CALVIN – Economic-Engineering Optimization Model of California's Inter-tied Water System

Name – CALVIN

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Availability of technical support

All documentation, software, databases, and reports are available on website at:
http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/

Documentation includes several hundred pages of method and data descriptions and discussions of limitations. Additional data documentation is available from the authors on 2 CDs.

Short courses are offered on demand. Entities with personnel knowledgeable of the model and software include: UC Davis, US Army Corps of Engineers Hydrologic Engineering Center, CH2M-Hill (Sacramento), and Montgomery-Watson-Harza (San Francisco), Valencia Politechnic University (Spain), and Federal Center for Technology Education CEFET (Brazil).

Analytical tool categories (list all that apply)

Integrated water resources management model (economics, management, operations, water conservation, conjunctive use, water marketing, surface and groundwater accounting)

Economic-engineering optimization

Main Features and Capabilities

- Integrated economic-engineering optimization model of California's inter-tied water system, intended to identify economically promising integrated combinations of water management activities over regional or statewide scales.
- Geographic scope – California's inter-tied water system, including: Central Valley, Southern California, Colorado Basin, San Francisco Bay Area; can be restricted to smaller regions of California
- Temporal scale – Monthly management, typically over 72-year historical record or climate change scenario
- Economic representation of water demands
- Preliminary estimates of economic values for expanded facility capacities
- Preliminary estimates of economic costs of environmental flow requirements

- Explicitly integrates operations of surface and groundwater supplies and water reuse with water use efficiency activities, including pricing and water markets.
- Documented database of facilities, hydrologic assumptions, and economic assumptions.
- Allows water managers to modify operations economically, within environmental and physical constraints.

Applications (reports on web site, with refereed journal citations, where available)

- Statewide and regional model development – proof of concept (1999)
- Statewide and regional model development and calibration – optimization and water markets within an integrated water management context (2001) (Draper et al. 2003; Jenkins et al. 2003, 2004)
- Southern California Regional Model (2000) (Newlin, et al. 2002)
- Importance of level of detail in model representation (2000) (Van Lienden and Lund 2004)
- Sacramento Valley Regional Model (2001) (Tanaka, et al. 2003)
- San Joaquin Valley Regional Model (2001)
- Tulare Basin Regional Model (2001)
- Southern California Conjunctive Use (2002) (Pulido, et al. 2004)
- O'Shaughnessy Dam removal (2003)
- Statewide climate change and water management for 2100 (2003)

Calibration / Validation / Sensitivity Analysis

Extensive testing against available models and data ca. 2001. Additional upgrades since. Extensive discussion of data and model limitations in 2001 report, available at: http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/

Peer Reviewed Development and Applications to California

Journal articles in a variety of professional journals:

Jenkins, M.W., J.R. Lund, R.E. Howitt, A.J. Draper, S.M. Msangi, S.K. Tanaka, R.S. Ritzema, and G.F. Marques, "Optimization of California's Water System: Results and Insights ," *Journal of Water Resources Planning and Management*, Vol. 130, No. 4, July 2004.

Pulido – Velázquez, M., M.W. Jenkins, and J.R. Lund, "Economic Values for Conjunctive Use and Water Banking in Southern California," *Water Resources Research*, Vol. 40, No. 3, March 2004.

Van Lienden, B. and J.R. Lund, "Spatial Complexity and Reservoir Optimization Results," *Civil and Environmental Engineering Systems*, Vol. 21, No. 1, pp. 1-17, March 2004.

Tanaka, S.K., J.R. Lund, and M.W. Jenkins, "Economic Effects of Increased Exports and Environmental Flows from the San Francisco Bay-Delta," *Journal of the American Water Resources Association*, Vol. 39, No. 6, pp. 1509-1519, December 2003.

Draper, A.J., M.W. Jenkins, K.W. Kirby, J.R. Lund, and R.E. Howitt "Economic-Engineering Optimization for California Water Management," *Journal of Water Resources Planning and Management*, Vol. 129, No. 3, May/June 2003.

Jenkins, M.W., J.R. Lund, and R.E. Howitt, " Economic Losses from Urban Water Scarcity in California , " *Journal of the American Water Works Association*, February 2003.

Newlin, B.D., M.W. Jenkins, J.R. Lund, and R.E. Howitt, " Southern California Water Markets: Potential and Limitations ," *Journal of Water Resources Planning and Management*, January, 2002.

Peer review of additional work currently underway.

