INTEGRATED ECONOMIC-ENGINEERING ANALYSIS OF CALIFORNIA'S FUTURE WATER SUPPLY

Report for the State of California Resources Agency, Sacramento, California

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CHAPTERS

APPENDICES

(green text = to be finished at a later date)

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a report for the

State of California Resources Agency
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PREFACE

This project is of unusual scope and scale for University researchers. It involved assembling an economics and engineering -based optimization model for the water supply of almost all of California, expanding and integrating the analysis of California water in several new ways. We are simultaneously grateful to have had this opportunity, excited by the interest shown in this work and its continuation, and more appreciative of the difficulties of working at this scale than we were before. We hope that this work helps others become better acquainted with the potential of economics and optimization in managing California's water resources.

This project began with discussions between Doug Wheeler, then Secretary of the California Resources Agency, and Henry Vaux, University of California Associate Vice President for Programs, DANR, regarding long-term financing of California's water supplies. This project would not have occurred without their initial and sustained interest. Financial support for this project came primarily from the California Resources Agency, with additional support from the National Science Foundation and US Environmental Protection Agency's Water and Watersheds program.

Great thanks are due to the Advisory Committee established by the Resources Agency for this project. Throughout the project, they have given freely of their time to attend meetings, provided sage and useful advice, and asked questions when our work and presentations were unclear. This committee and overall coordination with the Resources Agency were overseen most capably by Anthony Saracino. Members of the Advisory Committee were:

Anthony Saracino, Private Consultant (Chair)
Fred Cannon, California Federal Bank
Duane Georgeson, Metropolitan Water District of Southern California
Jerry Gilbert, Private Consultant
Carl Hauge, California Department of Water Resources
Steve Macaulay, State Water Contractors
Dennis O'Connor, California Research Bureau
Stu Pyle, Kern County Water Agency
Maureen Stapleton, San Diego County Water Authority
David Yardas, Environmental Defense Fund

This project involved an unusual amount of data gathering from many agencies from all over California. Particular thanks go to: Tariq Kadir, Scott Matyac, Ray Hoagland, Armin Munevar, Pal Sandhu, Paul Hutton, and Saied Batmanghilich (DWR); Ray Mohktari, Tim Blair and Devendra Upadyhyay (MWDSC); Lenore Thomas, David Moore, and Peggy Manza (USBR); Roger Putty and Bill Swanson (Montgomery-Watson); Terry Erlewine (State Water Contractors); Judith Garland (EBMUD); K.T. Shum, Rolf Ohlemutz and Bill Hasencamp (CCWD); Ralph Johonnot (USACE); Chris Barton (YCFCWCD); Ken Weinberg (SDCWA); Melinda Rho (LADWP); Richard McCann (M-Cubed); Jim McCormack (Sacramento Water Forum); Tim Niezer (ACWD); and Roger Mann and Steve Hatchett (consultants). The US Army Corps of Engineers Hydrologic Engineering Center's David Watkins, Bob Carl, and Mike Burnham, with assistance from Paul Jensen of the University of Texas, Austin, provided

technical support and technical extensions for the HEC-PRM code. Our apologies to others we have certainly missed. Additional thanks go to the people who attended two technical workshops on the project method and on California water infrastructure schematics. However, errors in the work remain our own.

This report and associated appendices can be obtained on the web at:
http://cee.engr.ucdavis.edu/faculty/lund/CALVIN

INTEGRATED ECONOMIC-ENGINEERING ANALYSIS OF CALIFORNIA'S FUTURE WATER SUPPLY

EXECUTIVE SUMMARY

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"When the well's dry, we know the worth of water."
Benjamin Franklin (1746), *Poor Richard's Almanac.*

California's water supply problems involve great financial and economic issues. What economic benefits arise from new water storage and conveyance facilities? Would significant economic benefits result from changing legal, contractual, and environmental limits on operating California's water system? What is the value of regulated water markets? What are the most beneficial new facilities and management changes? Who would be willing to pay for such facilities or institutional changes, and how much would they pay? What is the reliability of both water supply and revenues for new facilities? These are the kinds of questions this project has begun to answer.

This project takes an economic approach to managing and financing California's future water supplies. This new approach uses a computer model that combines water management and economic performance. The computer model (CALVIN) represents California's statewide water system, including its surface water and groundwater resources, storage and conveyance facilities, and agricultural, environmental, and urban water uses.

The model suggests how to operate the system to maximize statewide economic returns from agricultural and urban water uses, given specific practical and policy limits. These limits include the physical availability of water, storage and flow capacities of physical infrastructure, and environmental flow and other policy constraints. This is an economics-driven optimization model. There are no operating rules in the conventional sense of DWRSIM, PROSIM, or other common simulation models.

This economically-based modeling approach provides a variety of benefits for long-term planning. Specifically, model results can be used to:

1) Estimate regional and statewide economic benefits from new or enlarged storage and conveyance facilities or changes in water management policies;

2) Quantify changes in economic and supply reliability from changes in system facilities and management;
3) Assess the willingness to pay of different water users for specific new storage and conveyance facilities or changes in water management policies;
4) Explore how system operations and economic performance might change with different forms of water transfer activity; and
5) Suggest economically promising forms of coordination among regional water systems and promising forms of water transfers.

This report details this new approach and places it in the context of California's water supply problems and its structural, nonstructural, and institutional options. Examples of how the approach can be used are presented. The report also outlines additional work desirable to take this project beyond proof-of-concept and preliminary results. This executive summary briefly reviews the origins of this project, the modeling approach, sample results, innovations and limitations, accomplishments, technical lessons, future directions, and policy conclusions.

ORIGINS OF THIS PROJECT

The State of California Resources Agency funded an 18-month study starting in January 1998 to analyze finance options for California's future water supply. The study is entitled "Quantitative Analysis of Finance Options for California's Future Water Supply," or, the "Capitalization Project" for short. A team of University of California Davis economists and engineers performed this study.

This project began with an interest in the ability and willingness of the private sector to participate in water facilities of statewide significance for California. Rudimentary calculations showed that with CALFED costs ranging between $4 billion and $16 billion and likely state and federal funding in the range of perhaps $3 billion to $8 billion, that there remained a substantial potential finance gap. How much would users be willing to pay for water supply alternatives and could the private sector help?

It was realized quickly that this was an immense task. So much can change and be changed over such a long-term planning horizon. An economic-engineering analysis would be needed of unprecedented scope and flexibility. An optimization modeling approach was selected.

The project further evolved, with the support of its Advisory Committee, to have a broader interest in economic values of facility and management options for California's statewide water system.

MODELING APPROACH

The modeling approach taken for this problem differs from that commonly used for operations planning in the Central Valley. Currently, all operations models for the Central Valley are *simulation* models which use operating rules to allocate water and operate reservoirs. This study uses an *economic optimization* modeling approach, with no operating rules or explicit water rights or contracts, except where added as constraints to the model. Water is moved and stored only to maximize the total statewide economic performance, limited only by physical, environmental, and policy constraints on flow and storage.

Over the planning horizon for new facilities, many changes can be made in water contracts and operating agreements. In particular, water transfers, markets, and wheeling are likely to become more common. Such operational changes may have significant economic benefits and may reduce the need for costly structural solutions. Among the questions for this study is, “What is the economic value of more flexible and coordinated operation of California’s water system?”

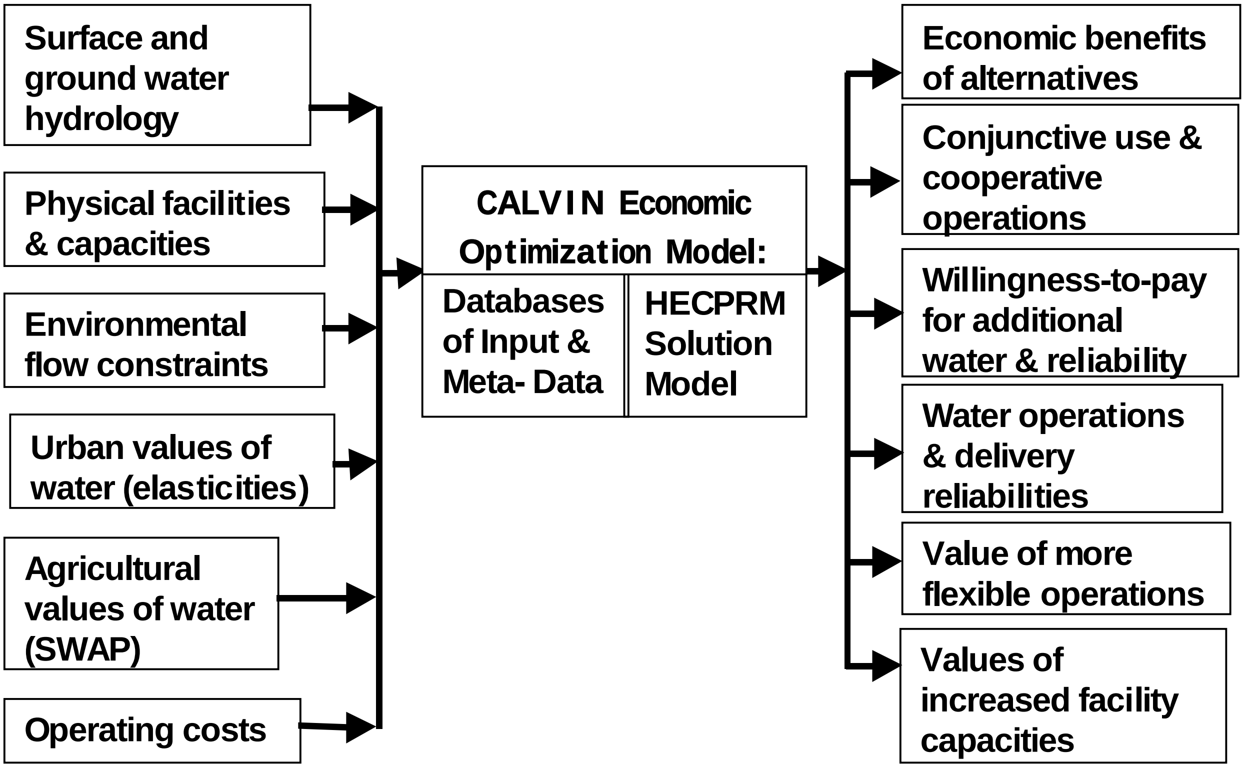
This optimization modeling approach is intended to answer specific economic and management questions and point towards promising potential solutions that are unlikely to emerge from simulation modeling. However, economic optimization does not replace simulation models. Optimization models usually require significant simplifications relative to simulation models. Simulation models are needed to conduct more detailed studies that test and refine planning and operating suggestions provided by optimization results. Together, these two types of models give an ability to look rigorously both at the big picture (optimization) and details (simulation).

The economic optimization model is called CALVIN (California Value Integrated Network). Required model input includes valuation of water uses by month. Values for agricultural water uses are estimated using a new model, SWAP (Statewide Water & Agricultural Production), that extends the approach of earlier CVPM models. Urban values for water use are estimated based on price elasticities of demand.

As illustrated in Figure ES-1, CALVIN consists of a database of model inputs and assumptions and a reservoir system optimization model. The database defines the state’s network of water infrastructure and includes capacities, losses, variable operating costs, and minimum instream flows for each element of the network. In addition, it includes surface and groundwater inflows and the economic values of water use at each major agricultural and urban water use location. The database also includes information on the origins of all input data, called metadata. The CALVIN model schematic represents California’s water supply system with roughly 1,250 spatial elements, including 56 surface water reservoirs, 38 groundwater reservoirs, 47 agricultural demand regions, 20 urban demand regions represented by 38 demand nodes, 163 stream reaches, 150 groundwater flow, pumping, and recharge reaches, 257 canal and conveyance reaches, and 78 diversion links.

The optimization solver for the water resource system is HEC-PRM (Hydrologic Engineering Center-Prescriptive Reservoir Model), a network flow optimization computer code developed by the US Army Corps of Engineers’ Hydrologic Engineering Center in Davis, CA. It was developed specifically to examine the economic operation of large water resource systems. HEC-PRM has been applied to the Columbia River, South Florida, Missouri River, Panama Canal, and Carson-Truckee systems by the US Army Corps of Engineers and the University of California, Davis.

Figure ES-1. Data Flow for the CALVIN Model



SAMPLE RESULTS

Preliminary results from CALVIN for the Central Valley and Southern California indicate that the model is working satisfactorily for initial runs. Current results are partial and preliminary and so are unsuitable for policy purposes. Nonetheless, current results can be used to illustrate uses for CALVIN model results. From model results for Southern California, an example urban water demand is supplied with less than full deliveries in 53 percent of all years, with a maximum shortage of 7 percent. Figure ES-2 illustrates the time-series of monthly shortages for the demand area during the hydrologic period from February 1958 to February 1963. The time-series of that area’s marginal willingness-to-pay for additional water also is shown, with a peak willingness to pay of about $1,200/af. This particular demand area is supplied largely by imported water through an external canal to a medium-sized local storage reservoir. Figure ES-3 shows the unit value of increasing the capacity (shadow value) of the supply canal and storage reservoir during this period. Just before each shortage, there is considerable value to increasing storage capacity (while there is water and source capacity to fill any new storage). Towards the end of each shortage event, when normal reservoir storage is exhausted, there is value to accessing the “dead storage” at the bottom of the reservoir (appearing as negative values for local storage). This would be the value of pumping additional water from the bottom of the reservoir during these shortages. During the shortage event, additional source canal capacity has considerable value, as high as $1,000/af-month. These types of results are useful for identifying desirable locations in the network for capacity expansion (raising storage capacities, accessing dead storage, or increasing conveyance capacities) and estimating local willingness to pay for additional water. Chapters 7 and 8 discuss additional sample model results and additional uses of CALVIN model results.

Figure ES-2. Example Local Shortages and Willingness to Pay for Additional Water

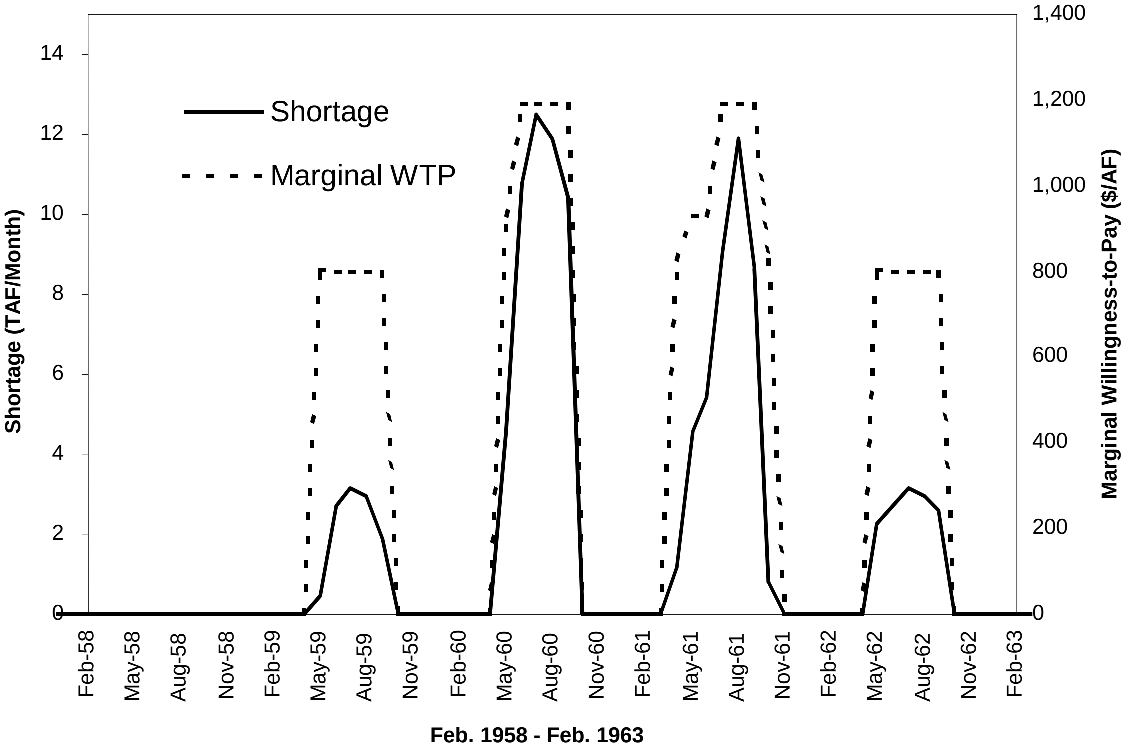
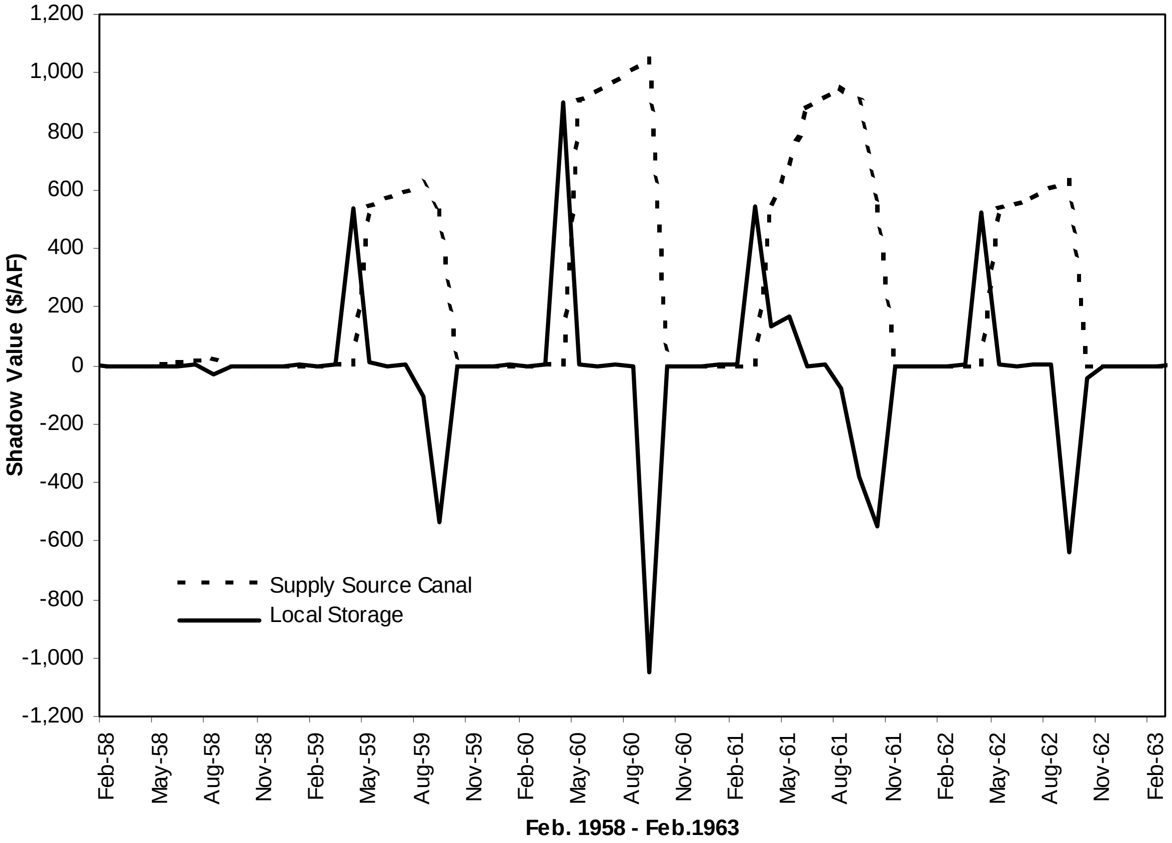


Figure ES-3
Supply Canal and Local Storage Capacity (Shadow) Values



INNOVATIONS AND LIMITATIONS

Some of the major project innovations are listed in Tables ES-1. These innovations were required for the purposes of this project and represent, in most cases, some attempts to broaden the analytical capabilities available for long-term water planning in California. Some of the limitations of the approach are included in Table ES-2. These and other limitations are further elaborated later in the report. Many of these limitations are the subject of additional work to be completed over the next 18 months.

Table ES-1: Selected Project Innovations

1. Optimization model

- More flexible operations and allocations can be examined
- System operations explicitly pursue economic performance objectives
- Provides rapid identification and preliminary evaluation of promising alternatives

2. Statewide model

- Model goes from Shasta to Mexico
- Tulare Basin, SF Bay area, South Coast, and Colorado R. areas are added
- Explicit examination of potential statewide impacts, operations, and performance

3. Groundwater

- Groundwater use is explicitly, though imperfectly, included
- Groundwater use is fully integrated with surface supplies and water demands

4. Economic Perspective

- Statewide economic performance is the explicit objective of the model
- Economic values for new storage and conveyance capacity are provided by the model
- Greatly enhanced capability to model water marketing/water transfers

5. Data and Model Management

- Explicit data management tools and documentation of model assumptions
- Relative ease of understanding and modifying assumptions
- Model, data, documentation, and software are public domain

6. Economic Values of Water Use

- Statewide understanding of economic values of water for agricultural & urban uses
- Reformulation and extension of CVPM models of agricultural water values (SWAP)
- Economic models developed and applied to Southern California agriculture
- Consistent, though simplified, statewide representation of urban water values

7. New Management Options

- Various statewide water marketing options
- Integrated operation of existing and new facilities
- Potential for private facility investments
- Flexible facility operations and flexible water allocations

8. Systematic Analytical Overview of Statewide Water Quantity

- Hydrology (surface and ground waters)
- Facility capacities
- Environmental limits, institutional limits, economic values

Table ES-2: Selected Project Limitations

1. Limited Ability to Represent Water Quality

- Water quality must be represented indirectly with costs and constraints
- Urban water quality impacts are represented by surrogate treatment and consumer costs

2. Environmental Flows

- Environmental flows are represented in very simplified ways, only as minimum flows

3. Limitations of Input Data

- Many sources of data; need to further reconcile data from different sources

4. Effective Precipitation for Agriculture

- Variation in effective precipitation by year is currently neglected

5. Optimization Limitations

- Requires significant simplifications over simulation modeling; groundwater is especially simplified
- The first models assume perfect hydrologic foresight
- Some system aspects are imperfectly represented as network flow optimization
- Additional detailed modeling is usually needed to refine and test the details

6. Simplified Representation of Groundwater

- Groundwater is modeled as simple storage reservoirs

7. Simplified representation of urban water shortage costs

- Elasticity approach is very simple, 2020 demand levels are controversial
- No annual variation in demands with weather

8. Monthly time step necessitates simplification of more complex phenomena

9. Hydropower currently not included in the initial analysis

10. Operating Cost Data

- Cost values from different sources are estimated inconsistently

ACCOMPLISHMENTS OF THE PROJECT

This project required completion of a number of activities, products, and tasks, summarized in Table ES-3. These are elaborated on and presented in the report and its appendices.

Table ES-3: Completed Activities, Products, and Tasks

1. Draft California Water System Schematic
2. Statewide Model Schematic
3. GIS Maps for Documentation and Post-Processing
4. New Economic Production Models for Agricultural Areas (SWAP)
5. Monthly Agricultural Water Valuations for the 21 Central Valley CVPM Regions
6. SWAP Model Extension to Southern California
7. Assembly of Operating Costs Systemwide
8. Monthly Urban Water Valuations for 20 Major Urban Areas
9. Preliminary Synthesis of Surface and Ground Water Hydrologies Statewide
10. Assembly of System Capacities
11. Assembly of Environmental Flow Requirements
12. Database for Input Model Data and Metadata
13. Software for Entering Data into HEC-PRM Model
14. Improvements to HEC-PRM Model
15. Design for Modern Data-Model Interface and Data Management System
16. CALVIN Model Runs for the Central Valley and Southern California
17. Conceptual Design for Post-Processing Tool
18. Interim Post-Processing Software
19. Model and Data Documentation

TECHNICAL LESSONS

Most of our technical lessons learned involve data, its availability, and data management.

Statewide Water Management Modeling is Possible

Model development, data gathering, and preliminary model runs completed so far are sufficient to indicate that it is possible to model the economic management of water statewide. Five years ago, the available data, software, and computing power were insufficient for an optimization model as integrated and disaggregated as the current CALVIN model. While important gaps, uncertainties, and limitations remain, the state's water management community should begin to consider how to use such integrated modeling to help resolve pressing policy evaluation, economic impact, coordinated operation, and project finance problems.

Most Data are Available

A great deal of useful water resources data and information has been collected and developed over the last century in California. Particularly in the last decade, much information and modeling has been developed which is useful for large-scale operations and planning modeling purposes. However, the development and use of data and information must continue to adapt to the newer problems faced by the state in recent decades.

High Level of Technical Cooperation

To develop the data for the economic optimization model, we have contacted dozens of agencies statewide. Almost all parties have been very helpful in providing data and useful information for this project. Without this high level of cooperation, our model would be far more approximate.

Data Gaps, Limitations, and Uncertainties

Some types of data need additional work to improve the value of statewide analysis. As detailed in the report, these areas include surface water and groundwater hydrology, local water management, and economic valuation of water demands.

Data Management is Important

For large-scale models intended for use in public resolution of controversial problems, the clarity and reasonableness of the model and its input data will be severely tested. In these situations, the modeling approach and supporting data should be transparent. This implies that information on the origins and quality of model data (metadata) should be readily available. The CALVIN model's input data is stored in a searchable Access database, including metadata on the origins and limitations of these data. Ultimately, these data and metadata will be accessible from the model schematic.

FUTURE DIRECTION

The project has demonstrated the feasibility of using a statewide economic optimization model to help plan for California's future water supplies, including estimating the value of particular proposed new facilities and changes in water management policies, such as water marketing. Such results can be used for evaluating various user financing mechanisms for particular system components, the economic desirability of various alternatives statewide or regionally, and suggesting various economically promising planning and operations alternatives. The interaction of groundwater, surface water, and water policy alternatives can all be preliminarily examined using this approach. Various data management ideas for making large-scale operations models more accessible for California water planning also will be demonstrated and developed.

For the results of this project to have more practical, widespread, and direct use for California, additional development and investment will be required. Some specific products for a one- to three-year time-frame are identified and discussed below. CALFED has agreed to fund much of the basic work needed along these lines over the next 18 months.

Some specific future development objectives include:

Better Data Management and Model Enhancements

Data-Model Input Interface Completion
Data Checking and Revision
Post-Processing Software
Variation of Urban and Agricultural Water Demands by Year-Type
Add Hydropower and Head-Dependent Pumping
Add Quadratic Economic Value Functions for Agricultural and Urban Water Demands

Applications

Groundwater Management and Economic Impacts
Develop Promising Conjunctive Use and Cooperative Operation Alternatives
Support for Economic and Financial Analysis of CALFED Alternatives
Implied Valuation of Environmental Water Use
Economic Evaluation of New Facilities and Alternative Water Transfer Policies
Finance of New Facilities or Management
Disaster Economic Impacts and Flexible Response

Longer Term Developments

New Optimization Algorithms
Web-based interface

POLICY CONCLUSIONS

1. *The complexity, controversy, interdependence, and importance of California's water supply system have grown to require new approaches to their analysis.*

California's water issues are interconnected statewide; water management and use in one area commonly affects water use in other areas. Surface water and groundwater systems are highly connected. Almost the entire system is complex and controversial. Most current analysis models used in California were developed at an earlier time to examine limited surface water options for a specific water project. Over time, these models have been expanded, but have become increasingly difficult to apply. More modern analysis methods can help.

2. *Economics should have a greater role in analysis of California's water system.*

The greater controversy, variability, and diversity of water uses and supplies in California's water system have made economic indicators of system performance increasingly desirable. Economics-based analysis and economic measures of performance provide a fairly direct basis for:

- Evaluation and comparison of alternatives;
- Developing new economically promising structural and non-structural alternatives;
- Financial and willingness-to-pay studies;
- Cost or benefit effectiveness studies;
- Development and evaluation of integrated effects of multiple water management options;
- Quantifying trade-offs among system objectives; and
- Quantifying benefits to society and users of changes in facilities, environmental flow requirements, and institutional policy constraints.

Water supply "yield" has become an increasingly obsolete and contentious indicator of performance. The economic value of water deliveries has become a more reliable and direct indicator of system performance that can better incorporate reliability and water quality concerns for agricultural, urban, and perhaps ultimately environmental water uses. While improvements in these estimates are desirable, there is sufficient data and professional consensus to use these economic methods in long-term water planning.

3. *Advances in computing and software provide substantial opportunities to modernize and improve the analysis of California's water resources*.

The California water community is at an unusual point in time where the limitations of old methods and the promise of new technologies are both abundantly apparent. This is a pivotal time for the California water community to develop new approaches, methods, tools, and data for planning, managing, and operating water statewide over the long term. Without such modernization, proposed solutions are less likely to perform effectively, and are therefore more likely to become controversial, discredited, and short-lived. DWR and USBR have moved energetically in this direction with the development of the CALSIM simulation model, which provides a platform for additional modernization efforts.

This project has demonstrated the feasibility and desirability of several more modern approaches to large-scale water system analysis. These include:
- More transparent data-driven modeling;
- Database documentation of model assumptions and parameters;
- Large-scale economic optimization; and
- Structures for automated computer management of modeling data.

The primary advantages of these techniques are to speed development and analysis of alternatives and to increase the transparency of modeling assumptions and results.

4. *California can choose from a wide variety of structural and non-structural options for addressing its pressing water resource problems.*

Chapters 3, 4, and 5 present a diversity of structural and non-structural options available to local, state, and federal agencies, firms, and water users. Nonstructural options are especially important and are necessary complements to structural options. In highly interconnected systems, such as California, the benefits of new water facilities are often reduced unless accompanied by complementary changes to the operations and management of other water facilities. However, it is typically difficult to study, develop, and integrate nonstructural options using conventional simulation models, prompting the need to use newer and more flexible analytical techniques. The need to integrate all manner of water management options further motivates the use of more modern system analysis methods.

5. *Groundwater must be integrated into the analysis of California's water supplies, even though we know relatively little about it.*

Groundwater provides about thirty percent of California's agricultural and urban water supplies in an average year. In drought years, use of groundwater increases greatly, and provides California's greatest source of drought water storage. While there is relatively less knowledge and regulation of California's groundwater, realistic analysis of California's water supplies must include explicit integration of groundwater. Such integration will support development of promising conjunctive use projects and accelerate development of improved understanding of the state's groundwater systems.

6. *Economic-engineering optimization models are feasible and insightful for California's water problems.*

This study has demonstrated the capability of a new analysis approach for California water using the CALVIN model. CALVIN is an economically-based engineering optimization model of California's water supply system. Given economic values developed for agricultural and urban water supplies, environmental flow constraints, inflow hydrologies, operating costs, and facility capacities, CALVIN suggests economic-benefit-maximizing operations of the statewide system, integrating all resources and options. This phase of work has proven the data availability and software performance required for CALVIN and the feasibility of implementing such a modeling approach.

7. *New optimization modeling analysis will almost always require more focussed and detailed simulation modeling to refine and test solutions*.

As good as optimization models have become, they do suffer some limitations and require sometimes important simplifications relative to simulation models. (CALVIN, for instance, has fairly crude methods of representing water quality.) Optimization model solutions provide promising solutions for refinement and testing by simulation studies, allowing simulation efforts to focus on the detailed analyses they are better suited for. For large, complex, and controversial systems, simulation and optimization methods complement each other.

8. *Better data is needed in some areas to allow better solutions to be realized.*

In assembling and developing input data for the CALVIN model, we identified some areas which merit greater long-term data development. These areas include:
- Surface water and groundwater hydrology;
- Operations and costs for local water facilities;
- Urban water demands and economics; and
- Water quality economics.

CALFED, DWR, and USBR are devoting effort to improving data in some of these areas, particularly regarding surface water and groundwater hydrology in the Central Valley.

9. *CALVIN needs more work.*

While this first phase of work has proven the concept of applying economic-engineering optimization to California's water system, much data checking and development is needed before useful policy-relevant results can be produced. Additional work in this regard is being undertaken with support from CALFED.

CHAPTER 1

INTRODUCTION

“It has been well said that ‘water is the wealth of California.’ If it has been so in the past, it will be more so in the future.” *Report of the Board of Commissioners on the Irrigation of the San Joaquin, Tulare, and Sacramento Valleys of the State of California* (1873), Chapter III

The water problems of California are among the most diverse, difficult, and economically important in the nation. They always have been and perhaps they always will be so. California is the most populous, the second most urbanized, one of the fastest growing, the most agriculturally productive, and perhaps the most environmentally disturbed state. Combined with its generally semi-arid climate, California’s dynamic economy and society depend on its ability to manage water.

Growing demands for water and water-related infrastructure pose serious challenges for managing California's water resource systems. California’s system managers are already struggling to meet increasing traditional demands while trying to devote more water and financial resources to rehabilitate and enhance environmental resources. Solutions to these problems will require substantial investments of capital and significant operational and managerial changes in the system.

This project takes an economic approach to managing and financing California’s future water supplies. This new approach combines analysis of water management and economic performance with a computer model. The computer model (CALVIN) represents California’s statewide water system, including its surface water and groundwater resources, storage and conveyance facilities, and agricultural, environmental, and urban water uses. The model suggests how to operate the system to maximize statewide economic returns from agricultural and urban water uses, given specific practical and policy limits.

Some uses of results from this economically-based modeling approach for long-term planning include:

1) Estimating regional and statewide economic benefits from new or enlarged storage and conveyance facilities;
2) Quantifying changes in economic and supply reliability from changes in system facilities and management;
3) Assessing the willingness to pay of different water users for specific new storage and conveyance facilities or changes in water management policies;
4) Exploring how system operations and economic performance might change with different forms of water transfer activity; and
5) Suggesting economically promising forms of coordination among regional water systems and promising forms of water transfers.

This report details this new approach and places it in the context of California's water supply problems and its structural, nonstructural, and institutional options. Examples of how the approach can be used are presented. Additional work also is outlined to take this approach beyond proof-of-concept and preliminary results. Early technical and policy conclusions are made.

ORIGINS OF THIS PROJECT

The State of California Resources Agency funded an 18-month study starting in January 1998 to analyze finance options for California's future water supply. The study is entitled "Quantitative Analysis of Finance Options for California's Future Water Supply," or, the "Capitalization Project" for short. This work was undertaken by a team of University of California Davis economists and engineers.

Future California water supply costs are known to be large. Rudimentary calculations showed that with CALFED costs ranging between $4 billion and $16 billion and likely state and federal funding in the range of perhaps $3 billion to $8 billion, that there remained a substantial potential finance gap. This project began with an interest in the ability and willingness of the private sector to fund and perhaps own and operate major water facilities of statewide significance for California.

It was realized quickly that private sector involvement would require substantial revenues from any new private facilities. To realize such revenues, facility operators would have to charge for use of these facilities. Water users would ultimately pay such charges. How much could users be charged before seeking other supply or conservation alternatives? How reliable would revenues be to investors? Implicitly, there would be a market for new facility capacity, as well as a market for water to make use of new facilities. In this system, the use of new facilities would be substantially affected by the operation of existing facilities and environmental, legal, and contractual constraints on system operation. Quantitative estimates of economic value and reliability under these conditions require a more comprehensive view of the system than has previously been attempted.

With the support of the Advisory Committee, the project developed to have a broader interest in economic values of facility and management options for California's statewide water system. The following study approach has resulted.

STUDY APPROACH

The study's approach includes the following tasks:

1. Review and summarize California's water problems and potential major infrastructure alternatives.
2. Identify and review the theoretical and practical approaches available for involving markets for improving California's water resource systems at local, regional, and state-wide scales.
3. Select several promising forms of market involvement for regional and state-wide water management.
4. Develop and apply regional and inter-regional water management and economic models to estimate the potential economic values and willingness-to-pay for a) new water sources and

new water storage and conveyance facilities and b) alternative water management policies. The bulk of this project was devoted to this task.

MODELING APPROACH

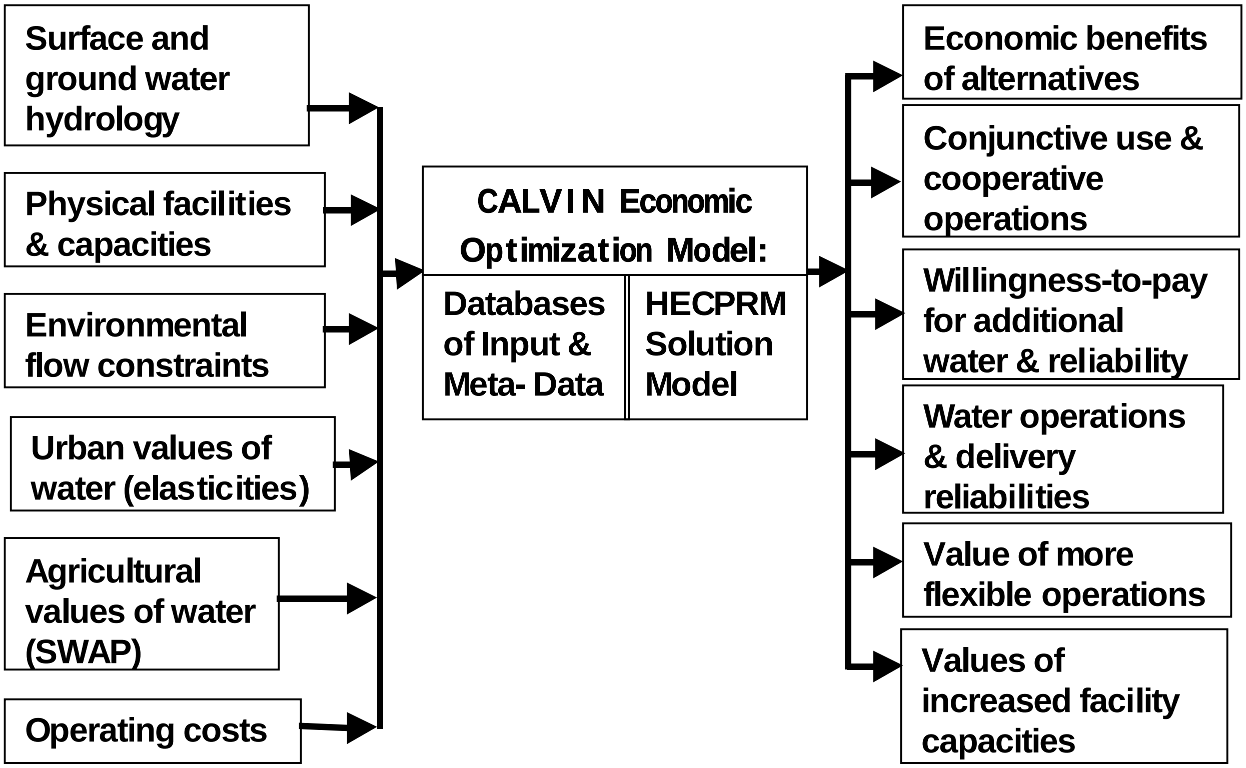
The modeling approach used here differs from that commonly used for operations planning in the Central Valley. Currently, operations models for the Central Valley are all *simulation* models which use operating rules to allocate water and operate reservoirs. This study uses an *economic optimization* modeling approach, with no operating rules or explicit water rights or contracts. Water is moved and stored only to maximize the total statewide economic benefits, limited only by physical, environmental, and policy constraints on flow and storage.

Over the planning horizon for new facilities, many changes can be made in water contracts and operating agreements. In particular, water transfers, markets, and wheeling are likely to become more common. Among the questions for this study is, “What is the economic value of more flexible and coordinated operation of California’s water system?” With additional policy constraints, operation of the system within historical operations and allocations can be examined.

This optimization modeling approach is intended to answer specific economic and management questions and point towards promising potential solutions that are unlikely to emerge from simulation modeling. It is important to realize that the economic optimization model does not replace simulation models. Optimization models usually require significant simplifications relative to simulation models. Simulation models are needed to conduct more detailed studies that test and refine planning and operating suggestions provided by optimization results. Together, these two types of models give an ability to look rigorously both at the big picture (optimization) and details (simulation). Our economic optimization model is called CALVIN (California Value Integrated Network). Values for agricultural water uses are estimated using a new model, SWAP (Statewide Water & Agricultural Production), that extends the approach of earlier CVPM models.

As illustrated in Figure 1-1, CALVIN consists of databases of model inputs and assumptions and a reservoir system optimization model. The databases store data to define a statewide network or schematic of California’s water infrastructure, including system capacities and hydrologic inflows and outflows. The databases also contain operating costs and the economic value of water use at each major agricultural and urban water use location. Lastly, these databases store management and operating policies as a seriec of constraints that include minimum environmental flows. These databases also include information on the origins of all input data, called metadata. The actual reservoir system optimization model is HEC-PRM (Hydrologic Engineering Center-Prescriptive Reservoir Model), a network flow optimization computer code developed by the US Army Corps of Engineers Hydrologic Engineering Center in Davis, CA. Developed specifically to examine the economic operation of large water resource systems, HEC-PRM has been applied to many systems by the US Army Corps of Engineers and the University of California, Davis.

Figure 1-1. Data Flow for the CALVIN Model



ORGANIZATION OF THIS REPORT

The remainder of this report is organized as follows. Chapter 2 reviews the major water problems of statewide importance for California. Infrastructure and facility options for improving California's water supply are presented in Chapter 3. Finance and operations options for California's future water supplies are reviewed in Chapter 4. Chapter 5 summarizes some relevant legal issues. Chapter 6 reviews the modeling approach and describes the CALVIN model in some detail. Chapter 7 is an overview of how this modeling approach can be used to compare long-term management alternatives. Chapter 8 presents some early model results and how CALVIN model results can be used to answer economic and financial questions regarding long-term water planning and management. Chapter 9 presents some technical lessons, accomplishments, and future direction for this work. Finally, Chapter 10 provides some policy conclusions.

The main body of this report is supplemented by detailed appendices documenting the development of model inputs. These include the major economic modeling efforts for valuing agricultural and urban water use throughout the state, the system schematic, cost and capacity estimates, surface and ground water hydrology, and data management. Software and database components to these appendices are gathered in electronic form and provide a complete inventory and description of the methods and data used in this work. In principle, the results are replicable given the data, software, and method documentation provided (although not without some effort).

CHAPTER 2

CALIFORNIA'S WATER SCARCITY PROBLEMS

"Will anybody compare the idle Pyramids, or those other useless though much renouned works of the Greeks with these aqueducts, with these many indispensable structures?"
Julius Frontinus (97 AD), *The Water Supply of the City of Rome*, 16.

The challenge of supplying water to an increasing population and productive agricultural sector has occupied the focus of California water managers for several decades. More recently, environmental water requirements and mitigation measures also have engaged California's water managers. As competing demands increase on a finite water supply, reliability becomes more difficult to achieve for all water uses.

Traditionally, California met water supply challenges with ever increasing infrastructure. During much of this century through the 1970's, reservoirs were built to store water from wetter periods for use in drier seasons or years, thus dampening natural seasonal and annual fluctuations in water availability. A complex and extensive network of canals and pipelines now exists to tie the more humid and sparsely populated northern and eastern regions of California to southern and coastal farms and cities. New surface storage opportunities to increase supply are now quite limited and face increasing costs and environmental barriers. These restrictions, along with growing water demands, have lead to consideration of other alternatives to improve California's water system including: demand management, water marketing, groundwater banking, conjunctive use, and more coordinated operations of storage, conveyance, and treatment facilities. Major efforts are now underway to identify and implement an environmentally sound and politically and financially feasible mix of options.

This chapter reviews current and anticipated 2020 water supply problems facing California and introduces some of the institutional challenges involved in their resolution. Some of these institutional issues are taken up in more detail in other chapters. Both structural and non-structural statewide long-term options for resolving these problems are currently under consideration. The next chapter provides a survey of proposed structural options. Subsequent chapters of this report discuss important issues and options for more flexible and coordinated operations of infrastructure through various non-structural options and coordinated agreements.

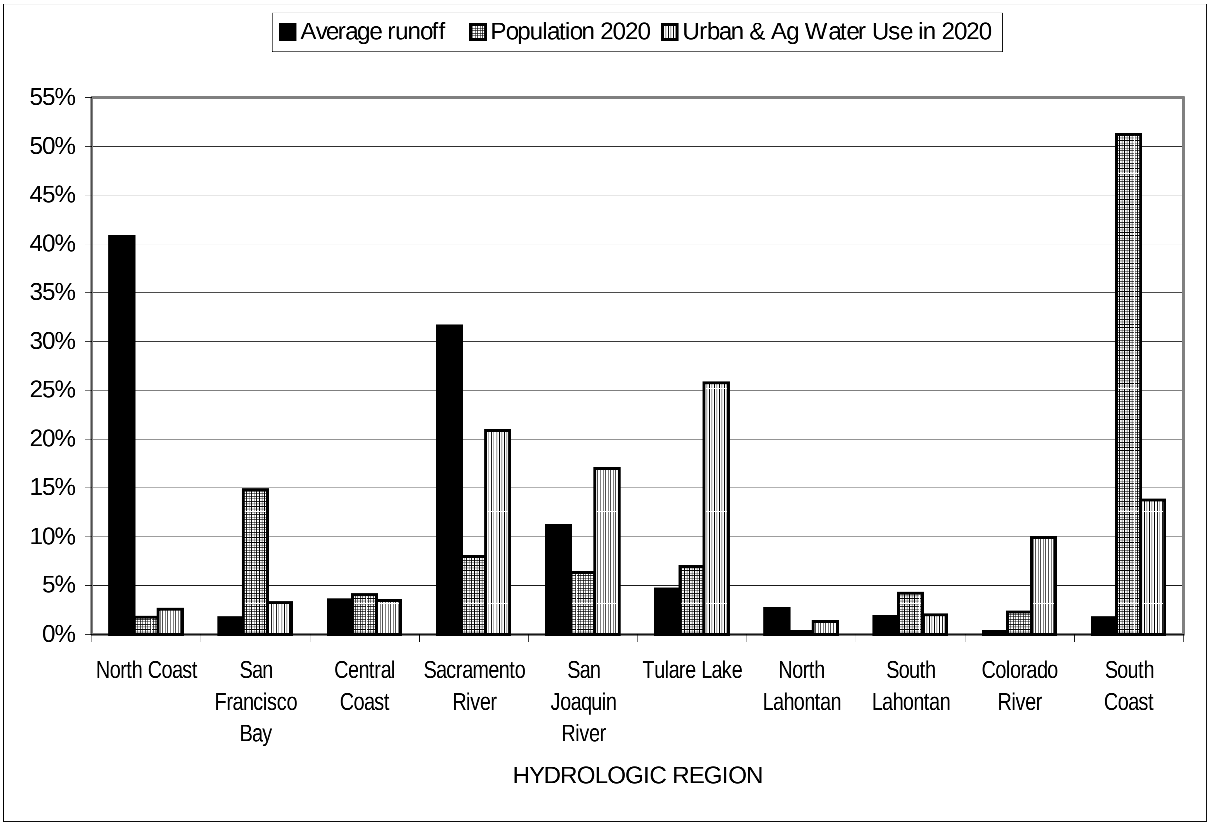
CURRENT PROBLEMS

Current and future predicted water scarcity in California is characterized by many inter-linked problems. These problems include the related issues of water supply availability and reliability, growing and competing water demands for urban, environmental, and agricultural sectors, water quality concerns, and groundwater overdraft. To water agencies, water supply reliability is a goal; to water contractors and individual customers, reliability is necessary for the success of most occupations and pursuits. Reliability changes with the balance between available supply and demand for water of a given quality and cost. Increased demand from urban, agricultural, or environmental sectors can lead to water shortages, as can natural reductions in precipitation and runoff. While less visible, water quality and groundwater are equally important aspects of water supply reliability in California. Many of the state's water supply reliability problems manifest themselves through groundwater overdraft and water quality degradation.

Water Supply Availability and Reliability

California's water availability varies regionally, seasonally, and annually. Precipitation and runoff are unevenly distributed with more than 70% of the 75 maf average statewide annual runoff occurring in Northern California (DWR 1998a). Most Californian's live where water is not plentiful and grow crops where climate and soils are advantageous but local water supply is limited. Figure 2-1 compares the distribution of anticipated population and water use (urban and agricultural) in 2020 to average annual runoff across the ten hydrologic regions of California shown in Figure 2-2. Receiving less than 2% of the average annual runoff, the South Coast hydrologic region is expected to have 51% of California's projected 2020 population. The North Coast and Sacramento River hydrologic regions with 72% of average runoff are expected to have less than 10% of the projected 2020 population.

