APPENDIX C

MODELING TOOLS AND RESULTS

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APPENDIX C
MODELING TOOLS AND RESULTS

C.1 INTRODUCTION

This appendix describes the analytical modeling tools and evaluation procedures that were used for this Preliminary Draft Environmental Assessment (PDEA) to characterize project-related effects on reservoir and river hydrology, as well as other selected modeling tools that are used to assess environmental impacts. Numerical modeling was used to evaluate Existing Conditions and estimate the likely effects that are expected to occur under Future No-Action Conditions, the Proposed Action, Alternative 2, and cumulative conditions. To provide a full range of comparisons, Future No-Action Conditions were evaluated with comparisons to both Existing Conditions and the Proposed Action and Alternative 2. The hydrologic results also served as important information for the evaluation of power production, flood management, water quality, fisheries, recreation, and economic effects.

C.2 SUMMARY OF MODELS USED FOR ANALYSES

The following operation, temperature, and sediment models were used in the environmental analysis of alternatives for the PDEA.

- **CALSIM II:** Modeled the State Water Project (SWP) and Central Valley Project (CVP) using a monthly time step. Allowed for assessment of water supply impacts and provides operational constraints for the other operations models.

- **Local Operations (HYDROPS^{TM}):** Modeled Oroville Facilities operations at an hourly time step with the goal of maximizing hydroelectric power production given input constraints.

- **Reservoir–River Temperature (WQRRS):** Modeled temperatures in the Oroville–Thermalito Complex and in the Feather River downstream of Lake Oroville to the confluence with the Sacramento River.

- **Flow-Stage (HEC-RAS):** Modeled channel geometry and flow resistance to develop flow-stage relationships along the Feather River from Lake Oroville downstream to the confluence with the Sacramento River.

- **FLUVIAL-12:** Modeled sediment movement in the Feather River. Used to provide input to the analysis of scour and erosion within the river.

C.3 MODEL INTEGRATION

The first three models identified above—the CALSIM II, Local Operations, and Reservoir–River Temperature models—made up the operations modeling system; that is, they were used to simulate how the Oroville Facilities are operated under varying conditions and assumptions. These models formed a single, integrated modeling system to perform the modeling of operations, hydroelectric power, and temperature required to produce results throughout the Oroville Facilities and the lower Feather River. The other models identified above were generally used to assess the effects of the resulting operations on specific resource areas, or to develop important data for input to other, impact assessment models.

For these models to pass data to each other, they had to be able to “talk” to each other. To ensure such communication, a unified, operations modeling database system was developed. The system allowed for translation of data from one operations model to another and translation of operations simulation data for input to the other modeling tools or for impact analysis. Implementation of the system required development of tools to translate the output from some models and prepare input to subsequent models. The system used a database to store operations modeling results and to serve as the conduit to pass data between the models.

As critical as it was for the operations models to share data (and subsequently to export operations modeling data to the impact models), it was also important to provide a feedback mechanism. This allowed results from lower level operations models to influence the assumptions made for higher level operations models; it also provided a means for feedback of information developed from the impact models to the suite of operations models. To enable feedback within the suite of operations models, the operations models were used in a series of steps, from higher level models to lower level models, as described below.

- **Statewide Operations Modeling:** Each scenario was first simulated using the CALSIM II model. The CALSIM II model is a long-term, large-scale, monthly time-step planning model of the SWP/CVP systems and their operations. The model incorporated operational decisions on the Oroville Facilities based on the SWP’s projectwide goals and provided information on potential statewide impacts for a given scenario. The results of these simulations provided the necessary constraints to lower level models for detailed simulation of proposed alternatives.

- **Local Operations Modeling:** CALSIM II simulations generate operational constraints for the Oroville Facilities based on statewide operational requirements. These constraints, along with other assumptions modified as required for the proposed alternative, were then used as input to the local operations model. The local operations model then operated the Oroville Facilities to optimize power production for each week within the operational constraints from the CALSIM modeling. The resulting simulation was evaluated and the assumptions were modified as required and the local operations simulation was repeated until the final results were acceptable.

