CVP Cost Allocation Study
November 19, 2013

Description of Analytical Tools

Name
CalSim2

Author/Developer
California Department of Water Resources and U.S. Bureau of Reclamation

Category
Reservoir-river simulation model, long term water supply reliability planning model

Main Features and Capabilities
- Monthly time step; 82-year period of record
- Spatial scale – CVP/SWP project extent. Extended Sacramento/San Joaquin river basins and associated imported water sources and export delivery areas.
- Simulation of CVP/SWP operations
  - using historical rainfall and runoff hydrology that has been adjusted to represent water supply and demands at a consistent level of development, and
  - depicting a consistent regulatory environment.
- Developed in WRIMS – a general-purpose river system modeling environment with a LP/MILP solution algorithm

Applications
CalSim2 is widely accepted as the planning model for depicting CVP/SWP system operations and has been used in numerous system-wide studies since it was first released in 2002, including multiple CALFED storage investigations, Operations Criteria and Plan (OCAP) 2004, OCAP 2008, DWR Delivery Reliability Reports, San Joaquin River Restoration, and the Bay Delta Conservation Plan (BDCP).

Calibration/Validation/Sensitivity Analysis
Because of the evolving nature of CVP/SWP facilities, demands, and governing regulations, true calibration/validation practices are not feasible with a model like CalSim2. DWR performed an historical simulation study (DWR, 2003) which demonstrated the model's ability to match historical operations when driven by time-evolving inputs reflecting historical demand levels and operating criteria.

Sensitivity/uncertainty analysis has been performed to determine sensitivity to a broad range of input data (DWR 2005).

Peer Review

Peer reviews of CalSim2 were conducted under the CALFED study program for the system-wide model (Close et al, 2003), and following an update to San Joaquin basin representation (Ford et al, 2006).

Anatomy of CalSim2

Conceptual Basis

CalSim2 depicts the water supply reliability of the CVP/SWP system, operating within the extended Sacramento and San Joaquin River Basins at a specific level of development and given fixed assumptions about project facilities and operations criteria.

Hydrology

The historical hydrology record has been affected by a particular sequence of natural characteristics (rainfall, temperature, runoff) and human impact (facility development, land use, population, regulations). Historical data is “unimpaired” by backing out the impacts of human activity to return to a data set that reflects a native condition, and then it is “re-impaired” by imposing a particular assumption about land use and urban demand. The resulting data set thus reflects the historical trace of precipitation and temperature, but local accretions/depletions, consumptive use demand, and urban demand reflect a consistent current or future level of irrigation and urban land use. The period of record used by the CalSim2 model is 1922-2003. The spatial resolution at which the hydrology balances and land-use analysis is performed is shown in Figure 1.