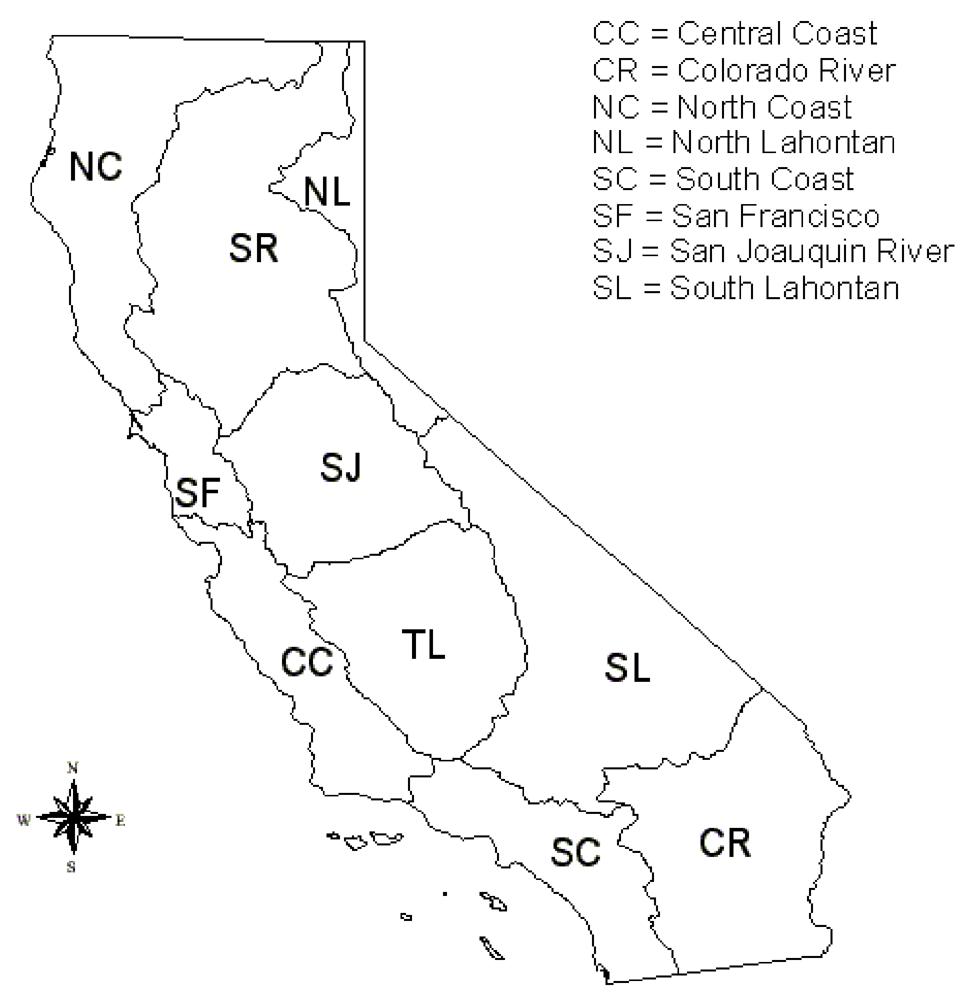
Figure 2-1. Demographics and Hydrology



Source: DWR (1998a)

These regional disparities in water availability and demand in California are compounded by a strong disparity in the seasonal pattern of water supplies and demands. The general pattern of a dry season from May to October and a wet season from November to April is opposite the cycle of high summer and low winter water use in urban and agricultural sectors (DWR 1994a). This mismatch drives the need for water storage to hold runoff for seasonal demands distant in time and place from natural precipitation.

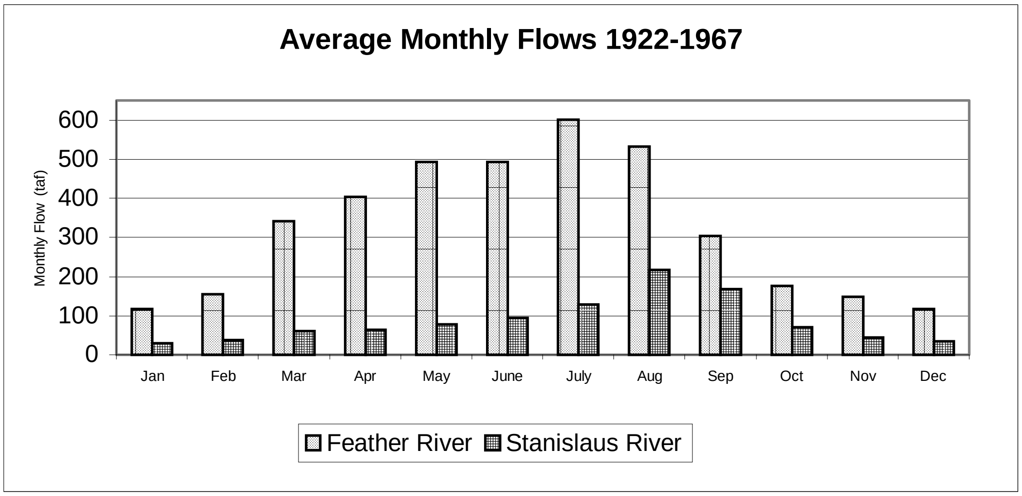
Figure 2-2. Hydrologic Regions and Counties of California



Source: DWR (1998a)

The natural or unimpaired flow in the Feather and Stanislaus Rivers illustrates the wet and dry extremes of California hydrology (Figure 2-3). Monthly flows increase steadily from November to April, when snowmelt usually commences, and then drop precipitously. Some rivers with smaller watersheds, such as the Stanislaus, show a more drastic transition to the dry season after snowmelt, with little or no natural flow in August and September (USBR 1997). Before dam construction, many other Central Valley rivers followed a similar runoff pattern, limiting crop options for Sacramento and especially San Joaquin Valley farmers. After dam construction, river runoff became more predictable and downstream water availability increased during dry seasons. Large imports of stored surface water are now used to supplement local water for most major urban and agricultural areas of the state.

Figure 2-3. Feather and Stanislaus River Monthly Flows



Source: USBR (1997)

Water supply reliability, the ability to meet demands in drought years as well as average years, is often more involved than the construction of a dam to regulate river flow. Major water projects, such as the State Water Project (SWP) and the Central Valley Project (CVP), depend on rainfall, snowpack, carryover storage, pumping capacity from the Delta, and regulatory constraints to meet south of Delta contractor requests (DWR 1998a). With existing facilities, DWR (1998a) predicts the CVP has a 20% chance of making full south of Delta deliveries under 1995 and 2020 levels of development, while the SWP has a 65% chance of making full 1995 deliveries and less than a 25% chance of making full 2020 deliveries. Under the present water supply system in California, Table 2-1 shows predicted shortages for both average and drought water years in 2020.

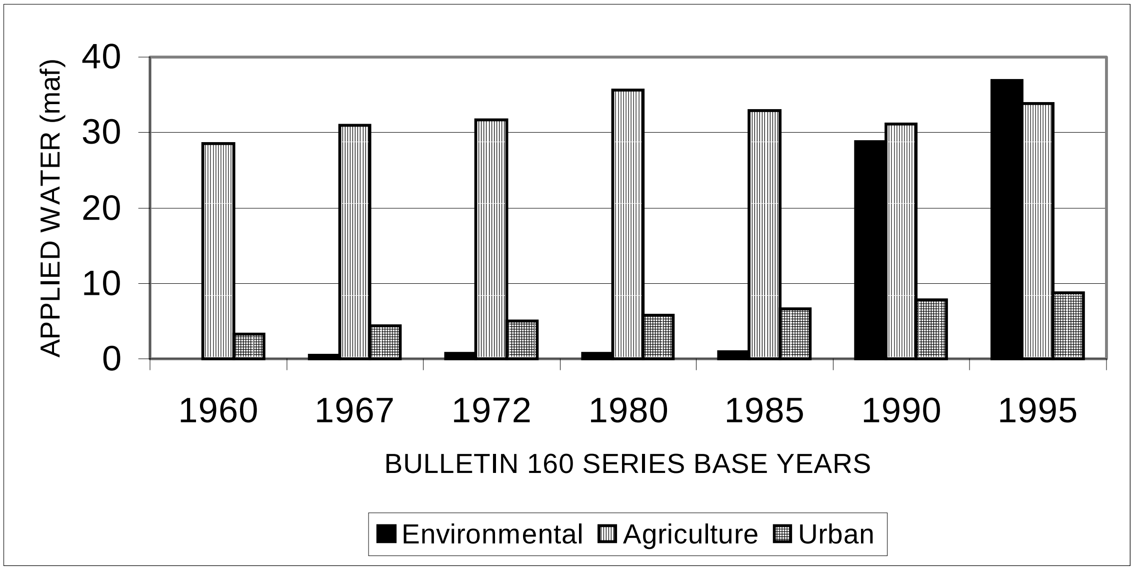
Table 2-1. State-wide Water Supply Shortages

With existing facilities and programs (maf)			
1995 Average	1995 Drought	2020 Average	2020 Drought
1.6	5.1	2.4	6.2
With options likely to be implemented (maf)			
1995 Average	1995 Drought	2020 Average	2020 Drought
1.6	5.1	0.2	2.7

Source: DWR (1998a)

The California Department of Water Resources (DWR) separates California water demand into three categories: agricultural, urban, and environmental. Water demands for all three categories have changed over time, with the greatest changes occurring in the definition and requirements of environmental water demands. Agricultural water use is estimated by multiplying the irrigated acreage of each crop by applied water use per acre. Urban water use is determined by estimates of per-capita use which include residential, commercial, industrial, and governmental portions of applied urban water. Environmental water allocation has increased steadily since approval of the 1957 California Water Plan (Figure 2-4). The most recent California Water Plan update (DWR 1998a) defines environmental water use as: dedicated flows in State and Federal wild and scenic rivers, Bay-Delta outflows, instream flow requirements, and applied water delivered to managed freshwater wildlife areas. The original purposes of most storage infrastructure in the state did not include environmental purposes. Consequently, conflicts have arisen for most of these reservoirs between original and evolving purposes of operation.

Figure 2-4. California Water Allocation Since 1960



Source: DWR (1966, 1970, 1974, 1983, 1987, 1993, 1998a)

<u>Agricultural Water Demands</u>

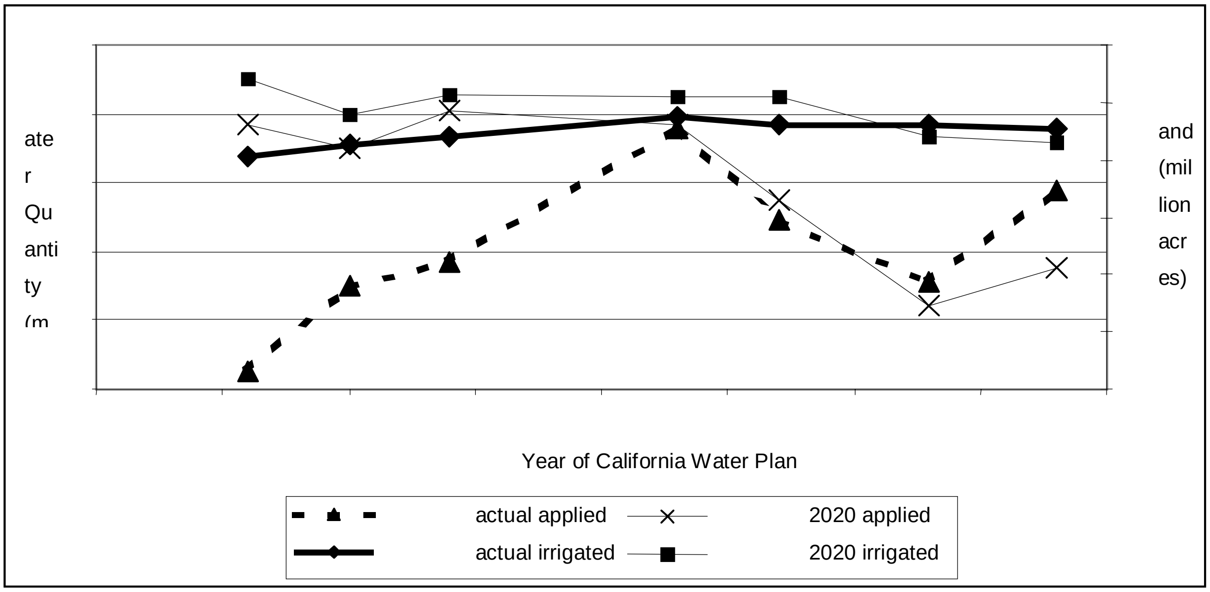
Figure 2-5 shows the evolution over time of “actual” (base year of the update) and 2020 forecasted total agricultural water demands in California according to updates of the California Water Plan starting in 1966. Both irrigated acres (not including double cropping) and applied water are shown. The forecasted 2020 applied water use in 1983 and 1987 is actually for the year 2010 (DWR 1983, 1987).

Before the 1993 update, the acreage of irrigated croplands in California was expected to continue growing as population increased. However, the peak in total irrigated land of 9.7 million acres occurred in 1981, one year after the base year of the 1983 update. Irrigated land declined to 9.1 million acres by 1995, the base year for the 1998 update (DWR 1998a). The last two updates to the California Water Plan (1993 and 1998) forecast a decrease in 2020 agricultural land as urbanization spreads. The latest update indicates a statewide decrease of 325,000 acres by 2020 (DWR 1998a). A regional example is Tulare Lake, which is expected to double in population and lose 5% of its cropland by 2020.

Trends in applied water in Figure 2-5 differ from those for irrigated acreage. An increase in agricultural acreage of 1.4 million acres between the 1966 and 1983 Water Plan updates was accompanied by an applied water increase of 7.1 maf. Much of the increase in agricultural acreage was due to the conversion of previously dry-farmed barley land to irrigated wheat (DWR 1983). Double cropping during this period also increased. Although the 1987 and 1993 California Water Plan updates both report a total irrigated land area of around 9.2 million acres for their respective base years, the amount of actual applied water in 1993 was around 1.8 maf less than in 1987. DWR (1994a) attributes this reduction in applied water to changes in cropping patterns and an average improvement in irrigation efficiency from 60% to 70% during the 1980s.

Actual applied water use then increased more than 2 maf by 1995, the base year of the 1998 update, to nearly 34 maf. The lowest forecasted 2020 applied water quantity was in the 1993 update to the California Water Plan. That forecast was increased by about 1 maf in the 1998 update as a result of increases in actual applied water. Currently, projections for 2020 indicate that average year total agricultural applied water use is expected to decline 7% or 2.3 maf from the current base year of 1995 (DWR 1998a).

Figure 2-5. Agricultural Land Use and Applied Water in California



Source: DWR (1966, 1970, 1974, 1983, 1987, 1993, 1998a)

Notes: Base years for updates are 1960, 1967, 1972, 1980, 1985, 1990, and 1995. The forecasted 2020 applied water use from Bulletins 160-83 and 160-87 is for the year 2010. The 1974 projected 2020 water use and population values are for scenario III, “most reasonable”. Applied water is for average water years (if the Bulletin makes a distinction between average and drought years). Bulletin 160-93 agricultural acreage is normalized, based on averages of the 1980s.

Environmental Water Demands

Environmental regulation has greatly changed water resources planning and management. “Before 1960…damming rivers to store water for irrigation, urban uses, and hydroelectric power production was not regarded as having a serious detrimental impact on the environment” (DWR 1987). “Taming” rivers was simply one aspect of making a region more suitable for human habitation and pursuits. A change in the common perception of wild rivers, perhaps instigated by alarm over the few remaining, occurred in the late 1960s and early 1970s. Two of the first major actions taken were enactment of the Federal and State Wild and Scenic Rivers Acts in 1968 and 1972, respectively (DWR 1970,1974,1998a). These acts effectively cancelled planned development and potential supply on rivers, especially in the North Coast hydrologic region.

Since the Davis-Dolwig Act of 1961 declared “ that recreation and enhancement of fish and wildlife are among the purposes of state water projects…” (DWR 1966), defining and quantifying environmental water demand has been a challenge. Simultaneous with the struggle to quantify environmental demand has been the development of an appropriate definition of what to include. Each successive update to the California Water Plan (see Table 2-2) has made some progress in meeting the challenge, beginning with mention in 1966 of the environmental benefits, especially to anadromous fish, of various mitigation measures. Typically, instream flow requirements are now established to support aquatic and riparian wildlife through maintenance of water temperature and oxygen levels, and the removal of sediments and waste, as well as for recreation. Because the water needs of ecosystems and particular species of concern are not completely understood, decisions on instream flows continue to change with the development of new knowledge.

Table 2-2. Current[a] and Predicted Quantified Environmental Water Use (maf)

Water Plan Update	Current Use	2020 Use	Description
1966	Not quantified	Not quantified	
1970	0.5	0.9	recreation, fish, and wildlife (consumptive use)
1974	0.7	0.8	recreation, fish, and wildlife (consumptive use)
1983[b]	0.7	0.8	recreation, fish, and wildlife (consumptive use)
1987[b]	0.9	1.0	wildlife refuges, energy, conveyance loss, non-urban public parks (consumptive use) <?>
1993	28.8	29.3	instream flows, wetlands, Bay-Delta outflows, some wild & scenic rivers
1998	36.9	37.0	instream flows, wetlands, Bay-Delta outflows, wild & scenic rivers

Notes:
[a] *Current refers to the actual water use estimated in the base year of the Water Plan Update; see notes Figure 2-4.*
[b] *For 1983 and 1987, 2020 use in this table is actually use forecasted for 2010 from these two updates*

Source: DWR (1966, 1970, 1974, 1983, 1987, 1993, 1998a)

Environmental water demand was not quantified in the 1966 update of the California Water Plan. However, monthly fish flow requirements below Lewiston (Trinity River), Whiskeytown (Clear Creek), Keswick (Sacramento River), Nimbus (American River), and Thermolito AfterBay (Feather River) Dams had already been determined by the California Department of Fish and Game and operating agencies. These flows totaled around 2.9 maf per year. The 1970 update listed the consumptive use of water reserved for wildlife management areas. Listed separately in 1970 were streamflow maintenance agreements with the California Department of Fish and Game totaling some 5 maf and including 9 hydrologic regions. It was recognized that these agreements were not sufficient for achieving fishery maintenance or adequate water quality levels.

Prior to the 1993 California Water Plan Update, environmental water demand was defined by consumptive use. Since then computations are similar to consumptive use analysis applied to quantify urban and agricultural water demands. For the first time in the 1993 update, recreation and fishery flow requirements were determined on a statewide basis when DWR presented a summary of present and proposed fishery flows for major California river systems. Based on inter-agency agreements and the “Instream Flow Incremental Methodology” (IFIM), these flows totaled 27.4 maf at the 1990 level of development, the base year for the 1993 update (DWR 1993). The unimpaired flows of some wild and scenic rivers such as those of the North Coast (18.9 maf) were included in this total. The five years between Bulletins 160-93 and 160-98 saw further changes and an increase in environmental water management concerns (see Table 2-2). Ten new waterways were added to the list of rivers with instream flow requirements and several other streams had their required flows increased (DWR 1998a). More changes are likely in the future with passage of the Central Valley Project Improvement Act (CVPIA) in 1992 and other environmental legislation.

The CVPIA, with 800 taf of CVP "yield" dedicated primarily for doubling the Central Valley's anadromous fish population, could mean a significant increase in instream flow for some rivers (DWR 1998a). Because the Environmental Impact Statement (EIS) process for the CVPIA is still underway, and it is not known if supplemental water will be acquired to meet the flow requirements, impacts of this change remain speculative. The implementation of the CVPIA raises many questions, particularly if the water used for instream flow needs can also be used for downstream Bay-Delta purposes.

Water quality concerns began to be addressed in the early 1970s with the Porter-Cologne Water Quality Control Act and Water Rights Decision 1379. The Porter-Cologne Act required implementation of a statewide program to control water quality. Decision 1379 was concerned with Delta water quality and started the process of quantifying necessary outflows. It culminated in 1977 with Decision 1485, the result of over 15 years of research on the development of relationships between Delta water quality and outflow that set new higher water quality standards for the Delta and Suisun Marsh. More recently, the interim order WR 95-6 amended Decision 1485 to better address water quality and flow in the Delta.

Urban Water Demands

Between 1960 and 1995, California's population increased 51% while statewide applied urban water use rose 63% (see Figure 2-6). In the 1960s population increased by 23%, slowed to 14% in the 1970s, and then rose to 21% in the 1980s. Most population growth in California is now due to natural increase rather than immigration. Population-of-birth forecasts during the 1960s and 1980s also were large (Figure 2-6). The latest 2020 forecast population is 47.5 million from a 1995 base year population of 32 million (DWR 1998a).

During the 1960s through 1980s, actual applied urban water increased more quickly than population in California at around 25% per decade. The trend of a greater rate of increase in water use than that of population is not expected to continue. Statewide, urban water use is expected to increase, but the per capita use by 2020 should decline in all hydrologic regions (DWR 1998a). Implementation of urban "Best Management Practices" (BMPs) is estimated to slow the growth of urban water use to 27% for a projected population increase of 33% by the year 2020. CALFED (1999a) expects to further decrease per-capita use of water beyond implementation of BMPs, resulting in a statewide 2020 projected average urban per-capita demand of 203 gpcd, 9% less than the 1995 rate of 224 gpcd.

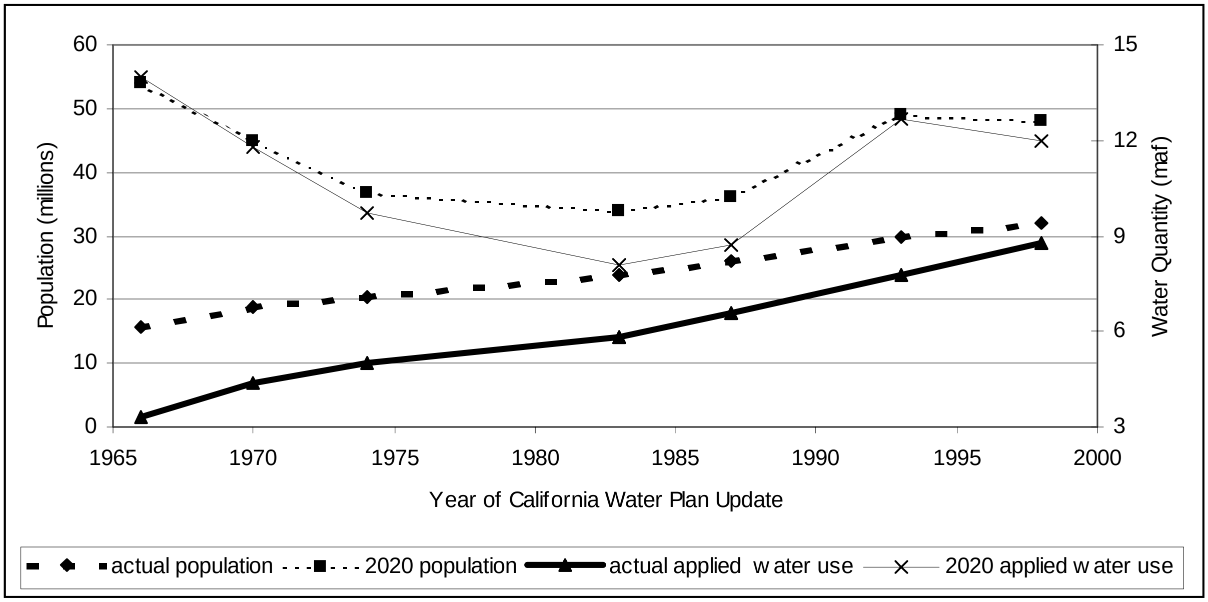
2020 Water Demand Situation

Projected water demands for agricultural, urban and environmental water use reflect several key trends in future statewide water demands (DWR 1998a):

1) stabilization or slight decline of agricultural water demands resulting from land conversion to urban use;
2) agricultural drainage problems in western San Joaquin Valley;
3) greater crop competition in agriculture;

4) significant population increases and urbanization of drier hotter inland and southern areas of the state raising urban water use and the demand for imported water supplies; and increasing water requirements for environmental purposes.

Figure 2-6. Population and Urban Applied Water Use in California



Source: DWR (1966, 1970, 1974, 1983, 1987, 1993, 1998a)

Notes: Base years for updates are 1960, 1967, 1972, 1980, 1985, 1990, and 1995. The forecasted 2020 applied water use in Bulletins 160-83 and 160-87 is for the year 2010. The 1974 projected 2020 water use and population values are for scenario III, "most reasonable". Applied water is for average water years (if the Bulletin makes a distinction between average and drought years).

Groundwater Overdraft

Groundwater provides about 30% of California's agricultural and urban water supplies in an average year. During drought years, more groundwater is extracted, supplying 40% or more of agricultural and urban use. The production of groundwater at the 1995 level of development on average is estimated at 12.5 maf per year (DWR 1998a). Of this amount, 1.46 maf/yr is estimated to be what is called overdraft (see Table 2-3).

A groundwater basin experiences overdraft if extraction is not replenished over time. Overdraft can diminish use of a basin as a supply or as storage. Higher pumping costs, changes in water quality, and subsidence are common consequences of overdraft. Land subsidence affects not only the structures and roads on the land surface, often with negative consequences for flooding, but can also permanently reduce water storage capacity of the aquifer. Banking groundwater for later use has been proposed and used as one remedy to mitigate overdraft. Banking groundwater during wet years is also a water storage option to improve system reliability in dry years.

The expected decreases in average annual groundwater overdraft from 1995 to 2020 levels of development in Table 2-3 are attributed to reductions in irrigated agricultural lands in the San Joaquin River and Tulare Lake hydrologic regions and to conveyance of SWP water through the

Coastal Branch of the California Aqueduct to the Central Coast hydrologic region (DWR 1998a). Increased overdraft in the Sacramento River hydrologic region may be due to expected increases in population, from 2.4 million in 1995 to 3.8 million in 2020.

Table 2-3. 1995 and 2020 Regional Groundwater Overdraft by Hydrologic Region

Region	Average 1995 taf/year	Projected Average 2020 taf/year
North Coast	-	-
San Francisco Bay	-	-
Central Coast	214	102
South Coast	-	-
Sacramento River	33	85
San Joaquin River	239	63
Tulare Lake	820	670
North Lahontan	-	-
South Lahontan	89	89
Colorado River	69	61
Total (rounded)	1,460	1,070

Source: DWR (1998a)

Water Quality Concerns

A reliable water supply delivers not only sufficient quantity, but also water of adequate quality for intended uses. Water quality impacts of urban and agricultural activities, through groundwater overdraft, waste disposal, and other generated pollutants, as well as seawater intrusion, are major concerns in California. Quality determines the utility of water and its environmental impact. Most uses of water are accompanied by quality standards that safeguard the health of communities and ecosystems.

Some of the major constituents and characteristics used to determine water quality are shown in Table 2-4. Different uses have different quality requirements. For example, drinking water standards are more stringent than those designated for irrigation or certain aquatic species. Additionally, urban water quality concerns encompass distribution system requirements. High salinity and total dissolved solids (TDS) levels in municipal water supply can reduce recycling and groundwater recharge opportunities, and decrease the useful life of water system equipment through corrosion (CALFED 1999b).

Table 2-4. A Partial List of Water Quality Constituents and Characteristics

Chemical constituents
Tastes and odors
Human health and ecological toxicity
Bacteria
Biostimulatory substances
Color
Dissolved oxygen
Floating material
Oil and grease
Pesticides
pH
Radioactivity
Salinity
Sediment
Settleable material
Suspended material
Temperature
Turbidity

Source: DWR (1998a)

Each water source has its own particular water quality issues that depend upon its flow history and environmental surroundings, and affect its practical use and reliability. The following water quality issues illustrate the complexity of California’s water quality problems. Such problems are likely to increase and expand as water demand, activities, and water quality standards intensify in the future.

The sensitivity of plants to salinity encourages the practice of leaching salts from agricultural lands to prevent plant toxicity. In the San Joaquin Valley, a salinity cycle (CALFED, 1999b) occurs where salts from the Delta are applied to crops as they are irrigated while the drainage water flowing back to the Delta through the San Joaquin River accumulates more salts from the soil. Attempts to break this cycle have been unsuccessful. For example, when San Joaquin Valley farm drainage was diverted to Kesterson Wildlife Refuge, unintended harm occurred to wild fowl due to high selenium levels in the agricultural drainage water (DWR 1983; Hundley 1992).

Water exported from the Delta is an important supply to southern portions of the state, especially urbanized southern California. As it is transferred through the Delta, water dissolves and accumulates organic compounds (often measured as total organic compounds (TOC)) that then react with the disinfectants used in municipal water treatment. Bromide present in Delta water from tidal mixing with seawater also can react with disinfectants. These disinfectant byproducts (DBPs) are a public health concern which has led to a lowering of maximum levels for some of them and a requirement to remove a high percentage of the DBP precursors (CALFED 1998a; DWR 1998a). The annualized capital and operating cost of removing DBPs and their precursors such as TOC and bromide from Delta drinking water supplies would be close to $0.5 billion dollars annually (CALFED 1999d).

The Colorado River illustrates another water quality problem in California. Colorado River water collects minerals both from natural and agricultural sources and, consequently, has a relatively high salinity level. To meet drinking water standards, the Metropolitan Water District of Southern California (MWD) blends Colorado River water with less salty Delta water before urban distribution (DWR 1998a). The economic costs of blending and salinity damage in the urban sector are large (MWD and USBR 1998).

Along California’s coast, seawater intrusion can accompany groundwater overdraft. The four coastal hydrologic regions all experience some seawater intrusion into their freshwater aquifers used for water supply (DWR 1998a). Measures used to control or reverse salinity intrusion include hydraulic barriers produced by injection wells or percolation artificial recharge, the replacement of groundwater with water from other sources (“in-lieu recharge”) usually imported, and groundwater management programs.

INSTITUTIONAL CHALLENGES

Compounding the interdependent water supply reliability problems discussed in the previous section are institutional issues that are critical parts to current and future resolution. These institutional challenges include:

- regulatory uncertainty created by an evolving institutional context for water management in California, particularly concerning long-term drinking water standards and resolution of the Delta;

- water rights and the need for more flexible water allocation when faced with decreasing water availability and reliability;
- wheeling and access to water supply through more coordinating operations as local, regional, and statewide systems become increasingly interconnected;
- lengthy time required to resolve these uncertain issues, provide institutional assurances, and develop long-term statewide solutions; and
- mechanisms and methods to acquire the substantial financing such plans are likely to require.

The following sections introduce these institutional challenges, several of which are discussed in more detail in subsequent chapters of this report as they affect achievement of alternative option solutions.

Regulatory Uncertainty

The management of water resources is characterized by uncertainty. Climate and hydrology are fundamental uncertainties. Changes in demand for water due to population growth, market changes for agricultural products, environmental concerns, and re-evaluation of the rules regulating water use contribute additional uncertainty. Climate is perceived as beyond control, not so with rules and regulations. As struggles continue to define the least environmentally and socially harmful methods of economically using water, changing regulations are inevitable. Many of the current regulatory disputes that create substantial uncertainty for water supply planning involve water rights and the Delta.

Water Rights

Water rights uncertainty has been a historical impediment to water development and many forms of water management. Such uncertainties data back to the long disputes between riparian and appropriative doctrines in the 1800s and early 1900s (Hundley 1992) and persist today in terms of water rights quantification, specification, and enforcement. Among the many on-going water rights issues are: quantification of pre-1914 and reserved Indian and Federal water rights; Colorado River "Law of the River" implementation; the public trust doctrine; area of origin protections; third party impacts; and groundwater rights (Pisani 1984; Hundley 1992; DWR 1998a).

Water contracts have an unusually significant role in California's water supply. Often, thick hierarchies of lengthy legal contracts are required to allow water to pass from a water rights holder to a final user. These contracts provide a vital source of flexibility for California's water management; think how much more complex water rights would be without contracts. However, contracts inherit the uncertainties of their sources' rights as well as additional ones associated with contract interpretation and implementation. The presence of uncertainties in water rights and contracts will continue to hinder innovation and flexibility, as they have historically.

The Delta

The Sacramento-San Joaquin Delta was identified as the "hub" of the California water system in the 1957 State Water Plan. Most Californians depend on the health and integrity of the Delta for their water supply. The rules and regulations governing the Delta affect its entire watershed and beyond. Inflows of water from both the north and southeast are transferred through and around the Delta to destinations south and west. Both of California's major water projects (CVP and

SWP) draw their water supply through the Delta. The North and South Bay Aqueducts, the Delta Mendota Canal, the Contra Costa Canal, and the California Aqueduct connect directly to Delta flows, while the Mokelumne Aqueduct traverses the Delta (see Figure 2-7 below). At the moment, the Delta's rules and regulations are in flux and highly uncertain, discouraging cross Delta transfers by the "lack of predictability in the timing or availability of project facilities for pumping, conveyance, and storage" (CALFED 1999c).

In 1957, the efficient movement of supply water through the Delta was the main focus of the first California Water Plan. Prevention of "undue loss in transit and impairment in quality" of project water being transported to contractors were the stated goals of a proposed "Trans-Delta System" (DWR 1957). This early Delta solution consisting of an isolated cross-Delta canal on the east side and running through the Delta, plus an Antioch crossing on the west side which siphoned under the Sacramento and San Joaquin Rivers. This concept was replaced by a "Peripheral Canal" in the 1966 Water Plan update which, although authorized by the State, was rejected by voters in a 1982 referendum. Since then, Delta issues have only increased in complexity with time as every update to the California Water Plan has recommended an option for Delta conveyance while none has yet been implemented.

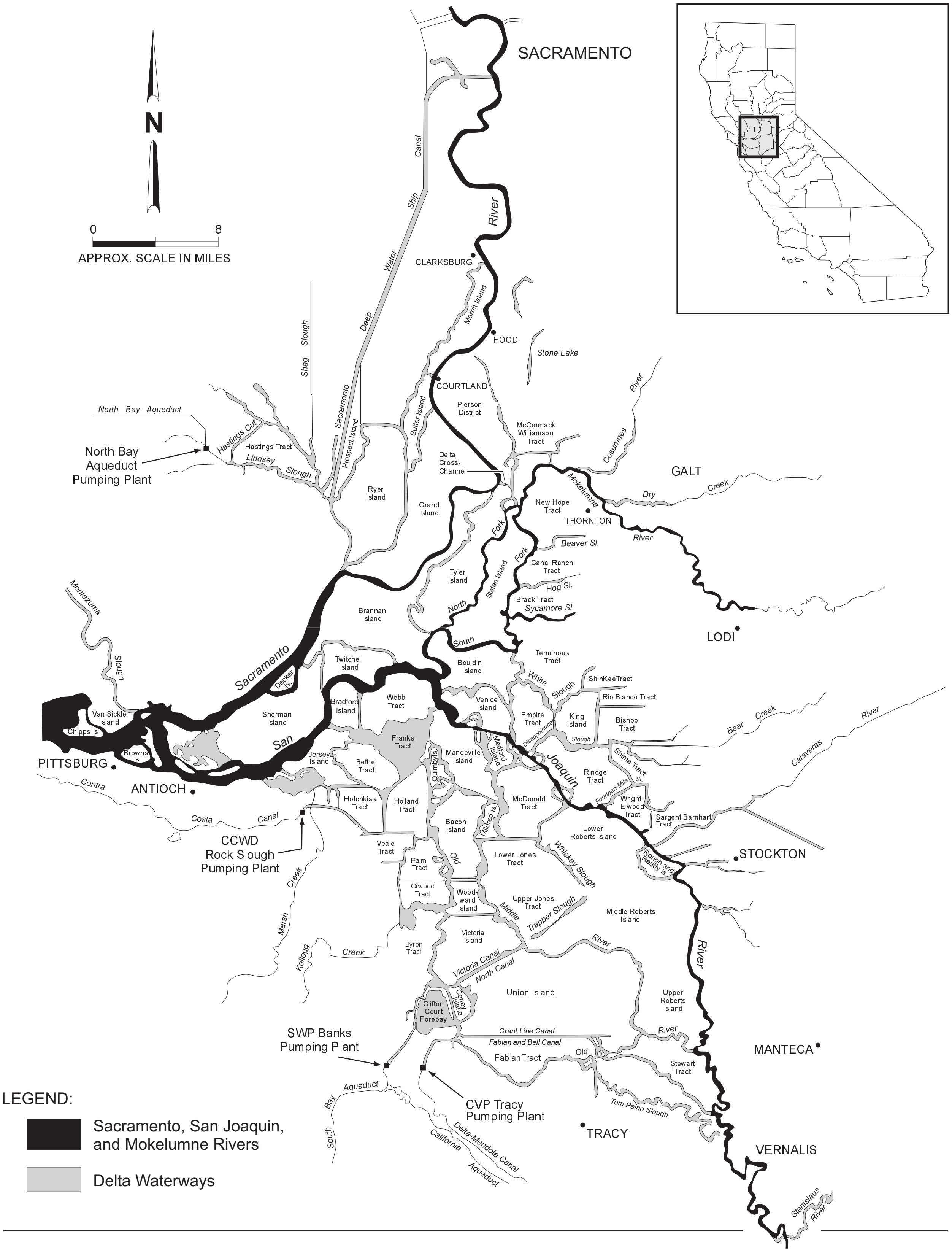
Today, efficient transport is still desirable but not at further expense of the Delta environment. In their *Blueprint for an Environmentally and Economically Sound CALFED Water Supply Reliability Program,* the Environmental Water Caucus (1998) attributes declining species and habitats to regulatory uncertainty in the Delta. Regulatory uncertainty also reduces water supply reliability, and the Delta is where many of California's water problems converge. Much of that uncertainty exists because piecemeal and single-focus projects, surrounded by competing interests, have failed to solve the environmental crisis in the Delta.

The CALFED Bay-Delta Program, a joint state-federal effort, was established in May of 1995 to develop a comprehensive long-term program to deal with four major conflicts in the Delta:

- fish mortality due to water diversions;
- habitat conversion to agricultural or urban use and habitat restoration;
- instream versus out-of-stream needs and the timing of those needs; and
- effect of human activities on water quality and water use.

These conflicts give some insight into the complexity and fragility of the Delta for all parties involved, and the timeline of the CALFED adaptive management process. The many interests in the Delta increases the time required to reach agreement and the likelihood of amendment, adaptation and controversy during or implementation.

Figure 2-7. Sacramento-San Joaquin Delta



Source: USBR 1997

Flexibility in Water Supply Allocation

The allocation of water in California is governed by a myriad of state and federal statutes, court decisions, water rights, contracts, and agreements (DWR 1998a). Reasonable and beneficial use is the basic requirement for all water allocation. Although water rights, contracts, and rules regulating water allocation form the institutional structure of the water system, they often do not adapt well to changing demands and extreme hydrologic events.

Water marketing is a commonly advocated method for flexibly reallocating water, although the transfer of water via statewide water marketing is a relatively new water management option (Lund et al. 1992). Emerging water transfers and markets are being developed by experience, by need, and by regulation. Storage and conveyance requirements are in discussion, as are the associated impacts on the water system and the environment of water transfers. As regulation of water marketing is being refined, so is regulation of other aspects of the State's water resources. Some important water transfer problems are summarized in Table 2-5. More detailed discussion of these issues and the potential role of water marketing and transfers as long-term options for California's water supply appears in Chapter 4.

Table 2-5. Issues in Efficient Water Transfer Development

Category	Issues
Environmental, Socioeconomic, and Water Resources Protections	third-party impacts, groundwater protection, local environmental protection
Technical, Operational, and Administrative Rules	defining transferable water, carriage water, reservoir refill criteria, regulatory process, real vs. paper water
Wheeling and Access to Facilities	cross-Delta conveyance, state or federal facilities use

Source: CALFED (1999c)

Operating Flexibility and Wheeling Water

Institutional arrangements across a variety of water sources can promote operational flexibility and reliability of water deliveries. Several water districts and others have used their access to a variety of water sources advantageously, especially when their supplies proved insufficient. Limits to East Bay Municipal Utility District (EBMUD) supplies were revealed in 1992 when EBMUD informed Dougherty Valley developers that it could not provide reliable service to their recently approved Contra Costa County development. Anxious to begin building homes, the Dougherty Valley developers purchased SWP water from the Berrenda Mesa Water District, water which will be stored in the Semitropic Water Storage District groundwater basin in Kern County until needed (DWR 1998a). Being connected to the SWP through the South Bay Aqueduct allowed them to purchase and store water in Kern County for later delivery to Contra Costa County. Access to the inter-tied water system delayed the need to construct new water supply infrastructure to meet future demand by allowing use of available storage elsewhere in the state.

Both the Metropolitan Water District of Southern California (MWD) and the Mojave Water Agency have found that the potential of local water supply infrastructure can be enhanced by connection to the inter-tied water supply system. The MWD's Eastside Reservoir in Riverside County is expected to fill with both Colorado River and SWP water. Once completed in 2004, the Inland Feeder connection of the East Branch of the California Aqueduct to the Colorado

River Aqueduct will deliver water by gravity to the new reservoir. The intertie between the SWP and Colorado River water gives MWD access not only to two different water sources but also two very different watersheds. Since the 1994 completion of the Morongo Basin Pipeline, the Mojave Water Agency also has access to two very different water sources: their local groundwater basin supply (now in overdraft) and SWP entitlement water. This connection also makes possible a multi-year banking and exchange agreement with the Solano County Water Agency allowing SCWA to bank up to 10 taf of its annual SWP entitlement with the Mojave Water Agency (DWR 1998a).

Blending water from different sources has been one MWD strategy for improving water quality. MWD tries to limit the TDS content of their urban deliveries to between 500 and 550 mg/L. Colorado River water has a higher TDS content (700mg/L) than other MWD sources of water, in particular, SWP water that averages 300 mg/L (DWR 1998a). Blending Colorado River and SWP water can be accomplished in the Eastside Reservoir and by carefully trading and balancing deliveries. MWD has increased its quantity of lower salinity SWP water by trading some of their Colorado River water to Coachella Valley Water District (CVWD) and Desert Water Agency (DWA) for CVWD and DWA's SWP entitlement water. The trade benefits these two agencies who lack the facilities to accept delivery of SWP entitlement water while giving MWD greater opportunity to blend Colorado River water.

Coordination of Water Supplies

Infrastructure options are constructed locally; a dam, canal, recharge area, or water recycling plant has a fixed location. However, any facility may have statewide impact since California is interconnected via the SWP, CVP, and other federal projects. California's inter-tied water system makes possible operational flexibility and an array of coordinated solutions to particular supply problems. To achieve this flexibility and manage impacts in an interdependent system, coordination is needed. The 1957 California Water Plan declares that "future development of the State's water resources must rely, to a constantly increasing extent, on coordinated, comprehensive planning on a state-wide level if the needs of all areas and all uses are to be met in the most effective and economical manner". The coordinated functioning of California's federal, state, and local water supply systems has thus far been made possible through various piecemeal institutional arrangements. More coordinated/cooperative agreements and arrangements are increasingly necessary for consistent, reliable, and efficient water management.

Coordination of operations requires interties between systems. System interties must be both hydraulic and institutional, allowing the system to function physically as well as legally and financially. The 1986 Coordinated Operation Agreement (COA) (see Table 2-6) began the process of cooperation and coordinated operations for the CVP and the SWP to improve both systems' efficiencies beyond what could be accomplished separately. The benefits of cooperation were extended to SWP contractors in the 1995 Monterey Agreement that provided more ways for local water agencies to increase water management flexibility and reliability of existing SWP water supplies. AB 3030 and Chapters 330 and 854 encourage organized planning as the basis for local involvement in the coordinated operations and planning of regional or statewide inter-tied water supply systems.

Table 2-6. Major Statewide Institutional Arrangements in California

Agreement	Description
1986 Coordinated Operation Agreement (SWP and CVP)	SWP wheels water for the CVP CVP water can be sold to the SWP CVP operation in conjunction with SWP to meet Delta water quality standards
1995 Monterey Agreement (SWP)	No initial agricultural water supply reduction in Drought Contractors can transport non-project water in SWP facilities Contractors may store water outside service area
1992 AB 3030	Local agency authority to adopt groundwater Management plans
Statutes of 1995, Chapters 330 and 854	Urban water management plans every 5 years (for 3 taf use or 3000 customers)
CALFED	Wheeling across the Delta is addressed

Source: DWR (1987, 1993, 1998a), Central Coast Water Authority (1995), CALFED (1999c)

Time Requirements of Water Supply Planning

Water supply planning has always been a complex and lengthy process. This is illustrated in Table 2-7 by the long time spans from the beginning of planning to the start of construction for major water supply development projects in California, at federal, state, and local levels.

Table 2-7. California Water Planning Time Requirements

Project Type	Description	Planning Begins	Construction Begins
Statewide	Federal - CVP (final plan in 1931)	1873	1937
	State - SWP (final plan in 1957)	1873	1960
Urban	Los Angeles - Los Angeles Aqueduct	1904	1908
	San Francisco - Hetch-hetchy	1901	1913
	MWD - Colorado River Aqueduct	1928	1933
Irrigation	Imperial Valley[a] - All-American Canal	1901	1929
	MID/TID[b] - La Grange Dam	1890	1891
	MID/TID - Don Pedro Dam	1908	1921
	MID/TID - New Don Pedro Dam	1931	1967
CALFED	Delta Solution	1995	?

Notes:
[a] *Turn of the century settlers began the struggle, became organized in 1911 with the Imperial Irrigation District*
[b] *Joint project of Modesto and Turlock Irrigation Districts*

Sources: Hundley (1992), DWR (1998a), and Barnes (1987)

Shortly after California was admitted to the Union in 1850, the need for a state water plan was recognized (Pisani 1984). Subsequent discussion, by individuals and a federal commission, spanned nearly sixty years before the state legislature began considering a plan. Following the water conference authorized for 1916, a general hydrographic survey was completed in 1923. Preliminary state water plans were introduced in 1923, 1927, and 1931. The 1923 plan was considered too narrow in focus and the 1927 plan failed to define costs and their financing. The more comprehensive 1931 plan was approved, but southern California chose to build the Colorado River Aqueduct on its own and the Central Valley portion of the plan formed the basis of the federal CVP in 1935 (Hundley 1992). Finally, after a century of discussion, design, population growth, politics, California weather, and underlying vision, the 1957 California Water Plan succeeded in getting SWP construction underway in 1960.

Irrigation districts and cities were the earliest groups to implement long-term water planning decisions for water resources in California. Los Angeles, San Francisco, and EBMUD acquired new water supplies each within about 12 years of planning commencement. The three joint Merced Irrigation District/Turlock Irrigation District irrigation dam projects on the Tuolumne River in Table 2-7 demonstrate the increased amount of time between planning and construction commencement with each successive project, as size increased and the 20th century progressed. The last one, New Don Pedro Dam, required more than 30 years to get from planning to the beginning of construction.

The complexity and need for a long-term perspective for water planning remain true today as evidenced by recent California planning activities leading to creation of the CALFED Bay-Delta Program and those now underway as part of this program.

Financing Water Supply Development

Major water supply projects and their management require substantial financing to assure their implementation and continued operations. Historically, this financing has been secured by a variety of traditional methods (see Chapter 4) including large amounts of federal financing. Many of these methods succeeded because, historically, water was viewed as a public good necessary for economic development and federal funding was relatively common. As a more comprehensive worldview has developed, the public good aspect of water has enlarged to include multiple and often conflicting purposes. Consequently, water projects are more thoroughly scrutinized and funding less easily won by voter approval. State referenda and regulations that make many of the traditional financing methods more difficult compound these financial difficulties. Furthermore, federal aid for water resources projects has decreased greatly since the 1980s.

The fundamental financing philosophy of the CALFED program is that the beneficiary, once identified, pays (CALFED 1998a). In anticipation of that identification, cost sharing agreements between beneficiaries and the state and federal governments must be developed, user fees evaluated, and the possibility of private investment considered. Having reasonable insight (such as is available through scenario modeling) into potential economic and other project impacts and how a project works within the context of the entire water system could reveal benefits attractive to different financing options. These ideas are further developed in Chapter 4.

CONCLUSIONS

California's water supply problems are diverse and long-standing. These are summarized as follows:

1) Water is scarce-- water is less available and water quality more impaired than many users would like.
2) Major environmental problems remain unsolved, particularly those associated with the Delta and fish migration and habitat.
3) Water demands for each sector are changing and growing overall.
4) Long-term availability of water for California is decreasing somewhat due to reductions in Colorado River availability, groundwater overdraft in many areas of the state, and increasing water quality requirements.

5) These conditions increase the need for and controversy of long-term and short-term changes in water infrastructure and management.
6) Given the complexity of the system, solutions will require an integration of systematic technical-engineering solutions with political, institutional/legal, economic and financial solutions.

CHAPTER 3

CURRENT STATEWIDE INFRASTRUCTURE OPTIONS

"To try to achieve anything is like digging a well. You can dig a hole nine fathoms deep, but if you fail to reach the source of water, it is just an abandoned well." Mencius (China, circa 300 B.C.) Book VII, PartA, 29.

The Department of Water Resources (DWR) and CALFED are currently considering many different statewide infrastructure options as possible long-term solutions to California's water scarcity problems. Statewide options in the 1998 California Water Plan update include State Water Project (SWP) reliability improvements, water marketing, multipurpose reservoir projects, and the CALFED Bay-Delta Program (DWR 1998a). CALFED has retained 14 surface water and 16 groundwater storage projects for further study in its Revised Phase II Report (CALFED 1998a). USBR is investigating ground water storage sites throughout the Central Valley to replace water dedicated to the environment by the Central Valley Project Improvement Act (CVPIA) (DWR 1998a). Local agencies continue to consider specific local and regional options.

Many of the options under consideration have been studied and proposed previously. While surface storage continues to be an option, the emphasis has shifted to off-stream and existing storage sites. Groundwater storage and water treatment methods also are increasingly important. Conveyance options can improve the reliability of water deliveries and offer mitigation of environmental impacts. This chapter discusses the current spectrum of infrastructure options, from new surface and groundwater storage to conveyance and treatment methods. Non-structural options, such as water marketing and coordinated operations, and their implications for operational, economic, and financial effectiveness are discussed in Chapter 4.

CONTEXT FOR CURRENT OPTIONS

Water in California can be delivered to environmental, urban, and agricultural uses by the Central Valley Project (CVP) and the SWP, from the Colorado River and other federal projects, and through many local projects. The CVP is the largest water supply system with seven main reservoirs constructed starting in the 1930's through the 1970's by the Federal government and having a combined storage capacity of 12 maf (DWR 1998a). The SWP has ten major reservoirs that were constructed during the 1960's and 1970's with a combined storage capacity of 5.5 maf (DWR 1998a). In both 1977 and 1991 CVP and SWP deliveries were curtailed significantly by drought.

