

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.