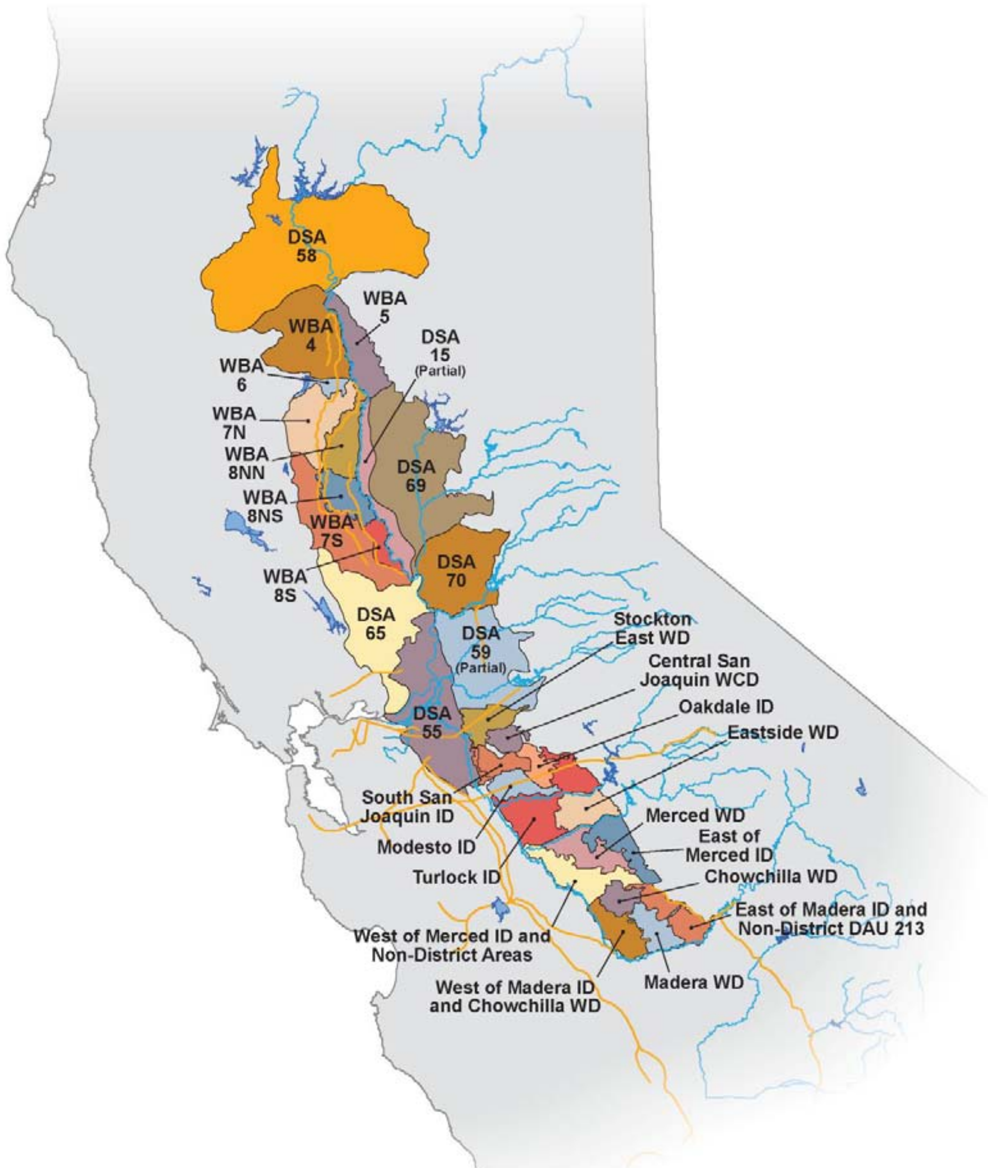

Figure 1 – Depletion Analysis Regions used by CalSim2 (Depletion Study Areas, Water Budget Areas)

Surface Water/Groundwater Interaction

Groundwater has a limited representation in CalSim2. Within the Sacramento Valley floor, groundwater is explicitly modeled using a multiple-cell approach based on depletion study area boundaries. There are a total of 12 groundwater cells. Stream-aquifer interaction, groundwater pumping, recharge from irrigation, and sub-surface flow between groundwater cells are calculated dynamically. All other groundwater flow components are preprocessed as part of the hydrology development and represented in CalSim2 as fixed time series'. In areas of high groundwater, CalSim2 calculates groundwater inflow to the stream as a function of the groundwater head and stream stage. In areas of low groundwater elevation where the groundwater table lies below the streambed, CalSim2 assumes a hydraulic disconnect between the stream and aquifer. In this case seepage is only a function of stream stage.

Agriculture Demands

CalSim2 demands north of the Delta (NOD) are determined in the hydrology development process and depicted as lumped time series (monthly) values for the areas shown above. Land use-based demands are calculated using the Consumptive Use (CU) model, which simulates soil moisture conditions for 13 different crop types over the historical period. Irrigation demand is triggered when soil moisture falls below a specified minimum. The CU model calculates the crop consumptive use of applied water. The consumptive use is subsequently multiplied by water use efficiency factors to obtain the regional water requirement to be met from stream diversions or groundwater pumping. Agricultural demands in the Delta are represented more simply as an overall mass balance between precipitation and crop evapotranspiration.

Non-recoverable losses are assumed to be 10 to 15 percent of the crop consumptive use of applied water. Non-recoverable loss factors are used to determine the portion of the supply that will return to the system as surface return flow or as deep percolation to groundwater. Efficiency factors may vary by month and by year.

Agricultural demands south of the Delta (SOD) are depicted as project contract obligations. SOD CVP demands are assumed to be fixed at maximum contract amount and do not vary year to year. SWP agricultural demands on the west side of the San Joaquin Valley are capped to the full assigned amount, but are reduced in wetter years using an index developed from annual Kern River inflows to Lake Isabella.

M&I Demands

Indoor urban water use is considered non-consumptive and is not dynamically represented by the model. Outdoor urban water use is treated as an irrigation demand and is combined with the agricultural demands. M&I diversions, although not entirely consumptive, can have a large influence on reservoir operations. Surface water diversions serving both indoor and outdoor M&I uses for the American and Lower Sacramento River areas have therefore been included in CalSim2 because they partially determine the operation of Folsom Lake. Outdoor urban demand is calculated by the CU model, with the irrigated area computed as a fixed fraction of the total urban area as measured by DWR in land use surveys.