Major local urban supply projects include the Colorado River, Mokelumne, Los Angeles, and Hetch Hetchy Aqueduct systems constructed, respectively, by the Metropolitan Water District of Southern California (MWD), the East Bay Municipal Utility District (EBMUD), Los Angeles, and San Francisco. These systems have historically produced average annual yields of 1,000 taf, 240 taf, 400 taf, and 270 taf, respectively. The most recent major urban project underway is the Eastside Reservoir being constructed by MWD in Riverside County to better manage wet and dry year fluctuations in SWP and Colorado River deliveries. To be completed in 1999, the 800 taf reservoir will provide a six month disaster emergency supply, drought protection, and peak summer supply.

Major agricultural supply projects include the All-American and Coachella Canals of the Colorado River system constructed in 1938 and 1947, respectively by United States Bureau of Reclamation (USBR) (DWR 1987), the Turlock Irrigation District (TID)/Modesto Irrigation District (MID) system of canals and reservoirs, the Glenn-Colusa Canal, and so on. For further discussion of the origins and historic development of the CVP, SWP, Colorado River and other major projects in California see Bain et al. (1966), Pisani (1984), Gottlieb and Fitzsimmons (1991), and Hundley (1992).

Since construction of the main elements of the SWP, expansion of water supply infrastructure has been very incremental. Following approval of the 1957 California Water Plan, many supply augmentation options have been recommended. Some options have been implemented, others rejected, and still others resurface periodically as summarized in Table 3-1.

Table 3-1. DWR Historic Recommendations for Water Supply Infrastructure[a]

Water Plan Update	Proposed River Development	Proposed Reservoirs	Proposed Conveyance (Canals, Aqueducts, Pipelines)
1966	Mad Van Duzen Trinity Eel	Marysville, Auburn, Spencer, Dos Rios, **New Don Pedro** (1971), **Buchanan** (1975), **New Melones** (1979), **Hidden** (1979)	Folsom South, Peripheral, West Sacramento, East Side **North Bay** (1987), **Coastal** (1968), **California** (1972)
1970	Cottonwood Thomes-Stony Creek	Marysville, Auburn	Folsom South, Peripheral, West Sacramento, East Side **San Felipe** (1987)
1974	Mad Eel Cottonwood Thomes-Stony Creek	Marysville, Auburn, Dutch Gulch, Tehema	Peripheral, Mid-Valley, **Cross Valley** (1975)
1983	Cottonwood Creek	Auburn, Dutch Gulch, Tehema, Shasta Enlargement, Los Banos Grandes	Folsom South, Mid-Valley, Delta Transfer Facility
1987		Auburn, Los Banos Grandes **Kern Water Bank** (transferred to Kern Water Bank Authority prior to completion)	Mid-Valley, Delta Improvement **East Branch Enlargement** (1996)
1993		Auburn, Los Banos Grandes **Eastside** (1999)	**Coastal Phase II** (1997) **Morongo Basin** (1994)
1998		Auburn, Friant Enlargement, CALFED	ISDP, CALFED

Notes:
[a] *Recommended options shown in **bold** have been constructed with work completed or expected complete in the year given in parentheses*

Source: DWR (1966, 1970, 1974, 1983, 1987, 1993, and 1998a)

The last century has seen the examination of hundreds, if not thousands, of potential reservoir sites in California. The last few decades have seen a more serious examination of off-stream and groundwater storage options. The feasibility of large, watershed-type projects consisting of several new on-stream reservoirs has declined with fewer suitable sites, rising costs, and rising environmental concerns. With passage of the Federal and California State Wild and Scenic Rivers Acts, further development of many North Coast rivers and sections of the American River was precluded. By 1987, most new on-stream reservoir water supply options had been abandoned in order to concentrate on conveyance and additional off-stream storage.

SURFACE WATER STORAGE OPTIONS

Currently proposed new surface water storage options include facilities at on-stream, off-stream, off-aqueduct and in-Delta locations. These options are reviewed and summarized in tables below. The classification of some options as on-stream or off-stream by DWR and CALFED differs. The most recent status of options was reported in CALFED's Revised Phase II Report (CALFED 1998a).

Very preliminary cost estimates are provided for some of these options. CALFED surface storage cost estimates (CALFED 1998a) were initially restricted to environmental documentation and pre-permitting studies. In further developing alternative cost summaries, CALFED (1998b) averaged total capital costs of selected project combinations and then applied these average costs to target regional storage capacities without distinguishing between on-stream and off-stream storage. At a 3 maf development level, Sacramento River tributary surface storage was estimated by CALFED, according to these procedures, to cost $2.9 billion for capital costs, or an average of $954 per acre-foot of storage. San Joaquin River tributary surface storage at a 240 taf level of development was estimated to cost $330 million or $1375 per acre-foot of storage. These estimates are the basis for CALFED costs reported in the following discussions and summary tables unless otherwise noted.

On-Stream Storage Options

On-stream options are summarized in Table 3-2. Of these, Shasta and Millerton Lake enlargements are the only two on-stream options retained by CALFED in its Revised Phase II Report (1998a). This report discontinued pursuit of any new on-stream sites and ended further speculation about Auburn Dam and other previously considered new reservoir construction. Several of the DWR proposed on-stream sites in Table 3-2 are now configured as off-stream sites among CALFED options (see Table 3-3).

Table 3-2. On-Stream Surface Water Storage Options

Reservoir Site	DWR Storage (maf)	DWR Cost Estimate[d] ($M)	CALFED Cost Estimate ($M)	CALFED Storage (maf)
Thomes-Newville[b]	1.4 - 1.9			-
Red Bank[a]	0.35			-
Tehama[a]	0.5 - 0.7			-
Dutch Gulch[a]	0.7 - 0.9			-
Shasta (enlargement)[b]	up to 10 additional	$123 to $5,800		0.29 additional
Kosk[c]	0.8			-
Millville[a]	0.1 - 0.25			-
Wing[a]	0.25 - 0.5			-
Auburn[b]	0.85 - 2.3	$2,300 at 2.3 maf		-
Folsom (enlargement)[b]	0.37 additional			-
Millerton (enlargement)[b]	0.5 - 0.9 additional	$580 at 0.5 maf		0.72 additional

Notes:

[a] *Evaluated by DWR as first tier storage facilities for CALFED alternatives*

[b] *Evaluated by DWR as second tier storage facilities for CALFED alternatives*

[c] *Evaluated by DWR as third tier storage facilities for CALFED alternatives*

[d] *DWR estimates: Shasta: preliminary study estimates, Auburn: capital costs in 1995 dollars, Millerton: in 1997 dollars, does not include property purchase, mitigation, utility relocation*

Sources: CALFED (1998a, 1998b), DWR (1998a)

Millerton Lake is the 520 taf reservoir behind Friant Dam on the San Joaquin River. Increasing the capacity of Millerton Lake is expected to provide supply for CVP water users, fish and wildlife; increase flood control; and improve San Joaquin River water quality with some negative effects on riparian wildlife habitat and infrastructure (DWR 1995b). Instream flow requirements below Friant Dam may change in quantity and timing of required release by an enlargement of Millerton Lake (DWR 1998a). Impacts of such changes are unknown at this time.

Shasta enlargement options listed by DWR range from raising the dam 6 feet at a cost of $123 million to increasing the dam elevation by 200 feet (9.3 maf additional capacity) at a cost of $5.8 billion. DWR, in preliminary studies, cites 760 taf of supply in average years and 940 taf in drought years for a 9 maf increase in storage capacity. These substantial increases in supply also involve unquantified, but probably substantial, financial and environmental consequences. Raising the dam at Shasta Lake 6.5 feet for a 290 taf increase in storage capacity is among the existing reservoir options retained for further CALFED consideration (CALFED 1998a).

Off-Stream Storage Options

Most off-stream storage options listed in Table 3-3 have passed DWR preliminary evaluation and have been retained by CALFED for further consideration (CALFED 1998a). Thomes-Newville and Red Bank are retained by CALFED with some differences in capacity from DWR's evaluation. Thomes-Newville is potentially larger and the Red Bank Project is limited to the Schoenfield Reservoir (CALFED 1998a). The Sites and Colusa off-stream sites were the most promising options identified in DWR's evaluation of very large reservoirs with few environmental concerns listed and minimal impacts assumed. CALFED (1998a) has retained these two options, with similar storage capacities to those of DWR, for further evaluation and screening.

Glenn Reservoir was evaluated by DWR as "second tier" (less environmentally and economically feasible) because of supply uncertainty. It is more likely that the smaller off-stream options that are part of the proposed Glenn Reservoir, such as Thomes-Newville, will be accepted. Berryessa is also second tier because of financial and environmental concerns. Off-stream conveyance of water to Berryessa would require a 31-mile facility with a 700 foot lift and both wildlife habitat and human activities would be negatively affected (DWR 1998a). CALFED (1998a) has not retained Berryessa as a potential reservoir site. Montgomery Reservoir, potentially located on Dry Creek upstream of the confluence with the Merced River, is considered a local option by DWR (1998a), providing drought year supply and collecting flood spills from Lake McClure on the Merced River. CALFED lists Montgomery Reservoir as a potential part of the Bay-Delta Program with an estimated price of $330 million.

Off-Aqueduct Storage Options

Storage south of the Delta has been studied for many years as an important component of SWP reliability. In DWR's evaluation of off-aqueduct storage south of the Delta, preliminary modeling results (DWR 1998a) showed that a few large reservoirs (500 taf or more) imposed less of a cumulative environmental impact than several smaller reservoirs. DWR storage ranges below 500 taf are included in Table 3-4 for easier comparison with CALFED off-aqueduct storage options. The evaluated storage options were ranked first by size, then by cost and environmental sensitivity. The five most favorable watersheds are listed first in Table 3-4 with all related dam sites. CALFED includes a substantial enlargement of the recently completed 100 taf Los Vaqueros Reservoir but does not include Los Banos Grandes (LBG) among the reservoir sites retained in its Revised Phase II Report (1998a).

Table 3-3. Off-Stream Surface Water Storage Options

Reservoir Site	DWR Storage (maf)	DWR Cost Estimate ($M)	CALFED Cost Estimate ($M)	CALFED Storage (maf)
Berryessa (enlargement)[b]	up to 11.5 additional			-
Thomes-Newville[a]	1.4 – 1.9			1.8 - 3.1
Glenn[b]	6.7 – 8.7			-
Sites[a]	1.2 – 1.8			1.2 - 1.9
Colusa[a]	3.0			3.3
Red Bank[a]	0.35			0.25
Montgomery	0.24 (local option)	$300/af [c]	$330 [d]	0.24

Notes:

[a] *Evaluated by DWR as first tier storage facilities for CALFED alternatives*

[b] *Evaluated by DWR as second tier storage facilities for CALFED alternatives*

[c] *Drought year cost for around 35 taf yield, not in millions of dollars, DWR preliminary cost estimate for the project is $135 million*

[d] *CALFED estimate is for total capital costs based on combined average method (see discussion in text)*

Sources: CALFED (1998a, 1998b), DWR (1998a)

Table 3-4. Off-Aqueduct Surface Water Storage Options

Watershed	Dam site	DWR Storage (taf)	DWR Unit Cost[a] ($/af of storage)	CALFED Storage (taf)
Garzas Creek	104	250 - 1750	2950 - 1310	139 – 1754
	105	290 - 630	2400 - 1660	
	106	100 - 310	3300 - 1820	
	107	100 - 250	3300 - 2020	
	108	100 - 250	4010 - 2870	
	109	500 - 940	2250 - 1730	
Ingram Canyon	37	250 - 980	3120 - 1400	333 - 1201
LBG/ Los Banos Creek	181	100 - 2000	3350 - 550	
Orestimba	170	250 - 900	2630 - 1410	380 - 1140
	171	250 - 1140	3000 - 1600	
Panoche/Silver Creek	112	250 - 1000	2250 - 1320	160 - 3100
	111	100 - 240	3480 - 2020	
	114	250 - 2000	3560 - 1210	
	45	500 - 990	2300 - 1920	
Los Vaqueros (enlargement)			2500 (CALFED estimate)[b]	965 additional
Quinto Creek	54	110 - 250	3120 - 2370	332 - 381

Notes:

[a] *These estimated capital costs are based on previous cost estimates developed for Los Banos Grandes facilities (DWR 1998a)*

[b] *From CALFED (1998b) for total capital costs*

Sources: CALFED (1998a, 1998b), Appendix 6G of the California Water Plan Update (DWR 1998a)

Authorized in 1984, the feasibility of LBG as an off-stream storage project was being reassessed in 1993 as Delta rules and regulations changed and SWP contractors expressed concern about costs. In the 1998 DWR evaluation of potential CALFED water storage facilities, Los Banos Grandes was found to be simultaneously the most cost effective and least environmentally sensitive site. In the most recent evaluations by CALFED (1998a), LBG is not retained as an off-aqueduct storage option.

In-Delta Storage Options

CALFED also considers water storage on Delta islands as possible options. Some preliminary studies were done on the flooding of Victoria, Woodward, and Bacon Islands with total capital costs estimated at $1.14 billion (CALFED 1998b). The Delta Wetlands Project, being developed privately, offers Bacon and Webb Islands as reservoirs and proposes two other islands for wildlife habitat (Jones & Stokes Associates Inc. 1995).

Table 3-5. In-Delta Surface Water Storage Options

Reservoir Islands	Storage Capacity	Cost estimates
Victoria, Woodward, Bacon	--	$1.14 billion (CALFED)
Bacon , Webb	250 taf combined	$200 - 250/af for marketed water (private development and estimate)

Sources: Jones & Stokes Associates Inc. (1995), CALFED (1998b)

NEW CONVEYANCE OPTIONS

Generally, canals have been associated with irrigation and agricultural endeavors while aqueducts (pipelines) bring water to cities. Continuing this tradition, the CVP, mainly an agricultural water supplier, has the Delta-Mendota, Folsom South, Contra Costa, Friant-Kern, and Madera Canals. In contrast, the SWP, more of an urban water supplier, has the California Aqueduct with its East, West, and Coastal Branches, and the North and South Bay Aqueducts. As major development of rivers in California has slowed, associated conveyance development has likewise been slowed. For example, instream flow requirements and uncertainties surrounding construction of Auburn Dam have suspended further expansion of the Folsom South Canal and its continuation down the Sierra foothills as the proposed East Side Canal. Intended to remedy groundwater overdraft in the San Joaquin Valley, the East Side Canal option has been replaced by proposed conveyance via an alternate route to achieve this objective (see discussion of the Mid-Valley Canal below).

Nearly all new conveyance facilities proposed by the DWR and CALFED (shown in Table 3-6) directly involve the Delta. As the hub of the California water system, effective transfer of water from north to south is a critically important Delta function. The exception in Table 3-6 is the Mid-Valley Canal designed to bring water to recharge areas of serious groundwater overdraft in the San Joaquin and Tulare Lake hydrologic regions.

Interim South Delta Program

Two purposes of the Interim South Delta Program (ISDP) are to:

- improve the reliability of SWP deliveries by increasing the frequency of full pumping capacity at Banks Pumping Plant; and

- increase the dependability of local irrigation water by improving water levels and circulation in south Delta channels.

Of the five components composing the ISDP preferred alternative (Figure 3-1), three address SWP reliability, one improves fishery conditions, and one enhances local water supply dependability. The CALFED Bay-Delta Program concurs with the ISDP on the new intake structure at Clifton Court Forebay and on an operable barrier on Old River (to improve the survival rate of San Joaquin River salmon) but recommends that Clifton Court Forebay diversions be sized to meet the full Tracy Pumping Plant (CVP) export capacity of 4600 cfs. In addition, it proposes a physical intertie between SWP and CVP, connecting the Delta Mendota Canal (CVP) with the Clifton Court Forebay (SWP), to enhance system reliability for both. Cost estimates for two variations of this intertie are shown in Table 3-6. Additionally, a 400 cfs capacity intertie between the Delta Mendota Canal (CVP) and the California Aqueduct (SWP) was proposed in the Revised Phase II Report (CALFED 1998a).

Table 3-6. Conveyance Facilities

Project	Description	Cost estimate ($M)
Interim South Delta Program (DWR)	Five components leading to an average supply augmentation of 120 taf per year, or 125 taf in an average year and 100 taf in drought years	$53.9
CCFB/DMC Intertie[a] (CALFED)	1) New fish screens at Skinner and Tracy + 2800 linear ft. earth canal; 2) New fish screens at Skinner and Tracy + new intake at CCFB + 2800 linear ft. earth canal	$370 $400
DMC/CAA 400 cfs Intertie[b] (CALFED)	Up to 400 cfs of pumping from the DMC to the CAA possible to overcome conveyance impediments downstream	
5,000 cfs Isolated Facility (CALFED)	Open, unlined channel, diversion at Hood, and siphon under major waterways	$1,100
15,000 cfs Isolated Facility (CALFED)	Open, unlined channel, diversion at Hood, and siphon under major waterways	$1,700
Mid-Valley Canal (DWR)	Beginning at either the CAA or an enlarged DMC, with a north branch nearly parallel to the Madera Canal and a south branch nearly parallel to the Friant-Kern Canal	$600 - $700[c]

Note:
[a] *CCFB = Clifton Court Forebay (SWP), DMC = Delta Mendota Canal (CVP)*
[b] *DMC = Delta Mendota Canal (CVP), CAA = California Aqueduct (SWP)*
[c] *Cost in 1980 price levels from DWR (1983)*

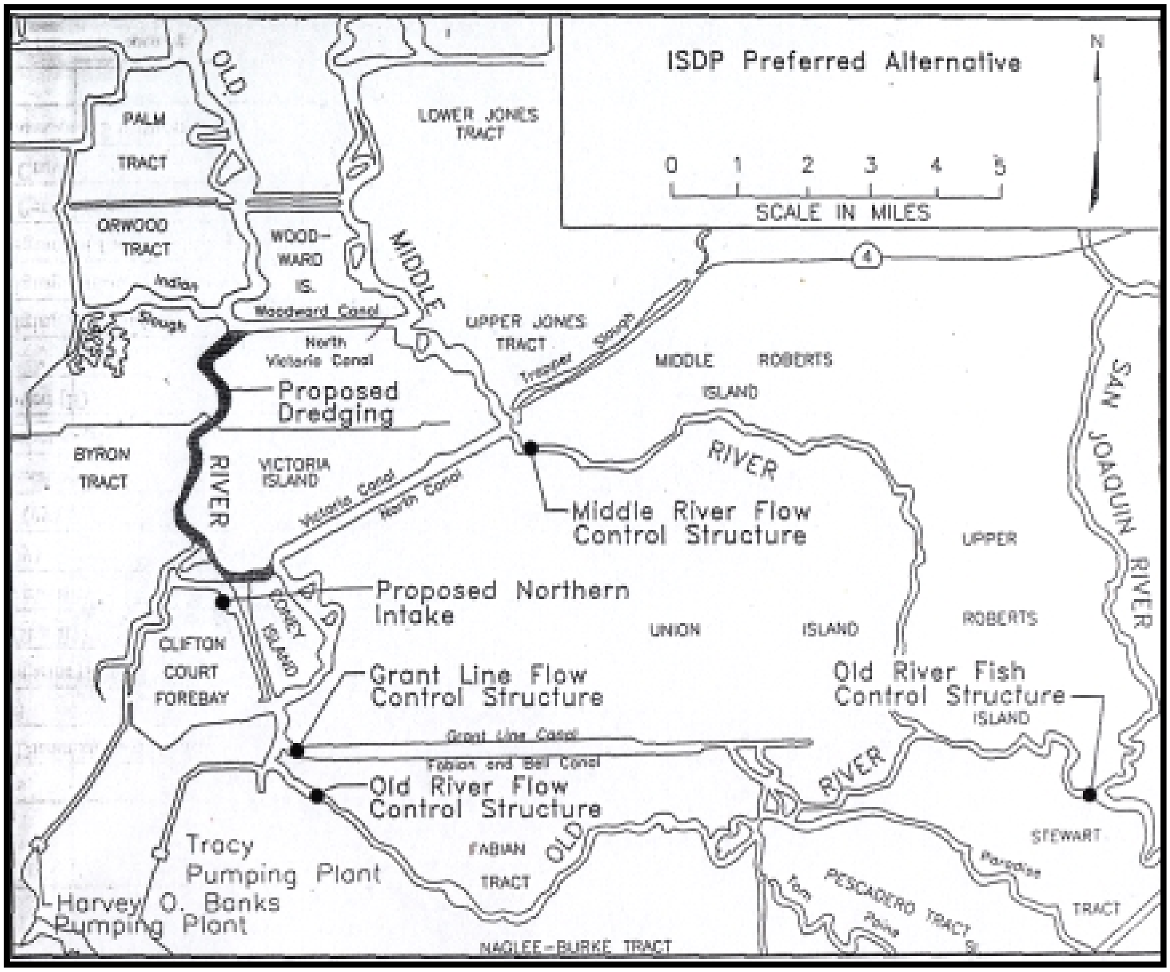
Sources: DWR (1983, 1996), CALFED (1998a, 1998b)

“CALFED’s strategy is to develop a through-Delta conveyance alternative based on the existing Delta configuration with some modification, evaluate its effectiveness, and add additional conveyance and/or other water management actions, if necessary, to achieve CALFED goals and objectives” (CALFED, 1998a). Other CALFED modifications and proposed actions to develop through-Delta conveyance include changes in dredging practices, some channel modifications, and the reconstruction of all Delta levees “to a particular standard…[possibly the USACE] PL 84-99 standard” (CALFED 1998a). With ISDP, full export capacity would be possible from the Delta. Only if these fail will an isolated facility be pursued.

Isolated Facility

Potential CALFED isolated facility configurations are sized from 5,000 to 15,000 cfs. If constructed, the facility would move water in a new canal or pipeline from a Sacramento River diversion at Hood to Clifton Court Forebay. A 5,000 cfs facility could convey about one-third of the full export capacity of the SWP and CVP facilities while a 15,000 cfs facility could supply full export capacity. The main purpose is improvement of export water quality and quantity. By avoiding contact with Delta water via an isolated facility, the salt content and organic compounds of water conveyed south of the Delta are reduced. The impact of an isolated facility on water quality within the Delta is less clear, although entrainment of aquatic species would certainly decrease.

Figure 3-1. Interim South Delta Program Components



Notes: Five project components:

1. *construction and operation of a new intake structure at the SWP Clifton Court Forebay*
2. *channel dredging along a reach of Old River just north of Clifton Court Forebay*
3. *construction and seasonal operation of a barrier in spring and fall to improve fishery conditions for salmon migrating along the San Joaquin River*
4. *construction and operation of three flow control structures to improve existing water level and circulation patterns for agricultural users in the south Delta*
5. *increased diversions in Clifton Court Forebay up to a maximum of 20,430 acre-feet per day on a monthly averaged basis resulting in the ability to pump an average of 10,300 cfs at Banks Pumping Plant*

Source: DWR (1996)

CALFED describes the isolated facility as a likely option for the future only if through-Delta conveyance proves an ineffective means of attaining CALFED Bay-Delta Program goals and objectives. More water storage and an intertie between the CVP and the SWP just south of the pumping plants is expected to increase the possible transfer opportunities through the Delta, while the development of procedures for Delta water transfers enlarges access. Proposed procedures to resolve difficulties encountered in cross Delta transfers include more flexible operating criteria, procedures for access to facilities, and disclosure of transfer windows and risk factors.

Non-Delta Conveyance Options

The purpose of a Mid-Valley Canal is not to bring new agricultural land into production. The 1994 Water Plan update identifies the Mid-Valley Canal as “the best option to develop a long-term solution to the valley overdraft problem” (DWR 1994a). The 1998 update (DWR 1998a) concurs and adds the enhancement potential for wetlands, wildlife habitat, and recreation. CALFED (1998a) does not specifically mention a Mid-Valley Canal but assumes its existence for two groundwater storage options south of the Delta (see Table 3-7). However, this canal option depends on a sufficient increase in water transferred through the Delta, as do most storage options already mentioned.

GROUNDWATER STORAGE OPTIONS

Groundwater storage options were divided into the following categories in Bulletin 160-70: terminal regulation of imported water supplies; regulation of surplus imported water; and conjunctive use. Terminal regulation provides a buffer between uniform monthly deliveries and non-uniform monthly demands. Regulation of surplus water and conjunctive use perform the same service of storing excess water during wet years for latter use in dry years. The 1998 California Water Plan update (DWR 1998a) lists three constraints on using groundwater storage: availability of recharge water; availability of storage capacity; and the wheeling capability of conveyance. Hydrologic regions vary in the severity of these constraints. Although the San Joaquin Valley has over 50 maf of available aquifer storage capacity, limited recharge water availability constrains the amount of water that can be stored in the ground (DWR 1998a). In contrast, the Sacramento Valley has recharge water but aquifer storage availability is constrained. In the following discussion, groundwater storage options are divided by location north or south of the Delta. Conjunctive use options, discussed at the end of this section, coincide with some of these storage locations.

Groundwater Storage Options North of Delta

Table 3-7 shows groundwater storage options that are being investigated north of the Delta by a variety of agencies. Among the list are nine potential locations north of the Delta included in CALFED’s (1998a) preliminary storage inventory. These locations are not specific and in most cases quantities are not determined, pending further study. Total Sacramento Valley groundwater storage for conjunctive use is assumed to be around 250 taf (CALFED 1998a). A representative capital cost for this total storage volume is $57.9 million or $232 per acre-foot of storage. This estimate is derived from the average of the storage capacities and total capital costs for three potential locations (Eastern Sutter County, Thomes Creek Fan, and Yuba County). As an element of CALFED's ongoing Integrated Storage Investigation, groundwater and conjunctive use will be a continuing and important focus (CALFED 1999e).

In the 1998 California Water Plan update, DWR presented groundwater storage options from USBR's *Least Cost CVP Yield Increase Plan*. Locations for these options, reported in Table 3-6, are also general, with each reference to a city in Table 3-6 indicating a different feasible site. Storage capacities for these sites are estimated for comparison purposes. Within Glenn and Yuba Counties the annual yield listed is for predicted developable yield. Yield for the other DWR/USBR options in Table 3-7 is based on active recharge from flood flows on adjacent rivers (DWR 1998a).

Table 3-7. Groundwater Storage Options North of the Delta

General Location	Program/Source	Capacity (taf)	Annual Yield (taf)	Estimated Cost of Storage
Butte Basin	CALFED			
Cache Creek Fan	CALFED			
Colusa County	CALFED			
East Sutter County	CALFED	280		$240/af
Sacramento County	CALFED			
Stony Creek Fan	CALFED			
Sutter County	CALFED			
Thomes Creek Fan	CALFED	220		$245/af
Yuba County	CALFED	280		$213/af
SW and W of Orland, Tehama Colusa Canal and vicinity	DWR/USBR[a]	360[b]	90	
Within Glenn County		N/A[b]	55	
S of Chico, near Wheatland, E. of Sutter Bypas, and NE of Rio Linda	DWR/USBR [a]	280[b]	85	
Within Yuba County		N/A[b]	25	
NW of Woodland and SW of Davis (near Dixon), Yolo Bypass nearby	DWR/USBR [a]	120[b]	30	
NE of Galt, SE of Elk Grove, SE of Lodi, and S of Manteca	DWR/USBR [a]	400[b]	185	

Notes:

[a] *Taken from USBR's "Least Cost CVP Yield Increase Plan"*

[b] *"Capacity is taken to be the amount of water that can be recharged and extracted over any area without causing a water level fluctuation of more than 30 feet compared to historical water levels and has been estimated using a large-scale regional [groundwater] model. Values are not maximums and are used for comparison purposes." (DWR 1998a)*

Sources: CALFED (1998a, 1988b), DWR (1998a)

Groundwater Storage Options South of Delta

Table 3-8 shows groundwater storage options that have been investigated south of the Delta. Total groundwater storage capacity south of the Delta for conjunctive use from among the seven CALFED locations in Table 3-8 is assumed to be around 500 taf (CALFED 1998a). This average capacity and total capital costs of storage were determined using the Kern River Fan, Madera Ranch, and Folsom South Canal Area locations (the Folsom South option is not included in the Revised Phase II Report). At 500 taf of groundwater storage development, the representative total capital cost estimate is $137 million or $237 per acre-foot of storage.

DWR considers two of the south-of-Delta CALFED groundwater storage options as local supply. The 1998 California Water Plan update lists Stockton East as a local option, with re-operation of Farmington Reservoir on Littlejohns Creek of the Stanislaus River for year-round groundwater recharge to reduce persistent local groundwater overdraft. DWR also considers Madera Ranch a local option because it was expected to supply only one group of CVP contractors. USBR has been investigating Madera Ranch for use as a water reserve account, but not specifically as a conjunctive use option to replace CVPIA water dedicated for environmental purposes. Surplus water from the Delta, probably conveyed to the Mendota Pool would be used for its recharge. As with the DWR/USBR "Least Cost CVP Yield Increase Plan" options north of the Delta, each reference to a city in Table 3-8 indicates a different site estimated to be feasible. The combined evaluated storage capacity of these DWR/USBR south-of-Delta groundwater sites is over one million acre-feet with an estimated annual yield of over 500 taf.

Table 3-8. Groundwater Storage Options South of the Delta

General Location	Program/Source	Capacity (taf)	Annual Yield (taf)	Estimated Cost
Stockton East	CALFED DWR (local)		8[e] to 22	$100/af storage
James ID/Raisin City WD, Mid-Valley Canal reaches 1-3	CALFED			
Kern River Fan	CALFED DWR	930 up to 1000	up to 140[e]	$257/af storage
Madera Ranch	CALFED DWR (local)	350 390	70	$328/af storage $226/af yield
Mendota Pool (N Branch Mid-Valley Canal)	CALFED			
Mojave River Basins	CALFED			
Semitropic WSD	CALFED DWR	900	114	
NW of Volta, Oro Loma	DWR/USBR[a]	275[b]	200	
N of Modesto	DWR/USBR[a]	100[b]	20	
E of Atwater, NE of Merced, W of La Vina, NE of Red Top	DWR/USBR[a]	350[b]	140	
N of Raisin City, S of Kingsburg, S of Hanford, W of Visalia, SW of Tipton	DWR/USBR[a]	Unknown	125	
W. of McFarland, SW of Bakersfield	DWR/USBR[a]	500[b]	50	
Kern Water Bank	DWR[c]	3000[d]	400[d]	

Notes:

[a] Taken from USBR's "Least Cost CVP Yield Increase Plan"

[b] "Capacity is taken to be the amount of water that can be recharged and extracted over any area without causing a water level fluctuation of more than 30 feet compared to historical water levels and has been estimated using a large-scale regional [groundwater] model. Values are not maximums and are used for comparison purposes." (DWR 1998a)

[c] Capacity and annual yield describe the original project before transfer to the KWBA (DWR 1997)

[e] Drought year estimate

Sources: CALFED (1998a, 1998b), DWR (1993, 1997, 1998a)

The Kern Water Bank (KWB) was developed in cooperation with the Kern County Water Agency to increase SWP dependability through increased storage of local water supplies, and to reduce local effects of groundwater overdraft. The original proposed project consisted of eight elements: Kern Fan, Kern County Water Agency Improvement District Number 4, Water Storage Districts of Semitropic, North Kern, Cawelo, Rosedale-Rio Bravo, and Kern Delta, and Buena

Vista and West Kern Water Storage Districts jointly (DWR 1993). Since transfer of KWB control from DWR to the Kern Water Bank Authority and the sale of the Kern Fan element property to designated agricultural contractors (directed by the Monterey Agreement), the project elements have often been referred to separately. Some of the smaller elements, such as Buena Vista and Cawelo, are now listed as local groundwater storage options in the 1998 California Water Plan update.

Conjunctive Use

The recharge of groundwater basins in wet years is a natural consequence of floodwaters. As floodwaters are controlled, natural recharge often diminishes and must be managed. One effective management method is conjunctive use in a groundwater basin. Conjunctive use projects, sometimes called groundwater banking, emulate natural processes by recharging an aquifer during wet years in preparation for drought.

Most hydrologic regions have some groundwater banking/conjunctive use projects to augment drought water supplies. Class II water from the CVP, generally only available in wet years, is used for recharge by Friant-Kern contractors in the Tulare Lake hydrologic region. This groundwater banking operation (Kern Water Bank) has been underway since 1985. The use of groundwater instead of surface water during the last drought enabled Sacramento Valley agriculture to continue, and made surface water available for downstream uses. MWD has a policy of discounting pricing for winter season deliveries to encourage groundwater recharge (DWR 1998a). DWR estimates an average of 100 taf/year of supply is produced as a result of this policy. The MWD has also identified the potential for 200 taf of additional groundwater supply during drought through development of local basin storage capacity.

Although the effects of conjunctive use projects can be regional or statewide, their individual scope is usually local. Table 3-9 lists new local conjunctive use options retained by DWR in the last update (DWR 1998a) some of which coincide with options in Table 3-7 and 3-8. Several projects with insufficient documentation and those with yields less than a thousand acre-feet per year are excluded from the list (DWR 1998a). Conjunctive use options lacking feasibility studies or environmental documentation include several banking projects in the Colorado River region and a joint EBMUD/San Joaquin County project. The Colorado River projects are under discussion by MWD and others. The EBMUD/San Joaquin County project would provide out-of-service area storage and improved system reliability for EBMUD during drought years while reducing groundwater overdraft in the San Joaquin County basin under consideration. In the Central Coast region, groundwater is the primary water source and overdraft induced saltwater intrusion is a major problem. Conjunctive use projects in this region serve the dual purpose of reducing such impacts of groundwater overdraft and providing supply during drought.

As noted earlier under groundwater storage options, CALFED (1998a) estimates storage capacity for preliminary studies of conjunctive use to be about 250 taf and 500 taf in the Sacramento and San Joaquin Valleys, respectively. Withdrawal and recharge capacities of these CALFED groundwater storage options, for study purposes, are designed at around 500 cfs (DWR 1998a). However, DWR (1998a) cautions that currently “a lack of recharge water limits opportunities for conjunctive operation in the San Joaquin Valley”.

WATER RECYCLING AND DESALINATION OPTIONS

Water recycling and desalting have been researched, methods and technologies tested, and pilot plants run for decades. Over the past decades these two options have held out promise for water supplies. Because they tend to be fully within the control of local agencies to plan, design, and build, these options are often considered local although their impacts can have regional and statewide significance. CALFED (1999b) notes that although recycling can have a regional or statewide impact, projects are local and locally funded. In contrast, other new supply development projects have been planned, financed, and built by regional, state, and federal agencies. To remedy this disparity somewhat, federal cost sharing is now authorized through the Reclamation, Recycling and Water Conservation Act of 1996 and the Water Desalination Act of 1996 (DWR 1998a). The following sections provide some background to and present the statewide status of current recycling and desalination infrastructure options.

Table 3-9. New Local Conjunctive Use Options Retained by DWR[a]

Region	Projects Retained	Project Name/Comments	Potential Yield Drought (taf)	Costs of Yield
North Coast	0	Limited by aquifer storage	-	$150/af
San Francisco Bay	2	Milliken Creek Lake Hennessey/Conn Creek	2 5	$150 - 280/af
Central Coast	2	College Lake Seaside Basin	2 1	$130 - 410/af
South Coast	1	Local groundwater banking	130	$350/af
Sacramento River	2	New wells (Redding, Butte, and Colusa Basins)	-	$30 - ?/af
San Joaquin River	2[c]	Stockton East Water District Madera Ranch	8 (22)[b] 70	$100 - 230/af
Tulare Lake	4	City of Clovis Kern Water Bank Buena Vista Water Storage District Cawelo Water District	11 339 29 13	$50 – 280/af
South Lahontan	0	Declining groundwater levels, lack of surface water, adjudication and recharge with SWP water	-	
North Lahontan	0	Groundwater uneconomical replacement for surface water, wildlife impacts	-	
Colorado River	0[d]	Coachella overdraft, MWD study to stabilize the basin and bank water using Colorado water	-	

Notes:

[a] *Table 3-8 shows new conjunctive use projects under DWR consideration. It does not catalog existing conjunctive use applications.*

[b] *Yield goes up to 22 taf for average conditions*

[c] *EBMUD/San Joaquin option not retained by DWR because study is not yet complete*

[d] *MWD option not retained by DWR because study is not yet complete*

Source: DWR (1998a)

Water Recycling

Although not discussed in the 1966 update, recycling wastewater has been studied by the DWR at least since the preparation of Bulletin 67 in 1959. By 1970, recycled water was being used at Golden Gate Park in San Francisco, by the Whittier Narrows Water Reclamation Plant in Southern California for downstream groundwater recharge, and in San Diego County (DWR

1970). The 1974 Water Plan update described reclaimed or recycled water as the "primary alternative to further surface development for meeting California's future water needs" (DWR 1974). Unplanned water recycling has always occurred in inland watersheds through use of return flows. Planned water recycling is a more recent and generally a coastal phenomenon driven by increasing demands on a finite freshwater supply. Planned water recycling was expected to become an increasingly significant part of the water supply in 1974, especially in the South Coast region where wastewater is discharged largely to the ocean.

Benefits of water recycling include new supply, reduced wastewater discharge, and improved water quality. DWR only counts new supplies generated from recycling when the outflow of treated wastewater would otherwise flow to a salt sink or the ocean. Currently, coastal discharge of wastewater is more than 2 maf and is expected to exceed 3 maf in the next 20 years (CALFED 1999b). CALFED (1999b) considers water recycling a significant means to improve water supply reliability in California, one of the primary objectives of their program. From their perspective, benefits of water recycling include reduced demand for Delta exports (improved availability of Delta supplies for all purposes), improved timing of diversions, increased carryover storage, reduced fish entrainment, reduced discharge of treated wastewater into useable surface water, and improved water quality.

In 1995, DWR and WateReuse Association of California conducted a survey of planned water recycling in the state amounting to 577 taf by 2020 (DWR 1998a). Most respondents planned to use the recycled water for irrigation, either for landscaping or agriculture. Out of 211 uses mentioned in the survey, 63% were for irrigation, 15% for industrial use, 10% for groundwater recharge, 6% for seawater barriers, 2% for environmental purposes, and 7% were listed as "other". Many of the planned recycling projects listed more than one use for their reclaimed water. Water reuse figures for 1995, shown in Table 3-10, also demonstrate that the dominant uses are irrigation and groundwater recharge.

Table 3-10. 1995 Total Water Recycling By Category

Category	Amount (taf/year)	Percent of Total
Agricultural Irrigation	155	32
Groundwater Recharge	131	27
Landscape Irrigation	82	17
Industrial Uses	34	7
Environmental Uses	15	3
Seawater Intrusion Barrier	5	1
Other[a]	63	13
Total	485	100

Notes:
[a] *Includes snow making, dust suppression, fire fighting and recreational ponds.*

Source: DWR (1998a)

Cost is often the limiting factor in development of a recycled water supply, although relative cost has decreased as more stringent treatment is required for wastewater disposal. Other factors that may offset cost are California Water Code definitions of waste and unreasonable use in the application of potable water to non-potable purposes, and the increasing scarcity of available fresh water supplies for growing urban populations.

The potential for additional water recycling by 2020 is significant (Table 3-11). The base level of 577 taf of water recycling for 2020 includes the current 485 taf (Table 3-10) plus full capacity production at existing plants and completion of new plants currently under construction (DWR 1998a). Additional options by 2020 in Table 3-10 are based on the 1995 DWR and WateReuse Association of California survey. The two major options under study are the Bay Area Regional Water Recycling Program and the Southern California Comprehensive Waste Reclamation and Reuse Study. The South Coast region generates the most new water through recycling. As a regional option likely to be implemented by 2020, the South Coast plans to repurify 367 taf per year at $500 per acre-foot. The San Francisco and Central Coast regions also plan to implement more water recycling programs by 2020, enough to produce 24 taf and 29 taf per year, respectively, both at around $500 per acre-foot (DWR 1998a). Major impediments to water recycling include salt management, treatment and redistribution costs, and a lack of public acceptance for potable reuse. If these can be overcome, “statewide urban water recycling could reach over 2 maf annually” (CALFED 1999b).

Table 3-11. 2020 Water Recycling Options and Resulting New Water Supply

Projects	Total[a] Water Recycling (taf/year)	New[b] Water Supply (taf/year)
Base	577	407
Potential Options	835	655
Total	1412	1062

Notes:
[a] Base includes the 485 taf at 1995 levels shown in Table 3-9
[b] New water supply means that portion of the recycled water that would have otherwise been lost to a salt sink or the ocean according to DWR

Source: DWR (1998a)

Water Desalination

Bulletin 160-66 identified four methods of desalination: distillation, membrane, crystallization, and chemical processes. In 1966, it was expected that distillation would be used on seawater and membrane processes such as reverse osmosis on brackish water. By 1974, DWR (1974) noted that there was virtually no water supply produced by desalting in California. Updates to the California Water Plan have identified cost, especially the cost of energy, as being the limiting factor in the development and use of desalination. Desalting costs increase with feedwater salinity. Thus, brackish groundwater recovery and wastewater desalting, with their significantly lower salt content than seawater, are more readily pursued, except where seawater is the only likely source or supplemental source of supply (Table 3-12). Generally, economical desalting of seawater remains unrealized at this time. Currently, 89% of the installed desalting plant capacity in California is reverse osmosis where at least 50 percent of the operating costs are energy (DWR 1998a).

Table 3-12. Statewide Current Desalting Plant Capacity and Costs

Type	Groundwater Recovery	Wastewater Desalting	Seawater Desalting
Installed Capacity	45 taf/year	13 taf/year	8 taf/year[a]
Cost Range	$300/af - $900/af[b]		$1,000/AF - $2,000/af[b]

Notes:
[a] Most on standby as drought reserve
[b] From South Coast region estimates

Source: DWR (1998a)

Although desalting is not mentioned by DWR (1998a) as a statewide supply augmentation option likely to be implemented by the year 2020, the South Coast and San Francisco hydrologic regions both have brackish groundwater recovery listed as likely local options. While the current seawater desalting capacity of 8 taf is included as average and drought year supply for DWR's 2020 projections, seawater desalting research continues. MWD, in cooperation with the federal government and the Israel Science and Technology Foundation, is completing final design of a research distillation plant with plans to demonstrate that a full scale plant could desalt seawater at a rate of 85 taf per year for $1000 per acre-foot.

CONCLUSION

California has a wide variety of infrastructure options available for improving long term water supplies. These options all entail considerable expense, and would provide benefits which would vary seasonally and yearly, based on hydrologic and demand conditions. More importantly, the benefits of such new facilities are likely to depend greatly on how the sizing and operation of each facility is integrated into California's already complex water supply plumbing system. The integration and operation of structural options has significant institutional and non-structural aspects essential to the effective operation of California's water supply system. The integrated economic and engineering analysis methods of this research project, described in Chapter 6, provide a technical approach to assess the performance and benefits of these available infrastructure options, at statewide, regional, and local scales, under different operating alternative.

Looking over the range of structural options available, some bits of conventional wisdom emerge:

1. Few new surface water storage options appear attractive compared with many groundwater storage options;

2. The availability of water and conveyance to service new storage is a major additional problem and cost for almost any new storage facility;

3. Water reuse has become a significant augmentation option, though limited by cost and the unacceptability of reuse;

4. Desalination has become more economically viable for water recycled and brackish waters, but has yet to become a significant option for seawater treatment in California.

CHAPTER 4

FINANCE AND OPERATION POLICY OPTIONS

> "As Elche [in Spain] ... the water belongs to parties who do not own the land. The land has no rights. When the farmer needs water, he buys it as he buys any other article. There is a daily water exchange, where one may buy the use of water in an irrigating channel for twenty-four hours, beginning at six in the evening. The prices that are stated to have been paid in times of scarcity, tax our credulity very much." *Report of the Board of Commissioners on the Irrigation of the San Joaquin, Tulare, and Sacramento Valleys of the State of California* (1873), p. 132.

A variety of finance mechanisms and policy approaches exist for managing water delivery and storage systems in California. A complex combination of federal, state, and local water agencies operate an inter-connected system that provides water for urban, agricultural, and environmental water uses. Table 4-1 reflects the historical involvement of public water supply agencies in development of California's water supply. Each level of government uses distinct methods of financing and water allocation. Private ventures have historically and are currently being proposed to complement governmental efforts in water supply.

Table 4-1. Reservoirs[a] Built by Different Levels of Government

Construction Date	Federal	State	Local/Regional[b]
pre-1940	5		23
1940-1949	3		3
1950-1959	8		11
1960-1969	8	6	17
1970-1979	5	4	3
1980-2005	1		3[c]
Total Number	30	10	60

Notes:

[a] *Only those of 50 taf or more are included in these numbers.*

[b] *Local/Regional includes reservoirs operated and maintained by local agencies, even though many of these reservoir were designed and constructed with significant federal assistance.*

[c] *Los Vaqueros Reservoir and Eastside Reservoir are included here.*

Source: DWR (1993)

This chapter describes the traditional finance and water allocation methods of federal, state, local, and private water systems and then discusses new methods of finance and water allocation arising out of recent drought conditions in California. These new methods include privatization, water transfers and marketing, and innovative institutional arrangements. An inextricable relationship exists between finance and water allocation methodology; traditional methods of finance such as federal government loans and grants complement more traditional methods of water allocation based on project contracts. Some traditional finance methods can cause conflicts and/or are incompatible with proposed allocation methods such as water marketing and water transfers. Likewise, new finance methods such as privatization may be ill-suited with traditional water allocation methods. The interactions of finance and water allocation policies are a major difficulty for long term water supply planning.

TRADITIONAL CALIFORNIA WATER INFRASTRUCTURE FINANCING

Water infrastructure has historically employed numerous government financing methods. This section briefly discusses conventional public financing options and then reviews financing historically adopted by federal, state, and local water agencies.

Conventional Finance Options

Conventional mechanisms to finance public water infrastructure include such things as user fees, taxes, bonds, grants, and loans as summarized in Table 4-2. User fees and taxes are often collected to repay bonds and loans obtained to finance up front construction costs and other expenditures. They also provide funds for recurrent operating costs.

Table 4-2. Summary of Finance Options for California Water Infrastructure

- User Fees (for transportation, administration, water) collected from
    - Agricultural water contractors
    - Urban water contractors
    - Hydropower contractors
- Bonds (one time full funding or incremental project bonds)
    - General Obligation
    - Revenue
    - Mello-Roos or Assessment Bonds
    - Revolving Funds
- Grants and Loans (Federal, State, and Other)
- Tax Revenue
    - General Revenue
    - Earmarked taxes on
        - Property
        - Sales
        - Special assessment districts
- Special Districts
- Private Financing (design, construction, ownership and/or operation by private sector)

User Fees/Taxes

Fundamental to most water financing schemes is the concept of user fees, where the individual benefiting from a project pays for the use of a facility by a unit of water delivered, a unit of watered contracted, or some combination of the two. Private, local, or regional water agencies sometimes derive funds from tax revenues. Tax revenues may be collected from general tax revenues or from earmarked taxes allocating a specific amount towards a particular project. Earmarked taxes are collected from property holders, sales, excises, or from special assessment districts composed of those who receive direct benefit from a project.

Taxes and user fees are often limited by the willingness to pay and are unable to cover large initial capital costs. In these cases, water agencies seek revenue from bonds, loans, and grants. Loans and grants entail a large financial commitment from a single funding source, often too great of a commitment. As a result, bonds have been one of the most commonly employed methods of public finance.

Bonds

Bonds occur in the form of general obligation bonds, revenue bonds, assessment bonds, and revolving funds. Designed to finance projects benefiting the community as a whole, general obligation bonds are secured by the “full faith and credit” of the water agency. Full faith and credit of a water agency involves invoking the agency’s “ad-valorem” taxing power, a difficult task in California considering the institutional resistance to more taxes. Aside from simple unpopularity, new taxes require a two-thirds majority voter approval in California, a consequence of the passage of Proposition 13 in the late 1970s. Such a voter consensus is virtually unheard of in water resource management in California (DWR 1998a).

Given the difficulties with general obligation bonds, other forms of bonds have become more commonplace. Revenue bonds have been employed as an alternative since they do not require an agency’s pledge of full faith and credit. Debt service for revenue bonds is paid from revenues generated from the financed infrastructure, via charges for hydropower and water delivery.

Mello-Roos bonds are another type of bond that does not require direct voter approval. They were introduced in the 1982 Mello-Roos Community Facilities Act. Mello-Roos bonds are paid through assessment levied on property benefiting from infrastructure improvements and are secured by placing a lien of the same property (CDAC 1990).

Revolving Funds

Revolving funds also are used by water purveyors to cover costs that exceed user fees. In a revolving fund, a grant is obtained from different financing sources and placed in a fund that can be borrowed against. Loans are then repaid to the fund with interest. Government entities will usually loan the fund out again in a revolving fashion while a private entity may wish to profit from the generated interest.

Shared Facility Financing

Many water infrastructure projects involve the sale or sharing of facility capacity, enabling smaller governmental or private entities to benefit from a large pool of financial resources. A single farmer would seldom be able to solely finance the construction of an irrigation canal. On the other hand, a mutual ditch company, a collection of farmers, has the capacity to accumulate enough resources for such infrastructure. Sale and sharing of facility capacity occurs at and between all levels of government.