  The CALSIM-based operational constraints noted above were treated as “soft” constraints; that is, the local operations model was allowed to deviate from them if necessary to achieve acceptable results. Furthermore, the local operations model might reveal instances when the assumptions used within, or operational decisions simulated by, the statewide modeling were not acceptable. In these cases, the process went back to Step 1 and repeated the statewide operations modeling with assumptions modified to reflect the new information from the local operations modeling.

- **Temperature Modeling:** Once the local operations modeling was completed, the temperature model was used to simulate the temperatures throughout the system using the operational data from the local operations simulation. The resulting simulations were then evaluated to determine whether they were acceptable and met the temperature goals throughout the system. If the simulated temperatures were not acceptable, there were several possible courses of action. Below is an example of a series of actions that could be tested to achieve an acceptable simulation of temperature operations:

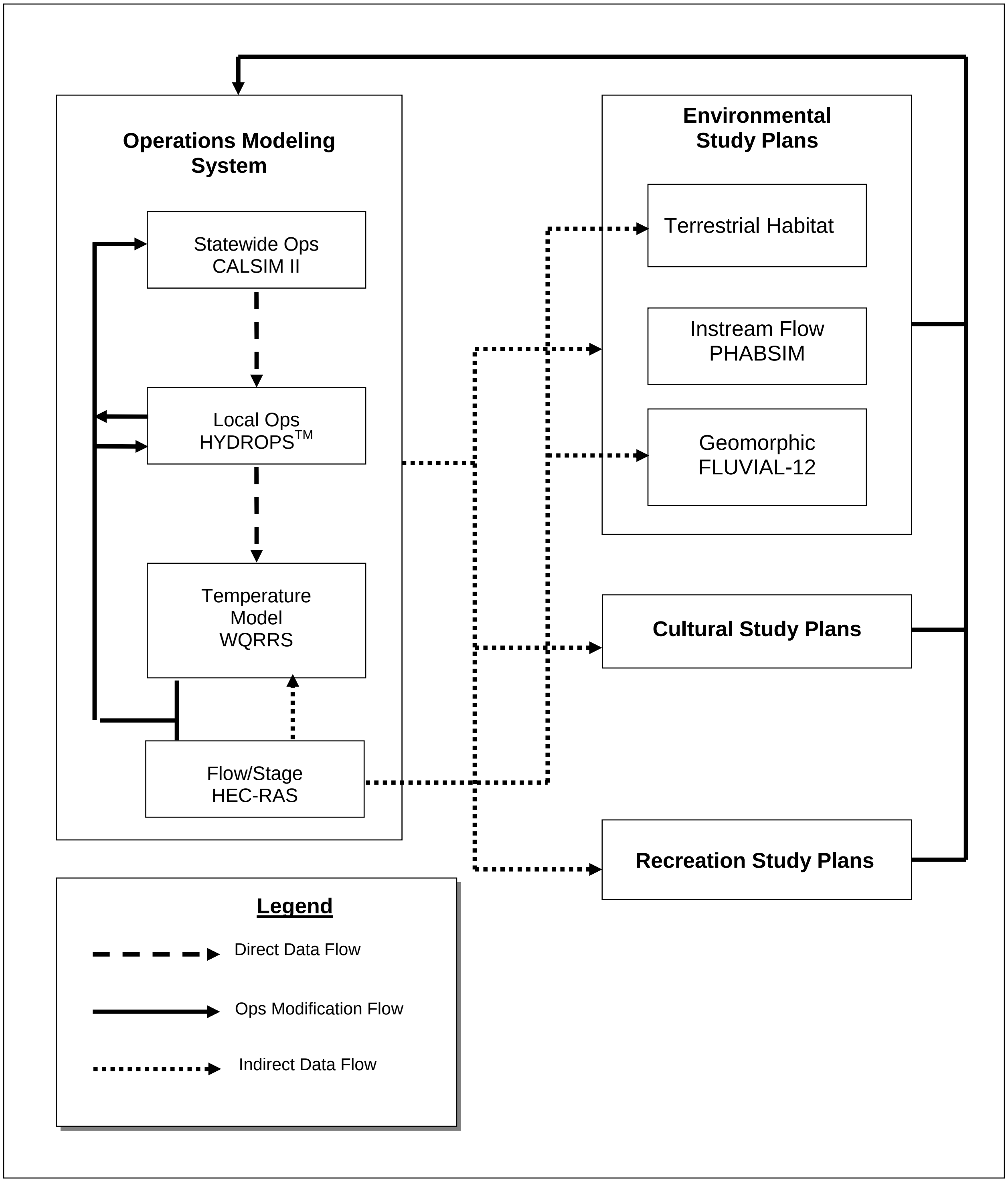
    - *Modify the outlet shutter operation at Lake Oroville.* The temperature of releases from Lake Oroville could be manipulated by changing the shutter configuration on the intake structure, with no other changes in operation allowed. In this case, only the temperature model would need to be re-run to perform the next simulation for evaluation.