CVP and SWP SOD M&I demands are based on contract amounts. CVP demands are assumed to equal contract amounts and do not vary. SWP M&I demands south of the Delta are split into Metropolitan Water District of Southern California (MWDSC) and others. MWDSC demands are either set at full contract amounts or are determined through a process of iteration between CalSim2 and MWDSC's integrated resource planning simulation (IRPSIM) model, and vary from year to year. Other SWP M&I contractors' demands are fixed at their full designated amount.

Project/Non-Project Split

Demands are disaggregated in CalSim2 into project demands and non-project demands. Project demands are subject to reduced water allocations based on CVP and SWP contract provisions, while non-project demands are satisfied from sources other than project storage and project conveyance facilities and are reduced as a function of water availability in the absence of project operations. For each Depletion Study Area (DSA), project demands are calculated as a fixed percentage of the total land use-based demand. The split between project and non-project demands is determined by comparing project acreage within each DSA to the total crop acreage within the DSA.

Total Demands/Contracts

Model diversions represent CVP project, SWP project, local project, or non-project operations which collectively meet the depletion area demands. Annual total CVP and SWP demands are summarized in Table 1 by category.

Table 1 – CVP and SWP Demands at a 2020 Level of Development

	2020 LOD	
	North of Delta	South of Delta
CVP		
• Settlement/Exchange	2194	840
• Agriculture	378	1937
• M&I	557	164
• Refuges	189	281
SWP		
• Feather River Service Area	796	0
• Agriculture	0	1032
• M&I	114	3024

CVP/SWP Project Allocation

CalSim2 assesses project water supplies based on storage conditions and forecasted inflow and determines project allocations based on rule curves that depict tradeoffs between current year delivery and carryover water supply. Estimates of export capacity through south delta pumps also affect allocation determination. SWP allocation is first determined in January, and updated every month based on evolving forecast data until May. CVP allocation is first determined in March and updated in April and May.

Storage Operations

- Flood Control: Flood control rules are imposed on all system reservoirs, maintaining required flood space in anticipation of spring runoff.
- CVP reservoir balancing: CalSim2 seeks to maintain a balance amongst storage levels in Trinity, Shasta, and Folsom, based on rules that consider the time of year, water supply conditions, and refill potential of each facility.
- San Luis Rule Curve: Target storage levels are set through the filling period (~ Oct-Mar) to guide the projects' releases from north of delta reservoirs for storage in San Luis Reservoir. The same philosophy is also used to dole out the use of storage reserves to each project through the water operations year, considering both seasonal demands and projected export capacities.

Delta Water Quality

The State Water Resources Control Board (SWRCB) specifies water quality standards for the Delta. Currently the CVP and SWP share the obligation to meet these standards as defined by the Coordinated Operation Agreement. Salinity standards must be translated into flow equivalents to be modeled in CalSim-II. However flow-salinity relationships in the Delta are non-linear.   CalSim2 uses DWR's Artificial Neural Network (ANN) model to simulate the flow-salinity relationships for the Delta by estimating the salinity at water quality stations in the Delta. The ANN model correlates DWR's Delta Simulation Model (DSM2) model-generated salinity at key locations in the Delta with Delta inflows, Delta exports, and Delta Cross Channel operations by estimating electrical conductivity at the following four locations for the purpose of modeling Delta water quality standards: Old River at Rock Slough, San Joaquin River at Jersey Point, Sacramento River at Emmaton, and Sacramento River at Collinsville. In its estimates, the ANN model considers antecedent conditions up to 148 days, and considers a "carriage-water" type of effect associated with Delta exports. CalSim2 passes antecedent (previous month) flow conditions and known (or estimated) current month flows to an ANN dynamic link library (DLL). The DLL returns coefficients for a linear constraint that binds Sacramento River Delta inflows to Delta exports based on a piecewise linear approximation of the flow-salinity relationship

Coordinated Operations Agreement (COA)

The COA is both an operations agreement and a water rights settlement defined by the SWRCB Decision 1485. Decision 1485 ordered the CVP and SWP to guarantee certain conditions for water quality protection for agricultural, M&I, and fish and wildlife use. The purpose of the COA is to ensure that the CVP and the SWP each obtains its share of water from the Delta and bears its share of obligations to protect the other beneficial uses of water in the Delta and Sacramento Valley. The COA balance equations and COA sharing formulas are coded in the model as goals, used as constraints in the LP problem formulation. CalSim2 uses mixed integer programming to determine in which of the two possible conditions the model is operating under for the given month – Balanced Water Conditions or Excess Water Conditions.

Other Operations Criteria

Multiple state water resources control board plans and decisions, environmental regulations, water rights, and legislative mandates collectively guide and constrain the operations of both the CVP/SWP.