Special Water Districts

California water supply has historically been developed by several thousand water districts established under 32 general and special acts of the state legislature (Porter et al. 1987). Smaller local districts are useful in stabilizing water supply needs of a local region by their ability to contract for imported water. Financing of infrastructure can come from tax assessments when allowed in the enabling legislation of a water district. Additionally, California water districts have the power to create sub-units in their service area known as improvement districts that can finance even more specific activities benefiting the inhabitants of their districts. Much of the water district enabling legislation allows great flexibility in the services provided to customers. These many kinds of special districts are not only a means to provide innovative financing via taxes and user fees, but also provide the flexibility to implement market solutions to water issues.

Private Involvement

With the contemporary wave of deregulation, private involvement in water resource infrastructure is being more widely explored. Private contracting by water agencies has traditionally been limited to consulting services, but private financing of water infrastructure investments may prove attractive to decision makers and private investors given the right circumstances.

Availability of Finance Options

Financing methods available to water agencies generally depend on agency size (Table 4-3). Self-financing is usually reserved for small projects in larger water agencies. Larger projects are generally paid through debt financing. Large water agencies have access to more financing options, from the conventional to the innovative. Smaller agencies must be innovative or qualify for a state or federal financial assistance program (DWR 1998a). Although federal aid for water resources projects has been decreasing since the 1980s, loans and grants for some specific objectives can be obtained. The state also funds particular types of water development, such as conservation/groundwater recharge facilities and water recycling (DWR 1998a).

Table 4-3. Financing Methods Typically Available to Water Agencies

Method	Small	Intermediate	Medium	Large
Self-financing			X	X
Short-term financing				
Fixed rate notes				X
Commercial paper				X
Floating rate demand notes				X
Conventional long-term financing				
Equity shares or stock			X	X
Bonds (GO and revenue)				X
Lease revenue bonds				X
Innovative long-term financing				
Bond pools	X	X	X	X
Privatization	X	X	X	X
Water transfers	X	X	X	X
Financial assistance programs	X[a]	X[a]	X[a]	X[a]

Notes:

[a] *State and federal loan and grant programs have limited application for private water agencies.*

Source: DWR (1998a)

Historical Finance of Water Infrastructure

Financing of water infrastructure has cycled from being composed of significant efforts by private and local entities (late 1800s and early 1900s), to intensive federal involvement (1900-1970) to the current period where local and private financing is actively sought, as reflected in Table 4-1. These efforts have been greatly complemented by active state involvement between 1960 and 1980 with the SWP. This section describes some historical examples of federal, state, local and regional, and private water infrastructure financing efforts.

Federal Financing: Central Valley Project

In 1922, the California state legislature, governor, and electorate approved the construction of the State Central Valley Project. Finding difficulty marketing the appropriate bonds and attracting Federal grants or loans to finance the project, the state asked the Federal Government to complete the construction of the CVP soon after its conception (USBR 1992). Congressional authorization and government directives (summarized in Table 4-4) have historically provided the financing of the CVP. These are reviewed next.

Table 4-4. Federal Laws and Directives Affecting CVP Finance

Law or Directive	Year	CVP provisions
Reclamation Act	1902	Legal basis for authorization of CVP
Reclamation Project Act	1939	Repayment of construction charges extended from 10 to 40 years plus a 10 year development period; authorized water sales to municipalities and irrigation users
Water Services Contracts	1944	Delivery quantities of irrigation and urban water to contractors
Water Right Settlement Contracts	1950	Supplementation of CVP water to riparian and senior appropriative rights holders on the Sacramento and American Rivers
Reclamation Project Act	1956	Right of renewal of long-term contracts with agricultural contractors not to exceed 40 years
San Luis Authorization Act	1960	San Luis Unit and financial participation in development of recreation
Reclamation Project Act	1963	Right of renewal of long-term contracts with urban contractors not to exceed 40 years
Reclamation Reform Act	1982	Concept of full-cost pricing, interest on unpaid pumping plant investment, and irrigation water deliveries to leased lands; increased acreage limitation to 960 acres
Public Law 99-546	1986	DOI and USBR directed to include total costs of water including distributing and servicing it in CVP contracts (capital and operation & maintenance costs)
CVP Improvement Act	1992	Significant changes to CVP legislative authorization (see effect of CVPIA)

Source: USBR (1992, 1997)

The Reclamation Act of 1902 established the Reclamation Fund, providing the legal basis for federal financing of the CVP. The Act defined the purposes of Reclamation projects, uses of Reclamation water, and provisions for repayment of Federal investment. Finances were to be developed from the sale of public land and directed towards surveying, constructing, and maintaining irrigation works (Wahl 1989). Initially, the Reclamation fund was set up as a revolving fund, with western settlers supposed to make repayments within a 10-year period. However, additional appropriations became so routine that the idea of a revolving fund was abandoned. Repayment difficulties in pre-CVP irrigation projects were severe enough to instigate an extension of the repayment period to 40 years under the Reclamation Project Act of 1939 (RPA of 1939), 12 years before Lake Shasta, the largest CVP reservoir, began to release water.

As the principal contracting authorization for the CVP, the RPA of 1939 allowed for two types of contracts: repayment contacts and water service contracts (Wahl 1989). The former contracts amortize capital costs over the repayment period in annual installments, with the fixed annual charge independent of the amount of water delivered. The later contracts levy a combined capital and operation and maintenance charge on each acre-foot delivered to the district. Both types of contracts are interest free with the ability to be adjusted downward dependent on a users' ability to pay. By the 1960s, the "average cost of service approach" was failing to fulfill the repayment obligation of the CVP as water rates were too low and the fixed rate contracts did not produce enough revenue. Th option to increase annual operating and/or capital investment costs was not covered under the original rate structure.

Pre-1982 CVP operation led to tensions with the California Department of Water Resources (DWR 1982). In a 1982 reconnaissance study, DWR found that: (1) CVP power sales had created a $150 million deficit in the previous decade in addition to not recovering operation and maintenance (O&M) costs; (2) many irrigation districts failed to pay their own O&M costs; (3) CVP contractors had repaid only one quarter of the cost of building the project despite the 37 year time period since construction; (4) failure to share protection of the Delta during drought years threatened the achievement of SWP objectives; and (5) potential water and energy savings could result from coordinated operation of the SWP and CVP by a single entity (DWR 1982).

After a series of partial reforms, the Reclamation Reform Act of 1982 (RRA of 1982) implemented “full cost” pricing. Interest payments were now included, although interest charges accruing between the time of construction and the date of RRA of 1982 were forgiven. Wahl (1989) demonstrates that the RRA “full cost” covers a range of 3 to 87 percent of actual full financial costs of irrigation water supply—the discrepancy mostly a result of forgiving past interest. Another important reform within the RRA of 1982 was the increase to 960 of the 160 acre farm size limitation established in the 1902 legislation. An extensive literature exists discussing the history and effects of the acreage limitation provision (Hogan 1972; USBR 1981; Wahl 1989; Hundley 1992)

To increase its yield and to help maintain the flows necessary to maintain the Sacramento-San Joaquin Delta water quality, DWR sought to purchase CVP water. In 1986, USBR and DWR entered into the Coordinated Operations Agreement, establishing the amount of CVP and SWP water needed to maintain water quality standards. Increased operational flexibility and efficiency would theoretically make 1 million af of CVP water available for contracting, water that DWR could purchase at the inexpensive CVP contractor rates (Wahl 1989).

The irrigation districts’ subsidized interest rate before 1982 and long repayment periods have led to water costs highly favorable for agriculture. Electricity and urban water users have historically paid their portions of the cost of constructing the project, while federal contributions to financing construction and operation of irrigation projects have covered about 85 to 90 percent of all irrigation-related project costs (Congressional Budget Office 1997). Given inequities associated with federal cost allocation policies, projected water supply shortages have led to increasing interest in changing CVP operation and cost allocation methods.

State Financing: The State Water Project

Subsequent to the completion of the CVP, Governor Edmund G. “Pat” Brown made a state owned and operated water project one of the highest priorities of his administration (Hundley 1992). The result of Brown’s toils and negotiation with 31 water districts and agencies was the State Water Project (SWP). Similar to the CVP, the SWP is largely financed and operated pursuant to legislative mandates and agency directives summarized in Table 4-5.

Table 4-5. Laws and Directives Affecting SWP Finance

Law or Directive	Year	CVP provisions
State CVP Act	1933	Authorized construction of State Central Valley Project (failed due to depression but used later to fund SWP)
California Water Resources Development Bond Act (Burns-Porter Act)	1960	Authorized issuance of $1.75 billion in general obligation bonds, subject to vote in Prop. 1
Proposition 1	1960	Enacted Burns-Porter Act; passed by 2,857,586 to 2,791,942 votes
Contracting Principles for Water Service Contracts	1960	Initiated cost allocation procedures, water rate determination, and a pledge of each contractor to ensure repayment of any and all charges
Table A Entitlements of Water Service Contracts	1965	Determines annual and maximum amount of water to be delivered to contractors
Monterey Agreements	1994	Agricultural deficiencies eliminated; potential transfer and retirement of Table A entitlement allowed; increased operational flexibility; SWP financial security ensured.

Sources: O'Connor (1994a)

Capital expenditures for the SWP totaled $5.84 billion as of 1999 (DWR 1999). Capital expenses include initial project facilities, Delta and Suisun Marsh facilities, power generation and transmission facilities, general construction expenditures, and a variety of other capital costs. Capital costs have been financed from five distinct sources shown in Table 4-6. SWP derives financing first from the California Water Fund consisting of state receipts of tideland oil revenues. Pursuant to the Burns-Porter Act, general obligation bonds can only be issued after this fund is used up. One of the largest sources of funding for SWP construction has been the Initial Project Facility Bonds, general obligation bonds issued after the California Water Fund was spent. Of the $1.75 billion bond authorized in the Burns-Porter Act, $1.48 billion has been used to finance SWP construction. Although the 1933 state CVP Act never produced a state CVP, DWR was authorized to issue CVP revenue bonds for the construction of SWP facilities including water system revenue bonds issued for the construction of non-power related SWP facilities such as the East Branch enlargement.

Table 4-6. Funding Sources for SWP Capital Expenditures[a]

Source	$ Billion
California Water Fund	0.51
Initial Project Facility Bonds	1.48
CVP Revenue Bonds	1.16
Water System Revenue Bonds	1.96
Miscellaneous Sources	0.73
Total	5.84

Notes:
[a] *Up to 1999*

Source: DWR (1997)

Operating expenditures for the SWP totaled $11.26 billion by 1999 as shown in Table 4-7. Included in this total is: operation, maintenance, and power; deposits in reserves for replacement of existing SWP facilities; interest payments; and, capital resource expenditures. To recover these costs, DWR has collected the majority of repayment from annual water contractor payments for transportation, availability (via the Delta Water charge), SWP expansions, and Water System Revenue Bond surcharges. Additional funding comes from various other sources. These cost recovery mechanisms have generated $0.36 billion in surpluses that are applied to California Water Fund repayment and capital expenditures.

Table 4-7. Funding Sources for SWP Operating and Debt Services Costs[a]

Source	$ Billion
Water Contractor Payments	9.48
Capital Resources Revenues	0.80
Interest Earning on Operating Revenues	0.44
Revenue Bond Proceeds	0.46
Miscellaneous Sources	0.44
Total	11.62

Notes:
[a] *Up to 1999*

Source: DWR (1997)

The State has depended on the ability to pass bonds for construction. The difficulty of this approach was demonstrated from the first passage by a small majority of votes (52.5% for and 47.5% against) of the Burns-Porter Act in 1960.

Improving SWP financing is hampered by the difficulty of achieving a consensus among interested parties (SWP contractors, DWR financial advisors, environmental groups, etc.) about what elements need improvement (O’Connor 1994b). Many improvements and criticisms of SWP financing were addressed in the Monterey Agreement negotiations (discussed later) and are summarized by O’Connor (1994b). Criticisms reflect discontent with the wide annual variation in SWP cost-per-af, the high cost-per-af of SWP water, an economically inefficient repayment system, an apparent lack of frugality by DWR, and contractor payments in excess of operation, maintenance, and loan repayment.

Local and Regional Financing: Los Angeles Aqueduct and Hetch Hetchy Financing

Early in the 20th century, as urbanization rapidly progressed in Los Angeles and San Francisco Bay areas, numerous municipalities sought to secure future growth with the acquisition and expansion of their water supplies from distant sources. For local and regional water agencies, user fees and system revenues account for most of the operating costs and a portion of the capital costs. Debt financing is the primary option used to cover capital costs.

Financing construction of the Los Angeles Aqueduct (LAA) could not have been achieved without the shrewd mind of William Mulholland, who instituted water metering directly after his appointment by the City of Los Angeles. Volumetric water fees encouraged more frugal water use and produced $1.5 million of profit in four years (Hundley 1992). Yet the major accomplishment of Mulholland would be in “conserving” a water source 233 miles outside the City’s limits. Aside from having to side step several political issues, an angry group of Owens Valley residents, federal permission to build an aqueduct overlying their lands, and purchasing water rights at elevated prices, Mulholland had to accumulate $25 million to complete the system, an immense amount of money in 1905. Winning the support of the Board of Water Commissioners and the LA city council, Muholland was able to secure $24.5 million of municipal bonds in two elections ($1.5 million in 1905 for the necessary water rights, and $23 million in 1907 for construction). Stimulated by contemporary drought hysteria and some of Mulholland’s hyperbole, the city’s voters eagerly passed these bonds to prevent the oncoming “water famine” (Hundley 1992).

In northern California, San Francisco faced a similar water shortage, despite being located next to San Francisco Bay where two-thirds of California’s natural runoff emptied into the Pacific. Equally as difficult in terms of political opposition, San Francisco’s financing approach was different from that of Los Angeles. San Francisco chose to ask for bonds in increments, resulting in a final cost of $100 million, $23 million more than the original estimate. Although much of these costs can be attributed to technical difficulties, Hundley (1992) asserts that the incremental financing approach was largely responsible for delays and excessive costs (the LAA was largely finished in 1913, while the Hetch Hetchy Aqueduct failed to deliver water to San Francisco until 1934.

Regional water agencies, such as MWD, use similar methods to finance capital costs. The most recent MWD financing of capital costs include $2 billion to build the Eastside Reservoir (to be completed in 2005) and the Inland Feeder (to be completed in 2003). MWD (1997) estimates 80 percent of this capital expenditure will be debt financed, and the remaining amount funded directly from water sales revenues.

One common difficulty for regional water agencies with several member districts is determining the appropriate water rate. These water rates are a complex composition of water availability, demand, and local conditions. When sales are greater during dry years, water rates will generate more plentiful revenues than average year sales. To maintain a steadier stream of revenues, MWD employs a rate stabilization fund. During dry years, excess water sales revenue is deposited in the fund. When followed by wet years, the fund serves as MWD’s first source of reserves and is used to cover costs that would normally entail a water rate increase.

Private Financing

At the end of the 19th century, before construction of the LAA and Hetch Hetchy aqueducts, water supply development relied on private industry financing. Los Angeles’ water supply was controlled and managed by the Los Angeles City Water Company prior to the reign of Mulholland and continually suffered from excessively high rates and poor service. This situation caused Los Angeles residents to issue an amendment to their city’s charter declaring that “no…water rights now or hereafter owned…shall be conveyed, leased, or otherwise disposed of, without two-thirds of the qualified electors” (Kahrl 1982; Hundley 1992). San Francisco faired similarly prior to the Hetch Hetchy undertaking when the Spring Valley Water Works, a private company, angered residents by providing an inadequate supply at excessive rates.

Following the dramatic period of federal and state involvement in developing water supply and the more recent period of stagnation in infrastructure development, the ideas behind private involvement in water infrastructure and provision have once again become a topic of discussion among California’s water managers. Privatization can be generalized to include any situation when the private sector becomes involved in design, financing, construction, ownership, and/or operation of a public facility or good. Several forms of privatization have been in place for long periods of time in the forms of consulting and construction. Recently, with the de-regulation of the electric and gas industries, interest has increased in investigating more active private sector involvement in water supply. However, many issues should be considered before any privatization or de-regulation of water supply goes forward, from the perspective of both water users and the private sector.

NEW DIRECTIONS IN FINANCING AND OPERATING WATER SUPPLY

This section presents some alternative finance mechanisms and water operations that have arisen in recent droughts, in response to CVP and SWP water allocation and repayment problems and the increasing importance of environmental water uses. As indicated in Chapter 2, water contractors were not the only water users dramatically affected by water shortages. The drought also significantly reduced flows with adverse consequences to fish and wildlife. Locally, systems such as the LAA came under increased scrutiny, as the increased diversions exacerbated damage to fish and wildlife. Several significant alternatives to the traditional finance mechanisms and water allocations of the CVP and SWP occurred in response to the 1976-77 and 1987-92 drought periods. These include, among others, significant legislation and contractual changes (including the ongoing CALFED process), the Drought Water Bank, water transfers, and groundwater banking. Droughts have also motivated increased use and consideration of demand management options.

CVP Changes

The allocation of CVP water was altered dramatically by passage of the Central Valley Improvement Act of 1992 (CVPIA). The CVPIA gave fish and wildlife mitigation, restoration, and enhancement equal priority with water supply and power generation. A brief description of CVPIA provisions appears in Table 4-8. Implementation of the CVPIA has proven especially difficult and remains one of the focuses of the CALFED process.

Table 4-8. CVPIA Provisions and Implications

Provision	Implications
Renewal of CVP Water Service Contracts	Most of the CVP water service contracts, except those for fish and wildlife purposes, are not allowed to be executed until environmental restoration activities are completed; renewal is limited to a 25 year period; contracts are to include CVPIA provisions such as tiered water pricing.
Transfers of Project Water	Transfer of project water outside of CVP service area is allowed under restricted conditions; water districts can veto transfers only if the transfers reallocate more than 20 percent of their CVP allocation; parties given the power to block a potential transfer are the Secretary of the Interior and SWRCB, only under justified conditions.
Fish and Wildlife Restoration	USBR is required to “dedicate and manage annually 800,000 af of CVP yield for the primary purpose of implementing the fish, wildlife, and habitat restoration purposes and measures…” authorized by the CVPIA (§3406(b)(2) of CVPIA); physical restoration measures; surcharge on CVP water and power contracts for creation of a Restoration Fund.
Land Retirement	DOI authorized to initiate an agricultural land retirement program for lands that “are no longer suitable for sustained agriculture production because of permanent damage resulting from severe drainage or agricultural withdrawals, or other causes…”

Source: DWR (1998a)

SWP Changes

Parallel to major changes in operation of the CVP, SWP contractors signed the Monterey Agreement in 1994. The agreement attempts to alleviate many of the difficulties arising out of the drought of 1987-1992. Provisions of the Monterey Agreement include (State Water Contractors and DWR 1994):

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.
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.

Drought Water Banks

Prior to the Monterey Agreement, DWR and USBR implemented Drought Water Banks and exchange agreements to deliver water from agencies with excess supplies to areas of dire need starting in 1977. The 1977 Emergency Drought Act granted the Secretary of the Interior authority to facilitate water purchases from willing sellers and deliveries to willing buyers. However, fixed administrative prices prevented sellers from receiving any profit or benefit from the trade and consequently restricted the amount of trading. USBR purchased 46,438 af of transfers at a cost of $2.25 million. Of this purchase, 42,544 af were delivered to buyers for $2.58 million (Wahl 1989).

With the experience acquired in the 1977 drought, the state implemented the Drought Water Banks (DWB) of 1991, 1992, and 1994. A breakdown of DWB purchases and allocations appear in Table 4-9. These banking arrangements allowed the State to act as water broker, while water contractors served as clients. Wahl (1994) and Howitt et al. (1992) examined the 1991 and 1992 droughts, concluding that the water bank had broken ground on water market implementation, although implementation improvements should be made before another drought bank is operated.

Table 4-9. Drought Water Bank Purchases and Allocations (taf)

	1991	1992	1994[a]
Supply:			
Purchases	821	193	222
Delta and instream fish requirements	(165)	(34)	(48)
Net supply	656	159	174
Allocation:			
Urban	307	39	24
Agricultural	83	95	150
Environmental	----	25	----
SWP carryover	266	159	----
Total allocation	656	159	174
Selling price ($/af)[b]	175	72	68

Notes:

[a] Includes deliveries for the SWP

[b] Price to buyers south of the Delta at Banks Pumping Plant. Includes the cost of the water, adjustments for carriage losses and administrative charges. Does not include transportation charges that have ranged form $15 to $200/af depending on the point of delivery and other factors.

Source: DWR (1998a)

Despite the problems of hurried formation and fixed prices, the 1991 DWB was a great success. By selling 390,000 af, the bank equilibrated water supply and demand under conditions of extreme drought, and in doing so, generated a substantial net economic surplus for California's economy. The actual quantity of water sold by the DWB was small in comparison to the total use. However, the price of water sold during the drought set a value for all potentially tradable water. Thus, the operation of the DWB changed the value of most of the State's water. This ability to increase the value of water without an increase in cost to the farmer is a politically acceptable way of sending the signal to users of the true value of water.

The 1991 DWB generated direct benefits for the State economy by creating a net gain in income of $104 million and net employment gains of 3,740 jobs by trading water from lower value to higher value uses (Howitt et al. 1992). The drought of 1987-91 continued in 1992 with improved water supplies, but drought conditions. Accordingly, the DWB was continued in 1992. Given the improved water supplies, the 1992 bank operated at a lower purchase and sale price and smaller quantities (see Table 4-9). Water was not purchased by fallowing crops in 1992, and supplies came from surplus reservoir storage (20%), and groundwater substitution (80%).

In 1992, total DWB purchases were 193 taf, and the price paid for the water was $50/af. Water sales amounted to 159 taf at $72/af, less than half the price of the previous year. In addition to supplies sold mostly to agricultural and some urban uses, 15% of the 1992 bank water was sold for environmental purposes. Public funds had been allocated to assist in the purchase of this environmental water. The differences in the price and quantity equilibrium between the 1991 and 1992 DWBs strongly support the contention that both the demand and supply of water in California is price responsive, even under severe drought conditions.

1994 was once again a dry year leading to establishment of another DWB. Given past bank experience and the similarity with 1992, the 1994 bank bought 222 taf from reservoir and groundwater substitution contracts. The average purchase price was the same as 1992 at $50/af. A total of 170 taf was sold to urban and agricultural interests in 1994 at a price of about $68/af, fractionally lower than the 1992 price. The administrative transaction costs of the DWBs were low, in the region of 7% (personal communication). The main reason for the substantial price spread between sellers and buyers was to finance the "carriage water" requirement (approximately 30% on the delivered quantity) that was needed to control salinity in the Sacramento-San Joaquin Delta. In short, the DWBs worked well within their restrictions of rigid price levels and regulatory controls on third party effects.

At the start of the 1995 water season precipitation and river flows were at low levels. To add some security and flexibility to a potential water bank, DWR initiated an option market in December 1994. The market took the form of purchasing options to buy water in the event of a drought at the fixed price of $3.50/af and selling options to purchase water at $10/af. Details of the operation of the option water bank are published in Jercich (1997).

A criticism of the DWBs was that due to the timing of the last rainfalls in California and the need for early agricultural planting decisions, the banks did not allow adequate time for adjustment on both the market supply and demand sides. Introduction of the option market in December 1994 induced a more elastic supply of water to the bank and a price structure that varied as the extent of water supplies become better known between December and April. In 1995, substantial precipitation and snow-pack occurred in the latter part of the season, removing the need to exercise the options.

Lund et al. (1992) made the following conclusions about the DWB of 1991 and 1992:

1. State-operated Water Banks provided a greater opportunity for completing transfers from sellers to buyers without third-party interference; a state operated DWB can substantially reduce transaction costs.
2. Urban, agricultural, and environmental interests demonstrated willingness to participate in DWBs.
3. A significant number of willing sellers exist, particularly in drought years.
4. Reservoir and conveyance operations can often limit ability to transfer water.
5. Legislative and institutional constraints were waived for the DWB of 1991 and 1992; long-term water banks may require special legislative assistance for enactment.
6. Excess purchases by DWR can be used as a hedge against more severe long-term drought.
7. The DWB of 1991 and 1992 increased interest in and attention to water transfers of various types, while crucial experience was gained in their operation and implementation.

Groundwater Conjunctive Use

Additional sources for increasing CVP and SWP water supply are conjunctive use of groundwater for the storage, recharge, and withdrawal of water (see options in Chapter 3). DWR initiated the Kern Water Bank (KWB) in 1985 for such purposes, before relinquishing ownership of the spreading grounds to KCWA and Dudley Ridge in the Monterey Agreements. Although conjunctive use had been part of normal operations of federal, state, and local water purveyors before the Kern Water Bank, it had yet to be institutionalized. Currently, DWR is investigating a conjunctive use project in the American River basin that could potentially provide 55 taf during drought periods at $50/af (DWR 1998a). USBR also has indicated interest in conjunctive use, suggesting the 800 taf dedicated for environmental flows by the CVPIA could come entirely from conjunctive use, although numerous feasibility and environmental investigations would first be required.

Several urban areas are exploring conjunctive use opportunities as well. MWD currently has agreements for storing up to 700 taf in the ground in the Semitropic Water Storage District and in the Arvin Edison Storage District for up to a total of 120 taf of drought yield. MWD has also crossed state lines in its conjunctive use efforts, executing an agreement to store up to 90 taf of its Colorado River entitlement in Central Arizona Water Conservation District's service area for a drought year exchange for Colorado River water (MWD 1993). In all these agreements, MWD supplies the excess water in wet years and contracts with out-of-area local districts for storage.

These groundwater storage and conjunctive operations increasingly rely on the ability to transfer or exchange water and often entail some form of water marketing or wheeling. The subsequent sections of the chapter explore these new water allocation mechanisms and operating policies in more detail.

PRIVATIZATION FOR FINANCING AND MANAGING CALIFORNIA WATER

Increasing implementation of conjunctive use and changes in CVP and SWP financing, combined with recent experience gained with drought water banking, have all contributed to interest in market oriented finance mechanisms to better augment water demands. Market oriented finance mechanisms may include altering traditional roles of state, regional, and local water agencies through privatization and redefining water agency responsibility; instituting changes to water allocation methodology through increased use of water transfers and water marketing; or some combination of both. Furthermore, with budget and environmental constraints on new surface storage persistently facing federal and state water policy-makers (see Chapters 2 and 3), and as local efforts for solutions to water resource problems continue to fall short, the concept of privatization has gained increasing attention along with water marketing. Although applicability to water supply financing has yet to become widespread, efforts in privatization have occurred in the gas, electric, wastewater, and other utility industries,

Privatization Alternatives

Several forms of privatization have been used historically to fund public infrastructure, and the water resources arena has extensive experience with privatizing wastewater treatment plant operations. Savas (1990) segregates privatization into three types: 1) delegation, 2) divestment, and 3) displacement. Table 4-10 provides specific examples of each of these types of privatization.

Delegation of Government Responsibility

Delegation of governmental responsibility has been commonly used in the water supply arena through the employment of consultants, who may provide technical expertise not internally available to a public agency. Public construction activities also are usually delegated to construction contractors. Delegation may also include franchise agreements with private companies to provide water supply or some other specific service as a monopoly or as an entrant to a specific market. In many areas, a private water company is provided with a franchise to provide local water service by a local government. Many USBR facilities are operated by local user groups or agencies, a form of local government delegation. Vouchers, community self-help, and governmental incentives also fall under the category of delegation. A practice where the government subsidizes private investments is in agriculture, which has historically received subsidized water, in part, to provide consumers with agricultural products at a reasonable cost.

Table 4-10. Description of Privatization Options

Delegation of Government Roles	
Contracting out	Government contracts with a private firm to produce and/or deliver a service or part of a service.
Franchise agreements	Government grants an organization either an exclusive or nonexclusive right to provide a particular service within a specific region.
Grants/subsidies	Government provides a financial or in-kind contribution to a private organization or individual to facilitate the private provision of a service at a reduced cost to consumers.
Vouchers	Government issues redeemable certificates to eligible citizens or agencies, who exchange them for services from approved private providers. Service-providers then typically return the vouchers to the issuing government for reimbursement.
Self-help	Individuals, community organizations, or agencies supplement or take over a service and in turn benefit from the acquired service.
Incentives	Local and regional government use legislative and taxing powers to encourage private firms to provide needed services or to encourage individuals to reduce their demand for such services.
Divestment of an Enterprise or Asset	
Sale	Selling a government owned entity to a single buyer or a group of buyers; entails sales to employees as well as customers or users.
Donation	Giving away a government owned entity, when government profit is no longer attained.
Liquidation	Selling the assets of a government owned entity when meager prospects exist for achieving profitability
Displacement of a Government Entity	
Default	Transfer of ownership from public to private sectors when government service is deemed inadequate by the public.
Withdrawal	Transfer of ownership from public to private sectors when government service is deemed inadequate by the government.
Deregulation	Used when a monopoly granted status is revoked (e.g., the electric and phone industry in the U.S.)

Source: Clarkson (1989), Savas (1990)

Divestment of Public Assets

Divestment of a publicly owned or operated enterprise is another form of privatization instigated through a sale, donation, or liquidation. Selling government infrastructure may be attractive when employees or customers of a service seek more autonomy or where the complexity of the system requires decentralized decision making. Donations occur when there is a lack of sellers or buyers, or it is deemed inappropriate to sell an asset or enterprise. This may occur with low valued services or public goods that should or could not be sold. Liquidation is the process of replacing a good or service with a cash value and allowing a private individual or group to use the resource as they wish, an option which may be attractive for assets which promise no profitability or other benefit.

Displacement of Government Entity

When government involvement is no longer desired or economically feasible, displacement of the governmental role occurs. This can take place in the form of default, when government service is no longer adequate and is simply displaced by privately provided services. Legislative mandates and directives requiring deregulation may also force the displacement of the government sector, although this often only involves allowing private venture to compete with what may have previously been government monopolies.

Limitations to Privatization

Several potential limitations to privatization are delineated in Clarkson (1989) and Starr (1987). These concerns include a private firm's possible failure to comply with contractual obligations, profiteers seeking excess profits at the public's expense, increased costs, and the displacement of public employees. Monopoly problems are common concern for private sector involvement in utility industries.

WATER TRANSFERS AND WATER MARKETING

Traditional approaches to finance and operations have resulted in numerous conflicts over water allocation procedures, cost allocation, and physical solutions to water resource problems (see Chapter 2). Market solutions to these problems have been offered and increasingly used to augment and manage water supplies. Allowing a market to allocate supplies will, in theory, achieve an efficient allocation, assuming limited transaction costs and numerous buyers and sellers.

This report adopts definitions of *water transfers* as defined 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. Market and non-market water transfers have been used in several forms as described in Table 4-11.

In some cases water marketing agreements may need to incorporate exchanges without a change in ownership (conjunctive use, for example) to circumvent legal obstacles and impacts to third parties. In addition, water wheeling and exchanges will be an important element of future water marketing transactions.

Difficulties of Water Market Implementation

Many of California's water managers have agreed that water marketing may provide substantial economic benefits and more efficient water usage. Thus, transfers are becoming ubiquitous in many long-range plans (MWD 1997; SDCWA 1997). However, numerous impediments have prevented widespread use of water markets.

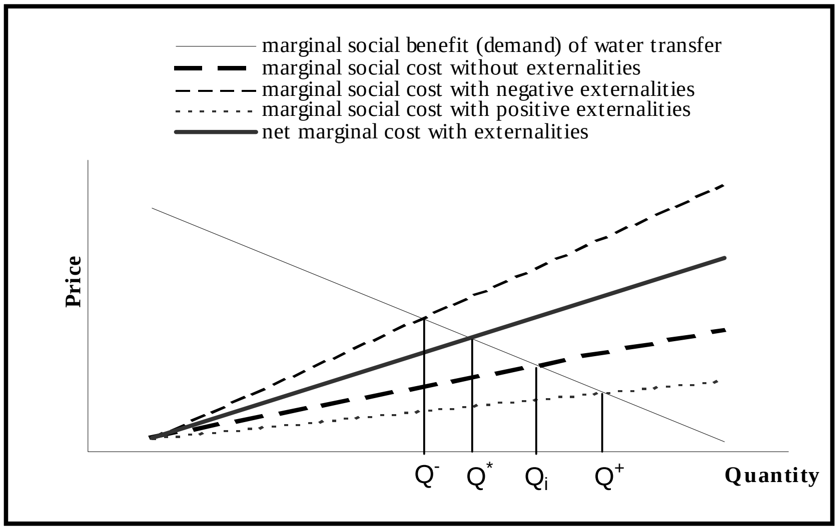
Table 4-11. Taxonomy of Water Transfers

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 1998).
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 et al. 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 1994a).
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: Lund et al. (1992)

The initial 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 water to be transferred. As illustrated in Figure 4-1, a buyer and seller in negotiations who neglect costs and benefits associated with third parties will transfer the amount Q_i, where the apparent marginal social cost is equivalent to the marginal social benefit. However, when negative externalities, third party impacts, and transaction risks and costs are included, the marginal social cost increases and the efficient amount to transfer is reduced to Q^-. When only positive externalities are considered, apparent social costs are less and transfers increase to Q^+. When both positive and negative externalities and transaction costs are considered, a more middling transfer quantity is ideal, Q^*.

Figure 4-1. Water Marketing with Externalities



In theory, a pure market in water can exist only if four criteria are achieved: 1) water property rights must be well defined; 2) there must be many buyers and sellers; 3) resources are easily transferable; and 4) adequate information must be available (Brajer et al. 1989).

Many water rights are poorly defined for market transfers. Additionally, the vast majority of water in California is allocated based on applied rather than consumptive use, while only consumptive use is available for transfer. This creates difficulty in separating “real” from “paper” water. Monopsonistic and monopolistic behavior can be present in water markets, as excess water is sometimes owned by few users or, more commonly, excess water is demanded by relatively few buyers. For example, Kern County Water Agency and MWD together hold entitlement to over 75 percent of the entire SWP supply. Marketing by one of these two agencies will likely alter water market conditions within the SWP.

Transferability of water in California is easy in theory and difficult in practice. Use of the extensive California infrastructure is often costly or currently politically infeasible. Water transfers may become increasingly restricted as excess conveyance capacity is appropriated, environmental concerns are raised, and parties external to the financial transaction object through political or legal means. In addition, market information about potential buyers and sellers may often be difficult to obtain. This problem was perhaps more significant before California instituted the DWBs, which caused many water agencies to rethink their preconceptions about water marketing.

Six criteria for evaluating resource allocation are presented in Howe et al. (1986) and further summarized 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 effects on third parties, those external to the buyer and seller.

An additional difficulty in implementing long-term transfers is the distinction between real and paper water (Lund et al.1992). Contracts are invariably written in terms of “wet” water that is defined in terms of consumptive use foregone by the seller. They should also reflect the interdependence of surface and ground water sources. 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.

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. Such impacts are common throughout the economy with many types of property. Water transfers potentially affect a variety of third parties as illustrated from Lund et al. (1992):

1. Urban: Downstream urban uses, landscaping firms and employees, retailers of lawn and garden supplies.
2. Rural: farm workers, farm service companies and employees, rural retailers and service providers, downstream farmers, and local governments.
3. Environmental: fish, wildlife, those affected by potential land subsidence, those affected by potential groundwater quality deterioration.
4. General: taxpayers.

Externalities associated with agricultural transfers include agricultural labor, equipment, material and service providers, and local government tax revenues. Examples in Colorado demonstrate the long-term damage associated with permanent transfers from agriculture to urban (Committee on Western Water 1992). Much of the literature considers the externalities associated with agriculture a greater threat since the focus of water marketing has emphasized agriculture to urban transfers or transfers from low value agriculture to high value agriculture (Howe et al. 1990; Dinar and Letey 1991; Reisner and Bates 1992; Michelson and Young 1993). Return flow, water quality, and instream flow effects of transfers can have both positive and negative impacts.

The California DWBs avoided many of the property right complications of longer-term transfers by invoking the drought emergency to avoid prolonged investigation of possible environmental problems and resolution of third party impacts. Often transfers occurred without any independent environmental review. Subsequent studies of third party environmental effects found the costs to be relatively small compared with the substantial social benefits of the water bank (Howitt et al. 1992; Dixon et al. 1993).

Economic third party effects of water trades have proved to be a notable source of objection to water markets in California. Conceptual analysis of third party impacts is widespread, but quantitative evidence of the extent of regional economic impacts is hard to find. Howitt (1994) used both county-level primary surveys and a simulation model to estimate the aggregate county-level income changes attributable to water sales. The results from Yolo and Solano Counties that supplied 25% of the water sales to the Bank ranged from 6.5% to 3.2% average reduction in income for those county residents not participating directly in the water sales. These low average third party costs mask considerable variation within the regions studied. Where sales from land fallowing were concentrated in small areas, several businesses associated with agricultural production suffered a substantial and unexpected reduction in business. It is hard to quote low average figures when faced with a harvesting contractor who lost half his normal contracts after committing to purchase new equipment. This increase in the third party economic cost was born out by empirical simulations that show a rapidly increasing cost per unit as the proportion of water sold in a local area increases. The key to keeping third party externalities from water sales at a politically acceptable level is to geographically disperse the sales and provide a means for associated businesses to anticipate when they will occur.

An advantage of option sales over spot markets is that the level of sales and the conditions under which they occur are well known to all businesses in the area. Accordingly, a supplier to agricultural firms can plan and anticipate his sales that are, or are not, interruptible by water markets.

Permanent transfer of water rights from a region lead to substantial impacts on the local economy. This type of sale is almost unknown in California, but Howe et al (1990) show regional losses in farm value added of 10 - 21 % in the Arkansas Valley of Colorado. Sales of water under options modulate these impacts in three ways. First, under option contracts the water remains in farming for the majority of the years, thus keeping the seller on the farm and providing a source of secondary income for associated businesses. Second, since the farmer is still active and resident in the region, the stream of option payments in years that the option is not exercised will add to the income in the region. Third, the negotiation of water sales options allows enough time to negotiate third party compensation where appropriate.

One method proposed by the Model Water Transfer Act of 1996 (see discussion later) in California to reduce water market transaction costs is to de-couple the actual water sale from third party compensation. The problem is how to reduce the uncertainty over individual or district property rights to water and at the same time ensure that mechanisms are in place to internalize legitimate third party costs. Traditional provisions to prevent or compensate third party impacts take the form of regulatory or hearings restrictions on actions.

One of the key tenets 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 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), industry has been hesitant to use these values in making instream flow allocations. Public opposition may outweigh any measure 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

What happens as the result of a water transfer is one element that cause hesitation initiating water marketing, but not the only one. The negotiating and administrative costs and perceived risks in developing a water transfer plan can inhibit such activity. Archibald and Renwick (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 conditions dictated by government decision-makers, including the legality of transfers, agency approval process, and possible adjustment of costs to account for third party impacts and litigation. Economic theory shows that high transaction costs reduce the operating efficiency of markets. Evidence from Colorado, New Mexico, and Utah over the 1975 to 1984 period suggests that current policies in these states do not overburden markets, while some suggest that costs may be too low (Colby 1990).

Transaction costs may become excessive in specific instances, often depending on the political feasibility of a transfer. MacDonnell (1990) found significantly higher transaction costs occurred in 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 state approval. In contrast, only 30 to 40 percent of transfers in New Mexico and Utah are out of agriculture, with only 5% and 15% respectively, of transfers protested, and average times for state approval at 5.8 and 9 months, respectively.

In addition to potentially high transaction costs, many elements of water marketing are perceived as risky. From this perspective, Lund (1993) suggests that market reluctance is a function of the probability of failure as much of the actual transaction costs. The probability of successful water transfers requires that the rights of water rights holders are assured, firm legal guidelines for management of third party impacts and clear legal guidelines for the water transfer approval process exist, and that necessary conveyance, storage, and treatment facilities are available to physically complete a transfer.

Solutions to the Difficulties in Water Marketing

Several legislative actions have been proposed to solve the problems that prevent water market implementation, the most comprehensive and recent being the Model Water Transfer Act (Gray 1996). Briefly, some summarizing suggestions include:

Streamline Water Transfer Laws

Current laws designed to protect third parties often inhibit possibly beneficial water transfers. Reisner and Bates (1992) suggest state water codes should be revised to protect *substantial* injury rather than *any* injury as currently applied.

Manage Third Party Protections

Several mechanisms for limiting third party impacts have been suggested by the Committee on Western Water (1992), CAN (1992) and Lund et al. (1992) and include:

- 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.

Strengthen Property Rights and Water Accounting for Area of Origin and Area of Storage Users

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

Strengthen Instream Flow Measures and Include in Water Market

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 condition, in a sense privatizing some instream flows (Griffin et al., 1993; Anderson et al. 1997; Willis et al. 1998).

Accommodate Public Trust Doctrine in 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 water allocation decisions. Transfers should account for the impact and implication on public trust values. Reisner and Bates (1992) suggest public interest determinations, although some find such methods too cumbersome and the public trust doctrine too vague in influencing transfer legislation (Anderson et al. 1997).

Status of Water Marketing in California

Given the impetus for water marketing from academia and from urban users during the 1987-1992 drought, several examples of water marketing are now in effect through out the state. For the first time since the concept of water marketing was developed, the 1988 California Water Plan update identifies water markets as a “water supply augmentation option.” The following section summarizes water supply programs identified as water market transactions by 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 of IID’s annual Colorado River entitlement (Reisner et al 1992).

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 the 350 taf storage capacity provided to MWD, other contracting partners include Santa Clara Valley Water District (SCVWD) with 350 taf capacity, Alameda County Water District (ACWD) with 50 taf, and Alameda County Zone 7 District (Zone 7) with 43 taf. This leaves SWSD with 200 taf of marketable storage available at $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 request by contractors, water could be extracted and delivered to the Aqueduct or pumped by SWSD farmers in exchange for SWP entitlement deliveries.

San Luis and Delta-Mendota Water Authority (Authority), SCVWD, and USBR

A three party agreement has been executed allowing some of the Authority's member districts to voluntarily act as drought water suppliers for SCVWD, an urban water agency. Part of SCVWD's CVP allocation will be delivered to these districts in normal and above-normal water years in exchange for allowing SCVWD to recover the allocation during drought years. This agreement ensures that SCVWD's 97.5 taf entitlement is delivered in years when CVP urban supplies are at 75% or less, thus increasing SCVWD's water supply reliability. Additionally, SCVWD has agreed to optimize its non-CVP supplies to ensure that this water transfer is requested only when needed. To date, the Westlands and San Luis Water District members of the Authority have agreed to act as drought water suppliers.

CVPIA authorization for Water Transfers

Federal efforts to promulgate 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, was intensely disputed and is very unlikely to deliver any water to MWD.

Arizona Water Banking Authority (AWBA)

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

CVP Interim Water Acquisition Program

Fish and wildlife requirements have been augmented by a temporary CVP program to help USBR fulfill Section 4306(b) of the CVPIA. In 1995, 1996, and 1997, approximately 39, 63, and 179 taf of water were purchased, respectively. Water from this program benefited wildlife refuges in the Sacramento and San Joaquin Valleys, spawning conditions for spring-run Chinook salmon and steelhead trout on Battle Creek, and instream flow requirements on the Stanislaus, Tuolumne, and Merced Rivers.

Other Agricultural to Urban Transfers

Of the 130 taf of SWP annual entitlement allocated for permanent sale to urban contractors in the Monterey Agreement, 25 taf has been relinquished to the Mojave Water Agency and 7 taf is in the process of being sold to Zone 7.

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 taf of water from land fallowing arrangements from southern agricultural regions could be provided to southern urban areas. IID also has contracted with the San Diego County Water Authority in a similar agreement, although implementation of this agreement is currently in litigation.

Initiating a short-term water buy-back program, Westlands Water District will purchase unused water supply from its water users and reallocate it to other users to meet their water supply needs. Complementing this buy-back program, Westlands is in the process of environmental documentation for the purchase and transfer of up to 200 taf/yr from external sources.

INNOVATIVE INSTITUTIONAL ARRANGEMENTS FOR CALIFORNIA

Altering the traditional roles of state, regional, and local government in financing schemes is not limited to privatization or to relinquishing of government control. State and local water agencies often have considerable flexibility to participate in joint ventures and cooperative efforts that develop innovative methods to use facilities and available funding.

Independent Authorities

Explicit language in California law provides agencies with the ability to solve regional or extra-boundary problems involving more than one governmental entity. California code §6502 states:

> "If authorized by their legislative or other governing bodies, two or more public agencies by agreement may jointly exercise any power common to the contracting parties.... [T]wo or more public agencies having the power to conduct agricultural, livestock, industrial, cultural, or other fairs or exhibitions shall be deemed to have common power with respect to any such fair or exhibition conducted by any one or more of such public agencies or by an entity created pursuant to a joint powers agreement entered into by such public agencies."

Several local water agencies have combined together to form water authorities gaining political and financial clout and the ability to plan over vast, politically heterogeneous regions, such as MWD and SDCWA. On a smaller scale, cities creating independent authorities have been able to better use existing resources, sharing services such as police departments and fire departments rather than overlapping their efforts in some areas (BAC 1983).

In exploring development of an ideal regional water organization, Ostrom et al. (1964) provides an outline of what should be considered. First, the authority's jurisdictions should include the relevant set of activities to be controlled (e.g., conveyance, storage, or hydropower facilities). Second, boundary conditions of the entity should consider appropriate economies of scale so that it does not suffer from lack of resources but avoids becoming too expansive. Third, representation from existing decision-making bodies should be included so the authority remains accountable and its development politically feasible. Finally, so the authority avoids becoming invasive and unresponsive to its member agencies, each member should have their desired level of autonomy.

Local Cooperative Efforts

Many solutions have been found without the creation of new governing entities. McGarry (1983) explains how a successful solution to potential water shortages on the Potomac River basin was attained not through private or federal assistance, but rather through more effective local agency cooperation. Infrastructure needs were determined to be much less than initially anticipated and more efficient use of existing facilities was attained. Task forces for the accomplishment of local objectives were formed consisting of elected officials subject to public scrutiny in contrast with public utility decision making. These task forces were guided by citizen leadership and affected every decision so as to continually gain public input. More rigid federal traditional planning concepts were ignored in exchange for local coordination. McGarry (1983) is careful to note the extreme personal dedication on the part of task force and citizen leaders to accomplish their objectives, dedication driven by the fear of drought.

Infrastructure Banking

In response to dramatic drought conditions, faced with future state deficits, and determined to maintain a triple A bond rating, the state of New Jersey instituted an ‘infrastructure bank’ in 1983 to attain their infrastructure needs (Arbesman 1983). Deposits into the bank include federal appropriations and outstanding state bond issues. Loans are then given out from a reserve account to supplement state-wide infrastructure needs. A revolving fund is created as the loans are paid back with user charges. Arbesman (1983) sees the ideal institutional arrangement for infrastructure banks as suppliers for local collection, distribution, and rehabilitation projects while the private sector provides for large capital investment, in a kind of private-public marriage. Alternatively, the French system of *affermage* uses public funding for infrastructure capital and private funding to support operating costs, a system sought to remedy nonexistent or low willingness-to-pay in developing countries (Young et al. 1989).

CONCLUSIONS

A wide variety of non-structural, operating and financial options are available for California’s water supply problems. Markets are likely to be a vital part of long-term solutions, especially those that seek to involve the use of private capital. Water demand management, another non-structural measure, will be discussed in Chapter 6, where user water demands are discussed and integrated into a state-wide representation of California’s water management.

CHAPTER 5

LEGAL ISSUES FOR MARKET FINANCING OF CALIFORNIA WATER

In part, this study investigates market methods for generating revenues for water resource system improvements. A prerequisite for a successful market is to have a fungible product that has similar financial characteristics. Traditionally, water is financed in terms of the units of delivered product and by fixed access charges for the system. Since different systems have different components that make up the final water charge, defining market units in terms of their function rather than the end product may make for a set of more homogenous financial products. In addition, pricing and trading the components separately rather than as a single end product might lead to greater flexibility and adaptability.

California's water supply system can be separated into components of water supply, conveyance, and storage. To date, most water users in California pay for water based on a rate that combines all three of these services (See e.g. Mecham and Simon 1995 regarding CVP pricing; O'Conner 1994a regarding SWP pricing). The California legislature passed three bills in 1995 aimed at water supply reliability for urban areas (Statutes of 1995, Chapters 330, 854, and 881) (DWR 1998a). One general obligation bond measure, Proposition 204, passed in November of 1996 for $995 million, has been earmarked to finance actions recommended by the CALFED process. By de-coupling the individual components, the CALVIN model is able to estimate the economic value and possible revenue generation that this added flexibility might produce.

This chapter, which addresses the legal ability to de-couple and market California's water supply components, is structured as follows. The following section is divided into subsections for each of the three components of water supply. Each subsection outlines the extent to which current law allows water supply, conveyance, and storage to be marketed as separate commodities. In addition, the next section explains recent developments that are extending current law, and presents areas where the law would have to change to allow further de-coupling. A further section discusses examples from the natural gas and electric industries where de-coupling has taken place, and the last section looks at some public and private financing issues that might accompany future policy options.

CURRENT LEGAL FRAMEWORK OF CALIFORNIA'S WATER SUPPLY SYSTEM

California's water supply is derived from surface water and groundwater. It is important to note at the outset that Californian's cannot possess a right to the corpus of water, but rather can only possess the right to use water (Water Code §§ 1000-1001). Rights to use or transfer surface water in California may derive from riparian, appropriative or contractual rights in the user.