    - *Modify the local power operations.* Heat gain can occur through pumpback, generation peaking, or Thermalito Complex operations. By changing power operations, and therefore the balance of water that flows through the Oroville Facilities and the Low Flow Channel of the Feather River, the temperatures in the Feather River could be manipulated. This type of evaluation would require that the local operations simulation be repeated with new assumptions, and that the temperature simulation be repeated with the new local operations results.

    - *Release water through the river valve.* During construction of Oroville Dam, a valve was used to allow water to bypass the Hyatt Pumping-Generating Plant. Because this valve is located at a very low elevation in Lake Oroville, it is possible to release very cold water from Lake Oroville for temperature control purposes. The valve was not designed for this level of use; therefore, limitations on its use for this purpose were included in the modeling.

Upon completion of the operations simulations, modeling data were processed and provided to other models as needed. Figure C.3-1 is a flow chart of the model interactions during the simulation and analysis process.

The core of model integration was a central modeling database that was used to store all data produced by the operations models and/or required to produce outputs for analyses or non-operations models. Time series data from the operations modeling were managed with the Data Storage System (DSS) developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC). This software was selected for several reasons:



Source: Developed by the Engineering and Operations Work Group

Figure C.3-1. Model interaction and data flow.

- It provides an efficient method for handling large volumes of time series data;
- It is in the public domain, and therefore is available for anyone to use;
- It provides a programming interface that allows for custom tool development if needed;
- It can interface with productivity tools such as Microsoft Excel through another publicly available software; and
- It is used to store the CALSIM II time series based input/output data.

The individual operations models do not read or write data directly to or from the central DSS database. Instead, a set of tools was developed that translated data between the DSS database and models. In addition to linking the central database to the models, the tools were able to:

- Perform any required data manipulation such as converting monthly reservoir inflow data to daily reservoir inflow data;
- Allow the review of specific model results interactively; and
- Produce customized outputs for additional analyses.

The final database and the tools developed to extract, analyze, and format outputs from the simulation were distributed when simulations for a scenario were completed and the modeling process was completed.