- Joint Point of Diversion – SWP wheeling of 128 taf/yr for CVP Cross-Valley Canal users through Banks Pumping Plant is represented in all simulations as the first priority after SWP discretionary operations are satisfied. Further wheeling by SWP of CVP water when unused Banks capacity exists is possible under (1) surplus conditions when SWP has filled San Luis and satisfied its Article 21 demand, and (2) balanced conditions when SWP no longer wishes to move Oroville water to San Luis.
- D-1641 – significant elements include the 1995 WQCP standards, net Delta outflow requirements, the Vernalis Adaptive Management Plan, X2 standard, export/inflow (E/I) ratio, pulse period export limits, Delta cross-channel gate closure requirements, and Rio Vista and Vernalis flow standards.
- CVPIA 3406(b)(2) – the 800,000 acre-feet of Central Valley Project yield dedicated through the Central Valley Project Improvement Act for fish, wildlife, and habitat restoration purposes is managed to augment river flows and curtail Delta exports. Flows reflecting the dynamic (b)(2) operation depicted in the 2008 OCAP studies are incorporated into current versions of CalSim2 as flow requirements. Export curtailments are not represented specifically, as it is commonly understood that these criteria are covered by the more recent constraints of the Biological Opinions.
- Reasonable and prudent actions (RPA's) in the 2008 Fish and Wildlife Service (FWS) and 2009 National Marine Fisheries Service (NMFS) Biological Opinions – certain RPA's are implemented in CalSim2, as developed through a coordinated process between Federal and State agencies.

A comprehensive list of all criteria for the CalSim2 study used to define CVP deliveries for Cost Allocation Study reservoir sizing analysis is provided at the end of this Tech Memo.

Theoretical Basis

Flows, deliveries, and storage conditions in the reservoir river system are defined as decision variables and weighted to designate system priorities. Constraints on the values of these decision variables can be expressed as hard constraints that cannot be violated (such as canal capacity, maximum reservoir storage), or as soft constraints with penalties for deviating from user-specified target values. Soft constraints are converted to auxiliary slack and surplus variables with weights set by the associated penalties. Weighted decision variables and the slack and surplus variables all become elements of the objective function. The dynamic evaluation of constraint coefficients at run time allows both hard and soft constraints to be conditionally determined based on the state of the system – they can vary with water supply, water year type, timestep, or any other user-defined category.

Multiple simulations can be layered within a single timestep to accommodate constraints that tier off of interim conditions. Previously determined values for decision variables, from previous cycles or timesteps, can be accessed for use in constructing current cycle or timestep constraints.

The use of a mixed-integer programming solver enables the use of binary integers to construct "either-or" type constraints, which are useful for such applications as weir operations or dynamic switch settings.

Numerical Basis

Solutions in CalSim2 are resolved by the XA solver, which is tasked with maximizing the value of the objective function constructed as the sum of each decision variable multiplied by its weight and each slack or surplus variable multiplied by its associated penalty. Solutions are also conditioned by the values of several integer variables depicting the status of weir flows and the COA balance. An Artificial Neural Network (ANN) depicts the relationships between flow and salinity at several locations in the interior Delta, based on and serving as a surrogate for the DSM2 model.

Input and Output

Inputs include rim inflows, local accretions/depletions, delivery requirements, consumptive use requirements, irrigation efficiencies, return flow functions, stream/groundwater interaction parameters, contract amounts, reservoir bathymetry, flood control rules, physical capacities, and environmental and legal criteria which control operations. Outputs include average monthly river channel flows and deliveries, including Delta outflows and exports, end-of-month storage conditions, and information on governing regulations.

Data Management

ASCII text ".wresl" files contain scripting language variable definitions and goals statements. ASCII text ".table" files contain relational (lookup) input data. HEC-DSS (USACE 1995) files hold input time series data and store time series results.

Software

CalSim2 is developed in WRIMS (Water Resources Integrated Modeling System) – a generalized reservoir-river basin simulation modeling environment that allows for specification of user-defined system variables and associated constraints or goals. Solutions are determined by the XA Linear Programming/ Mixed Integer Linear Programming (LP/MILP) solver (Byer 2001) which is integrated with WRIMS as a dynamic linked library. WRIMS is produced and maintained by the California Department of Water Resources. The software platform is free, and links to the latest available versions can be acquired by contacting wrims2.group.developers@gmail.com. A hardware license (~ $1200) is required to use XA, and this solver is necessary to run CalSim2 models. Smaller models may be run using free public-domain LP solvers that are available with the WRIMS package. WRIMS runs under Microsoft Windows.

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