A variety of water code provisions enacted in the 1970's and 80's provided for the transfer of surface water in California (Water Code Sections 109, 1011, 1435, 1706, 1725, 1736, 1810(d)). The Central Valley Project Improvement Act of 1992 (CVPIA) and various California Department of Water Resources (DWR) and US Bureau or Reclamation (USBR) regulations and guidelines control transfers dealing with contractual rights and/or use of State Water Project

(SWP) or Central Valley Project (CVP) facilities. Groundwater rights, on the other hand, are derived from common law and are not comprehensively addressed in the Water Code (Littleworth and Garner 1995).

The following discussion outlines the extent to which each type of water right in California can be transferred. This discussion also addresses the different types of transfers allowed under the Water Code, federal law, and DWR and USBR's regulations and policies.

The Water Itself

Surface water: appropriative, riparian, and contractual water rights.

Appropriative Rights in the Transferring Party: The holder of a valid appropriative right may transfer all or a portion of the water available under that right (Water Code §§474 – 484). However, if a transfer involves a change in place of use, point of diversion, or purpose of use for an appropriative right established after 1914, the parties must petition the State Water Resources Control Board (SWRCB) for approval of the change, regardless of the duration of the transfer. The right to use water under pre-1914 appropriative rights may be transferred without SWRCB approval as long as there is not adverse impact on another legal user of water (Bookman-Edmonston Engineering 1996).

When the Transferring Party does not hold the Appropriative Right: Often, a contracting district or water company holds rights for water, which it delivers, to individual users. The Water Code provides that such water suppliers may transfer water allocated in a given year to its water users, provided that the water needs of the suppliers' service area are still met (§§1745.04 -1705.06). These provisions allow water to be freed for transfer via conservation and fallowing, to a limited extent (O'Brien and Gunning 1994).

Transfers of Water Under Contract: In cases of transfers of contractual water rights from DWR or USBR, the transfer must be consistent with DWR and USBR policy and any applicable federal law (Gray 1994). In addition, since DWR and USBR are the actual water right holders, they must make any necessary change petitions to the SWRCB to effectuate a transfer. Transfers of SWP contract water must occur pursuant to California law and DWR policy. Transfers of CVP contract water must occur pursuant to Federal law (section 3405 of the CVPIA), California law, and USBR policy (Gray et al. 1991; Roos-Collins 1987). In this regard, USBR has adopted interim guidelines for the implementation of the CVPIA (USBR 1993a; USBR 1993b).

Under the CVPIA, transfers of CVP water between districts in the same county, watershed, or area of origin are simple and are deemed to have met the conditions specified in the statute (CVPIA §3405(a)(1)(I)). Transfers of CVP water become more complicated as the water is transferred further from the district, to non-CVP contracting entities, or if a transfer is initiated by a member of a contracting district rather than the district itself. All such transfers require USBR approval, invoking the NEPA process.

Most CVP districts have internal policies that require district approval for transfers initiated by their members. In addition, the CVPIA provides that the contracting water district must approve transfers that involve more than 20 percent of its long-term contract supply. The CVPIA also authorized transfer of CVP water outside the CVP service area, subject to several conditions and a right of first refusal by existing CVP users within the service area. Such transfers must be consistent with state law, approved by USBR, and must obtain the relevant change in place-of-use, point of diversion, and purpose of use order from the SWRCB.

The CVPIA also imposes pricing conditions on transfers of CVP water that are in addition to the regular charges for the water paid by the district. Transferees who are Municipal and Industrial (M&I) users or non-CVP contractors must pay the USBR established temporary full cost rate for the water. M&I purchasers must also pay a $25 surcharge per acre-foot of transferred water.

Riparian Rights: Although there are no statutory procedures for transfer of riparian rights, riparian rights were purchased as part of the Drought Water Bank (O'Brien and Gunning 1994; Wahl 1994). Water Code §1707 authorizes the SWRCB to approve a petition to transfer water under any type of right, including a riparian right, for the purpose of preserving or enhancing wetlands habitat, fish and wildlife resources, or recreation in or on the water. Water rights quantified by statutory adjudication may be transferred pursuant to Water Code §1740 (Bookman-Edmonston Engineering 1996).

Groundwater

Common law has historically governed groundwater rights and use. Under this regime, overlying landowners have paramount rights to groundwater. Those who extract groundwater for use on public or non-overlying land are appropriators whose rights to groundwater are junior to those of overlying owners (Guy and Cordua 1997; Littleworth and Garner 1995).

Increasing recognition of the connection between surface water and groundwater in a region has led to several water code provisions dealing with groundwater. These provisions do not expressly allow the sale and/or transfer of groundwater, but do allow groundwater to be used as part of a conjunctive use program. Other Water Code provisions allow for the management of groundwater basins (AB 3030 Water Code §§ 10750 et seq.) which can include conjunctive use. An increasing number of local county ordinances also seek to govern the use of groundwater, especially for conjunctive use (DWR 1998a). Some of California’s groundwater basins have been adjudicated. In these basins, a court-appointed water master regulates groundwater extraction (DWR 1998a).

Conjunctive use programs can include in-lieu operations and groundwater substitution (DWR 1998a). A transferor of surface water can resort to groundwater for the duration of a transfer (groundwater substitution), or a groundwater user will take surface water in-lieu of pumping to recharge the groundwater basin with a like amount of water for a particular person’s benefit (in-lieu operation) (Guy and Cordua 1997). Groundwater Substitution was widely employed in the Drought Water Banks. Potential concerns involving groundwater substitution include its effect on neighboring groundwater users and its possible inducement of additional basin recharge that depletes usable stream flow (DWR 1998a).

Conjunctive use programs are often useful tools to improve groundwater levels. However, active recharge programs involve allocation of the rights to water that is recharged. Rights to recharge water lies with those who recharge it rather than the overlying landowners. The extent to which these programs vest in those who pay for additional recharge to the basin, but are not overlying groundwater owners, a paramount right to recapture water stored in the basin is a keenly contested issue (Kletzing 1988; Guy and Cordua 1997; Kidman 1999).

The Water Code provides that a transferor may only substitute groundwater for the transferred water if the groundwater use is consistent with a groundwater management plan or if the water supplier determines that the transfer will not lead to overdraft conditions (§1745.10). DWR and USBR have similar requirements in their guidelines for the approval of transfers of water under a contractual right, or the approval of wheeling of non-project water through their facilities. In addition to the provisions addressing groundwater in the context of transfers, Water Code §1011.5 provides conditions on the use of conjunctive use programs in general that are designed to preserve the health of California's groundwater basins.

The Logistics of Water Transfers in California

Transfers can generally be categorized as either short-term, long-term, permanent, or leases. Transfers may include transfer of actual water rights, contractual rights to receive water, or just an assignment of the right to receive water under another's water right for a specified period.

Temporary Urgency Changes: Water Code §§1435-1442 allows temporary urgent changes to be made for 180 days with SWRCB authorization upon a showing of urgent need. The no-injury rule applies to these changes, as does CEQA. The SWRCB can renew the permit approving a temporary change for successive 180-day terms.

Short-term or temporary transfers: Short-term or temporary transfers are for one year or less and are governed by Water Code §§1725 - 1732, requiring SWRCB approval for any required changes in place of use, point of division, or purpose of use. Such changes must comply with the no-injury rule, but are exempt automatically from CEQA compliance. This is the most commonly used practice for water transfers in California, evidenced by a variety of spot market transfers (Howitt 1996), the Drought Water Banks of the early 1990's (DWR 1998a; Israel and Lund 1995), and the CVPIA interim water acquisition program (DWR 1998a).

Long term transfers: Water Code §§1725-1737 provides for petitions to the SWRCB for a change in point of diversion, place of use or purpose of use for more than one year. Unlike short-term transfers, all transfers of a duration longer than one year require CEQA compliance. The SWRCB must also hold a hearing before approving a long-term transfer petition (Water Code §1736). The no-injury standard for long-term transfers is different than that for short-term transfers - a long-term transfer may not be approved if it will result in a substantial injury to another legal user of water.

Permanent transfers: Permanent transfers involve the transfer of water rights themselves, rather than just the right to use water available under someone else's water right for a given period of time. Permanent changes in place of use, point of diversion, or purpose of use require SWRCB approval, a hearing, and compliance with the no-injury rule and CEQA (Water Code §1740). Examples of permanent transfers include (1) the Monterey Agreement, which provides for up to 175,000 af of permanent transfers of SWP entitlement away from agricultural uses, (2) the CVPIA Interim Water Acquisition Program, and (3) the CVPIA AFRP Water Acquisition Program (DWR 1998a).

Leases: A water lease allows the water right holder to retain the water right, but allows the leaseholder to use the water under certain conditions for a specified period of time (DWR 1998a). Generally, parties to agreements to lease water must comply with the applicable Water

Code provisions relating to short or long term transfers, outlined above, depending on the duration of the lease. However, parties to a lease might choose to structure their lease in accordance with section §§1020 et seq. of the Water Code under certain circumstances.

In 1991 the Legislature added Chapter 1.5 to the Water Code (§1020 - §1030) providing for water leases of up to 25% of the water the lessor would have applied or stored in the absence of the lease, for a period not to exceed 5 years (Water Code §§1020, 1021). The benefit of structuring a lease under this Chapter is that the parties do not have to petition the SWRCB for any change in place or use, point of diversion, or purpose of use associated with the transfer (Water Code §1025.7). On the other hand, all leases under this chapter are subject to CEQA, including those for less than one year (Water Code §1029). This chapter also has specific noticing requirements, environmental and other no-injury rule protections, and outlines how the proceeds of the lease agreement are to be distributed. For these reasons, the provisions in this chapter have not been used as of 1994 (O'Brien and Gunning 1994).

Transactions Costs for Transfers: Water transfers in California that are more than just annual transfers between contractors of either the state or federal projects can be quite complex and involve significant transaction costs. The following requirements outline the hurdles that the transfer must cross:

1. DWR and USBR must approve transfers of water under their permits, invoking NEPA compliance. USBR requires that the party requesting the transfer cover the agency’s costs to comply with this law.

2. SWRCB change petition: If a transfer involves a change in place of use, point of diversion, or purpose of use for an appropriative right established after 1914, the parties must petition the SWRCB for approval of the change, regardless of the duration of the transfer. In such cases, DWR or USBR holds the actual appropriative right and must petition the SWRCB for any change required for the transfer. The reality of this scenario is that the transferring parties have little control over the time in which a change petition is actually completed and presented to the SWRCB for approval. The petition to the SWRCB must be accompanied by a nominal processing fee.

3. Fees and Notice to Fish and Game: In all cases that require a notice to or petition of the SWRCB, the Water Code also provides for notice to the State Department of Fish and Game. The notice to Fish and Game requires a $850 fee (Water Code §§1726 and 1736).

4. CEQA compliance: In all change petitions for more than one year, or for temporary urgency changes, CEQA is invoked. DWR requires that the party requesting the transfer cover the agency’s costs to comply with this law.

The No-Injury Rule

Complying with the no-injury rule is a significant transaction cost for water transfers. California has led the nation in adopting the no-injury rule for water transfers. The no-injury rule basically means that an appropriator cannot change a point of diversion, place of use, or purpose of use so as to cause injurious consequences to the rights of another (Gould 1988; O'Brien and Gunning 1994). This rule is codified expressly in the Water Code §§ 1702 and 1706, but the same principle also appears in most of the other Water Code provisions dealing with water transfers. In addition, the no-injury rule has been extended to protect fish and wildlife (Senate Bill 301 of 1991 amended Water Code sections 1703, 1707, 1726, and 1736 in this regard) (O'Brien and Gunning 1994).

Since transfers involve changes in the place of use of water, they are also often accompanied by a change in consumptive use, invoking the no-injury rule (O'Brien 1988). Water Code §1725 specifically limits the amount of water that can be transferred to that which would have been consumptively used or stored in absence of the transfer. In addition, both DWR and USBR have guidelines limiting transfers to the amount of water historically consumptively used by the transferring party. These guidelines do not use the same definition of consumptive use found in the Water Code, which has led to controversy (O'Brien and Gunning 1994).

Conveyance Capacity

California's statewide water conveyance system is primarily comprised of three large systems. The CVP operated by USBR, the SWP operated by DWR, the Colorado River Aqueduct (CRA) operated by Metropolitan Water District of Southern California (MWD). In addition, there are a wide variety of locally developed systems. The right to use the capacity in this conveyance system for a given water user is generally tied to a contractual right to receive water from either USBR or DWR, and is not sold as a separate commodity. However, recent legislation established a "wheeling" policy that encourages agencies that control conveyance systems to make unused space available to others for fair compensation (Water Code §§ 1810-1814). In addition to the Water Code, the SWP and CVP each have their own regulations regarding wheeling for contractors and others.

The SWP

The SWP's California Aqueduct is the only large conveyance facility connecting north to south in California, and its use is required for most transfers. The Monterey Agreement provides a mechanism for using SWP facilities to transport non-Project water for SWP contractors. However, first priority for use of the Aqueduct is reserved for project purposes. Second priority is reserved for wheeling of contractor to contractor transfers of project water. Third priority goes to wheeling of non-project water for State contractors. The last priority is kept for wheeling of non-project water for non-contractors. These priorities have yet to be formalized (USBR 1993a).

The CVP

The Delta-Mendota canal is the primary federal conveyance facility for water transfers in California. Use of this, and other CVP facilities, must be either tied to an existing CVP contractual right to delivery of water through the facility or a Warren Act contract for conveyance of non-CVP water (43 U.S. Code §§523-525, 2212) (USBR 1993a). Entering into a Warren Act contract requires that the USBR comply with NEPA and other federal environmental laws (Bookman-Edmonston Engineering 1996). The same priorities outlined above for wheeling in the State Aqueduct apply to wheeling in federal facilities (USBR 1993a).

Fair Compensation under the California Wheeling Statutes

Water Code sections 1810-1814 authorizes joint use of unused capacity in water conveyance facilities. Under this statutory scheme, state, regional, and local public agencies that own conveyance facilities are required to make available up to 70% of their unused capacity for a bona-fide water transfer upon payment of fair compensation, as long as certain no-injury conditions are met. The statutes define "fair compensation" to included reasonable charges incurred by the owner of the conveyance system, including capital, operation, maintenance, and replacement costs. However this definition as been the subject of substantial controversy with respect to MWD's conveyance facilities, and is the subject of currently proposed legislation, SB 506 (1999, Peace).

In a recent California validation action interpreting California's water wheeling statutes (*Metropolitan Water District of Southern California v. All Persons Interested in the Matter, et al.*, Case No. BC164076, San Francisco Superior Court (1998), MWD argued that it should be able to include portions of its system-wide capital costs in wheeling rates for the Colorado River Aqueduct in order to avoid stranded costs.

In this case, San Diego County Water Authority (SDCWA), one of MWD's member agencies, challenged MWD's approval of postage stamp wheeling rates for interruptible and firm transportation service through the CRA. SDCWA will need to wheel any water it obtains through a long-term transfer agreement with IID through the CRA. As approved, MWD's postage stamp wheeling rates included MWD's costs of obtaining water from the State Water Project and conservation programs, as well as the costs associated with operation and maintenance of the CRA. The postage stamp rates were also fixed per acre-foot, regardless of the distance the water was to be wheeled through the CRA.

MWD's defended its postage stamp rate structure by arguing that if member agencies such as San Diego were allowed to use the CRA for only the variable costs of conveyance, the remaining member agencies would bear the burden of paying larger shares of MWD's system wide costs. Theoretically, more member agencies could follow San Diego's lead and secure alternative, lower cost supplies and MWD would have to allow them to use the CRA for only variable costs of transmission thereby leaving fewer and fewer MWD customers to pay increasingly larger shares of the system wide costs.

The court rejected MWD's arguments on several grounds. First, the wheeling statute only requires MWD to sell its excess capacity at "fair compensation", which does not include system-wide costs. Thus MWD should actually benefit from being able to sell capacity in the CRA that would otherwise generate no revenue. The rationale for this decision assumed that MWD would still have sufficient demand to continue moving the same amount of water through the CRA that it had in the past, and thus could cover anticipated system-wide costs.

Second, the statute was clearly written to encourage creative water transfers and improve the efficiency of California's water industry. If conveyance facility owners such as MWD were allowed to impose unrelated system-wide costs on all parties wishing to move water secured by a water transfer, many water transfers would become cost prohibitive. The court noted that this result would contravene the intent of the Legislature in enacting the wheeling statutes.

In response to the ruling described above, legislation was introduced this year by Senator Steve Peace to amend the definition of "fair compensation" in §1811 (SB 506). The amendment would ensure that the State, regional and local public agencies may charge for the reasonable point to point charges that they incur as a result of a water transfer. However, they may not charge system-wide operation and maintenance costs, or other costs that are not directly related to the specific facilities and services utilized for the water transfer at issue.

Storage

Storage in above ground reservoirs

Currently the water code does not address rights to storage in surface reservoirs. These rights are generally tied to contractual rights to receive water from either the state or federal water projects. Under the Monterey Agreement between DWR and its contractors, carryover storage is permitted by contractors in state owned reservoirs, subject to a spill priority that favors project water stored within a contractor's proportional share of the available storage capacity. Storage for non-state contractors will be spilled first (DWR and State Water Contractors 1994).

To effectuate storage in a federal reservoir beyond that allocated pursuant to a water service contract, a Warren Act contract must be executed with the United States. USBR also had guidelines for rescheduling water for carryover storage (USBR 1993a).

Storage in groundwater basins

The Water Code does not currently expressly provide for the marketing of groundwater basin storage capacity. However, several provisions of the code allow conjunctive use and groundwater banking as part of groundwater basin management strategies. The Monterey Agreement also created the ability for SWP contractors to store water outside their service area either directly or through exchanges utilizing another agency's reservoir or groundwater basin (DWR and State Water Contractors 1994). This provision has helped firm up water supplies for contractors and the smaller agencies that are storing water on their behalf. Urban water supply agencies with insufficient water storage capacity in their own service areas store water with smaller agencies in wetter years, in exchange for the ability to recover a smaller amount of water in drier years (DWR 1998a).

Groundwater banking agreements are generally characterized as water transfers, but they also inherently involve storage rights. When surface water is transferred to a district to be "banked" the transferor receives a "credit" that can be redeemed later. When the transferor seeks to redeem its credit, the redeemed water will be obtained from either the storing district's surface water, foregone in exchange for groundwater, or the storing district's groundwater, pumped into conveyance facilitates and sent to the transferor. In either case, the storage capacity of the storing district's groundwater basin is utilized. Similarly, conjunctive use programs also utilize the storage space available in groundwater basins. It is still unclear how the rights of various agencies to engage in groundwater banking and/or conjunctive use interact with the paramount rights of overlying owners to groundwater (Guy and Cordua 1997; Kidman 1999).

Several examples of groundwater banking programs can be found in Kern County, including Semitropic Water Storage District's groundwater storage program (DWR 1998a) and a similar program between Arvin-Edison and MWD (DWR 1998a).

LESSONS IN DEREGULATION FROM OTHER UTILITIES

Similar to the natural gas and electricity industries, California's water supply system can be divided into water production and transmission components. Also similar to these utilities, California's water supply and transmission has been linked together and sold as a bundled commodity, administered by a few large organizations, at regulated prices. Thus, some of the gains achieved with deregulation in the natural gas and electricity sectors may also be achievable for California water industry.

Natural Gas Industry

Like many large utilities, natural gas distribution is a natural monopoly. In the 1930's the Federal Trade Commission recognized a high level of power and potential for market abuse in the natural gas industry, leading to the Natural Gas Act (NGA). The NGA placed regulatory controls on interstate transportation of gas. The United States Supreme Court later read the NGA as regulating the production of gas as well, if it moved within interstate commerce (McArthur 1997).

Thus a system of regulated pipelines developed. Similar to the way the USBR and DWR act with respect to water today, each company that operated such a pipeline performed all of the services necessary to bring gas from the field to the market. These services were "bundled" together and sold at a single price. Pipelines made no profit on the purchase and sale of gas. Rather, pipelines bought gas from unaffiliated gas producers under long-term contracts at regulated prices. Until the early 1980's the FERC set cost-based pipeline rates that covered costs and achieved a "reasonable" rate of return (McArthur 1997). The cost of the gas itself was also regulated by FERC's wellhead pricing scheme. Customers paid for the cost of the gas on a pass-through basis.

The energy crisis of the 1970's triggered the downfall of natural gas regulation. Regulators and industry learned that the regulated pricing structure they operated under could not respond to market conditions. Natural gas deregulation began in 1985 with a FERC Order that created open access transportation for pipelines (Order 436). Order 436 required pipelines to provide transmission services for their customers who were now able to directly purchase natural gas from lower-cost suppliers. In 1989, FERC removed price controls on wellhead sales of natural gas. In 1992, FERC issued Order 636, requiring pipeline companies to provide open-access transportation and storage and to separate sales from transportation services completely. This order also mandated capacity release, electronic bulletin boards, and straight-fixed-variable rate design. Order 636 also provided for a new pricing structure to reflect the full range of services that come with purchasing natural gas including gathering, processing, transmission, and marketing. In recent years, several states have followed suit by requiring local gas distribution companies to unbundle their services and allow for retail customer choice (Costello and Lemon 1997; McNulty 1986).

Today, wellhead gas prices are virtually free of regulation while transmission services remain regulated to some extent. The natural monopoly character of the pipeline industry has led to a series of mergers among pipeline companies. FERC's transmission pricing policy allows pipelines to petition FERC to implement market-based delivery rates for customers who are shown to have reasonable alternatives (Threadgill 1995). In other words, FERC’s policy is aimed at preventing monopoly pricing in the natural gas transmission business (McArthur 1997).

Most natural gas distributors now offer unbundled services - allowing large end users to select the most cost effective and efficient mix of supply, transportation, storage, and backup services, among others. Gas Marketing Firms have also emerged offering “value-added” gas supply services (Costello and Lemon 1997). Deregulation has also improved efficiency and technology, from 1988-1994 gas production increased 11%, real well-head prices fell by 11%, and proved reserves fell 2%.

Deregulation of the natural gas industry is credited with lowering well-head gas prices and transmission costs, resulting in customer savings of at least $50 billion. The ability to use existing transmission pipelines to transport direct purchases of natural gas from lower cost suppliers allowed customers access to these lower cost supplies. It also stimulated investment and exploration for these alternate supplies. Thus market prices for gas allowed the market, rather than regulators, to control long-term investment decisions in the natural gas industry (Costello and Lemon 1997).

However, deregulation has not come without costs (Abbott and Watson 1983). The energy crisis of the 1970’s and early 1980’s caused gas suppliers to enter into long-term high-priced supply contracts. The costs of these contracts were passed on to gas customers. The deregulation orders, however, allowed customers to get out of their obligation to buy gas under these higher-priced contracts, and forced pipelines to transport the gas that customers could now purchase from lower-cost producers. Traditional gas suppliers were stuck with the long-term higher-priced contracts and a lack of mechanisms to hold customers accountable to their contracts to purchase gas under these contracts. In the end, the traditional gas suppliers were forced to absorb the stranded costs associated with the older, higher-priced contracts to the tune of forty billion dollars, or eighty-percent of the settlement costs.

As gas customers are offered a larger variety of alternatives, pipeline owners fear pipeline customers (shippers) will fail to renew their contracts for firm transportation service (Abbott and Lemon 1983). If pipelines are unable to resell that released firm capacity they may have to absorb these new stranded costs. Local gas distribution companies (LDC’s) now have the responsibility for managing their contractual rights to interstate transmission and storage capacity (Order 636). State public utility commissions are encouraging LDC's to minimize the costs they pass on to end-users. Thus as most firm transportation contracts are set to expire before 2002, LDC's are often choosing to relinquish these contracts in favor of a more diversified value-added service packages offered by emerging gas service companies (McArthur 1997).

Deregulation has allowed more flexible use of pipeline receipt and delivery points and has expanded the use of pipeline interties, thereby increasing transactional efficiency on and between pipelines. A group of emerging gas supply companies is using this new flexibility in the system to offer LDC’s value-added supply services that diminish the need for the firm transportation services (traditionally provided by the big pipelines), and at a lower price. Having these market-center services with access to a diverse portfolio of gas supplies and local storage options, provides alternatives for meeting peak-day demands that are less expensive for LDC’s than maintaining primary firm transportation capacity contracts (McArthur 1997).

FERC and the natural gas industry are currently trying to establish policies to help allocate the stranded costs associated with released firm transportation pipeline capacity. So far, the imposition of exit fees on customers to pay for stranded costs has been rejected by FERC. However, it is increasingly acknowledged that forcing pipeline stockholders to absorb all the uncontracted capacity costs is inequitable to shareholders, when external regulatory forces changed the contracts. Possible solutions to the stranded cost conundrum include the following:

1. Split the costs using rate structures that depart from the straight fixed-variable method (SFV),
2. Consider seasonal SFV - volume of FT and monthly demand charges to accurately reflect need for and value of capacity (McArthur 1997),
3. Eliminate the price caps for interruptible and short term deliveries, and
4. Auction all available capacity at any price exceeding the pipeline's variable cost

Before deregulation, the natural gas industry was similar to the California's water industry in that the pipeline conveyance system was integrated with the supply system and controlled by the same entities. Furthermore, market forces did not affect bundled services or future investment. However, the natural gas industry is also drastically different than the California water industry in that water is ingested (i.e. quality is important), and subject to a far greater variety of laws, making it questionable as to whether California water is as fungible a commodity as natural gas.

FERC accomplished natural gas deregulation in a series of orders, and courts have followed along. Companies that owned both gathering and transportation assets have easily divested their gathering assets and become solely transporters. Alternatively, they have spun-down gathering operations to affiliated companies. Given the financial and social benefits from deregulating the gas industry, it is worth asking if the same can be done for California's water industry?

The Electric Industry

The deregulation process of the electric utility industry has learned from the natural gas industry. Congress began deregulation of the electric utility industry in 1997. Previously, electric service providers had to buy power as part of a "bundled" service from a company that provided both generation and transmission. Now, all transmission facility owners must provide open access in an anti-discriminatory manner, regardless of whether a service provider is purchasing power from that owner or from another generator. By being able to purchase power from the lowest-cost generator, and purchase transmission from the lowest-cost transmitter, FERC estimates an annual saving for retail providers ranging from $3.5 billion to $5.4 billion. FERC expects that these savings will eventually be passed on to retail customers. Other goals of electricity deregulation include: (1) better use of existing assets and institutions; (2) development of new market mechanisms; (3) technical innovation; and (4) less rate distortion.

FERC Orders 888 and 889 are largely responsible for electricity deregulation. FERC order 888 requires all electric utilities that own transmission facilities to provide "unbundled" transmission service to private and public utilities and electric cooperatives under strict anti-discrimination requirements. Public utilities must completely separate their wholesale power marketing and transmission operation functions. Order 888 allows full recovery of stranded costs from departing customers for prudent investments. Order 888 also establishes a priority system for obtaining transmission service, in that conditional reservations can be displaced by competing requests for longer-term firm service, which is then followed by requests for longer-term nonfirm service. For comparable requests, price is a tiebreaker. Also Order 888 established that firm transmission customers do not lose their rights to capacity if they don't use it for a period of time. Existing customers get the right of first refusal when potential customers request the use of their previously used capacity, only if they are willing to match price and contract duration. Finally, reassignment is allowed for point-to-point transmission service because it sets forth clearly defined capacity rights. No such rights can be defined for network transmission service (Hebert 1998).

FERC Order 889 established OASIS and the Standards of Conduct for companies participating in the deregulated electricity industry. OASIS stands for "Open Access Same-time Information System" -- an electronic system for information sharing about transmission capacity. Public utilities that own transmission facilities must use OASIS to obtain information about available capacity on their own system for their own wholesale power transactions, the same way their competitors do (Baumol and Sidak 1995; Hebert 1998).

The similarities and differences of the electricity industry to California Water raise the following questions that are addressed by the CALVIN model.

1. Unbundling in electricity was motivated by the availability of more economic power generated by utilities or by non-traditional sources such as independent power producers. Do the cost differences in supply from market sources such as fallowing and conjunctive use and those required to construct new dams in California have a similar motivation?
2. Can we use CALVIN or a similar model to distinguish "point-to-point" and "network" transmission capacity in California's water conveyance systems? Or is our system too integrated to establish "rights-to-capacity"?
3. FERC is an overriding authority that can police monopoly power and discriminatory practices. Can the dominant agencies in California be persuaded to form a counterpart for California's water supply industry?
4. OASIS allows all participants equal access to system information. Can this type of equal access to information exist for California water in the form of a publicly available CALVIN model?
5. Electric transmission facilities are owned by a variety of utilities. The state and federal government primarily own California's water conveyance systems. One decision by FERC controlled the entire electric utility industry. Reforming California's water conveyance system will require coordinated actions by state and federal governments.

STEP-WISE ALTERNATIVES FOR THE FUTURE

Current California laws has "unbundled" California's water supply, distribution and storage systems to some extent. Water transfer provisions allow market prices to control the supply of water to particular users. Wheeling provisions allow those who purchase water to move it from one place to another using existing facilities owned by another agency. However, California law has yet to expressly allow variety in the rates for water delivery based on reliability (Kucera 1995).

Increasing regulation in the Bay-Delta is projected to reduce water supply reliability to those with CVP and SWP contracts. These contractors will seek to replace this lost reliability or to increase total water supply reliability. This is especially true for contractors serving urban and industrial customers who must ensure a stable water supply for their existing population as well as for any growth. By unbundling California's water supply, delivery, and storage systems by increasing degrees, these contractors may be able to purchase this reliability efficiently through various forms of water transfers and/or expansion of physical infrastructure. The premium paid for this increase in reliability can generate revenue necessary to finance water infrastructure. The following discussion presents a variety of policy options for California.

Supply

Determining the amount of water available for transfer.

The current no-injury rule in the Water Code and DWR and USBR policy makes it difficult, time consuming, and often expensive to determine exactly how much water is available for transfer. In particular, DWR and USBR have different definitions of consumptive use, neither of which is the same as that found in the Water Code (§§484, 1725) (O'Brien and Gunning 1994). There is also an inherent conflict of interest in that DWR and USBR must approve transfers that may ultimately affect their ability to meet their contractual commitments to other parties (O'Brien and Gunning 1994). The time and expense involved in determining the amount of water available for transfer often inhibits smaller transfers (Young 1986). An active water market in California will require that this transferable amount become easier and faster to determine.

Who is the final decision-maker for transferring water?

The final decision on the transfer of water raises a conflict that will require some reorganization of the decision process in agencies and districts. Currently most water rights are held by the authorizing districts or agencies whose boards and managers perceive themselves to have a mandate to allocate the water. The current allocation priorities seem to have a greater emphasis on equity rather than efficiency. This is to be expected of institutions whose founding was based on equitable rural development goals such as are stated in the Reclamation Act. However, the requirement of greater efficiency in water allocation means that the decision to transfer water and substitute capital investment, reduced yields or fallowing should be taken by the end user of the water, namely the farmer. Simply put, the farmer has the detailed knowledge that enables him to make efficient water allocation decisions, whereas a district manager has to work from district averages. However when assessing the third party impacts of water transfers to a district, the district agency level is the logical level for decisions. In short, the implementation of market systems requires that the initial decision to buy or sell water be taken at the farmer level, and the district level decisions are changed to a secondary filter to prevent excessive third party cost, or at least compensate these costs if they occur.

The shift in decision making can be approximated by some simple quantitative rules. For example, the 20 percent rule for transfers without requiring district approval under the CVPIA has a de facto assumption that the third party effects of a 20 percent transfer are not excessive. Up to this level, the farmer is the sole decision-maker. For water trades greater than 20 percent, the district has the responsibility to its members to minimize third party impacts. A similar devolution of the property rights towards the farmer is needed for all Californian water rights if market allocation methods are going to achieve their potential gains by more efficient and flexible water allocations.

Conveyance

Increasing environmental protections in the Bay-Delta have created bottlenecks in California's current conveyance system. Potential water transfers are hindered by the lack of reliability in being able to physically move water through California's water supply system when and where desired. The CALFED process has examined three possible solutions that will help alleviate this bottleneck and improve conveyance through the Bay-Delta. Unlike previous water infrastructure ventures, the solutions under consideration do not increase water supply or provide additional water supply contracts. Thus the new water transmission capacity created by these new solutions has yet to be committed to any particular water user.

Decoupling conveyance capacity in new facilities

To increase flexibility, and possibly generate additional revenue, California could maintain its current water supply system in its regulated form, but allow new facilities to be market controlled, to some extent. For example, any new conveyance channels constructed as part of the CALFED solution could become joint public and private facilities. While the facility would be constructed and operated in conjunction with other state and federal facilities, the capacity in it would be allocated using market mechanisms. This capacity could be purchased at auction and then traded among those who make the initial purchases. Alternatively, the capacity could be auctioned off on a yearly or seasonal basis. Temporal differences in the demand for water, and the environmental restrictions on pumping would establish premiums for capacity at various times of the year. Thus units of capacity could be divided to reflect these differences. For example, units of July capacity in the new facility might be more expensive than units of February capacity.

To market new conveyance capacity separately, the legislature would need to amend California's existing wheeling statutes. Water Code sections 1810-1814 requires state and public agencies with excess water conveyance capacity to make up to seventy percent (§1814) of that excess capacity available to bona fide transferors for "fair compensation." The legislature defined fair compensation as including reasonable charges incurred by the owner - including capital, operation, maintenance, and replacement costs (Water Code §1811(c)). Theoretically, if California was to construct a new water conveyance facility without allocating its capacity through long-term supply contracts, that capacity could be sold to bona fide transferors as excess capacity under California's wheeling provisions. However, the current provisions fall short in at least two important respects. First, the definition of "bona-fide transferor" in §1811(a) is too limiting. Second, the current provisions preclude the imposition of opportunity costs in "fair compensation," unduly limiting the revenue potential of new capacity.

Section 1811(a) requires a bona-fide transferor to have a contract for sale of water, which may be conditioned upon the ability to convey that water. Thus, only entities with water contracts would be able to purchase new conveyance capacity, and only to the extent of their existing contracts. In order to market the new capacity created by a new conveyance facility, the state will need to be able to sell capacity to entities who are speculating that they will have such contracts in the future or will be able to sell the capacity they acquire to others. Having such conveyance rights might lower the transaction risks of water market transfers (Lund, 1993). Thus, new legislation is required to expand the definition of who may acquire excess capacity in a conveyance facility.

Also, section 1811(b) does not allow the owner of conveyance capacity to include the opportunity cost of that capacity in the fair compensation charged for that capacity. A recent California Superior Court interpretation of the wheeling provisions noted that the statutes do not allow an owner to charge different rates for firm and interruptible capacity. Similarly, more extensive reliability-based charges that account for temporal and environmental constraints would not be allowed under the current provisions. This can be remedied with new legislation that would allow the state to sell new capacity in an initial primary market and the purchasers of this capacity to re-sell it in a perpetual secondary market.

The price charged in the primary market would at least equal “fair compensation”, as defined in the current statute- in other words, the marginal cost of the new facility. Primary purchasers could bid for new capacity at a price higher than “fair compensation,” generating two distinct advantages over the strict “fair compensation” limitation. First, those desiring higher reliability could purchase this reliability. Second, the premium paid for this reliability would generate additional revenue necessary for ancillary water supply improvements.

New legislation also would be required to establish the legality of a secondary market for capacity in a new facility. Purchasers in the primary market would then be able to either use the capacity purchased for their own conveyance needs, or market that capacity to other persons or agencies. If the price that could be charged for capacity in the secondary market was limited to “fair compensation” as currently defined, there would be no incentive to purchase capacity in the primary market, because it could not be sold at a profit in the secondary market.

Clearly, the notion of a secondary market in conveyance capacity brings up issues of monopoly or oligopolistic pricing power. Similar to the market for natural gas pipeline conveyance capacity overseen by FERC, it may be desirable to establish an oversight committee for the rate structure used in the secondary market for conveyance capacity (See e.g., McArthur 1997).

Decoupling conveyance capacity in existing facilities

Taking these ideas a step further, it might be possible to eventually use market mechanisms to allocate the capacity in existing California water delivery facilities. Currently, water contractors have “rights” to receive certain quantities of water, but these rights are not divided into a supply right and a time-of-delivery right. With the advent of more sophisticated conjunctive use programs, it may be possible for contractors with local storage facilities to buy and sell the right to capacity in a given delivery system at a given time of year.

New legislation would likely be required to allow conveyance capacity in existing water conveyance facilities owned by the state and federal government, local public agencies, and private companies to be sold in a secondary market.

Storage

Marketing storage capacity in reservoirs

While numerous reservoirs in California are owned by local districts, it not well known whose capacity has been marketed on a per-unit basis. Cost recovery for reservoirs has always been based on charges for water service. Despite the absence of examples, there does not seem to be any fundamental problem in marketing reservoir capacity on a long or short-run basis.

Marketing storage capacity in conjunctive groundwater projects

Several technical aspects of conjunctive use need to be defined. The principle problems can be summarized in terms of the "take-put" ratio and the lateral flow problem. The "take-put" ratio is central to actively recharged conjunctive use, and is the proportion of water extracted from the bank compared with the water recharged into the bank. The ratio corresponds to the yield-to-storage ratio of a reservoir and critically determines the cost of storage in a conjunctive project. Conceptually, the physical aspects of the aquifer and recharge system should determine the "take-put" ratio. However, a low "take-put" ratio may confer benefits on the overlying water users, and has thus become a bargaining point in conjunctive use negotiations. The few conjunctive use agreements consummated in California and those under negotiation have "take-put" ratios ranging from 0.8 to 0.5.

Another serious problem in defining property rights for conjunctive use projects is that few groundwater basins in California are completely self contained. Most basins have some lateral flow through them. The problem is to define the property right in terms of the holding capacity of the aquifer rather than the water contained in it. During the hearings on the Madera Ranch project the lateral flow problem was posed in the form of the question: "Are the water molecules that are extracted from the basin the same ones that were recharged into it?" The answer was ‘no’, and the discussion on water rights degraded from that point. Without some new legal concepts of capacity rights in aquifers, conjunctive use agreements will be susceptible to confusion over water rights as distinct from water storage rights.

Agreements entered into to date have expressly treated groundwater storage capacity as an asset that is sold at market rate. Examples of current agreements include the MWD/Arvin-Edison Agreement and the ongoing Madera Ranch negotiations

Privatization Issues

Private Financing

General obligation bonds and tideland oil revenues, as authorized under the Burns-Porter Act of 1960 initially financed the State Water Project facilities. Subsequently, additional revenue bonds and capital resources were raised to develop the project. These bonds and the maintenance, operation, power, and replacement costs associated with the facilities are repaid by the 29 agencies or districts who have long-term water supply contracts with the Department of Water Resources. One option for consideration is the divestment of part of this existing system to private interests (O'Conner 1994b; Savas 1989-90).

New legislation would be needed to allow the private market to generate revenue for construction, or agencies to issue bonds to purchase additional capacity. The Model Water Transfer Act Financing Options contains several ideas for new financing options (Mitchell and Moss 1996).

Private Operation

The operation of private agency water trading in conjunction with public facilities and operation introduces new types of public/private partnerships that will require further modification to the current system of property rights under pure public ownership. Suggestions for changes in the current structure can be found in the following publications:

1. Physical Operation of the System (O'Conner 1994b),
2. Private Brokers for Transfers/Water Banks (Wahl 1994), and
3. The benefits of a centralized water bank (Israel and Lund 1995).

CONCLUSIONS

A transition towards the market financing of additional water supplies will require changes in the legal structure. The most significant changes will have to occur in the areas where there is least development of property right definition, namely groundwater. Since the process of market development will change the value of groundwater and groundwater storage capacity, the legal code in this area will evolve. Hopefully, groundwater rights will evolve towards a more flexible form without eroding the protection of third party interests. Another area of significant legal change will involve the marketing of some of the storage and conveyance capacity in existing public water facilities.

While many of the property rights for surface water are not well suited to market exchanges, there are many rights in California under which the water can be traded. The evolution of the legal code for surface water can wait for the initial market developments under way to highlight the shortcomings in the current code before making changes to the majority of surface water rights.

The experience of the natural gas and electricity industries has valuable lessons for the market-based development of California water. Of particular note is the requirement of a common technical basis to measure the impact on third parties of movements of gas. This created a common fungible commodity whose property rights were technically defined in terms of third parties, as well as those involved in the exchange. The definition of third party property rights must be clarified before the transaction costs of water sales will be low enough to facilitate an active market. The "no injury" rule that currently dominates discussion of third party impacts implies a "no trade" situation if taken to its literal extreme. An important development of the water code would be to clarify the "no injury" rule as a "no significant injury" rule that would serve the greater public interest of increased water trades without exposing third party interests to excessive costs.

CHAPTER 6

ECONOMIC ANALYSIS OF STATEWIDE WATER OPTIONS

"The man that would be truly rich must not increase his fortune, but retrench his appetites."
Lucius Annaeus Seneca (circa 70 AD), *Of a Happy Life*.

"The stoical scheme of supplying our wants, by lopping off our desires, is like cutting off our feet when we want for shoes." Johnathan Swift (1706), *Thoughts on Various Subjects.*

California's water scarcity problems reviewed in Chapter 2 are forecast to increase. If no new actions are undertaken, by 2020 average year shortages of 2.9 maf are forecast, increasing to 7.0 maf in a drought year (DWR 1998a). However, as reviewed in Chapters 3, 4 and 5, numerous institutional and infrastructure options are available to accommodate, mitigate, and reduce these shortages. This chapter presents the development of a set of economic analysis tools for evaluating structural and non-structural water supply options statewide. These tools are organized into a new optimization model, named CALVIN (California Value Integrated Network).

WHY ECONOMIC ANALYSIS?

Current water policy is often driven by historical water allocation mechanisms intended to stimulate the development of the Western US. A new phase of possible system expansion and re-operation requires a different paradigm for policy making. In an increasingly populous and thirsty state, we need to revisit historical allocations and management of very limited supplies. If system expansion is to be undertaken, we should know how the state's economy would benefit, who would be the beneficiaries and how the great costs of expansion should be allocated or recovered. Federal financing of new water projects is no longer assured. Could new infrastructure investment attract private investment? Users' willingness-to-pay for additional water supply reliability should be the cornerstone for assessing the need for additional facilities, both storage and conveyance. The original operational objectives of the State Water Project (SWP) and Central Valley Project (CVP) have changed and will continue to evolve. Economic performance provides a suitable measure for comparing the great variety of alternatives. Water markets and water transfers are possible reallocation mechanisms for closing the gap between supply and demand. An economic model would reveal the benefits achieved through trade by exploiting spatial and temporal differences in the marginal valuation of water. Economic models might also help point to promising roles for private and inter-governmental involvement in financing and managing water facilities.

SELECTION OF AN ANALYTICAL TOOL

Requirements

This study's objectives are outlined in Chapter 1. The purpose of an analytical tool is to investigate ways of improving water supply reliability and to quantify the associated benefits. As such the chosen tool should:

- Identify promising sites or ‘hot spots’ for economical new infrastructure development;
- Show how the operation of new facilities could be integrated into California’s existing water system;
- Identify the potential economic gains from changes in the current operating procedures, policies and regulations; and
- Quantify willingness-to-pay by group or agencies for system changes.

Computer models are necessary for working with complex systems, such as California’s water supply. A plethora of water management models are already used by California’s water agencies, ranging from simple spreadsheets to very large FORTRAN models. The complexity of these simulation models has increased over time in response to changing water management issues and the increasing interdependency within the system. Solutions to new problems require the examination of many alternatives. It is often difficult and time-consuming to use existing detailed simulation models to analyze large numbers of alternatives. In such cases, it is desirable to develop a separate “screening model” for identifying promising solutions and assessing preliminary performance of a wide range of alternatives. A smaller number of promising alternatives can then be refined and tested with more detailed simulation modeling tools.

Existing Models

Why yet another model and what is different about CALVIN? Before answering these questions, existing large-scale models for California’s water system are briefly described. It should be noted that all of the models described are procedural in design, driven by operating rules derived from current water allocation practices. None includes explicit measures of economic performance.

DWRSIM

The DWR Planning Simulation Model (DWRSIM) was developed by DWR for water resources planning studies related to the operation of the CVP and SWP (Barnes and Chung). The model was originally based on HEC-3 Reservoir System Analysis for Conservation model developed by the USACE’s Hydrologic Engineering Center (HEC) at Davis, CA. However, since its conception DWRSIM has undergone many additions and enhancements. This includes the addition of a network flow algorithm to model the operation of the California Aqueduct (Chung et al. 1989). DWRSIM utilizes reservoir rule curves based on pre-determined target storage levels to balance storage between reservoirs and between months. The model operates the system for a mixture of water supply, flood control, instream flow augmentation and hydropower generation (DWR 1985).

PROSIM

PROSIM is USBR’s Projects Simulation Model. It is a monthly planning model designed to simulate the operation of the CVP and SWP (USBR 1997). It is used by USBR to analyze long-term water supply impacts on the CVP-SWP system primarily due to regulatory changes affecting system operation. The area represented by the model includes the entire SWP system and the CVP system north of the Stanislaus River.

SANJASM

Similar to PROSIM, the San Joaquin Area Simulation Model (SANJASM) is a monthly planning model developed by USBR. The modeled system covers the east-side streams that are tributary to the Delta and the San Joaquin River Basin (USBR 1997). Much of the SANJASM has been incorporated into DWRSIM.

CVGSM

The current Central Valley Groundwater and Surface Water model (CVGSM) was developed as part of the Programmatic Environmental Impact Statement for the CVPIA (USBR 1997). It is Valley-wide groundwater model that simulates changes in groundwater storage in response to groundwater pumping, and both artificial and natural recharge. The model is based on the Integrated Groundwater and Surface Water Model (IGSM) code that was developed under funding by DWR, USBR, SWRCB and the CCWD. The model includes: a soil moisture budget to simulate direct runoff, infiltration, deep percolation and evapotranspiration; a 1-D stream flow network; unsaturated flow simulation; and groundwater flow simulation using a multi-layered 2-D finite element grid.

Need for a New Model

None of the existing models that simulate operations over a hydrologic period-of record are statewide. None use economic performance as a criterion for operating the system and none of the larger models are sufficiently flexible to screen large numbers of alternative operation and system capacities. It was therefore decided to use a model that is driven by economic indicators of system performance and is designed to examine and choose between large numbers of alternatives. This latter requirement resulted in the abandonment of simulation modeling in favor of optimization. It should be emphasized that while CALVIN represents a new approach in modeling California's water system, it uses existing and previously used and well tested computer programs as its core. The particular technique chosen for CALVIN is known as network flow programming, a subset of linear programming (Jensen and Barnes 1980). Optimization models have previously been used to model the operation of the SWP (Lefkoff and Kendall 1996), but not with an economic objective function. The use of economic optimization models for large-scale water resources planning has been used by the World Bank as part of its investment studies (World Bank 1993).

Optimization

Optimization, a form of mathematical programming is well documented in academic and research literature but its application to real water resources problems is relatively new. An optimization model will set the value of all decision variables so as to maximize (or minimize) the value of the objective function subject to meeting all constraints. To apply an optimization model to a particular problem several questions need to be answered:

- What variables are to be optimized?
- What is the performance objective to be maximized or minimized?
- What constraints should be considered?
- What models/mathematical solution techniques should be used?

As applied to this particular study, the performance objective is to maximize statewide economic benefits for agricultural and urban water use minus operating costs. The decision variables to be optimized are a time-series of reservoir storages and water allocations. Constraints include the need to conserve mass (inflows - outflows = change of storage), capacity limits of the system (storage, conveyance, and treatment) and regulatory or policy requirements (minimum instream flows, restrictions on allocations and transfers etc.).

Optimization models differ from the simulation models described above section in that they are not driven by a predetermined set of operating rules. Optimization models determine the "best" water allocations and operations given a set of economic values. In contrast, simulation models could be used to derive the economic benefits from a *given* a set of water allocations. These two types of model should be used together. An optimization model can be used to quickly assess many alternatives but requires many simplifications. Detailed simulation modeling of promising alternatives is subsequently required to confirm the potential and refine or adjust promising solutions (Lund and Ferreira 1996).

Network Flow Programming

This study uses network flow programming to represent California's water system and solve for economically desirable operation. Network flow programming involves representing the system as a network of nodes and links. For a reservoir/stream system, nodes represent reservoirs, points of diversion, return flow locations or other fixed-point features. The nodes are connected by links that represent possible paths for flow between the nodes. To represent time, identical networks are 'placed parallel to each other- each network representing a particular time step. Links connect reservoirs on adjacent networks so that storage can be conveyed through time. Cost factors or penalties are attached to the links. Where the cost factors are non-zero, each unit of flow through the link will incur a penalty. These penalties may have constant unit values or vary as a function of flow through the link (see Appendix C of USACE 1991a).

The network flow algorithm computes the value of flows in each link at each time-step that optimizes the objective function subject to the constraints of maintaining a mass balance at nodes and not violating user-specified upper and lower bound on flow through the links. Network flow programming has long been used to help solve complex logistics problems in commercial and military areas. In water management, network flow programming has long been used as part of some simulation models (Israel and Lund 1999); some parts of DWRSIM use this technique to achieve storage and delivery targets (Chung et al. 1989).

Economic Objective Function

The objective function consists of a single equation that expresses the objective in terms of decision variables. An economic objective function may be either to maximize benefits or minimize costs. Benefits for CALVIN are based on water user's willingness-to-pay. This is defined as the amount a rational informed buyer should be willing to pay for an additional unit (of water). Under a competitive, unregulated market the willingness-to-pay will equal the market price.

Optimization models with economic objective functions provide, in addition to the value of the objective function, additional economic information in the form of shadow prices or dual costs.