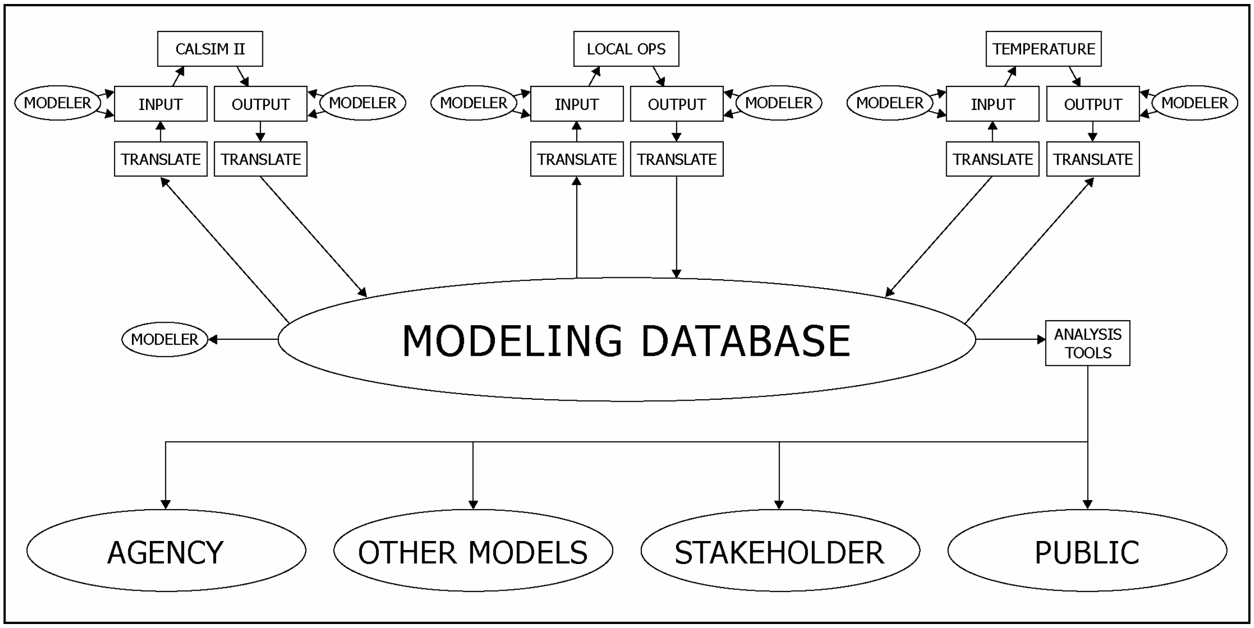
Figure C.3-2 shows data handling methods within the modeling system as well as the interactions with other modeling, analysis, or presentation processes.

C.4 STATEWIDE OPERATIONS MODEL—CALSIM II

C.4.1 Description

CALSIM II is a monthly time-step simulation model of the combined SWP and CVP systems and areas tributary to the Sacramento–San Joaquin Delta (Delta), including important nonproject facilities on the east side of the Central Valley. CALSIM II is designed to be used for SWP/CVP planning purposes. For a given simulation the model adopts a static depiction of land use, water management facilities, and their operational rules and constraints. The model sequentially applies this depiction to the hydrologic conditions encountered in California during the period of 1922–1994. In effect, the model attempts to simulate what the response of the system, as described in the simulation, would have been if it had been operated over the period of record.

The geographic coverage of CALSIM II includes the valley floor drainage area of the Sacramento and San Joaquin Rivers, the upper Trinity River, and the San Joaquin Valley, Tulare Basin, and Southern California areas served by the SWP. The focus of



Source: Developed by the Engineering and Operations Work Group

Figure C.3-2. Database dataflow schematic.

CALSIM II is on the major CVP and SWP facilities, but operations of many other facilities are included to varying degrees.

CALSIM II determines an optimal set of decisions for each time period given a set of weights and system constraints to route water through a network. The user can specify the physical system (dams, reservoirs, channels, pumping plants, etc.), operational rules (flood-control diagrams, minimum flows, delivery requirements, etc.), and priorities for allocating water.

Agricultural and urban target demands vary according to variations in precipitation (i.e., all SWP demands and CVP north-of-Delta demands) or are fixed at contract entitlement levels (i.e., CVP south-of-Delta demands). Elements of a depiction of the system can be adjusted from one simulation to the next in order to explore the implications of land use, infrastructure, and regulatory changes in the system.

Regardless of the system depiction adopted for a simulation, the model employs a specific set of priorities in making water allocations for the CVP and SWP. The model first meets environmental and in-basin requirements and then meets project contract and export delivery targets. Under the Coordinated Operating Agreement (COA) the SWP and CVP operate jointly to meet Delta water quality requirements and other water demands within the Sacramento River basin. These requirements are referred to as “in-basin” demands.

C.4.2 Usage

CALSIM II is most useful when it is used to compare the results of one simulation against another in a way that isolates the impact of specific elements of the system depiction. Model results provide information on expected reservoir storage, river flow, and water supply deliveries throughout the system as well as SWP and CVP exports from the Delta.

For the Oroville Facilities CALSIM II was used for two basic purposes:

- Provide input regarding the operation of the Oroville Facilities that would support detailed modeling and analysis of conditions in Lake Oroville, within the Thermalito Forebay/Thermalito Afterbay complex, and at an appropriate distance downstream in the Feather River.