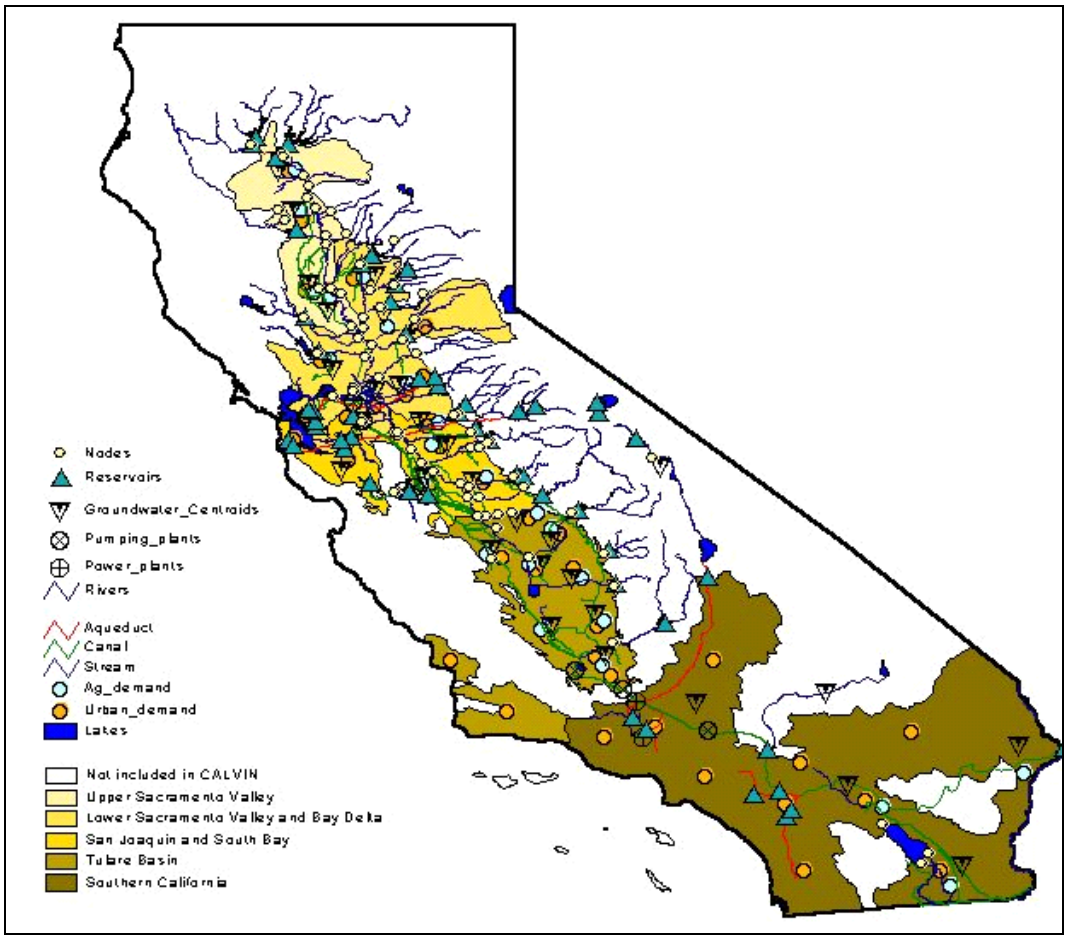

Figure 1. CALVIN Schematic and major regions superimposed on map of California

Anatomy of tool:

Conceptual Basis: CALVIN is a statewide model of economic and engineering aspects of California's integrated water supply system. Its spatial coverage and schematic appear in Figure 1, and cover over 90% of estimated 2020 urban water demand and almost 90% of estimated 2020 irrigation water demands. The model integrates a wide variety of aspects of this complex system, including:

- Surface and groundwater hydrology,
- Water management facilities and their capacities,
- Environmental regulations,

- Economic values for water deliveries, and
- Economic costs of operations

within a framework of economic optimization within an engineering and planning context, illustrated in Figure 2. The model outputs provide an economic and engineering view of promising integrated management strategies, in an optimization, rather than a simulation context.