The shadow price represents the increase in the objective function performance for a unit relaxation of a constraint. Given that flow and storage are constrained by system capacities, the shadow price identifies directly the economic benefits of increasing those capacities. The shadow price for a particular facility will vary with time. For example, the value of additional conservation storage will only be non-zero only when the reservoir is full and forced to spill.

CALVIN MODEL OVERVIEW

CALVIN is a collection of computational tools and data that permit the economic analysis of California's inter-connected water infrastructure using optimization. The optimization engine uses a generalized network flow to allocate water to maximize economic benefits (or minimize economic penalties). Economic demands for water use are represented at a fixed 2020 level of development. Supplies are represented by a time-series of monthly inflows based on the historic Oct. 1921- Sep. 1993 hydrology. Table 6-1 summarizes the components that differentiate CALVIN from other existing models.

Table 6-1. Comparison of Selected California System Models

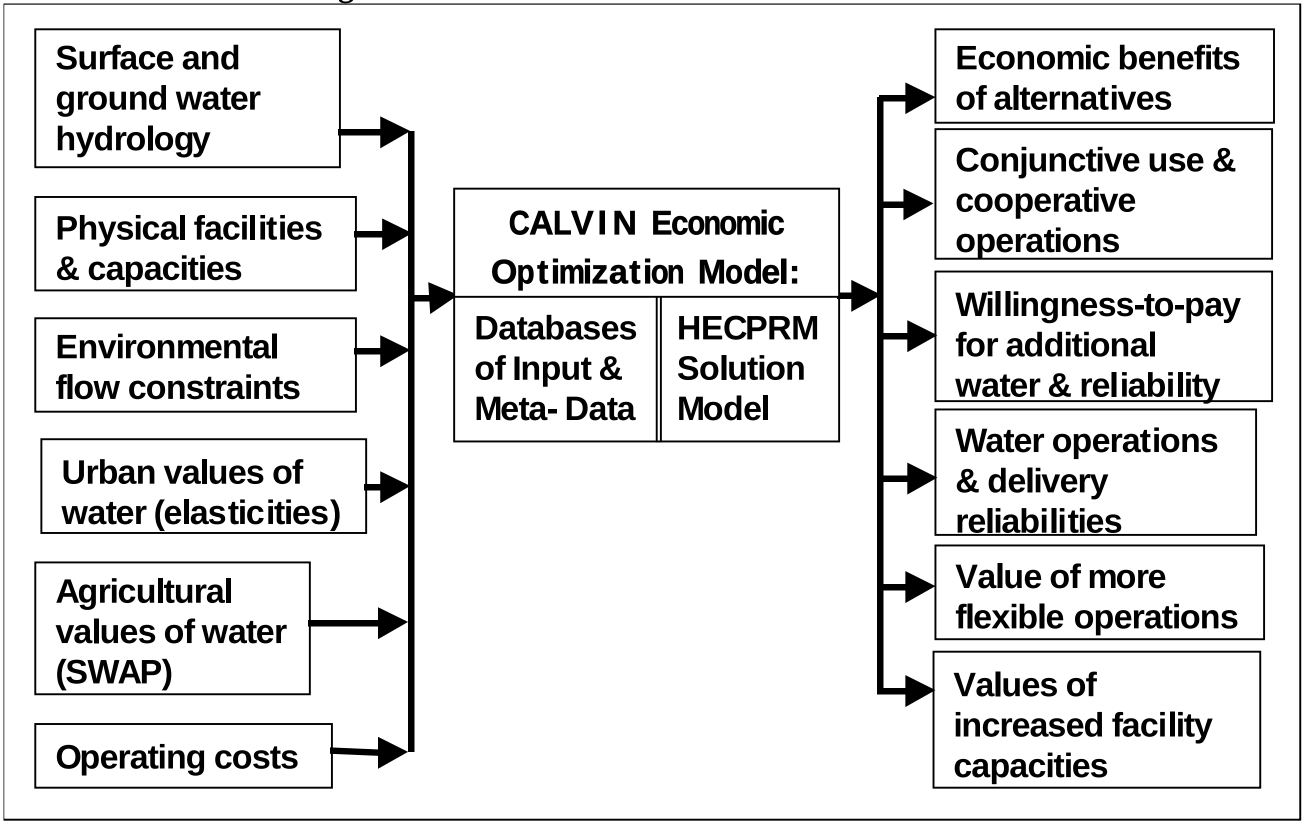
	DWRSIM	PROSIM/ SANJASM	CVGSM	CALVIN
Operation				
rule-based	✓	✓	✓	
economically based				✓
legal/contractual	✓	✓	✓	
Projects/regions represented				
CVP	✓	✓	✓	✓
SWP	✓	✓	✓	✓
Tulare Basin				✓
S. California				✓
Outputs				
time-series of deliveries	✓	✓	✓	✓
quantified benefits				✓
"best" operation				✓
Data-driven				✓

Figure 6-1 represents the flow of data through CALVIN. Model inputs are composed of six components: (1) network representation of California's rivers, reservoirs, aquifers, canals, aqueducts and demands; (2) surface and groundwater inflows; (3) urban economic value functions; (4) agricultural economic value functions; (5) environmental flow requirements; (6) other policy and physical constraints. The derivation of these six inputs to CALVIN is described in later. For urban and agricultural value functions, separate economic models have been developed.

CALVIN can be decomposed into two major components: a set of databases and a reservoir system optimization model. The optimization model is a generic network flow optimization solver that is entirely data driven. All the inputs that define its application to the California system are stored in the databases.

Output from the model consists of a monthly time-series of storages, flows and water allocations over the 72-year modeled period. This output is postprocessed to obtain information on the benefits of different alternatives to system management and operation.

Figure 6-1. Data Flow for the CALVIN Model



Model Components

Databases

Input data for the optimization model consists of the network configuration for California, time-series (hydrologic inflows and time varying constraints), scalar values (fixed constraints, fixed costs and fractional gains and losses) and relational or paired data (functional relationships e.g. between elevation-area-capacity for reservoirs, between quantity of water delivered and the cost of shortage for urban and agricultural users). Time-series and paired data is stored using the HEC'S Data Storage System (HECDSS). This system was developed specifically for water resource applications (USACE 1994). It provides storage of continuous data. An Excel 'add-in' or utility has been developed to store (or retrieve) data from Excel to DSS. All other input data is stored in a Microsoft Access database. Within the database, tables define the properties associated with nodes and links within the network and pathnames to access data from DSS.

Too often large computer models are poorly documented and inscrutable to the user. For modeling intended for use in public policy discussions, model assumptions and data should be readily available and understandable. This study has taken a new approach in storing metadata within the Access database. Metadata is descriptive information about model data. For

CALVIN the metadata contains information on the origins, content, quality and reliability of all inputs to the model.

Reservoir System Optimization Solver

The optimization solver for CALVIN is the HEC-PRM (Hydrologic Engineering Center-Prescriptive Reservoir Model), a network flow optimization computer code developed by the USACE's Hydrologic Engineering Center in Davis, CA. Base on user-specified value functions of system performance, the model produces a time-series of flows and reservoir storage scenarios that optimize system operation. Developed specifically to examine the economic operation of large water resource systems, HEC-PRM has been applied to many systems by USACE and the University of California, Davis. These studies are summarized in Table 6-2.

Table 6-2. Previous Optimization Studies Using HEC-PRM

Year(s)	Basin (No of Reservoirs)	Study Purpose(s)	Citation(s)
1990-1994	Missouri River (6)	Economic-based Reservoir System Operating Rules	USACE 1990, 1991a, 1992a, 1992b, 1994b; Lund and Ferreira 1996
1991-1996	Columbia River System (14)	Economic-based Reservoir Operating Rules Capacity, Expansion, & Multi-Purpose Operations Seasonal Operations	USACE, 1991b, 1993, 1995, 1996
1997	Carson-Truckee System (5)	Prioritization of Uses & Performance Assessment	Israel 1996; Israel and Lund 1999
1997	Alamo Reservoir (1)	Multi-objective reservoir operation	Kirby 1994; USACE 1998b
1998	South Florida System (5)	Capacity Expansion & Multi-objective performance	USACE 1998a
1999	Panama Canal System (5)	Drought Performance & Economic Reservoir Operations	USACE 1999
1999-present	California Intertied System (86)	Economic Capacity Expansion & Financing	Present report

As reflected in the number of reservoirs, the present study represents a very large increase in the size of the system modeled. This has been made possible due to recent and continuing increases in computer processing speed. In addition some specific alterations and enhancements have been made to the HEC-PRM code as part of the study. This includes output of shadow prices and reduced costs, which can be interpreted as the value of relaxing the constraints.

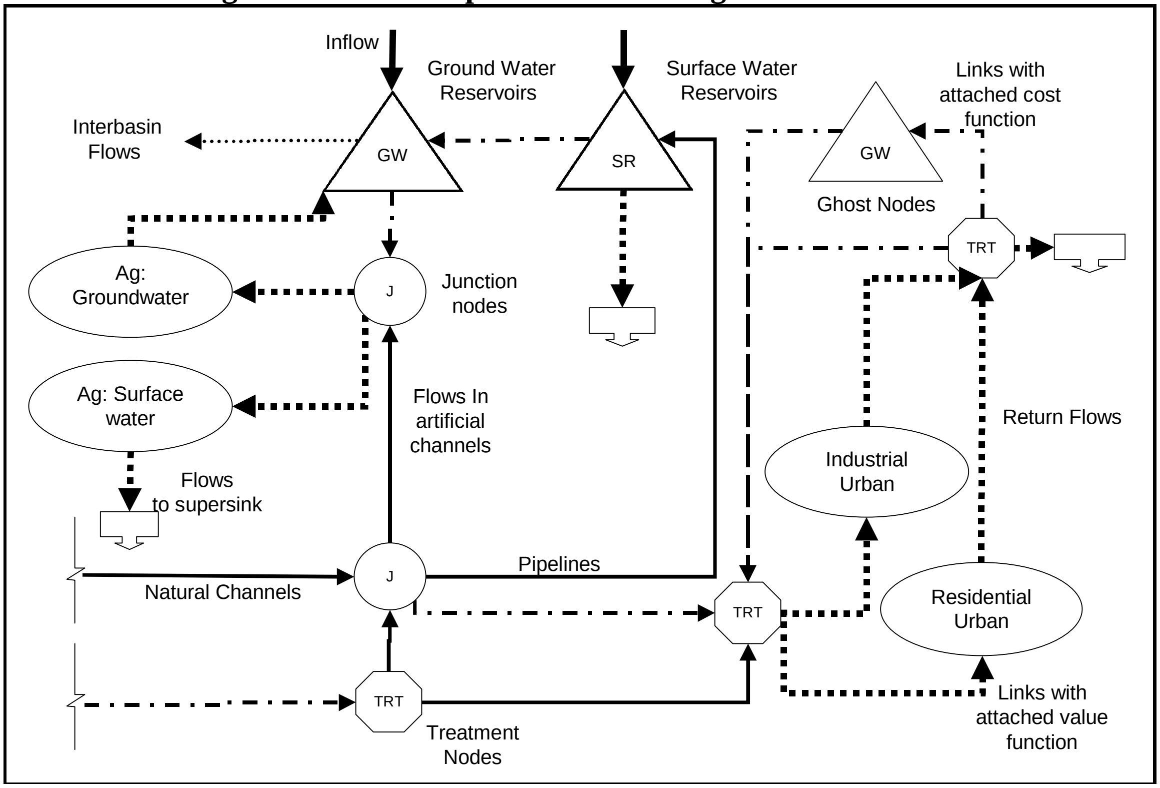
The following sections describe how the various CALVIN model inputs have been established.

NETWORK REPRESENTATION OF CALIFORNIA'S WATER

California's inter-connected hydrologic system has been represented by a network flow diagram as a series of links and nodes as illustrated in Figure 6-2. Where possible, this representation is based on DWRSIM but is extended to include the Tulare Basin, Owens Valley, Imperial & Coachella Valleys, the Colorado River and the South Coast. The CALVIN network is also entirely physically based. Each element of the network has a physical counterpart. The representation of the intricate MWD delivery system is based on an aggregation of MWD's Integrated Resources Planning Distribution System Model (IRPDSM). Conversations with MWD staff and data availability led to the disaggregation of MWD into three components: MWD's central pool (including 24 of MWD's water contractors), Eastern and Western MWD (2 MWD water contractors), and the San Diego County Water Authority (1 MWD water contractor).

The actual schematic is contained in Figures 6-3 and 6-4. Although it is difficult to interpret when printed at this scale, these figures illustrate the complexity of both the system and how it is being modeled.

Figure 6-2. Example Schematic Diagram for CALVIN



Network Flow Diagram Elements

Storage Nodes

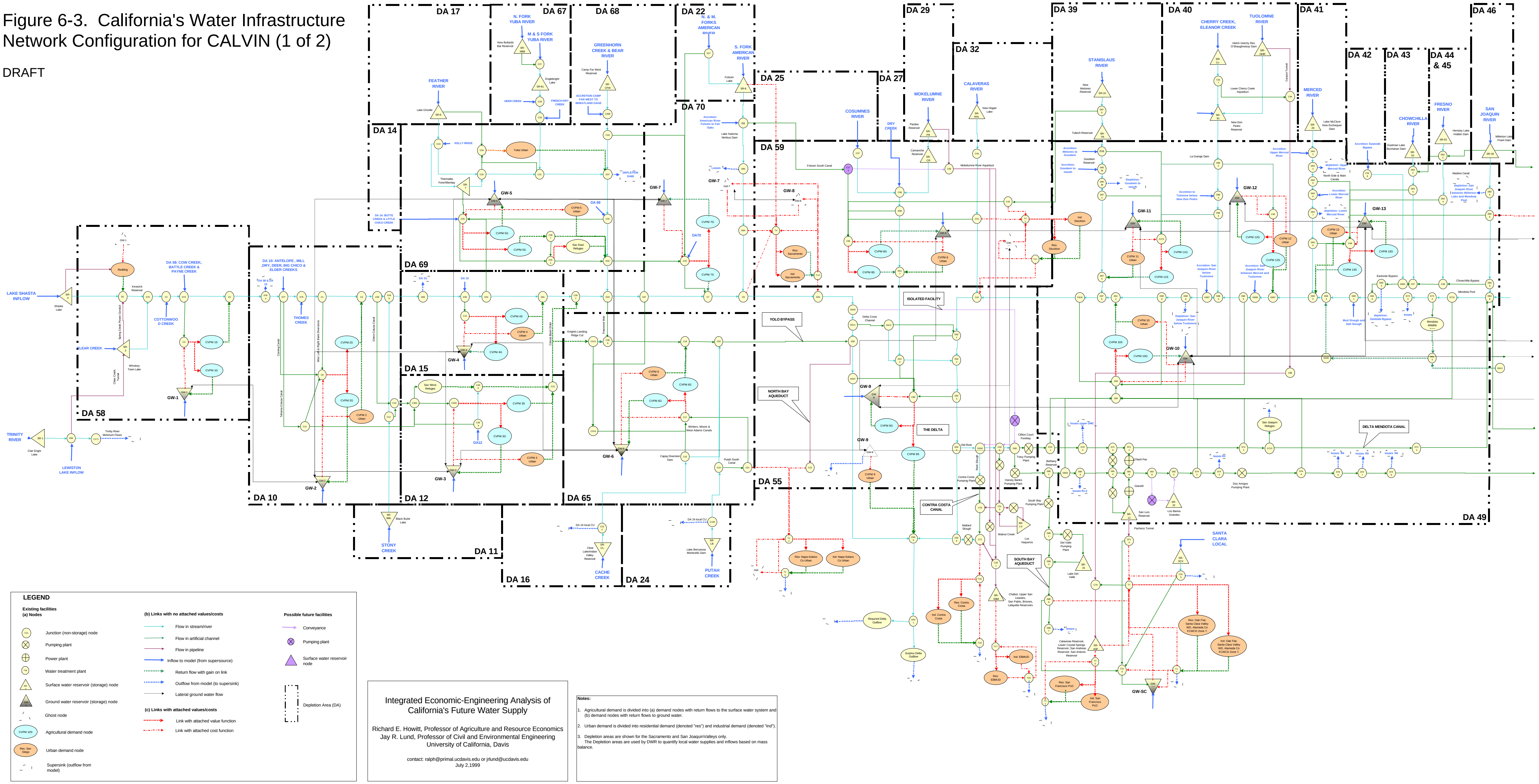
Storage nodes represent both surface reservoirs and groundwater basins. Each storage node may have any number of inflows and outflows but mass balance requirements must be met. Included in CALVIN are 56 surface water storage nodes and a further 30 groundwater storage nodes.

Surface Reservoirs

In general only surface reservoirs with a usable capacity exceeding 50 taf were included in CALVIN. In two cases a single storage node represents two adjacent reservoirs with a combined capacity. For each surface storage node constraints are set on the minimum/maximum monthly storage volumes and beginning/end-of–period storage. Monthly evaporation is calculated from

Figure 6-3. California's Water Infrastructure Network Configuration for CALVIN (1 of 2)

DRAFT



Integrated Economic-Engineering Analysis of California's Future Water Supply

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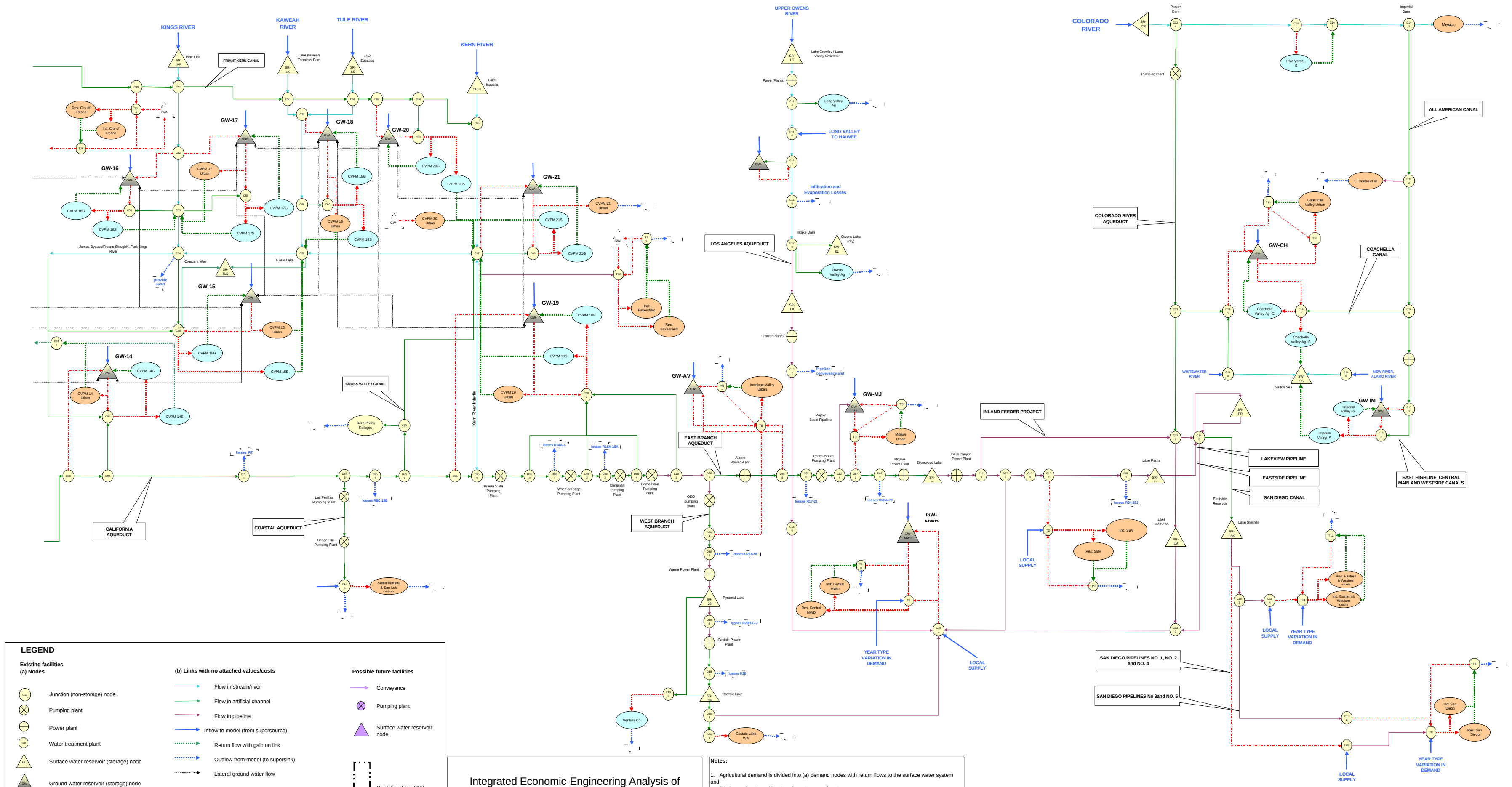
July 2,1999

Notes:

1. Agricultural demand is divided into (a) demand nodes with return flows to the surface water system and (b) demand nodes with return flows to ground water.
2. Urban demand is divided into residential demand (denoted "res") and industrial demand (denoted "ind").
3. Depletion areas are shown for the Sacramento and San JoaquinValleys only.
The Depletion areas are used by DWR to quantify local water supplies and inflows based on mass balance.

Figure 6-4. California's Water Infrastructure Network Configuration for CALVIN (2 of 2)

DRAFT



LEGEND

Existing facilities
(a) 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
CVPM 10S	Agricultural demand node
Res: San Diego	Urban demand node
	Supersink (outflow from model)

(b) 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

(c) Links with attached values/costs

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

Possible future facilities

→	Conveyance
⊗	Pumping plant
▲	Surface water reservoir node
[ ]	Depletion Area (DA)

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   The Depletion areas are used by DWR to quantify local water supplies and inflows based on mass balance.

the product of monthly evaporation rates and reservoir surface area. The surface area is estimated by multiplying the storage by a constant factor.

Groundwater Reservoirs

The division of groundwater basins into discrete reservoirs is somewhat subjective. Within the Central Valley, groundwater is represented by 21 reservoirs. The boundaries of these reservoirs follows those established for the CVGSM model and coincides with the definition of agricultural model regions (see Appendix A). Outside of the Central Valley, a further nine groundwater basins are represented for Southern California. Associated with each reservoir are links representing natural and artificial recharge, pumping, and regional groundwater movement. Similar to surface water storage nodes, the groundwater nodes have specified usable storage capacities and both initial and end-of-period storage volumes. In addition, constraints are set on minimum and maximum monthly pumping and recharge.

Junction Nodes

Junction nodes provide for the interconnection of links. They may represent pumping and power plants, diversion points, or forks in pipelines, channels, and rivers. They also represent points on the model boundary and, as such, receive inflows or ‘external’ flows. The only imposed limitation on junction nodes is the requirement that the sum of inflows equals the sum of outflows. Although some of the 303 junction nodes on the schematic represent hydropower operations, hydropower analysis is excluded from this initial phase of the study.

Demand Nodes

Demand nodes represent some aggregation of agricultural, urban or environmental demand for water. They are essentially identical to junction nodes – representing a specific location within the network - but are distinguished from junction nodes by having a single inflow and a single outflow. The inflow represents deliveries and has a value function associated with it. Consumptive use at the node is represented by a gain factor on the downstream link. The “gain” factor is the ratio of link outflow to link inflow. For example, consumptive use equal to 80% of deliveries is represented by a gain factor of 0.20 on the downstream link. The limitation of a single outflow necessitates the splitting of each agricultural demand: one demand node has return flows to the surface water system; the other returns to groundwater (see Figure 6.2).

Links

Links represent either a stream, artificial channel, or pipeline and can be constrained by minimum and maximum flows. Over 770 links exist within CALVIN. In some cases a single link represents the aggregation of many minor canals. For example, the CALVIN representation of the Kings River designates only two diversions from the Kings River to the Fresno area. These links represent upwards of 100 diversion canals and ditches used by several different local water districts (Woodman et al., 1997). Determining the canal capacity on such an aggregated system would be very time-consuming so that in such a case it has been assumed that canal capacity is not a constraint on deliveries. Operating costs are imposed on some links to represent pumping and treatment costs.

External Flows

External flows represent the addition of surface water and groundwater to the system and are specified for each month of the modeled period. They are described below.

HYDROLOGY

Time Horizon

Although CALVIN's operation is based on a monthly time-series of inputs, CALVIN is in some sense a static model. Demand is estimated from a static agricultural production model and a static urban demand model. The time-varying hydrology can be viewed as representing the possible future range of flows. In this sense the model is static with an implicitly stochastic representation of input hydrology. The chosen level of development is the year 2020.

The hydrologic period represented in CALVIN is Oct. 1921-Sep 1993. This 72-year period was chosen primarily due to the ready availability of data prepared for other large-scale simulation models. This period also represents the extremes of California's weather. Included in the 1921-1993 time period are the three most severe droughts on record: 1928-1934, 1976-1977, and 1987-1992 (DWR, 1998a). Table 6-3 illustrates the severity of these droughts in the Sacramento and San Joaquin Valleys.

Table 6-3. Severity of Extreme Droughts in the Sacramento and San Joaquin Valleys

Drought Period	Sacramento Valley Runoff		San Joaquin Valley Runoff	
	(maf/yr)	(% Av. 1906-96)	(maf/yr)	(% Av. 1906-96)
1929-34	9.8	55	3.3	57
1976-77	6.6	37	1.5	26
1987-92	10.0	56	2.8	47

Source: DWR (1998a)

Surface Water

Adjustment of Historic Flows

California's hydraulic infrastructure has progressively developed over the last 60 years. Matching this development has been the conversion of native vegetation to agriculture and spreading urbanization. These two developments have changed the hydrologic regime that existed historically. Land use changes have altered the amount and timing of runoff. On-stream storage and diversion of stream flows have modified the seasonal variation in stream flow. To determine the input hydrology, CALVIN uses the same approach as existing Central Valley simulation models, such as DWRSIM and PROSIM.

Rim Flows

For inflows from areas upstream of the modeled region, the historic flow is modified to reflect the stream flow that would have occurred with the current infrastructure in place, but with a projected operation and under a 2020 projected land use. This can be interpreted as the flow that would occur if the historic pattern of precipitation were repeated.

Accretion/Depletions

Inflows that originate within the modeled area, resulting from direct runoff or groundwater gains and losses along a stream, are represented slightly differently. Assuming that all major facilities, stream diversions and return flows are represented explicitly in CALVIN, the historic accretions/depletions are modified for land use changes only.

The derivation of surface water inflows is discussed in detail in Appendix I.

Groundwater

Flows in and out of groundwater reservoirs or basins have been divided into several components:

- Natural recharge from precipitation
- Lateral groundwater movement between reservoirs representing large-scale regional flows
- Accretion/depletion to/from stream flow
- Subsurface inflow from outside the model area
- Groundwater pumping
- Recharge from irrigated agriculture and wastewater
- Artificial recharge (conjunctive use/groundwater banking)

Only the last three components are determined dynamically by CALVIN. All other components of groundwater flow and recharge are pre-processed and are represented as fixed inputs. Details of how these flows have been estimated are described in Appendix J.

Data Sources

Surface water inflows for the Central Valley are primarily based on DWR's depletion analysis (see Appendix I). This is supplemented by USGS and USACE data for the Tulare basin. For Southern California data was obtained from the Los Angeles Department of Water and Power and the City of San Diego.

Groundwater flows for the Central Valley are based on the CVGSM groundwater model constructed as part of the CVPIA Programmatic Environmental Impact Statement (USBR 1998). Elsewhere groundwater flows are estimated from published model studies and water master reports.

ECONOMIC VALUE FUNCTIONS

Operations and allocations made by CALVIN are driven by economic values for agricultural and urban water use in different parts of the state. These water demands are estimated using separate economic models for each water use sector. The economic value functions implicitly include the economics of water conservation measures by water users.

Statewide Agricultural Production Model (SWAP)

<u>Origins</u>

The Statewide Water and Agricultural production Model (SWAP) has been developed in parallel with CALVIN to value the economic use of water and how this varies in time and space. SWAP is an economic optimization model that maximizes farmer's returns from agricultural production subject to production and resource constraints on land and water. SWAP extends the work presented in the Central Valley Production Model that was developed as part of the CVPIA Programmatic Environmental Impact Statement. SWAP uses much of the original data contained within CVPM. The model represents the original 21 CVPM regions that cover agricultural within the floor of the Central Valley as well as agricultural production regions in Southern California within Imperial, Riverside and San Diego counties. Details of the SWAP model are presented in Appendix A.

Model Enhancements

SWAP represents various enhancements and changes to the original CVPM model. These are summarized in Table 6-4. The most important change for CALVIN is the use of a monthly rather than an annual time step. Agricultural production is still modeled on the basis of an annual or seasonal planting decisions. However additional constraints are introduced into the model so that monthly water use can be estimated. The revenue from producing a particular crop is distributed across the growing season in accordance with crop water requirements so that the marginal value of water is equal across months.

Table 6-4. Agricultural Model Comparison

Aspect	CVPM	SWAP
Regions	21 regions of Central valley	26 regions for Central Valley and Southern California
Production cost function	Single crop quadratic PMP costs	Quadratic multi-crop costs estimated from maximum entropy
Production technology	Fixed yield CES trade-off between cost and water use	Variable yield with CES production function in land, water and cost
Output price	Prices change with total production	Fixed price with regional differences
Water use	Annual	Monthly

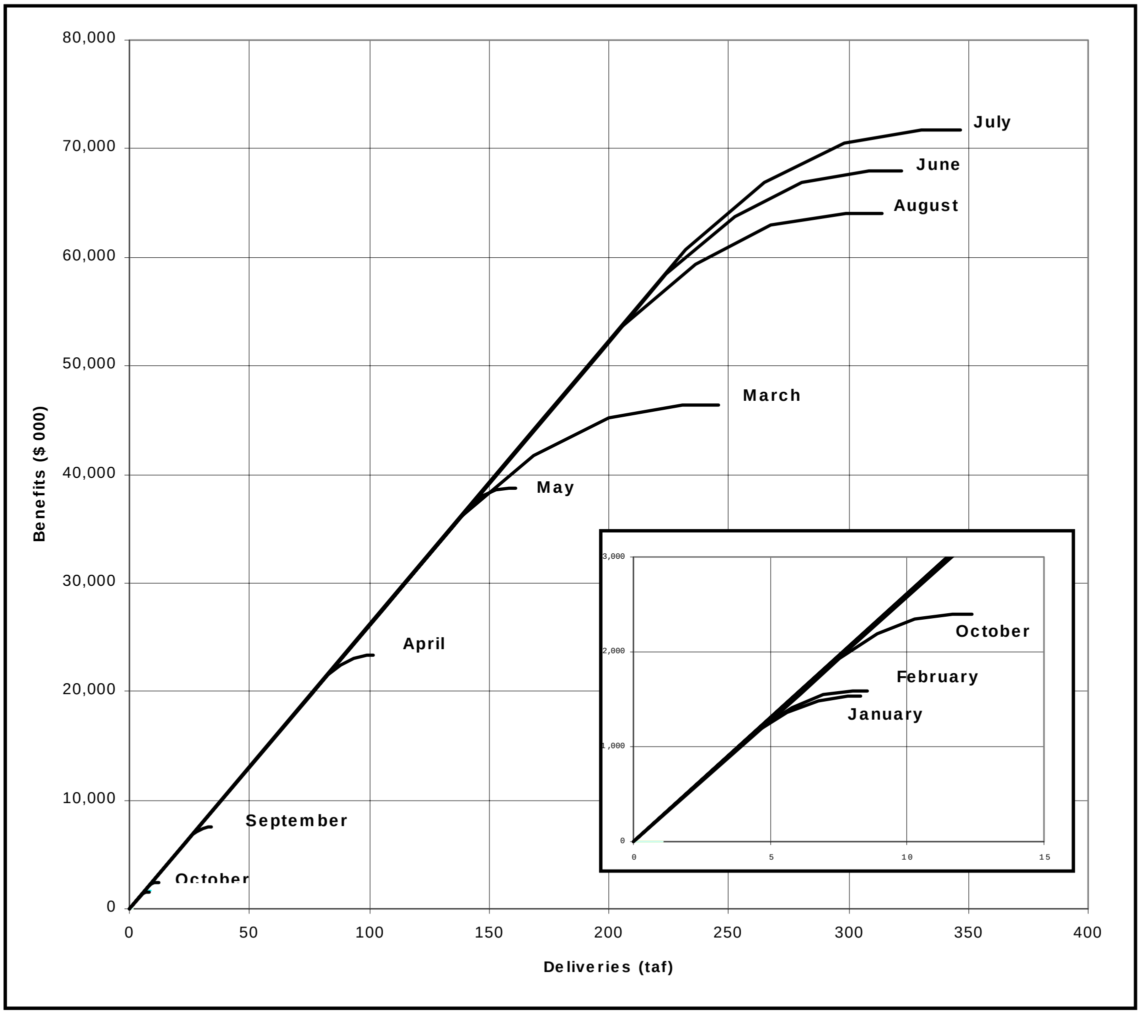
Crop Production

Crop production is modeled using a production function that varies for each region and for each crop. The wide range of agricultural inputs have been aggregated and simplified to just three: land, water and capital. The model captures the manner in which farmers adjust crop production when faced with changes in the price or availability of water. This reaction was observed during California's recent drought. Farmers can make three adjustments. The largest impact on water use is brought about by a reduction in cropped area, i.e. land fallowing. A second means of reducing water use is the adjustment of the cropping mix. Finally farmers can practice, to a limited extent, deficit irrigation.

Water Value Functions

The SWAP model is run several times for different levels of water availability. The marginal value of water is imputed from the shadow prices associated with the different water constraint levels. Typically, shadow prices for eight water availability levels are obtained for each region and for each month. Plotted against water availability they represent points on a continuous function. The integrated area under this function is the value of agricultural production as a function of water. For input to CALVIN this relationship is approximated by a piecewise linear function. These value functions vary from region to region, reflecting the diversity of California agriculture and also vary from month to month indicating the temporal variation in the value of water. A typical set of functions for input to CALVIN is shown in Figure 6-5. Since the value functions represent the net values of irrigation water, maximizing the function yields the "maximum demand" for irrigation water, in the absence of system operating costs or constraints.

Figure 6-5. Agricultural Value Functions



Urban Demand Model

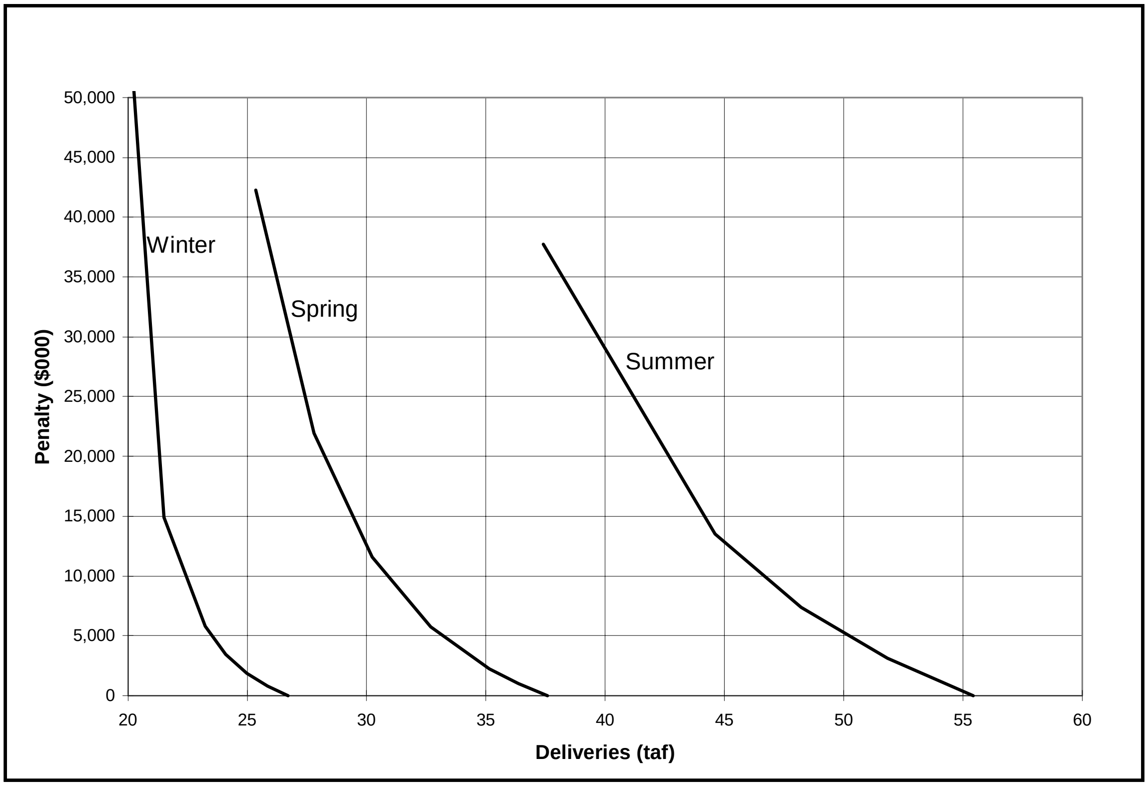
Like the agricultural regions, urban value functions will be preprocessed as input to CALVIN. As reflected in the Figure 6-2, urban regions are separated into industrial and residential demand nodes for most areas of California. Residential nodes include residential, commercial, and public (government) water use sectors. The maximum 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 (see Appendix B). Commercial and public water usage, for which neither price elasticity estimates of demand nor other economic value data exist are treated as having zero elasticity and are added to the residential demand function. In effect, the residential demand function is shifted to the right by the target demand for commercial and public water use. This composite residential demand function is then integrated to determine the costs (lost consumer surplus) associated with delivery levels to the residential, commercial, and public sectors that are less than the maximum demand in 2020.

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 derived 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.

Typical urban value functions for the residential sector are shown in Figure 6-6. Due to lack of data related to the value of water deliveries at low volumes, the figure expresses ‘value’ in terms of the cost of shortage measured relative to a target delivery.

Figure 6-6. Urban Residential Monthly Cost of Shortage



Operating Costs

Unit operating costs are attached to links to represent operation costs. Costs include only those variable costs associated with a specific operation related to water delivery: surface and ground water pumping, groundwater recharge, waste water discharge, and water quality treatment. Capital and administrative costs are excluded. These unit costs are assumed to have a constant value and are expressed in terms of a cost per unit of flow through the link. Total operational cost along a link during a time period (one-month) is equal to the unit cost times the volume of water passing the link during the month. Details are given in Appendix G.

Surface Water Pumping

Pumping costs associated with surface water conveyance are included only for the major aqueducts and canals. Pumping within local delivery systems is excluded. In all cases a fixed pumping head is assumed. Costs are calculated using a unit cost of $0.05/af per foot.

Groundwater Pumping for Agriculture

Unit costs are assigned to links that represent withdrawal from groundwater. These costs include energy costs based on typical local pumping lifts and an allowance for maintenance costs such as pump impeller wear. They do not include for capital depreciation or pump replacement. Pumping lifts represent average values for an assumed groundwater operation and do not vary dynamically in the model. Results will be post-processed to check that groundwater levels do not depart significantly from these values. The pumping lift includes an allowance for pipe friction, seasonal drawdown and local drawdown around the well. Pumping lifts are typically100 feet greater than the depth to groundwater. The assumed pumping cost is $0.20af per foot (~0.20KWh/af per foot) of pumping head. In the Central Valley the average depth to groundwater was computed from ground surface and initial groundwater elevation data contained in the CVGSM No Action Alternative (USBR, 1997). Outside of the Central Valley, depth to groundwater was assessed by review of representative wells and water resources / master reports.

Groundwater Pumping for Municipalities

Urban pumping costs are largely based upon published groundwater extraction costs for urban areas and information contained in local watermaster and planning reports. In addition to energy and O&M, operational costs include groundwater treatment (limited to chlorination).

Water Treatment

Unit water treatment costs have only been applied to differentiate the water quality of alternate water supplies.

Waste Water Discharge

By law, direct recharge of reclaimed wastewater requires additional treatment to remove nutrients and further minimize health risks. Where treated wastewater is directly recharged to an aquifer, an incremental wastewater treatment cost was assessed of $33af. The incremental cost reflects the difference between treatment of effluent for discharge to a water body (which is required at wastewater treatment plants and not included in the model) and treatment for direct recharge (Richard et al, 1992).

Artificial Recharge

Artificial recharge costs represent O&M of the spreading basins and the opportunity cost of the land affected by the works. Two values are used in CALVIN: $5/af in rural areas and $10/af within urban areas.

CONSTRAINTS

Physical, institutional, and environmental constraints all limit the way in which the system can be operated. In CALVIN all constraints must be represented as either an upper bound, lower bound or equality constraint on flow through a particular link during a particular time step. Flow constraints in cfs must be converted to average monthly values in taf. If a constraint is dependent on other parameters, such as year type, the values must be preprocessed.

Environmental Flow Requirements

CALVIN has no explicit environmental value functions. All environmental flow or storage requirements are represented as constraints. These may represent minimum instream flow requirements or fixed monthly deliveries to wildlife refuges. Where restrictions are based on water quality, such as specified salinity limits in the San Joaquin River at Vernalis, they must be interpreted in terms of monthly discharges. DWRSIM provides the basis for establishing the majority of environmental constraints within the Central Valley together with State Water Resource Control Board (SWRCB) mandates.

Physical Capacity

Physical constraints within CALVIN represent capacity constraints (flow and storage) usually modeled as an upper bound or a lower bound on reservoirs representing dead storage or a usable limit on groundwater.

Operational Constraints

Operational constraints usually dictate minimum and maximum monthly storage levels. For surface water reservoirs these reflect the upper limit on the conservation pool that varies according to the need to maintain flood storage. Recreation needs also may dictate storage levels.

Unless deliberately trying to mimic output from simulation models, CALVIN does not use target storage levels, such as minimum carry-over storage.

Institutional Constraints

Different policy constraints may be included in CALVIN depending on the scenario being analyzed. Priority in CALVIN is determined according to economic value. The value of deliveries is weighed against associated costs, e.g. pumping. However minimum or maximum deliveries may be specified to mimic contractual agreements. CALVIN's initial analysis does not include any such institutional constraints.

MODEL EXECUTION

HEC-PRM is a data driven model that requires an ASCII main input file to specify the network structure and file locations for hydrologic inflows, economic value functions, and constraints. Time-series and relational data inputs must be stored in HECDSS format. To make the model more accessible to users without specialized knowledge of HEC-PRM, several utilities have been developed using Visual Basic to create the required input file directly from the Access database.

INITIAL MODEL RUNS

To aid debugging during model development and testing, the State was divided into five regions. Initial runs were made for Region 1 only, but with appropriate boundary conditions to represent flows to Regions 2 through 5. Once the results had been inspected and appeared reasonable further regions were added working from the north to the south of the State. This staged approach eased the identification of input data errors, conceptual errors in the network representation causing infeasibilities and shorter initial run times. Table 6.5 describes the delineation of the five regions.

Currently two models are working. The first consists of Regions 1 to 4 and represents California north of the Tehachapi Mountains. The second model represents Region 5 or Southern California. A single boundary flow links these two models: the California Aqueduct.

Table 6-5. Regions used for CALVIN Development

Region	Description	Northern Boundary	Important Surface Water Sources
1	Northern Sacramento Valley	Lake Shasta, Englebright Reservoir	Sacramento R., Trinity R., Feather R., Yuba R., Bear R.
2	Southern Sacramento and the Delta	Feather-Sacramento confluence, Knights Landing Ridgecut	Sacramento R, American R, Cache Ck, Putah Ck, Cosumnes R, Mokelumne R
3	San Joaquin Valley	Banks PP, Tracy PP, Mokelumne River Aqueduct	SWP/CVP import, Stanislaus R., Tuolumne R., Merced R, Chowchilla R., Fresno R., San Joaquin R.
4	Tulare Basin	San Joaquin River, Mendota Pool	SWP/CVP import, Kings R., Kaweah R., Tule R., Kern R.
5	Southern California	Edmonston Pumping Plant	SWP import, Owens R., Colorado R.

MODEL OUTPUT AND POSTPROCESSING

Model output consists of a time-series of flows (e.g. diversions, deliveries, releases and groundwater pumping), volumes (e.g. storage and reservoir evaporation) and economic values (dual costs or shadow prices) of water at links and nodes throughout the network. This output is written to a HECDSS file. In addition, CALVIN produces a total minimized cost (‘penalty’) for each model run reflecting the integrated value of all water allocation decisions represented in the model. Interpretation of the considerable volume of results output from CALVIN is a challenging task. Postprocessing software is being developed to distill information from the considerable volume of output from each model run (see Appendix E). The design is object-oriented and can be applied to time-series and paired data from water resources system models. Its development in subsequent phases of this study could be of general value to water resources agencies and institutions in California.

The function of the post-processor is to analyze, combine, compare and display in tables and charts the different model runs. This often requires manipulating both input data (e.g. value functions for agriculture and urban water) with output data (e.g. time-series of deliveries). Results are usually displayed in the form of summary statistics and exceedance plots. These summarize the cost of water shortage and indicate the reliability of water supply to different users.

INNOVATIONS OF THE STUDY

Some of the major project innovations are listed in Table 6-6. CALVIN represents a new approach in large-scale water resources planning. The model determines water operations and allocations based on economic performance. CALVIN is the first statewide model and includes both surface and groundwater explicitly. Model results therefore provide: (a) a systematic overview of statewide water availability; (b) quantitative analysis of statewide economic impacts due to changes to the system's infrastructure and/or operation. The use of an optimization engine allows the rapid identification and preliminary evaluation of promising alternatives to the current system. This combined with the economic measures of performance gives the model several new and innovative capabilities. It is able to:

- Provide an understanding of the statewide economic value of water for agriculture and urban use
- Quantify the economic value of new storage and conveyance capacity
- Represent water marketing and water transfers
- Identify the potential for private facility investment
- Calculate the economic cost of increasing environment flow requirements

CALVIN also represents a new approach in data and model management. All input data is stored in a set of databases. Metadata is provided that describes the content, source and reliability of this data. Software tools have been developed to allow the user to quickly inspect, compare and edit all input data without accessing the databases directly. This approach ensures that data is entered in the correct format and is internally consistent. Software is also being developed to handle and store the multiple file and data sets required for multiple runs of the model.

Table 6-6. Selected Project Innovations

1. **Optimization model**
    - More flexible operations and allocations can be examined
    - System operations explicitly pursue economic performance objectives
    - Provides rapid identification and preliminary evaluation of promising alternatives
2. **Statewide model**
    - Model goes from Shasta to Mexico
    - Tulare Basin, SF Bay area, South Coast, and Colorado R. areas are added
    - Explicit examination of potential statewide impacts, operations, and performance
3. **Groundwater**
    - Groundwater use is explicitly, though imperfectly, included
    - Groundwater use is fully integrated with surface supplies and water demands
4. **Economic Perspective**
    - Statewide economic performance is the explicit objective of the model
    - Economic values for new storage and conveyance capacity are provided by the model
    - Greatly enhanced capability to model water marketing/water transfers
5. **Data and Model Management**
    - Explicit data management tools and documentation of model assumptions
    - Relative ease of understanding and modifying assumptions
    - Model, data, documentation, and software are public domain
6. **Economic Values of Water Use**
    - Statewide understanding of economic values of water for agricultural & urban uses
    - Reformulation and extension of CVPM models of agricultural water values (SWAP)
    - Economic models developed and applied to Southern California agriculture
    - Consistent, though primitive, statewide representation of urban water values
7. **New Management Options**
    - Various statewide water marketing options
    - Integrated operation of existing and new facilities
    - Potential for private facility investments
    - Flexible facility operations and flexible water allocations
8. **Systematic Analytical Overview of Statewide Water Quantity**
    - Hydrology (surface and ground waters)
    - Facility capacities
    - Environmental limits, institutional limits, economic values

LIMITATIONS TO CALVIN MODEL

Along with its advantages and disadvantages, CALVIN, like all models, has limitations. Such limitations must be borne in mind when considering model results and in refining a model approach. Some limitations of CALVIN are described briefly below.

Limited Ability to Represent Water Quality

Water quality is a crucial element in urban water supply and one of the key reasons to construct an isolated facility around the Delta. Water quality is represented in CALVIN by assigning different water treatment costs to different water sources. CALVIN will allocate water to urban users by selecting the least cost water source – this may include other delivery costs in addition to water treatment (e.g. pumping costs, opportunity costs). In practice this decision process is complicated by the process of blending, where a water user may blend lower quality supplies with higher quality supplies to meet the necessary standards. Blending capability may depend on the amount of local supply, the desired use of water, and the specific constituent concentration, parameters largely simplified or ignored in CALVIN's formulation. Given the inherent relationship between water quality and quantity, CALVIN's representation of water quality remains a serious limitation.

Environmental Values Modeled as Constraints

No explicit economic value functions for environmental needs are included since few, if any, credible statewide 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 of consensus comparable to agriculture and urban water demands (Colby 1990; Water Resource Update 1997).

Implicit valuation of environmental constraints can be derived from the sensitivity analysis when such constraints "bind' system operation. However these values reflect only the urban and agricultural water users' willingness-to-pay and not society's existence values.

Limitations of Input Data

One of the most common problems in modeling efforts is the availability of reliable data. While CALVIN was fortunate enough to benefit from data collection efforts of several other modeling efforts (DWRSIM, SANJASM, PROSIM, CVGSM, and several local sources), it also inherits all of the limitations of these data. The reliability of the hydrology is particularly in question. There are many difficulties in estimating surface water supplies from incomplete records and ungaged streams. The problem is compounded by changes in land use affecting runoff. There have been difficulties in disaggregating surface and groundwater supplies from water supply availability calculated using DWR's depletion analysis (see Appendix I).