- Allow identification and quantification of potential systemwide effects that could arise as a result of specific facility or operational changes associated with meeting relevant management objectives in Lake Oroville, within the Thermalito Forebay/Thermalito Afterbay complex, and at an appropriate distance downstream in the Feather River. This could include effects on SWP water supply and power generation, environmental requirements, or effects on CVP operations.

Because the model is capable of emulating systemwide operations of the SWP and CVP, it facilitated analysis of appropriate system-level measures that might be considered as part of a cumulative impact assessment.

C.4.3 Limitations

CALSIM II is a planning tool designed for analysis of the long-term effects of facility or operational changes in the system. It has limited usefulness in the analysis of effects during specific years resulting from short-term trends or operational changes. Because it uses a constant level of development, a single simulation cannot be used for direct analysis of changes over time. To account for the effect of land use changes on runoff and for the effects of storage regulation and stream diversions that are upstream of areas simulated in the model, CALSIM II modifies historical hydrology by using inflows to major reservoirs and developing local accretions and depletions. This is a complicated process that invokes multiple assumptions and requires many months to complete. As such, it is difficult to make changes to the underlying hydrology to evaluate the effect of these changes in a reasonable timeframe.

For the CALSIM II model to be used properly, the analyst using the model must have extensive knowledge of the CVP/SWP systems.

CALSIM II employs a monthly time step, which limits its ability to describe:

- Operational decisions or inputs at intervals shorter than a month, without implementing appropriate assumptions or simplifications;

- Event-specific flood control scenarios (only seasonal flood control criteria such as flood control reservoir reservation can be modeled); and

- Detailed hydroelectric power analysis related to total capacity or on- or off-peak power generation (only gross energy production potential can be evaluated).

The level of certainty with which CALSIM II model results can be used to assess impacts is limited by the precision of the model. In particular, CALSIM II makes adjustments at individual model nodes based on numerical criteria such as flow-stage calculations and other relational triggers. The certainty of model results is only as precise as the relationships that govern model decisions. CALSIM's dynamic responses to system conditions can create large changes in model results under relatively small initial changes in model inputs or operations. The large model responses generally average out over several months and thereby serve as appropriate data values for evaluating long-term model response and environmental impact assessment purposes.

C.4.4 Assumptions

CALSIM II is used to facilitate the analysis of a set of desired assumptions and the comparison of the effects of these assumptions to a benchmark. There are very few assumptions about the system in CALSIM II that are not under direct user control. For example, the user can produce a depiction of the system with virtually any type of facility or operational assumptions by adjusting the parameters, operational logic, and weights used by the model. However, it would be difficult and time consuming to change a relatively small set of processes in the system that use a complicated and extensive set of logic. For example, the decision process that sets the SWP delivery each year is a sequence of computations and procedures that follow a set logic. While changing the parameters used in the process is easy, changing the underlying logic itself is more difficult, although not impossible. Some examples of processes that rely upon logic internal to CALSIM II include:

- The delivery decision process;
- Operation of San Luis Reservoir; and
- Implementation of the Environmental Water Account (EWA) and Central Valley Project Improvement Act (CVPIA) Section 3406(b)(2).

Inputs that shape the assumptions of a particular simulation consist of special program code (called WRESL), data files for numeric inputs, and parameters for specific rules.

Some of the major CALSIM II assumptions used for the Oroville Facilities modeling scenarios are listed below:

- Delta standards set by State Water Resources Control Board (SWRCB) Water Right Decision 1641 (D-1641) with discretionary use of CVPIA Section 3406(b)(2) by the U.S. Fish and Wildlife Service (USFWS), and discretionary use of the EWA by fisheries agencies.
- San Joaquin River Agreement in support of the Vernalis Adaptive Management Program (VAMP).

- Meeting upstream Anadromous Fish Restoration Program (AFRP) flows (November 20, 1997, AFRP document) below Keswick, Whiskeytown, and Nimbus Dams.