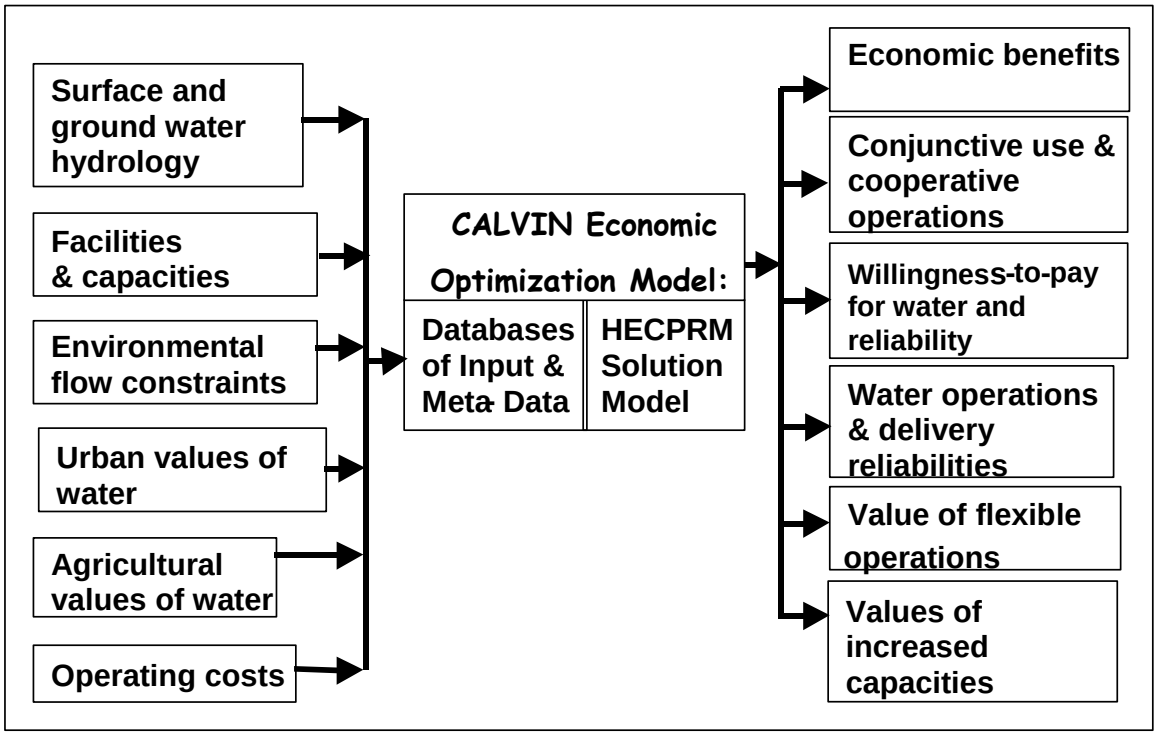

Figure 2. Conceptual schematic of CALVIN model

Theoretical Basis: Minimize total costs of water scarcity and operations to all users over all time periods (wet and dry), within environmental, operational, and physical constraints. This is summarized in the mathematics below:

Minimize: $$Z = \sum_i \sum_j c_{ij} X_{ij}, \quad (1)$$

Subject to: $$\sum_i X_{ji} = \sum_i a_{ij} X_{ij} + b_j, \text{ for all nodes j,} \quad (2)$$

$$X_{ij} \le u_{ij} \quad \text{for all arcs,} \quad (3)$$

$$X_{ij} \ge l_{ij} \quad \text{for all arcs,} \quad (4)$$

where Z is the total cost of flows throughout the network, X_{ij} is flow leaving node i towards node j, c_{ij} = economic costs (ag. or urban), b_j = external inflows to node j, a_{ij} = gains/losses on flows in arc ij, u_{ij} = upper bound on arc ij, and l_{ij} = lower bound on arc ij.

Numerical Basis: HEC-PRM generalized network flow optimization code for reservoir systems (US Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA). This system has been applied by the US Army Corps of Engineers to the Missouri River System, the Columbia River System, Southern Florida/Everglades System, Panama Canal, and Alamo Reservoir in Arizona. It also has been applied to the Carson-Truckee System in California/Nevada by UC Davis. For more information refer to: http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/

Input and Output Data

Rather a lot of input and output, taken from a variety of sources. Extensive documentation of data, data preparation, and data limitations. Extensive use of post-processors to visualize complex output data. Some types of data need additional work to improve the value of statewide analysis including data on surface water and groundwater hydrology, local water management, and economic valuation of water demands.

Following is a general list of **input** data to CALVIN:

- Surface and groundwater hydrology
- Facilities and capacities (storage and conveyance)
- Urban water use
- Ag water use
- Environmental flow constraints
- Operating costs

Some major **outputs** are as follows:

- Water allocations and delivery reliabilities
- Willingness to pay for water and reliability
- Economic benefits
- Conjunctive use operations
- Value of flexible operations
- Values of increased capacities

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Data management

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. CALVIN uses a modern data-model interface and data management system. 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. This includes documentation of data HEC-DSS storage of time series and cost data. GIS Maps are used for Documentation and Post-Processing. A Software is used for entering data into HEC-PRM Model. HECPRM output is stored in the Hydrologic Engineering Center's Data Storage System (HEC-DSS). HEC-DSS data is classified into two generic data types - time series data, in which one value is given for each time step, and paired data, in which two variables are related to each other by a piece-wise linear function.

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Software

CALVIN software is based on an optimization solver for the water resource system called 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.

Availability of source code – CALVIN is a public domain freeware.

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