Effective Precipitation for Agriculture

Precipitation, particularly in the Sacramento Valley, meets a significant proportion of agricultural demand. Rainfall during the winter and spring decreases pre-irrigation requirements or contributes directly to meeting crop evapotranspiration. Estimates of the percentage of precipitation that is 'effective' in meeting demand vary substantially. DWR's Consumptive Use model appears to be over optimistic.

Precipitation varies significantly from year to year. However, SWAP currently estimates agricultural demand for irrigation based on average precipitation values. This will result in an overestimate of the water supply in drought years. In the next phase of the project it is hoped to develop agricultural water demands that vary by year type.

Optimization and Foresight

The algorithm used to find an optimal solution to water allocations involves a systematic and efficient examination of all possible solutions. A set or matrix of equations is created that describe all possible flows in links and all possible storages at nodes for all time steps. As such the optimization model has perfect foresight and is able to adjust reservoir operation in anticipation of flood or drought.

Although an initial reaction might be to reject this approach as unrealistic, it has several advantages and implications. It should be noted that for the California system foresight beyond 5-6 years has little value as the recurrence of wet years fills reservoirs to capacity and precludes any hedging. The implications of this perfect foresight are as follows:

- Results will represent an upper bound to the potential or economic benefits of a particular system configuration and set of constraints;

- Although the model can be run consecutively for shorter time periods this poses difficulties in specifying economic values for the end-of-period storage to prevent reservoirs being drawn-down dry;

- Operating rules for new facilities based on CALVIN's prescribed operation, will include some measure of hedging for shortage events.

Previous applications of this approach have been successful despite perfect foresight, and techniques are available to handle this limitation (USACE 1994b, 1995, 1996, Israel 1996).

Network Flow Algorithm

Network flow solution algorithms offer advantages of efficiency and speed. However, the use of a network flow formulation for CALVIN limits the ability of the model to represent complex environmental operating constraints. All constraints must be represented as bounds on flow through a link. This requires approximating environmental restrictions that depend on other state variables within the system such as reservoir storage. Examples of this type of constraint are:

- 'If … the reservoir level [Oroville] will be drawn to elevation 733ft, releases for fish life … may suffer monthly deficiencies…(DWR 1986)

- Carriage water is additional water required to prevent saline intrusion into the Delta. It becomes effective as a function of the Delta pumping to Delta outflow ratio.

These types of constraints are represented by assuming a certain system operation and calculating the required environmental flows that become fixed model inputs. Model output has to be subsequently postprocessed to check that the constraints have not been violated under the prescribed model operation.

Additional simplifications are necessary to model non-linear physical constraints, such as reservoir release capacities that are a function of head.

Simplified Representation of Groundwater

Modeling groundwater aquifers as simple reservoirs ignores the effect of piezometric head on regional groundwater flow and stream flow interaction. Much of the data used in CALVIN's groundwater system is derived from a particular model run (‘no action alternative’) of CVGSM and is not determined dynamically within the model. Implicit is the assumption that groundwater will be exploited in a similar manner to the specific run. Postprocessing is required to check the validity of this assumption. When operations do vary considerably new groundwater inflows will need to be developed.

Primitive representation of urban water shortage costs

Given the heterogeneous characteristics of California urban areas, splitting 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. Elasticity approaches, while conventional and feasible for application across California are very simple representations of fairly complex demand processes.

Monthly time step necessitates simplification of more complex phenomena

Several system constraints and operations criteria are based on finer time scales. For example water pumped from the Sacramento-San Joaquin Delta is constrained by real time salinity levels. Additionally, some reservoirs base their flood control rules on antecedent rainfall conditions, soil moisture conditions, and snow pack levels - all parameters absent from CALVIN.

Hydropower is not included in the initial analysis

Although a crucial part of the California water economy, time constraints prevented reservoir hydropower benefits from being included in CALVIN. Future efforts will be directed towards including hydropower.

CONCLUSIONS

Recent developments in computing, data, and data management allow water managers to practically employ more extensive, detailed, and explicitly performance-based approaches to water supply planning. These new tools allow us to explore and analyze new approaches to water management. It is fortunate that these technological and data developments have appeared at a time when the historical management of California’s, and many other large region’s, water resource systems have become ill suited or acutely controversial with present and growing societal demands for water uses.

This chapter reviews the methods and approaches used to apply large-scale databases and economic-engineering optimization to California’s water supply system. The details of the approach appear in appendices to this report. This economic-engineering optimization approach is an extension of similar exercises undertaken in recent years for river basins throughout the US.

Each of the components of this approach has achieved a reasonable degree of professional and technical consensus. While there are difficulties and limitations in implementing and integrating these components, these can be addressed and improved with time and attention. Perhaps the greatest challenges are in expanding our understanding of water management to allow development of improved water management infrastructure, policies, and operations.

CHAPTER 7

STRATEGY FOR COMPARING ALTERNATIVES

“… all aspects of water management would be improved by planning that would maintain flexibility for the future, foreclose as few choices as practicable, and put fresh demands on science to predict consequences and to provide alternatives to meet changing needs.” Gilbert F. White (1966), *Alternatives in Water Management*, National Academy of Sciences, Washington, DC, p. 48.

Many options exist for addressing California’s water resources problems. Structural options are examined in Chapter 3. Chapters 4 and 5 discuss non-structural options that require institutional and regulatory changes. Traditional structural options include new or expanded surface water storage and conveyance. New structural options are becoming possible due to both new technology and the rising cost of developing new water sources. These new options include advanced treatment to utilize wastewater and brackish and saline water. These options to overcoming the present and projected imbalance between supply and demand can be complimented by a series of non-structural measures. The ability to increase supplies through improved co-ordination and operation of surface water facilities alone probably remains limited. Conjunctive use of surface and ground water is increasingly advocated as a means to harness ‘surplus’ winter runoff to recharge aquifers in wet years (NHI 1998). Water transfers and water markets are also being examined as a reallocation mechanism to boost economic revenues and close the gap between supply and demand.

Chapter 6 introduces the CALVIN model, a new tool for rapidly screening and identifying both structural and non-structural options that promise significant economic benefits. The present chapter builds on the foundations of previous chapters to explain how this new modeling tool will be used systematically to explore the myriad of options available to the state’s water managers and policy makers. This exercise is only part of the need to develop, test, and refine promising alternatives.

SINGLE VS MULTIPLE MODEL RUNS

Results from a single model run of CALVIN represent an ‘optimal’ solution or set of operations for one particular configuration and set of the physical infrastructure, one set of economic value functions and one set of environmental and policy constraints. ‘Policy’ in this sense refers to any set of rules or limits that constrain reservoir releases, stream diversions and allocations. A single model run, in isolation, will reveal how the system could be optimally operated, the level of shortages and reliability of supplies for the modeled scenario. However, economic values from the model are more meaningfully assessed in comparison to other model runs with different inputs. It should be reiterated (see Chapter 6) that only variable costs that are a function of flow or storage are included in CALVIN (e.g. pumping and water treatment costs). Other costs (e.g. management costs, maintenance of conveyance infrastructure) and fixed capital costs are not included.

BASE CASE

To provide a common benchmark for comparison, model runs will be compared to a base case. The choice for this base case is 2020 level demands but with existing facilities plus those that will definitely be in-place by the year 2020. This latter includes facilities for which construction has already begun or for which detailed engineering plans exist and financing obtained. For the base case, CALVIN is constrained to mimic current projected operations. Water is allocated to users according to current contractual agreements and water rights. Deficiencies are imposed in dry years in line with current projected estimates. The operation of surface reservoirs will be constrained to follow projected operations. The cycle of groundwater pumping and recharge will be similarly constrained to reflect current projected estimates of groundwater extraction.

ALTERNATE MODEL RUNS

Table 7-1 lays out the strategy for making and comparing model runs. A total of 13 basic model runs are envisioned, representing different combinations of policy and infrastructure options. Moving from column to column, left to right, represents the addition of new facilities. Moving from row to row represents different policy options. The first row represents water allocation in an idealized water market. The last row represents current regulation and practices. It is interesting to note that from a modeling perspective, policy 1 is the easiest to model. No operational or regulatory constraints are imposed on the model other than environmental requirements. Moving down the table, the model becomes increasingly complex as additional layers of constraints are added reflecting the complexity of current operating rules.

Table 7-1. System Alternatives

	Facility Options			
Policy Options	Projected (a)	Additional Storage (b)	Isolated Facility (c)	(a), (b), & (c)
1. Price Allocation	1a	1b	1c	1d
2. Minimum Deliveries	2a	2b	2c	2d
3. Fixed Operation & Min Deliveries	3a	3b	3c	3d
4. Fixed Operations & Deliveries (Base Case)	4a	-	-	-

New and Expanded Facilities

Four scenarios for new facilities will be investigated:

- 2020 ‘existing’ facilities,
- additional storage and expanded conveyance,
- isolated facility, and
- additional storage, expanded conveyance, and an isolated facility

The specific locations and capacities for expanded storage and conveyance facilities will be determined at a future time.

Policy Options

The four policy options are depicted in Figures 7-1 to 7-4.

Policy 1: Price Allocation

Policy 1 represents allocation according to price (Figure 7-1). Operation of the infrastructure is constrained only by the physical capacities of the system and by environmental demands. This reflects a free market operation or the implementation of an unregulated water market. Within the limits of the system and environmental constraints, water is transferred and allocated to users with the highest willingness-to-pay. The model 'assumes' that users will trade water driven by their temporal differences in the valuation of water. Under this operation it is expected that there will be a general reallocation away from low value agriculture to urban demand and high value agriculture. Urban water supply reliability should improve while agriculture will suffer more 'shortages' during dry years. This option also makes the most economically beneficial and flexible use of the operations of storage and conveyance facilities.

This policy option should produce the highest economic benefits (least costs). It is not advocated that this policy be implemented. Rather it provides an upper bound to the economic benefits of restructuring water operations.

Policy 2: Water Market with Minimum Deliveries

Policy 2 represents a regulated market. As for policy 1, there are environmental and physical constraints. However, an additional set of constraints is introduced to ensure minimum deliveries to urban and agricultural users (Figure 7-2). Minimum deliveries correspond to existing contractual agreements and water rights but with deficiencies imposed in dry years. These deficiencies will be based on projected deficiencies calculated by detailed simulation models (DWRSIM, PROSIM, SANJASM, and CVGSM). Operation of the surface reservoir and groundwater system will be unconstrained. Under policy option 2, CALVIN will be able to store and allocate any 'surplus' water to the highest economic use. Surplus water might be obtained through better system operation, conjunctive use or the use of expanded or new facilities.

This policy option allows CALVIN the chance of 'doing better' than current project operation and deliveries. It should point to promising new and innovative ways in operating reservoirs as one integrated supply system rather than a series of separate project and non-project facilities.

Policy 3: Water Market with Minimum Deliveries and Constrained Operations

A further layer of constraints is added under policy 3 (Figure 7-3). Existing surface water reservoirs are operated in accordance with current projected operating rules. Monthly reservoir target levels and annual carry-over storages are met where possible. Existing rules governing the sequence of drawdown and refill of project (CVP and SWP) reservoirs are followed. In addition the projected pattern of groundwater extraction is enforced. Policy option 3 still allows CALVIN to allocate surplus water to the highest economic value. However it is expected that without new facilities the amount of surplus water will be minimal. This policy enforces current projected operations under which water in all but wet years is fully allocated.

The purpose of this option is to evaluate the benefits of new facilities or expanded capabilities under the current system operation. It will be of particular use to identify who gains from specific infrastructure developments and: (a) whether there is sufficient economic benefits to justify system expansion; (b) allocation of project costs in the case of public financing of new facilities; (c) to measure whether benefits are sufficient to attract private investment.

Figure 7-1. Policy 1: Price Allocation

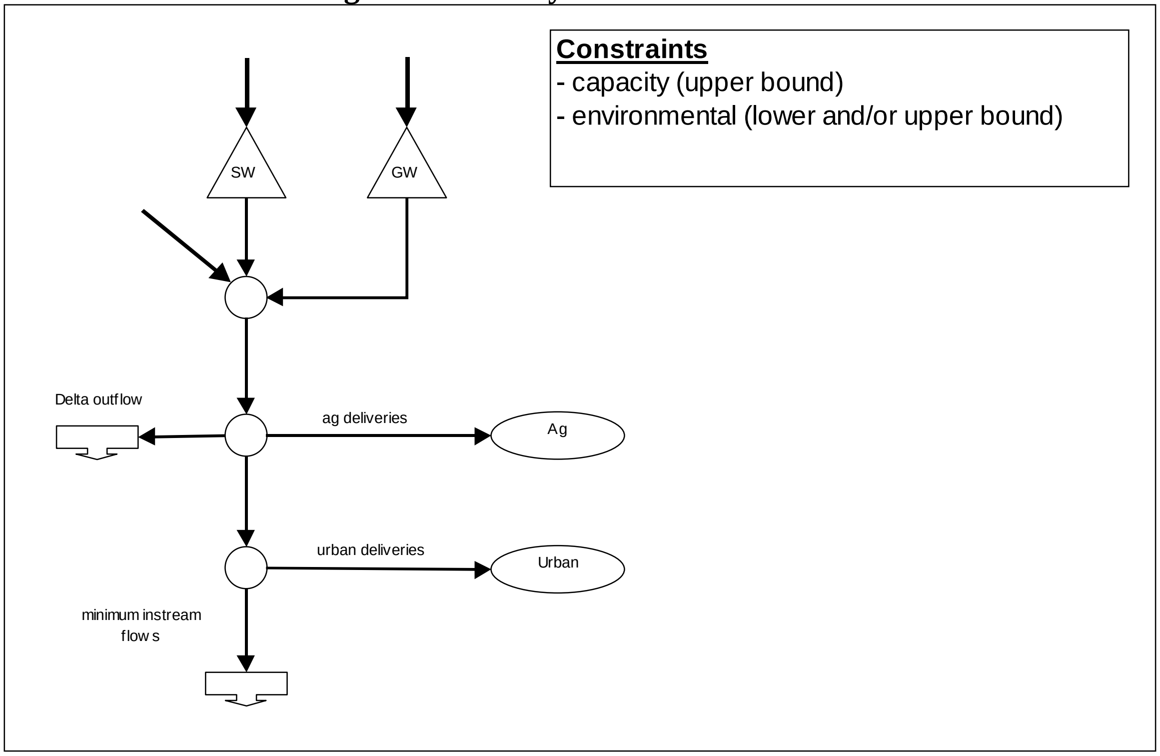


Figure 7-2. Policy 2: Minimum Deliveries

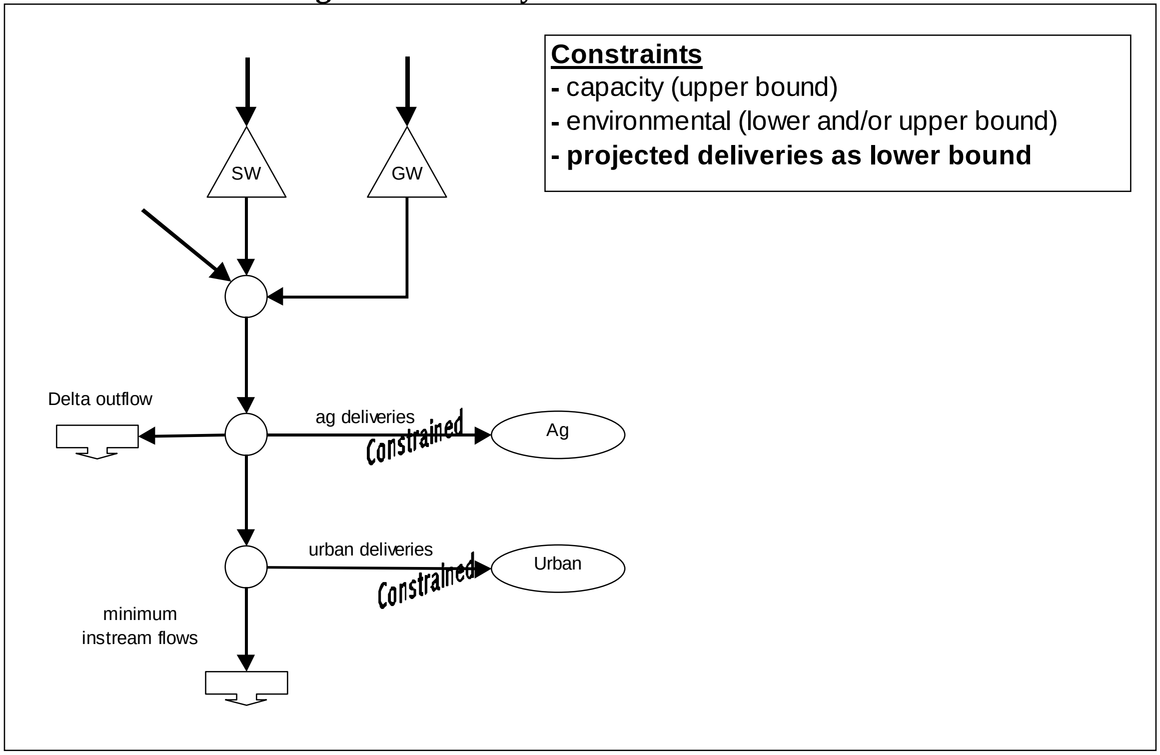
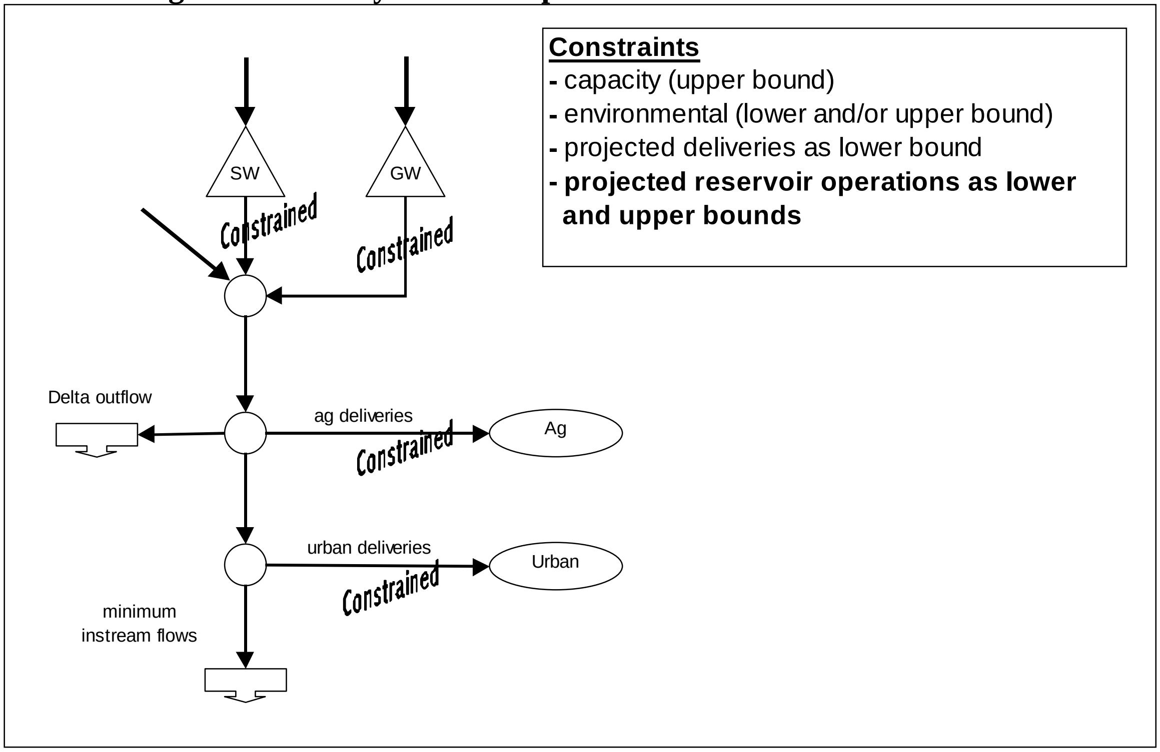
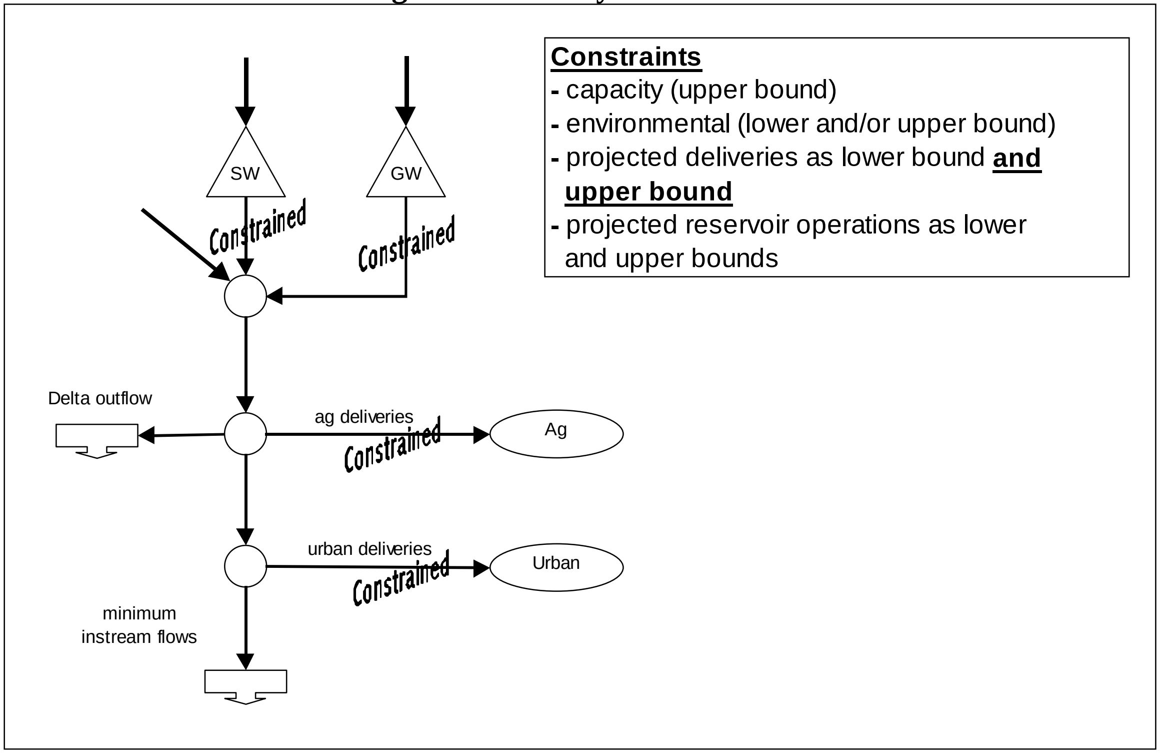


Figure 7-3. Policy 3: Fixed Operations and Minimum Deliveries



Constraints
- capacity (upper bound)
- environmental (lower and/or upper bound)
- projected deliveries as lower bound
- **projected reservoir operations as lower and upper bounds**

Figure 7-4. Policy 4: Base Case



Constraints
- capacity (upper bound)
- environmental (lower and/or upper bound)
- projected deliveries as lower bound **and upper bound**
- projected reservoir operations as lower and upper bounds

Policy 4: Current Operations and Allocation Policies

As mentioned above policy 4, run 4(a), represents the base case scenario for comparison of economic benefits predicted for other alternatives. Under this policy, CALVIN is constrained so as to equal the currently projected deliveries of detailed simulation models and to exactly match their reservoir operation. Deliveries and storages are now constrained as both lower and upper bounds. CALVIN is so fully constrained that it cannot improve on current projected operations.

Economic benefits predicted from CALVIN for the CVP/SWP should match those that could be obtained by postprocessing results from DWRSIM. Modeling of this policy will also provide cross-model validation of the model and inputs by comparison with DWRSIM results (run 514).

Demand Management

CALVIN seeks to manage demand in an economically optimal manner. Demand management is handled implicitly by CALVIN through the use of economic value functions. Implicit in the agricultural value functions is the move to less water demanding and higher value crops and acreage reduction in response to water scarcity and high water prices. Similarly the urban value functions reflect the implementation of short-term conservation measures in response to water high water prices.

To examine the economic desirability of capital infrastructure changes in irrigation or urban water use technologies would require additional urban and agricultural economic modeling to modify CALVIN's economic value functions, with separate incorporation of fixed capital costs, much as how new facilities are handled.

MEASURES OF PERFORMANCE

The performance of an alternative can be assessed in several ways using CALVIN's outputs. Some of these are described below.

Physical

Reliability of supply is the key indicator. The time-series of water deliveries to urban and agricultural users will be compared with the input demands and expresses as an exceedance plot. This shows the percentage of years/months that demand is met and for the case of shortages the percentage of demand that is met.

Environmental

Environmental flow requirements are constraints and so are automatically satisfied by CALVIN. However, many environmentalists regard regulatory instream flows as inadequate or as minimums. Additional flows are desirable. Although impossible to quantify the absolute benefits, stream flows can be compared between runs and expressed in the form of minimums, averages, standard deviations and quartiles.

Environmental needs and regulations are pre-processed and are always represented in the model as a time-series of flows or storages. Postprocessing of results is required to check whether the original environmental objectives have been violated. This is particularly true for the Delta outflow requirements.

Economic

Economic benefits are derived from increased supplies, improved supply reliability, and, in some cases, quality. Scarcity provides incentives to change infrastructure and system operation. From the combination of the input value functions and the time-series of deliveries, the economic benefits of different model runs can be evaluated and broken down by sector and by region. The agricultural deliveries will be post-processed through SWAP to: (a) confirm that CALVIN is correctly allocating water across months; (b) to obtain a breakdown of the crop mix.

Financial

The ability of any new infrastructure to attract private investment capital may be crucial for the expansion of the current system. Output from CALVIN includes a time-series of shadow values on storage and flow capacities. These indicate where, when, and by how much a unit increase in capacity would result in economic benefits. Comparison of two model runs with different system capacities is required to quantify the total overall benefits. 'Winners' from increased capacity can be identified and the increase in consumer surplus (urban sector) or revenues (agricultural sector) can be used to create a time-series and statistical distribution of expected revenues. As an investment this can be compared to other types of investments with risk and fluctuating returns.

The refinancing of existing public facilities can also be examined. For example, the capacity of the California Aqueduct may limit water transfers to the south. The state recovers the canal's capital cost from state water contractors via a combination of charges that are a function of water deliveries and contractors entitlements. The wheeling of water for third parties through the aqueduct as part of a regulated water market has financial implications for both the state and the state water contractors.

CONCLUSIONS

By comparing various CALVIN model runs, the relative economic performance of particular facility and policy alternatives can be assessed. These relative alternative assessments are in addition to the information gained from a single run, as discussed in the next chapter.

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:

Marginal Willingness-To-Pay for Additional Water

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.

Cost of Shortage

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.

Marginal Values of Water

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.

Shadow Values on Constraints

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 Colarado 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

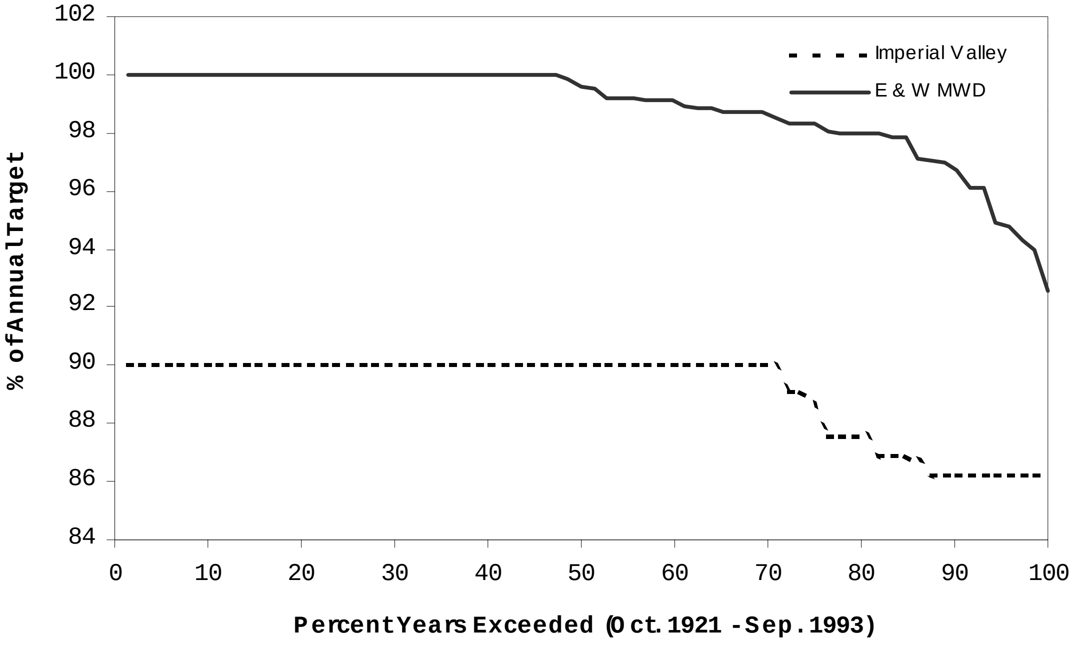


Figure 8-2. E & W MWD Deliveries
Plot of Total Annual Time Series

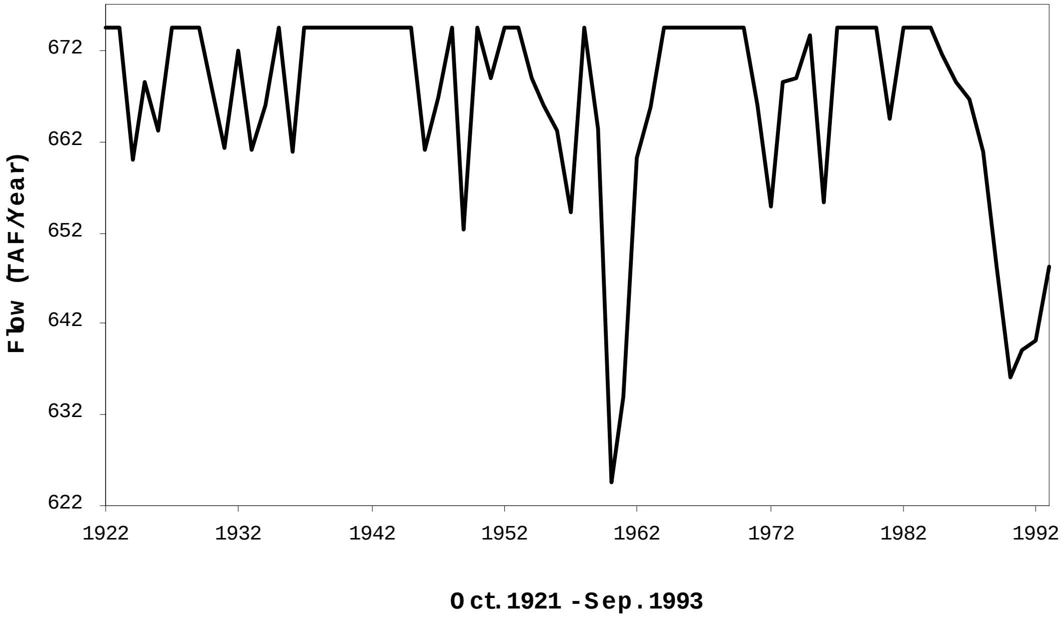


Figure 8-3. E & W MWD Deliveries
Plot of Monthly Time Series

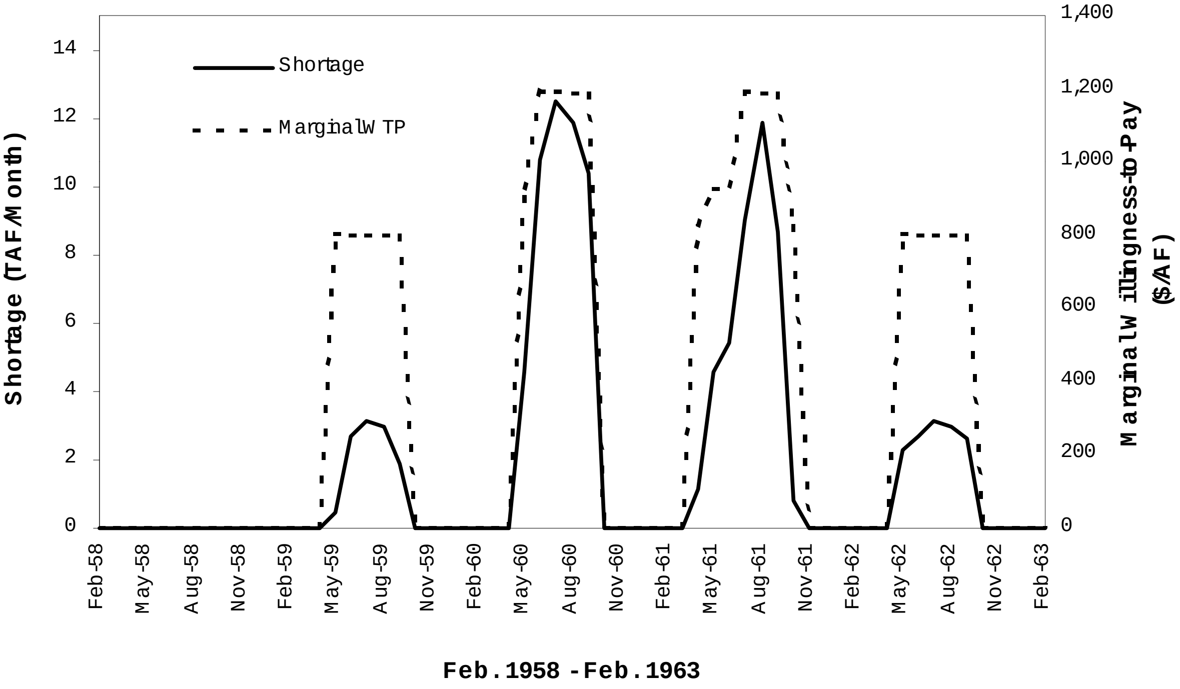


Figure 8-4. San Diego Canal and Lake Skinner Shadow Values
Plot of Monthly Time Series

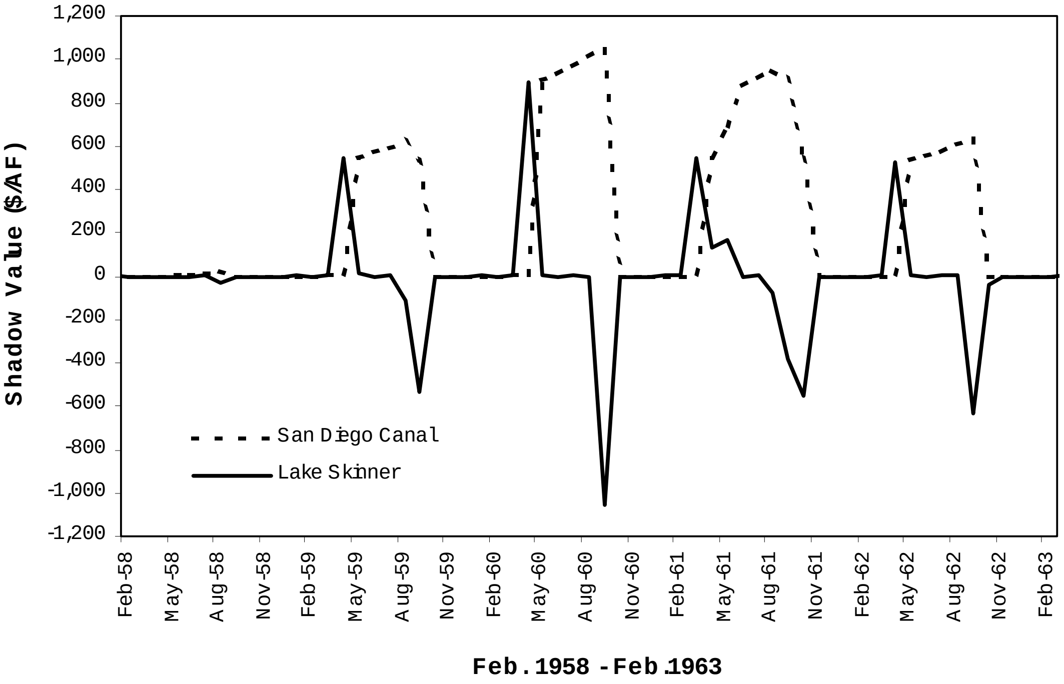


Figure 8-5. Imperial Valley Deliveries
Plot of Monthly Time Series

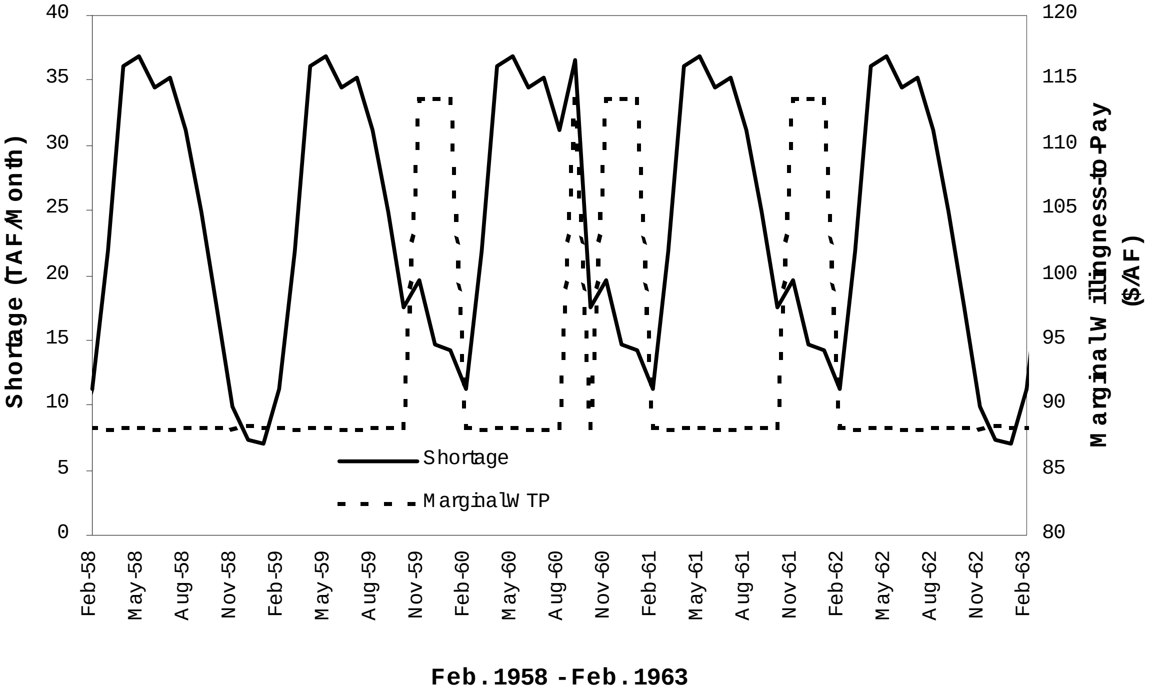
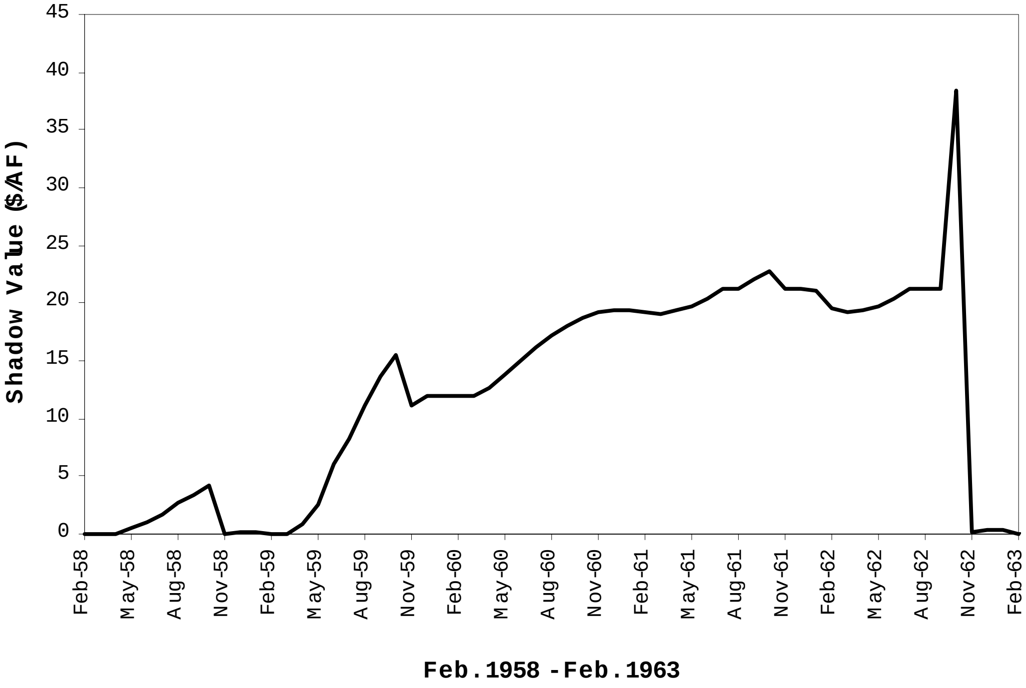


Figure 8-6. Colorado River Aqueduct Shadow Values
Plot of Monthly Time Series



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

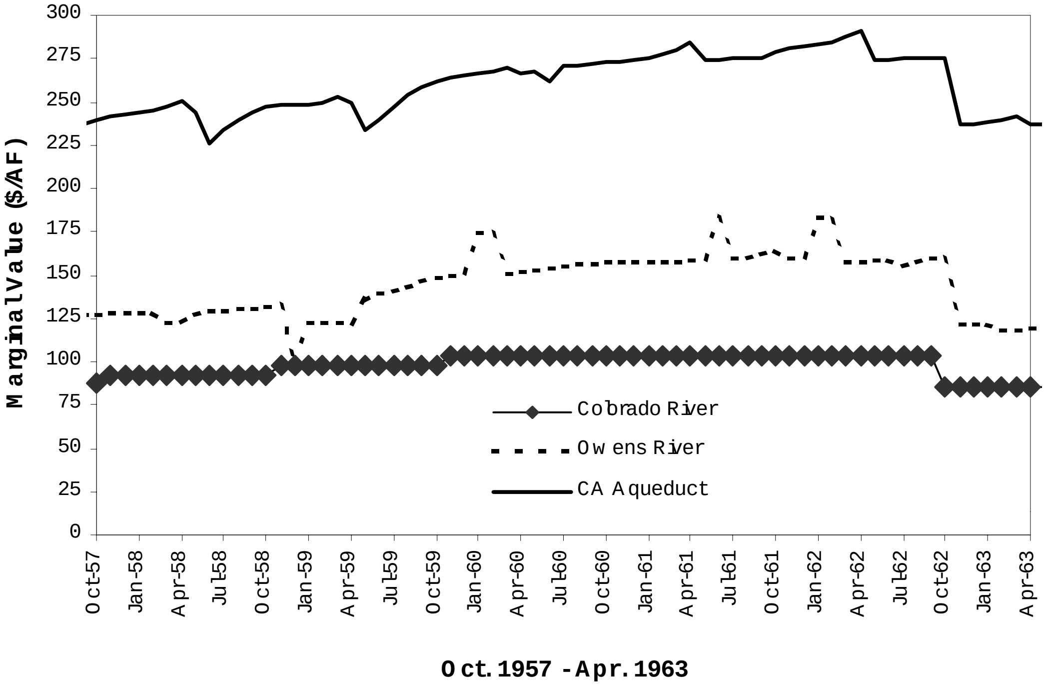
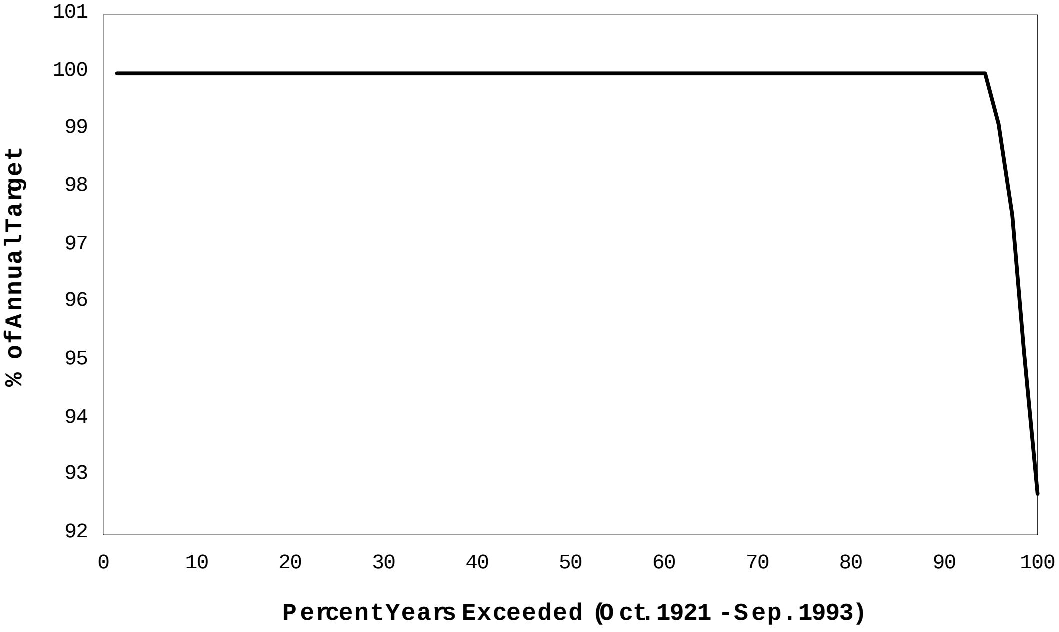


Figure 8-8. EBMUD Deliveries
Annual Probability of Exceedence



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

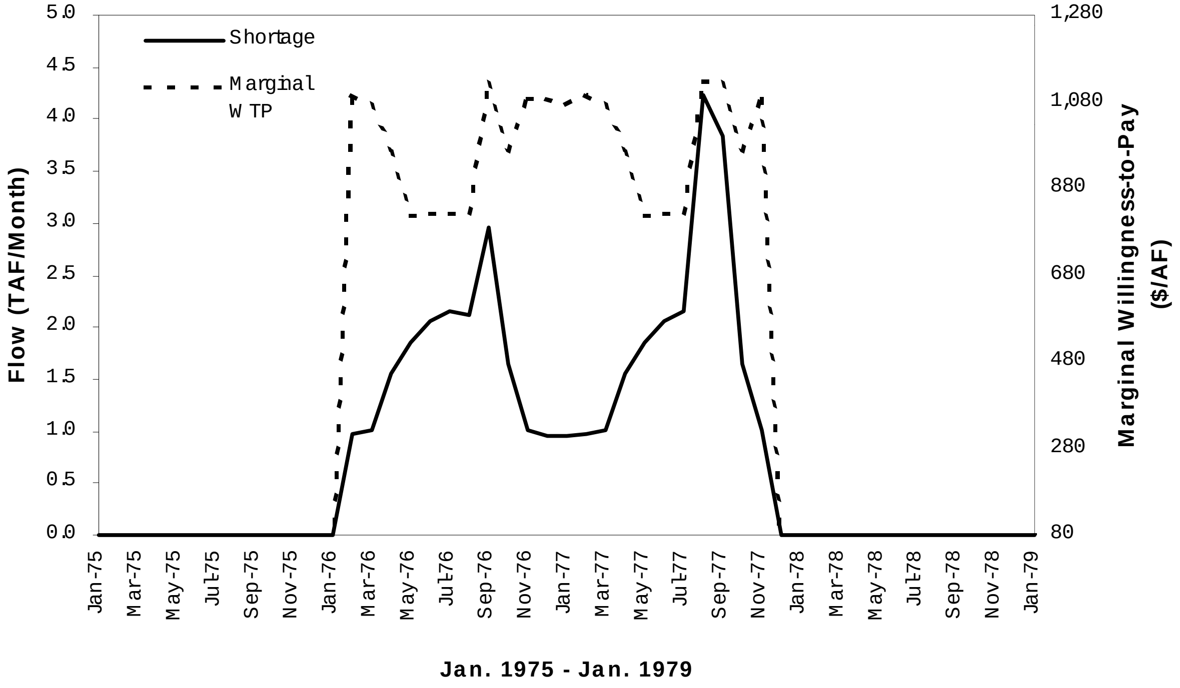
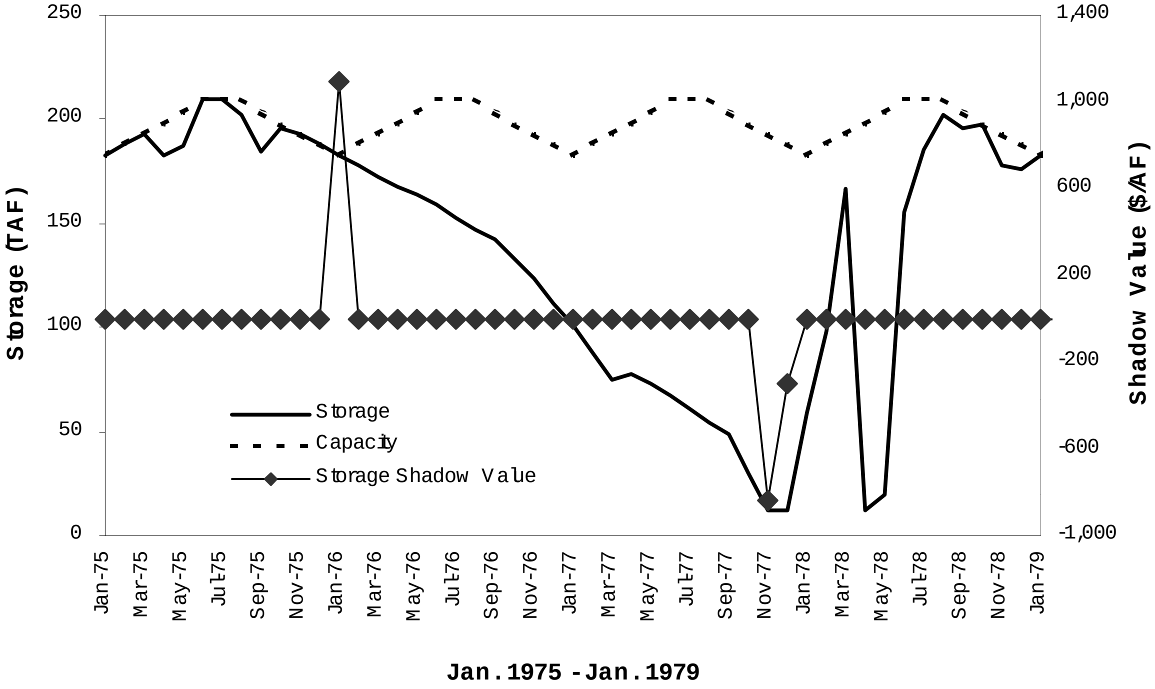


