promising Areas for Facility Expansion

Shadow values on storage and conveyance capacity indicate the value of increasing capacity on those facilities. Shadow values can be used in conjunction with marginal willingness-to-pay to indicate which facilities should be expanded, which demand areas will benefit most from expansion, and how much areas would be willing to pay for construction and additional water. Because shadow values only denote the value of small increases in capacity, the shadow values on each facility are most valuable when deciding which facility expansion alternatives to study in future model runs. Values of both existing and proposed facilities can be tested in this manner. For example, if proposed facilities are included in the system with zero capacity (as with the Folsom South Canal extension for EBMUD), the shadow value on that capacity will indicate whether it is worth constructing.

Economic Value of Changing Environmental Flow Requirements

Environmental flow requirements in CALVIN are represented as minimum flow or delivery constraints on various links in the system. Consequently, CALVIN output provides a shadow value for all environmental constraints in the system. These shadow values measure the net benefits (positive) or costs (negative) of increasing the minimum environmental flow or delivery constraint by one unit of water. In general, they reflect the economic costs or value to agricultural and urban demand areas of environmental flows that might be diverted out-of-stream and delivered for water supply uses, either upstream or downstream of the instream requirement. These environmental shadow values provide a lower bound estimate of the opportunity cost to agricultural and urban users of environmental water uses at different locations in the system.

System Operating Rules

Storage release decisions made by CALVIN can be used to develop new reservoir operating rules that could then be tested and refined in a simulation model of the system (Lund and Ferreira 1996). Because CALVIN is a deterministic optimization model, its decisions are made with perfect foresight of future inflows into the system. Operating policies can be developed, however, that incorporate only information known to the simulation model at each time step, such as current reservoir storages and the next month's inflows. Comparisons shown above between CALVIN's and DWRSIM's results demonstrate that simulation and optimization models can sometime operate the system very differently. While some differences are due to simplifications required by optimization models such as HEC-PRM, they also indicate the system might be operated more efficiently with operating rules implicit in the release decisions prescribed by CALVIN. If such operating rules or policies can be identified, CALVIN provides a powerful screening tool for alternatives to be tested in simulation models.

LIMITATIONS OF RESULTS

This preliminary CALVIN model run has very limited applicability. The primary limitations of the model run are outlined below.

Incomplete Input Data

The input data entered in the CALVIN model contain some known errors that, at the time these results were generated, had not yet been corrected. Furthermore, hydrologic inputs in the Sacramento Valley have not been finalized and economic value functions for agricultural water use generated by SWAP underestimate the total Central Valley agricultural water demand in 2020 by approximately 3 MAF/year. These input data problems, largely related to the original data obtained for CALVIN and SWAP inputs, result in very few shortages and unrealistic increases in groundwater storage in the Central Valley. There may be additional omissions in the input data related to gains and losses in the system that affect the water imbalance in the Central Valley and need to be checked. Some urban-related operating costs are still being refined and are therefore missing in CALVIN at this time.

The representation of Southern California is also preliminary. Preliminary value functions for the three agricultural demand areas in Southern California are being used until SWAP model results for these demands are finalized. South Coast agricultural demands may need to be represented separately from residential urban demand, where they are currently included, for the three Metropolitan Water District urban demand areas. Hydrologic inputs also need adjustment. Surplus inflows on the Colorado River may need to be considered. Presently, in CALVIN the Colorado River supply is limited to 4.4 maf/year. The Owen's Valley water balance needs refining as well. In spite of these limitations, the results for Southern California appear to be more reasonable than are those for the rest of the state.

In addition to being incomplete and preliminary in places, it is likely that the input data contains a number of accidental errors that may affect the results. All input data needs to be thoroughly checked for errors before the results can be considered reliable.

Absence of Alternatives for Comparison

Many of the inputs in CALVIN have been generated with limited information. Development of data used in the model has often involved the adoption of a number of assumptions. Because it is always difficult to convert a small amount of data into input that accurately and reliably corresponds with real-world conditions, model results generated from only one model run should not be taken at face value. Much more valuable are the differences in results between two or more alternative model runs, each of which would be similarly affected by the biases of the assumptions made in developing the input data.

Results presented in this chapter are those of only a single alternative. Because of biases inherent in the input data, gross outputs from this model run are not meaningful by themselves. Once subsequent alternative model runs have been developed, CALVIN can be used to evaluate the water allocation and economic changes resulting from the differences between alternatives.

Current Model Does Not Include Policy Constraints

As explained in Chapter 6, Policy Option 1a does not include any policy constraints. Thus, these model results depict an unfettered water market constrained only by physical and environmental constraints. This model was developed first to be certain that the physical system and statewide hydrology represented in CALVIN give reasonable results and contain no infeasibilities or major inconsistencies, before adding further layers of operating constraints.

Policy 1a is not an accurate representation of current water operations and therefore cannot be considered a base case against which to determine the value of proposed infrastructure and policy options. Thus, Policy 1a shadow values of storage or conveyance expansion are likely to be lower than when water allocations are constrained by current operations that severely restrict water transfers. In the next phase of this project, a fully constrained model will be developed to serve as the base case for the evaluation of alternatives.

CONCLUSIONS AND DIRECTIONS

When reliable results have been generated, CALVIN will be a valuable tool for understanding and evaluating the integrated performance, both physical and economic, of different alternatives at statewide, regional, and local scales. In addition, it can help determine new more optimal operating rules for existing and new infrastructure in the context of the entire California water system. CALVIN’s output includes large amounts of valuable information, including flow values in every link, deliveries to every agricultural and urban demand node, and storage (and evaporation) values for every surface and groundwater storage node. In addition, the marginal willingness-to-pay for additional water and the total and average unit costs of all shortage events is produced for every demand node. The marginal value of water is available at every location and the shadow values available for every constraint on storage and flow in the system.

The preliminary results presented in this chapter derive from inadequate input data and show unrealistically small water supply shortages. Even so, they demonstrate that the output generated by CALVIN yields much insight into the operation of the system. The performance of the model under drought conditions appears to be realistic. The local examples presented have demonstrated a high correlation between shadow values on capacity and marginal willingness-to-pay for additional water of urban and agricultural demand areas.

In future, input data will be corrected to adequately represent the current statewide water system. Once a reliable model has been developed for Policy Option 1a, it will be used as the foundation for building the other alternatives and base case model outlined in the previous chapter.