- Restriction of CVP export during April 15–May 15 to the 2:1 export criteria (1995 delta smelt Biological Opinion), computed as 50 percent of the result of the maximum of VAMP flow – 50 percent Biological Opinion target flow or 1,500 cubic feet per second (cfs).

- Restriction of SWP export during April 15–May 15 to the 1:1 export criteria, computed as 50 percent of the result of the maximum of 100 percent of Vernalis base flow or 1,500 cfs.

- Meeting temperature control flows from the 1993 winter-run Chinook salmon Biological Opinion below Keswick in April through September. These flows are assumed to be in the range of 5,500–11,000 cfs for most years and reduced to 3,750–7,125 cfs in drier years.

- Full and unlimited joint point of diversion (SWP wheels for the CVP whenever unused capacity at Banks Pumping Plant is available).

- Stanislaus River operations in accordance with the U.S. Bureau of Reclamation's (USBR) New Melones Interim Operation Plan.

- 800 thousand acre-feet per year (taf/yr) (or 600 taf/yr in Shasta critical years) for Section 3406(b)(2) accounting in EWA or other environmental water actions.

The Existing Conditions and No-Action Conditions represent hydrologic conditions that would be expected without implementation of either the Proposed Action or Alternative 2. For the evaluation of Existing Conditions, the CVP/SWP system conditions are representative of those facilities that existed before adoption of the CALFED Bay-Delta Program (CALFED) Record of Decision (ROD). CALSIM II simulations for this project were performed with assumptions on hydrologic conditions that incorporate actions prescribed by CVPIA Section 3406(b)(2). This analysis does not consider potential operational changes of nonproject facilities within the Central Valley.

Several assumptions regarding regulatory standards and operations criteria used for the studies merit further detailed explanation below because some studies are ongoing or have yet to be fully resolved through court-ordered decision and/or settlement processes.

In December 2000, the ROD for the Trinity River Mainstem Fishery Restoration Environmental Impact Statement (EIS)/Environmental Impact Report (EIR) was signed. However, the EIS/EIR was challenged in Federal District Court and litigation is ongoing. The District Court has limited the flows available to the Trinity River until preparation of a supplemental environmental document is completed. Consequently, the Existing Conditions run was conducted to be consistent with the ongoing USBR Operations Criteria and Plan (OCAP) modeling, which includes variable flows (between 369 and

452 taf/yr depending on hydrologic conditions) up to the limit established by the court. The No-Action Conditions scenario uses the full Trinity ROD flows of 369–815 taf/yr depending on hydrologic conditions.

The joint powers Freeport Regional Water Authority (FRWA) comprises Sacramento County Water Agency (SCWA) and East Bay Municipal Utility District (EBMUD). FRWA recently released for public review the draft EIR/EIS for a new water supply project for a long-term supplemental water supply from the Sacramento River at Freeport. EBMUD's portion of the FRWA project represents new demands and deliveries under its CVP contract and was added into the studies modeling scenarios. SCWA's portions of the deliveries from the FRWA project are already included in Water Forum demands in the American River. EBMUD deliveries would range from 0 taf/yr to 112 taf/yr and would occur during years when overall EBMUD system storage and deliveries are projected to be less than target thresholds.

CALSIM II includes a hydrology developed jointly by the California Department of Water Resources (DWR) and USBR. Water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiency, return flows, nonrecoverable losses, and groundwater operation are components that make up the hydrology used in CALSIM II. Hydrology for the Sacramento Valley and tributary rim basins are developed using a process designed to adjust the historical sequence of monthly streamflows to represent a sequence of flows at a future level of development. Adjustments to historic water supplies are determined by imposing future land use levels on historical meteorological and hydrologic conditions. San Joaquin River basin hydrology is developed using fixed annual demands and regression analysis to develop accretions and depletions. The resulting hydrology is the water supply available from Central Valley streams to the CVP and SWP at a future level of development.

CALSIM II uses DWR's Artificial Neural Network (ANN) model to simulate the flow-salinity relationships for the Delta. The ANN model correlates DSM2 model–generated salinity at key locations in the Delta with Delta inflows, Delta exports, and Delta Cross Channel operations. The ANN flow-salinity model estimates electrical conductivity at the following four locations for the purpose of modeling Delta water quality standards: Old River at Rock Slough, the San Joaquin River at Jersey Point, the Sacramento River at Emmaton, and the 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.