Figure 8-10. Pardee Reservoir
Plot of Monthly Time Series



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

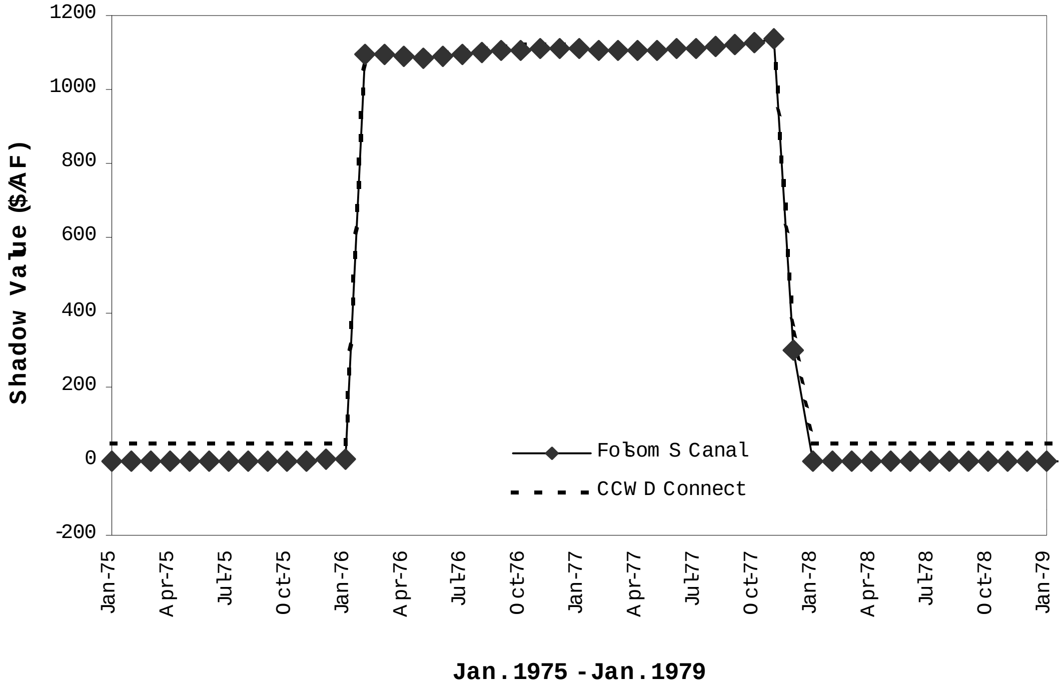
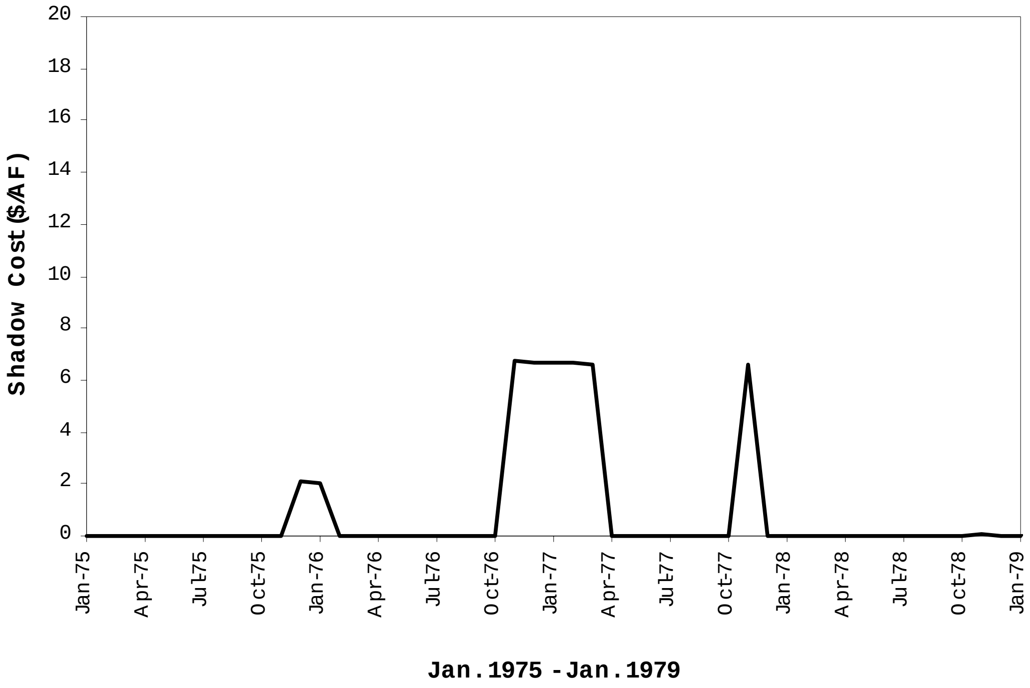


Figure 8-12. Mokelumne River Minimum Flow Shadow Cost
Plot of Monthly Time Series



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

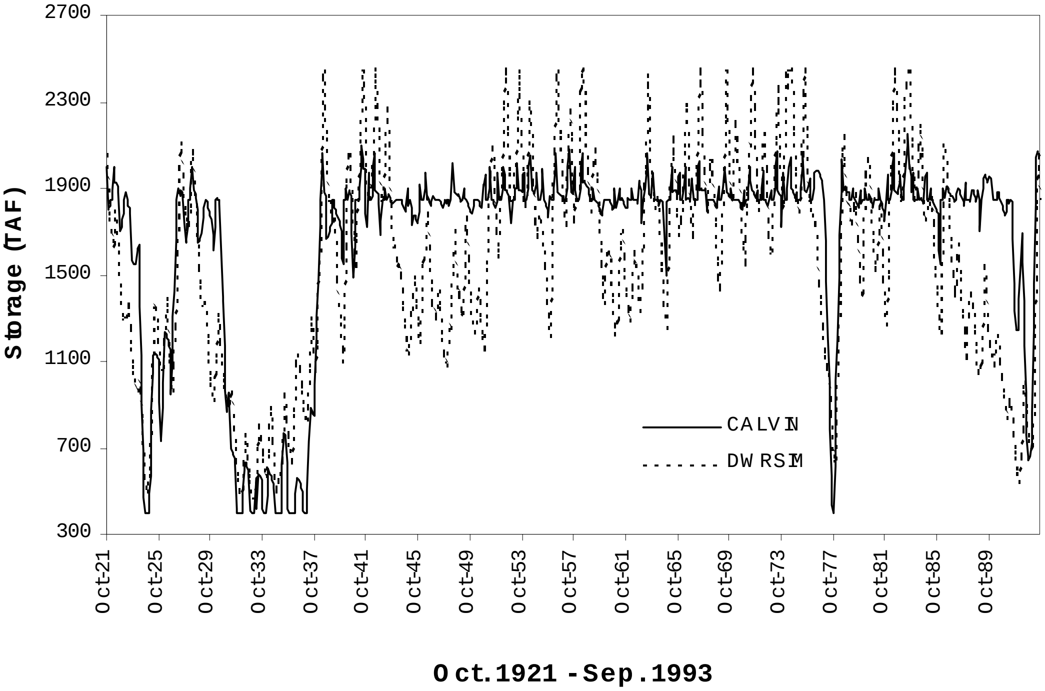


Figure 8-14. Lake Oroville Storage
Plot of Monthly Time Series

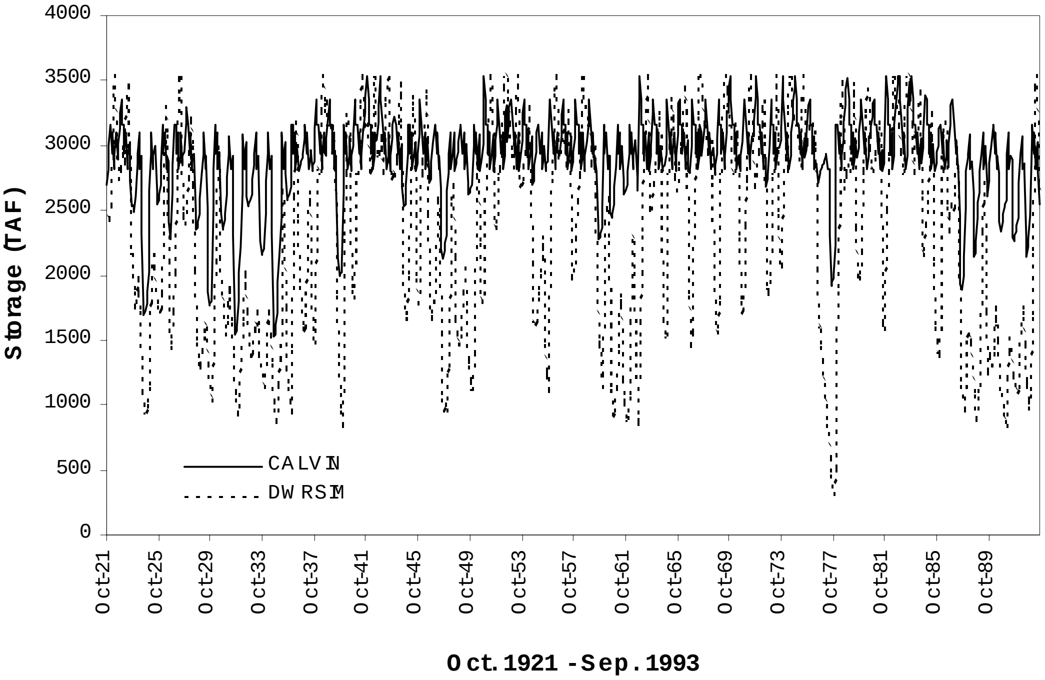


Figure 8-15. Groundwater Storage in CVPM 14
Plot of Monthly Time Series

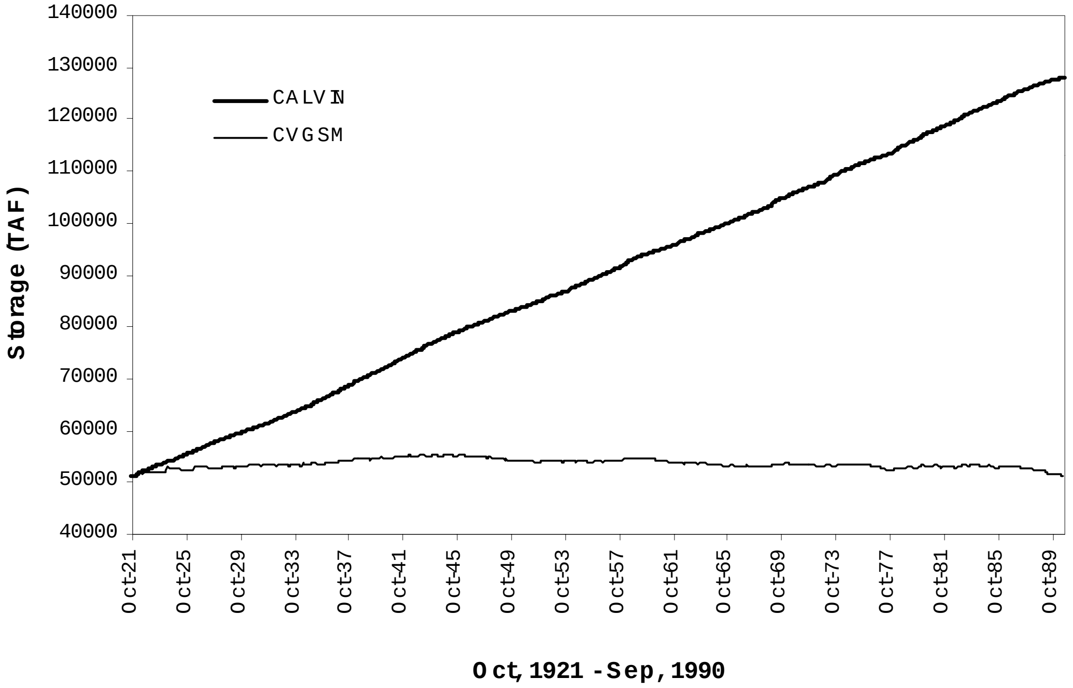


Figure 8-16. Groundwater Storage in CVPM 18
Plot of Monthly Time Series

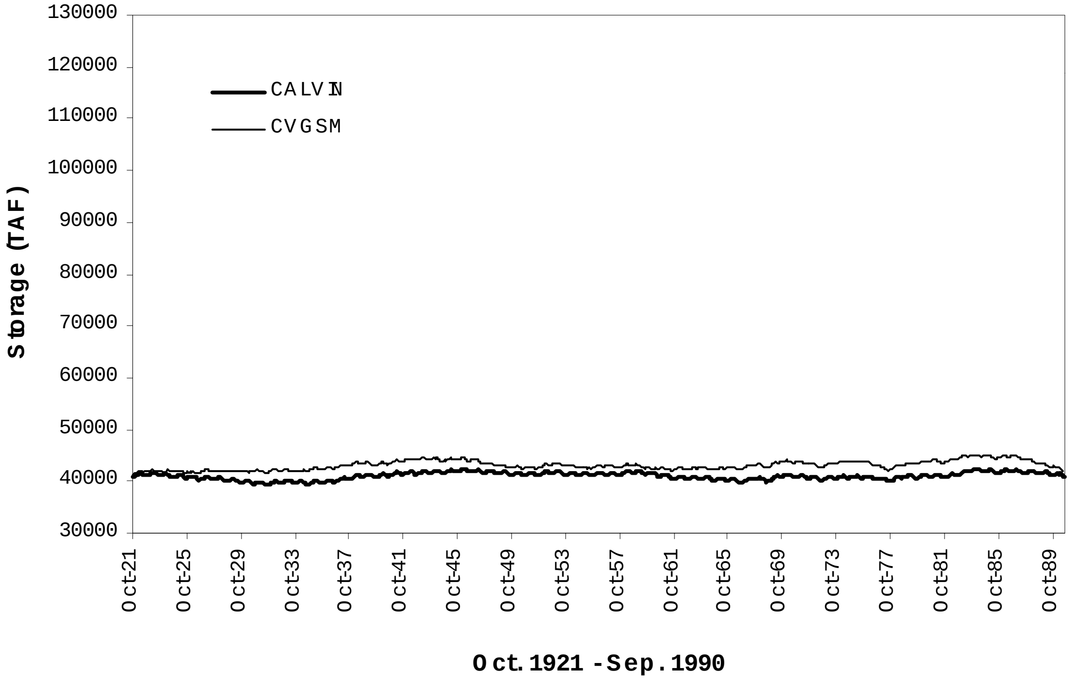


Figure 8-17. Sacramento River Flow
Plot of Monthly Time Series

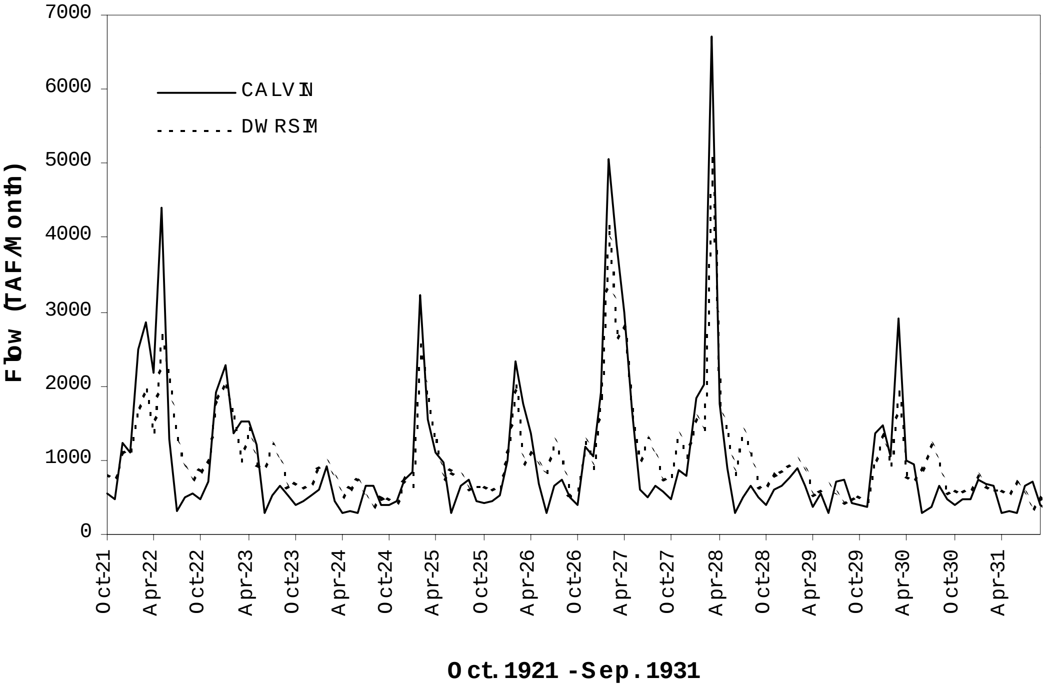
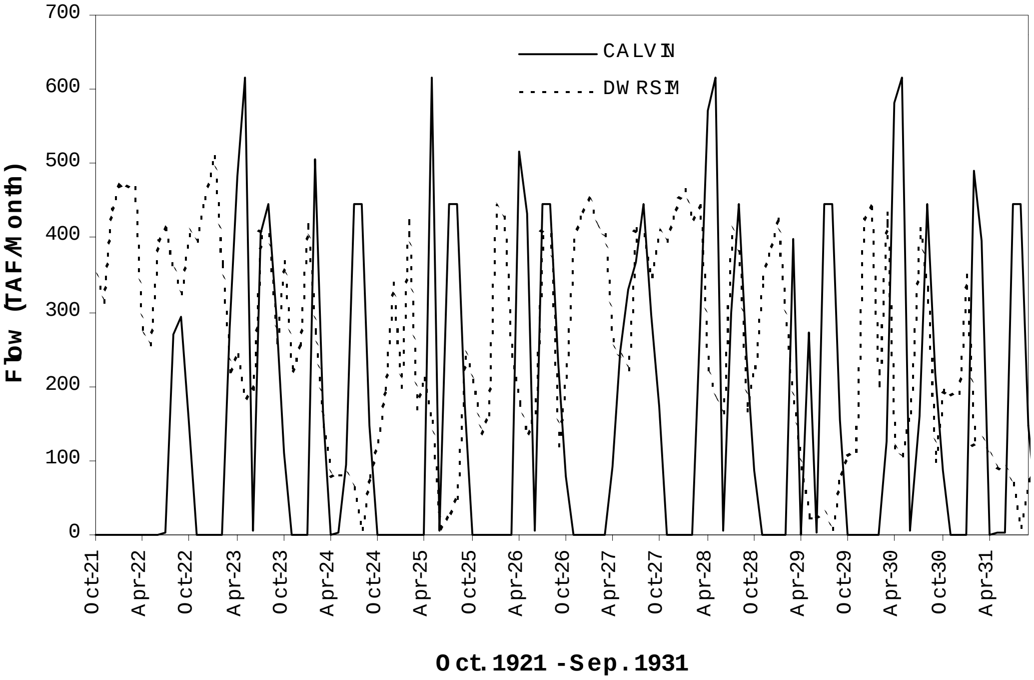


Figure 8-18. California Aqueduct Flow
Plot of Monthly Time Series



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.

CHAPTER 9

ACCOMPLISHMENTS, LESSONS, AND FUTURE DIRECTIONS

“Errors using inadequate data are much less than those using no data at all.”
Charles Babbage

The 18 months of this project have not been sufficient to resolve the economic and financial questions of California’s future water supplies. However, this project has produced and demonstrated a credible approach to analyzing the economic and financial potential of a wide variety of structural and non-structural statewide water supply options. This chapter summarizes some of the technical accomplishments achieved as part of developing this economic analysis approach, some of the lessons learned, and some future technical directions for this project. More policy-oriented conclusions are presented in Chapter 10.

WHAT HAS BEEN ACCOMPLISHED?

The following activities, products, and tasks have been completed.

California Water System Schematic

A schematic of the physical network available to store and transport large quantities of water statewide has been developed. To our knowledge, this is the only detailed schematic available of the state’s major intertied water systems and forms the basis for the statewide model schematic.

Statewide Model Schematic

A slightly simplified and updated version of the California system schematic has been developed for modeling purposes. The schematic is entirely physically-based. This statewide model schematic is available at: http://cee.engr.ucdavis.edu/faculty/lund/ftp

The CALVIN model schematic has roughly 1,250 spatial elements, including 56 surface water reservoirs, 38 groundwater reservoirs, 47 agricultural demand regions, 20 urban demand regions represented by 38 demand nodes, 163 stream reaches, 150 groundwater flow, pumping, and recharge reaches, 257 canal and conveyance reaches, and 78 diversion links. This schematic extends beyond current DWRSIM and PROSIM models to include Tulare Basin and Southern California water demands, facilities, and supplies (including the Colorado River).

GIS Maps

A set of 21 maps have been completed, depicting each CVPM region in the Central Valley, the location of urban and agricultural demands, and irrigation district and water agency boundaries.

New Economic Production Models for Agricultural Areas

The Statewide Water and Agricultural Production Model (SWAP) is developed for Central Valley agricultural areas and Southern California regions. The Central Valley component uses an updated data set from the Central Valley Production Model (CVPM) used in the CVPEIS process and has been developed and implemented for all 21 CVPM regions in the Central Valley. Refinements to the CVPEIS CVPM data include updated county cropping data. The method used in the SWAP model is similar to that used in the CVPM model, but differs in three significant ways:

1) The regional crop production function used in SWAP is more general than the CVPM. The fixed yield trade off between applied water and cost is replaced by a quadratic production function for each regional crop that allows the same trade-off between applied water and the cost of irrigation. This more general production function also allows for yield change due to improved management or stress irrigation.

2) Since many water management decisions are made on a monthly basis, water use in SWAP is disaggregated into monthly periods.

3) The agricultural cost function used in SWAP is more flexible than the CVPM specification, in that it allows the production cost of a given crop to depend jointly on the levels of other crop production as well as its own level.

The SWAP model is detailed in Appendix A.

Agricultural Water Valuations for the 21 Central Valley CVPM Regions

Results from the SWAP model have been used to estimate the value of monthly water use for agriculture throughout the Central Valley. These monthly functions for the value of water for agricultural production are used as objectives in the CALVIN optimization model.

Urban Water Valuations for 20 Major Urban Demand Areas

Monthly estimates for the economic value of urban water use have been produced for 20 urban regions. These estimates are based on price elasticity of demand estimates for residential water use, a survey of the costs of industrial water shortage, and current and 2020 estimates of water use, water price, and population. The method is explained in Appendix B.

Preliminary Synthesis of Surface and Ground Water Hydrologies Statewide

The Capitalization project’s modeling effort brings together a wide range of hydrologic information in the framework of a single statewide model. Beyond our preliminary hydrology effort, a far more substantial effort is underway between the USBR and California DWR to resolve the Central Valley’s hydrology. Our largely completed preliminary effort in this regard includes:

- Modified DWRSIM, PROSIM, and SANJASM surface hydrology for most of the Sacramento and San Joaquin Valleys and tributaries;
- DWR surface hydrologies for Yuba, Bear, and other Sacramento Valley streams;
- US Army Corps of Engineers hydrologies for Tulare Basin surface water;
- Modified CVGSM hydrology for Central Valley groundwater; and
- Local reports and plans for groundwater and surface water hydrology outside the Central Valley.

Assembly of System Capacities

A major network model requires assembly of information on surface and ground water storage and flow capacities system-wide. Much of this information for the state's surface water system has been taken from DWRSIM, PROSIM, and SANJASM. Groundwater storage and pumping capacities have been estimated from CVGSM and local and statewide groundwater reports. Other statewide, regional, and local plans and reports also have provided needed information.

Assembly of Environmental Flow Requirements

The CALVIN network model requires that environmental flow targets be met. Such flow targets are and will continue to be a source of controversy. We have assembled a set of such flow requirements, largely adapted from those used by DWRSIM, PROSIM, and SANJASM. These environmental flow requirements can be easily changed for preliminary estimation of the economic costs or benefits to urban and agricultural water users from changes in environmental flow requirements.

Database for Input Model Data and Metadata

For modeling intended for use in public policy discussions, model assumptions and data should be readily available and understandable. (Transparency is desirable.) Identifying and explaining the assumptions of modeling efforts have been major problems in the past. For this project, a database (in Microsoft Access format) contains all the data required to model water operations and economics statewide. This database also includes metadata, detailing the origins and assumptions inherent in these data, documenting the model's input data.

Software for Entering Data into HEC-PRM Model

Several major items of software development are required to accomplish such a statewide optimization model. Software now exists for loading all data necessary for the optimization model (network connectivity, capacities, policy constraints, and economic values) into HEC-PRM from the database. HEC-PRM is the network optimization software developed and used by the US Army Corps of Engineers for reservoir system optimization studies. HEC-PRM solves the optimization problem and processes much of the data within the CALVIN model.

Improvements to HEC-PRM Model

For the Capitalization project, several modifications to the HEC-PRM solver code were necessary or desirable. These have been completed under sub-contract with the US Army Corps of Engineers Hydrologic Engineering Center. Modifications include: improved handling, checking, and output for reservoir evaporation, output of shadow prices (indicating the economic value of small changes in storage and flow constraints or capacities), initial starting solutions (to reduce computing time), quadratic value functions (adding flexibility and smoothing representation of the economic value of water uses). These modifications have been included in updated HEC-PRM documentation.

Conceptual Design for Post-Processing Tool

Runs for large system models produce immense quantities of output data. These output data must be checked for reasonableness and later manipulated and applied to answer questions of policy, planning, and operational relevance. A conceptual design has been developed for a generic post-processing tool to be programmed in object-oriented code. This code would be useful for any type of operations or operations planning model.

Design for Modern Data-Model Interface and Data Management System

A data management system and graphical user interface (GUI) have been designed using object-oriented analysis. The GUI is being implemented using Microsoft Excel 97 to leverage the graphical object capability provided as part of Excel. The data management software for each model alternative will be implemented using distributed component design with Visual Basic. These components can be used easily with a different graphical interface if desired in the future.

A common problem experienced when performing model studies of large complex systems such as California is managing the multiple files and data sets (both input and output) for various alternatives. An object-oriented analysis is underway to provide an active data management system for use with this and other models.

CALVIN Runs for the Central Valley and Southern California

The CALVIN network optimization model is being de-bugged in a series of five-staged regions. The first four regions (the Sacramento Valley, Delta, San Joaquin Valley, and Tulare Basin) are currently running as one model. Southern California (the fifth region) currently runs as a separate model. These two models will be interconnected with the California Aqueduct. While these models run, they are not yet tested and ready for policy evaluations.

SWAP Model Extension to Southern California

A new sector of the SWAP model is complete for agricultural areas of Southern California. Water use and economic production in these major agricultural regions have not been modeled before in a manner comparable with Central Valley regions.

Assembly of Operating Costs Systemwide

Operating costs for pumping, treatment, recharge, and fixed-head hydropower are being gathered or estimated system-wide. Preliminary values are largely complete. Urban water quality issues (including water quality impacts) are represented, where possible, as part of these costs.

Post-Processing Software

Interim post-processing software has been developed. Where possible, this is done using the long-term post-processor design. However, in the interests of time, more limited spreadsheet macros are used for this phase of work.

Model Documentation

Documentation for the first version of the model is now complete, including written text, spreadsheet calculations, and databases of model assumptions, data, and metadata. This documentation appears in text, data, and software appendices.

WHAT HAS BEEN LEARNED?

Given the status of the project, most of our technical lessons learned involve data, its availability, and data management.

Statewide Water Management Modeling is Possible

Model development, data gathering, and preliminary model runs completed so far are sufficient to indicate that it is possible to model the economic management of water statewide. Five years ago, the available data, software, and computing power were insufficient for an optimization model as integrated and disaggregated as the current CALVIN model. While important gaps, uncertainties, and limitations remain, the state's water management community should begin to consider how to use such integrated modeling to help resolve pressing policy evaluation, economic impact, coordinated operation, and project finance problems.

Most Data are Available

A great deal of useful water resources data and information has been collected and developed over the last century in California. Particularly in the last decade, much information and modeling has been developed which is useful for large-scale operations and planning modeling purposes. However, the development and use of data and information must continue to adapt to newer problems facing the state.

High Level of Technical Cooperation

To develop the data for the CALVIN model, we have contacted dozens of agencies statewide. Almost all parties have been very helpful in providing data and useful information for this project. Without this high level of cooperation, our model would be far more approximate.

Data Gaps, Limitations, and Uncertainties

As expected with such an extensive and large-scale model, the input data suffers from uncertainties, limitations, and gaps in availability. Particular input data issues are:

Hydrology

Major limitations and uncertainties have been found in the surface and groundwater data available for statewide and Central Valley planning purposes. In particular, there is limited quantified understanding of the interaction of surface and groundwater flows. Particularly absent are records of actual groundwater pumping for most regions. These gaps in hydrologic data and understanding are well recognized by the water modeling community and hinder efforts to develop workable and effective statewide and regional water plans by any means.

Local Water Management

Most water management facilities and decisions are local. Yet there is little comprehensive understanding of the costs, capacities, and operation of local water facilities. Local flow and storage capacities have not been comprehensively and consistently collected and checked for regional and statewide planning purposes. While local information is available for some regions, it is very difficult to find for other regions, hindering the quality control of statewide and regional modeling studies. As more detailed integration of local, regional, and statewide water management efforts becomes desirable, such information will be required.

Economic Valuation of Water Demands

While some important uncertainties remain, the economic valuation of agricultural water demands is fairly well understood after several decades of study in California. However, despite many water demand elasticity studies and several contingent valuation studies, the economic valuation of urban water demands remains poorly understood compared with agricultural water demands. There is some need to improve the representation of both agricultural and urban water demands and their valuation, particularly their variation with hydrologic conditions. The effects of water quality on the economic value of water use also merits greater attention.

Data Management is Important

For large-scale models intended for use in public resolution of controversial problems, the clarity and reasonableness of the model and its input data will be severely tested. In these situations, the modeling approach and supporting data should be transparent. This implies that information on the origins and quality of model data (metadata) be readily available. The CALVIN model's input data is stored in a searchable Access database, including metadata on the origins and limitations of these data. Ultimately, these data and metadata will be accessible from the model schematic.

DIRECTION FOR THIS WORK

The project has demonstrated the feasibility of using a statewide economic optimization model to help plan for California's future water supplies, including estimating the value of particular new proposed facilities and changes in water management policies, such as water marketing. Such results can be used for evaluating various user financing mechanisms for particular system components, the economic desirability of various alternatives statewide or regionally, and suggesting various economically promising planning and operations alternatives. The interaction of groundwater, surface water, and water policy alternatives can all be preliminarily examined using this approach. Various data management ideas for making large-scale operations models more accessible for California water planning will also be demonstrated and developed.

For the results of this project to have more practical, widespread, and direct use for California, additional development and investment will be required. Some specific products for a one- to three-year time-frame are identified and discussed below. CALFED has agreed to fund much of the basic work needed along these lines over the next 18 months.

Better Data Management and Modest Model Enhancements

The following tasks and products are proposed for the next phases of CALVIN development.

Data-Model Input Interface Completion

Completion of the Model Data Manager (see Appendix C) and refinement of the input data interface and management system will greatly speed the application of the CALVIN model for policy purposes and improve its transparency.

Data Checking and Revision

Additional checking and revision of data is desirable for some types of CALVIN model input, particularly that related to the water imbalance in the Central Valley. The Southern California portion of the model is currently the most preliminary and will merit from further refinements. Groundwater and costs of water operations also merit additional scrutiny and effort to make up for data gaps.

Post-Processing Software

Completion of the post-processing software will enhance the utility of the model. Such software also would be available to improve the use of results for any operations or operations planning model which stores time-series results in HEC-DSS format, as is becoming increasingly common in California.

Variation of Urban and Agricultural Water Demands by Year-Type

Water demands and the value of water for urban and agricultural uses can vary significantly with hydrologic year-type. In dry years, farmers often begin planting earlier in the season and urban areas demand more water for landscape irrigation. Between average and dry years, there are estimates of 3-11% variation in water demand. In future work, it would be useful to incorporate such water demand variations.

Add Hydropower and Head-Dependent Pumping

Hydropower and head-dependent groundwater and surface-water pumping are important factors in the actual operation of surface and ground water storage. HEC-PRM, the solution code for the CALVIN model, has capabilities to handle these more challenging technical problems, but would require considerable additional data gathering and digestion to better represent these more complex pumping costs and benefits statewide. While solving optimization models with these additional features makes run-times slower, adding these aspects of the California system would make the model more realistic and more useful for operating policy studies required for more detailed analysis and development of operations plans.

Add Quadratic Economic Values for Agricultural and Urban Water Demands

Currently, urban and agricultural water demands are represented as a series of linear values. While this is sufficient for many purposes, the results of the model will be somewhat more accurate if replaced with quadratic functions. HEC-PRM now supports such quadratic value functions. Implementing quadratic functions for CALVIN would require re-calibration of agricultural and urban water value functions and a determination of whether quadratic representations would excessively slow computer solution times.

Applications

A wide variety of potential applications can be made of this type of model for planning purposes. Some of these are presented below.

Groundwater Management and Economic Impacts

Groundwater mining and depletion is a major issue for several parts of California. This computer model can be used to explore the economic and regional costs of such depletions and the potential of conjunctive use to manage groundwater depletions and increase economic production.

Develop Promising Conjunctive Use and Cooperative Operation Alternatives

The model incorporates both surface and groundwater supplies and is able to suggest promising approaches and locations for conjunctive use operations. The optimization model also can suggest promising opportunities for cooperative operations of surface and groundwater facilities that are currently operated by independent organizations.

Support Economic and Financial Analysis of CALFED Alternatives

It has been suggested to us that the technical abilities of our model might be useful to CALFED for various purposes, particularly in the economic and financial evaluation of alternatives.

Implied Valuation of Environmental Water Use

Environmental water uses are represented in the optimization model as minimum flow constraints. If these constraints are varied, the change in statewide economic production estimated by the model might be useful for evaluating the desirability of alternative forms of environmental flow regulations.

Economic Evaluation of New Facilities and Alternative Water Transfer Policies

The statewide economic value of various structural and non-structural alternatives, as estimated by the statewide economic model, might be useful in evaluating the desirability of various planning alternatives. The CALVIN model is particularly suitable for examining economic benefits where storage and conveyance alternatives are being considered in conjunction with alternative water transfer policies.

Finance of New Facilities or Management

The results of the statewide economic optimization model also can be used to estimate the willingness-to-pay of various water users for improvements in facilities or agreements for water management. This information would be useful for cost allocation purposes for public projects or financial analysis for public or private entities interested in providing water management facilities or services.

Disaster Economic Impacts and Flexible Response

The model can estimate the economic costs of natural and man-made disasters in the Delta and elsewhere. Such disasters might include Delta conveyance failures due to earthquake, flood, or other outages of Delta pumping as well as loss of major aqueducts elsewhere in the state due to earthquakes, terrorism, or other disasters. In addition, as an optimization model, promising emergency operations can be suggested for specific disasters.

Longer Term Developments

Over the long term, several additional enhancements are likely to be desirable.

New Optimization Algorithms

More flexible optimization algorithms would greatly improve the realism of the CALVIN model. A linear program solver would allow more water quality and water allocation representation in the model, such as mixing of water qualities in Southern California, Delta flow requirements, and use of an environmental water account. A linear-quadratic solution algorithm would go much further, allowing the economic water value models for agricultural and urban users to be directly and explicitly embedded in the statewide CALVIN model. The availability, cost, speed, and ability to reprogram the CALVIN and HEC-PRM model will determine the feasibility and desirability of using more flexible solution algorithms.

Web-based interface

A web-based interface for the CALVIN model would allow users anywhere to inspect and run the CALVIN model. However, the value and effectiveness of this feature require further consideration.

CHAPTER 10

CONCLUSIONS

1. *The complexity, controversy, interdependence, and importance of California's water supply system have grown to require new approaches to their analysis.*

California's water issues are interconnected statewide; water management and use in one area commonly affects water use in other areas. Surface water and groundwater systems are highly connected. Almost the entire system is complex and controversial. Most current analysis models used in California were developed at an earlier time to examine surface water management for a specific water project over a limited area with fairly inflexible operations. These models have been expanded like a rambling old house to accommodate new analytical requirements, but have become increasingly uncomfortable to live with. More modern analysis methods can help with these problems, providing a more integrated representation of the entire problem, improved indicators of system performance, more efficient solution procedures, and a wider range of problem solutions.

2. *Economics should have a greater role in analysis of California's water system.*

The greater controversy, variability, and diversity of water uses and supplies in California's water system have made economic indicators of system performance increasingly desirable. Economics-based analysis and economic measures of performance provide a fairly direct basis for:

- Evaluation and comparison of alternatives;
- Developing new economically promising structural and non-structural alternatives;
- Financial and willingness-to-pay studies;
- Cost or benefit effectiveness studies;
- Development and evaluation of integrated effects of multiple water management options;
- Quantifying trade-offs among system objectives; and
- Quantifying benefits to society and users of changes in facilities, environmental flow requirements, and institutional policy constraints.

Traditionally, "water supply yield" has been used to indicate water system performance. However, "yield" has become an increasingly obsolete and contentious indicator of performance, given its wide hydrologic variability, neglect of important water quality and economic considerations, and sensitivity to detailed assumptions (Linsley et al. 1992). Economic measures of performance are generally more important to people and help to characterize water supply reliability in terms meaningful to society. As economic measurement methods have improved, using the economic value of water deliveries has become a more reliable and direct indicator of system performance that can better incorporate reliability and water quality concerns.

This work, in developing and applying an improved agricultural economic production model (SWAP) and an elasticity-based urban water demand model, has produced preliminary estimates of the economic value of monthly water deliveries to agricultural and urban users throughout

California. These results and the analysis methods are presented in Chapter 6 and Appendices D and E. These economic models extend economic valuations of agricultural and urban water use used in the Draft CVPIA-PEIS and CALFED work (USBR 1997; CALFED 1999d). While improvements in these estimates are desirable, there is sufficient data and professional consensus to use these economic methods in long-term water planning.

3. *Advances in computing and software provide substantial opportunities to modernize and improve the analysis of California's water resources*.

Computers are much less expensive and more available and capable than when most current models and analytical methods were developed. Software for computing, storing, organizing, displaying, and optimizing is far more available and usable than in the past. Data of all sorts, while always lacking and imperfect, is available, sufficient, and improving for more extensive and detailed studies than have been done. The internet makes it possible for data, models, and computing resources to be shared and communicated among a wide range of users and interests, hopefully helping educate us all about problems and potential solutions.

The California water community is at an unusual point in time where the limitations of old methods and the promise of new technologies are both abundantly apparent. This is a pivotal time for the California water community to develop new approaches, methods, tools, and data for planning, managing, and operating water statewide over the long term. Development of such methods, software, and data are a vital strategic need for all parts of California's water community. Without such modernization, proposed solutions are less likely to perform effectively, and are therefore more likely to become controversial, discredited, and short-lived. DWR and USBR have moved energetically in this direction with the development of the CALSIM simulation model, which provides a platform for additional modernization efforts.

This project has demonstrated the feasibility and desirability of several more modern approaches to large-scale water system analysis. These include:
- More transparent data-driven modeling;
- Database documentation of model assumptions and parameters;
- Large-scale economic optimization; and
- Structures for automated computer management of modeling data.

The primary advantages of these techniques are to speed development and analysis of alternatives and to increase the transparency of modeling assumptions and results.

4. *California can choose from a wide variety of structural and non-structural options for addressing its pressing water resource problems.*

Chapters 3, 4, and 5 present a diversity of structural and non-structural options available to local, state, and federal agencies, firms, and water users. Traditional structural options include new or expanded surface water reservoirs, canals, and aqueducts. New structural options include groundwater storage and advanced (and expensive) treatment options to utilize wastewater, brackish water, and even seawater. Nonstructural options include water transfers and markets, water conservation, conjunctive use of surface and ground waters, and improved coordination of water storage, distribution, and treatment facility operations. Additional water conservation options are included in the economic value functions used in CALVIN. The finance of these options, most of which are costly, can also be accomplished in a variety of ways, as reviewed in Chapters 4 and 5, ranging from self-financing and bonds to privatization and joint ventures among agencies.

Nonstructural options are especially important and are necessary complements to structural options. In highly interconnected systems, such as California, the benefits of new water facilities are often reduced unless accompanied by complementary changes to the operations and management of other water facilities. Such changes in operations and management can be accomplished by cooperative operating agreements among facility owners, water transfers or markets, or changes in contracts or other agreements. Operations also can change by modifying user demands through various water conservation or transfer options. Nonstructural options provide many opportunities and might be cost-effective, especially in conjunction with structural measures. However, it is typically difficult to study, develop, and integrate nonstructural options using conventional simulation models, prompting the need to use newer and more flexible analytical techniques. The need to integrate all manner of water management options further motivates the use of more modern system analysis methods.

5. *Groundwater must be integrated into the analysis of California's water supplies, even though we know relatively little about it.*

Groundwater provides about thirty percent of California's agricultural and urban water supplies in an average year. In drought years, use of groundwater increases greatly, and provides California's greatest source of drought water storage. Groundwater overdraft is also one of the greatest manifestations of water shortage in California. While there is relatively less knowledge and regulation of California's groundwater, this has not made groundwater less important for managing California's water supplies. Realistic analysis of California's water supplies must include explicit integration of groundwater. In addition to providing more realistic analysis, such integration will support development of promising conjunctive use projects and accelerate development of improved understanding of the state's groundwater systems.

6. *Economic-engineering optimization models are feasible and insightful for California's water problems.*

This study has demonstrated the capability of a new analysis approach for California water, the CALVIN model. CALVIN is an economics-based engineering optimization model of California's water supply system. Given economic values developed for agricultural and urban water supplies, environmental flow constraints, inflow hydrologies, operating costs, and facility capacities, CALVIN suggests economic-benefit-maximizing operations of the statewide system, integrating all resources and options. This phase of work has proven the data availability and software performance required for CALVIN and the feasibility of implementing such a modeling approach.

Sample runs of statewide models demonstrate some of the desirable features of economic-engineering analysis of California's statewide water supply problems, as presented in Chapter 8. Values of facility expansions and new water are produced. The willingness of water users to pay for additional water and new facilities also is produced. The costs of environmental and other policy or operating constraints on the system can be quantified. Economically optimal and integrated facility operations are produced.

The application to California of this economic-engineering optimization approach embodied in CALVIN is the largest of its kind, with over 75 surface water and groundwater reservoirs. However, this approach has also been applied to other large water systems by the US Army Corps of Engineers (Columbia River system, Missouri River system, and Panama Canal system) and the World Bank.

7. *New optimization modeling analysis will almost always require more focussed and detailed simulation modeling to refine and test solutions*.

As good as optimization models have become, they do suffer some limitations and require sometimes important simplifications relative to simulation models. (CALVIN, for instance, has fairly crude methods of representing water quality.) Optimization model solutions provide promising solutions for refinement and testing by simulation studies. Use of optimization avoids the need to make and interpret many thousands of simulation model runs to explore the wide range of alternative solutions, a virtually impossible simulation task for large and complex systems. This allows simulation efforts to focus on the detailed analyses they are better suited for. For large, complex, and controversial systems, simulation and optimization methods complement each other.

8. *Better data is needed in some areas to allow better solutions to be realized.*

In assembling and developing input data for the CALVIN model, we identified some areas which merit greater long-term data development. These areas include:
- Surface water and groundwater hydrology;
- Operations and costs for local water facilities;
- Urban water demands and economics; and
- Water quality economics.

CALFED, DWR, and USBR are devoting effort to improving data in some of these areas, particularly regarding surface water and groundwater hydrology in the Central Valley.

9. *CALVIN needs more work.*

While this first phase of work has proven the concept of applying economic-engineering optimization to California's water system, much data checking and development is needed before useful policy-relevant results can be produced. Additional work in this regard is being undertaken with support from CALFED.

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ACRONYMS

AB	Assembly Bill
ACWD	Alameda County Water District
ACFCWCD	Alameda County Flood Control and Water Conservation District
af	acre-foot/acre-feet
AFRP	anadromous fish restoration program
AVEKWA	Antelope Valley East Kern Water Agency
AWBA	Arizona Water Banking Authority
BMP	Best Management Practices
CAA	California Aqueduct
CALFED	State (CAL) and federal (FED) agencies participating in the Bay-Delta Accord
CALVIN	California Value Integration Model
CCFB	Clifton Court Forebay
CCWA	Central Coast Water Authority
CCWD	Contra Costa Water District
CDAC	California Debt Advisory Commission
CDEC	California Data Exchange Center
CEQA	California Environmental Quality Act of 1970
cfs	cubic feet per second
CLWA	Castaic Lake Water Agency
COA	Coordinated Operation Agreement
CRA	Colorado River Aqueduct
CUWA	California Urban Water Agencies
CVGSM	Central Valley Ground-Surface Water Model

CVP	Central Valley Project
CVPIA	Federal Central Valley Project Improvement Act of 1992
CVPM	Central Valley Production Model
CVWD	Coachella Valley Water District
DAU	detailed analysis unit
DBP	disinfection by-product
DEIR	draft environmental impact report
DEIS	draft environmental impact statement
DMC	Delta-Mendota Canal
DOI	United States Department of the Interior
DSS	Data Storage System developed by HEC
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
EBMUD	East Bay Municipal Utility District
EID	Eldorado Irrigation District
EIR	environmental impact report
EIS	environmental impact statement
ET	evapotranspiration
ET_o	reference evapotranspiration
ETAW	evapotranspiration of applied water
E&W	Eastern and Western
FERC	Federal Energy Regulatory Commission
GPCD	gallons per capita per day

GUI	graphical user interface
HEC	Hydrologic Engineering Center of the USACE
HEC-PRM	HEC's Prescriptive Reservoir Model
HDWD	Hi Desert Water Agency
HR	hydrologic region
IFIM	Instream Flow Incremental Methodology
IID	Imperial Irrigation District
IRPDSM	Integrated Resources Planning Distribution System Model
ISDP	Interim South Delta Program
IV	Imperial Valley
kaf	thousand acre-feet (can also be listed as taf)
KWBA	Kern Water Bank Authority
KWB	Kern Water Bank
LA	Los Angeles
LAA	Los Angeles Aqueduct
LBG	Los Banos Grandes
LDC	local gas distribution company
maf	million acre-feet
MID	Modesto Irrigation District
MWA	Mojave Water Agency
MWD	Metropolitan Water District of Southern California
M&I	Municipal and Industrial
NEPA	National Environmental Policy Act of 1969
NGA	Federal Natural Gas Act of 1938
NHI	Natural Heritage Institute

OASIS	Open Accesss Same-time Information System
O&M	Operations and Maintenance
PCWA	Placer County Water Agency
PEIR	programmatic environmental impact report
PEIS	programmatic environmental impact statement
PROSIM	USBR's operations model for the CVP/SWP
PSA	Planning sub-area
PVID	Palos Verde Irrigation District
RPA	Federal Reclamation Project Acts of 1939, 1956, and 1963
RRA	Federal Redemption Reform Act of 1982
SANJASM	USBR's San Joaquin Area Simulation Model
SBA	South Bay Aqueduct
SCVWD	Santa Clara Valley Water District
SCWA	Solano County Water Agency
SDCWA	San Diego County Water Authority
SFPUC	San Francisco Public Utilities Commission
SFU	Straight fixed variable method
SWAP	State-Wide Agricultural Productioin Model
SWP	State Water Project
SWRCB	State Water Resources Control Board
SWSD	Semitropic Water Storage District
taf	thousand acre-feet (can also be listed as kaf)
TID	Turlock Irrigation District
TDS	total dissolved solids
TOC	total organic compounds

UCD	University of California at Davis
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
WD	water district
WR 95-6	SWRCB Order WR 95-6
WSD	water storage district
WTP	willingness to pay
Zone 7	Zone 7 of ACFCWCD