The CALSIM II CVP and SWP delivery logic uses runoff forecast information, which incorporates uncertainty and standardized rule curves (i.e., Water Supply Index versus Demand Index Curve) to estimate the water available for delivery and carryover storage. Delivery levels are updated monthly from January 1 through May 1 for the SWP and March 1 through May 1 for the CVP as water supply parameters become more certain. The south-of-Delta SWP delivery is determined based upon water supply parameters and operational constraints. CVP systemwide delivery and south-of-Delta delivery are determined similarly based on water supply parameters and operational constraints, with specific consideration for export constraints.

CALSIM II incorporates procedures for dynamic modeling of CVPIA Section 3406(b)(2) water and the EWA, under the CALFED Framework and ROD. Per the October 1999 Decision and the subsequent February 2002 Decision, CVPIA Section 3406(b)(2) accounting procedures are based on system conditions under operations associated with the regulatory requirements of SWRCB D-1485 and D-1641. Similarly, the operating guidelines for selection of actions and allocation of assets under the EWA are based on system conditions under operations associated with SWRCB D-1641 regulatory requirements. Note that the EWA components are not incorporated into the analyses for relicensing of the Oroville Facilities. This requires sequential layering of multiple system requirements and simulations. CVPIA Section 3406(b)(2) allocates 800 taf (600 taf in Shasta critical years) of CVP project water to targeted fish actions. The full amount provides support for implementation of SWRCB D-1641. According to monthly accounting, Section 3406(b)(2) actions are selected dynamically according to an action matrix. Several actions in this matrix have defined reserve amounts that limit Section 3406(b)(2) expenditures for lower priority actions early in the year such that the higher priority actions can be met later in the year.

Feather River flow minimums and rates of changes are constrained in accordance with the 1967 agreement between DWR and the California Department of Fish and Game (DFG), *Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife*, amended by the 1983 FERC relicensing process. The 1983 agreement specifies that DWR release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fishery purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and Feather River Fish Hatchery pipeline. In CALSIM II, this minimum required flow is imposed at Node 200A in the Feather River. Table C.4-1 identifies the minimum flow requirement downstream of the Thermalito Afterbay Outlet. This information applies if the surface elevation of Lake Oroville is greater than 733 feet above mean sea level (msl). Normal runoff is defined as the mean (1911–1960) April–July unimpaired runoff: 1,942 taf.

Table C.4-1. Feather River minimum flow schedule.

Percent of Normal Runoff	Oct–Feb (cfs)	Mar (cfs)	Apr–Sep (cfs)
> 55	1,700	1,700	1,000
< 55	1,200	1,000	1,000

In addition, if the hourly flow is greater than 2,500 cfs between October 15 and November 30, then the flow minus 500 cfs must be maintained until the following March unless the high flow resulted from flood control operation or mechanical problems. This requirement is to protect any spawning that could occur in overbank areas during the higher flow rate by maintaining flow levels high enough to keep the overbank areas submerged. In practice, the flows are maintained below 2,500 cfs from October 15 to November 30 to prevent spawning in the overbank areas. In CALSIM II, this minimum required flow is pre-processed and input as time-series data imposed at Nodes 203 and 223 in the Feather River. CALSIM uses mixed integer programming to determine whether the 2,500 cfs limit is exceeded. The 1,500 taf Oroville storage criterion for determining this minimum flow is not modeled in CALSIM II.

Under contracts between DWR and each of the Feather River Service Area (FRSA) diverters, deliveries can be reduced, because of "drought," by no more than 50 percent in any 1 year, and by no more than 100 percent in any series of 7 consecutive years. In addition, reductions cannot exceed the percentages for the reduction in annual Table A amounts for water to be put to agricultural use by water supply contractors in the San Joaquin Valley. There are certain amounts of entitlement that are not subject to reduction: Joint Water District Board, 5 taf; Western Canal, 145 taf; Garden Highway, 5.13 taf; Plumas Mutual, 6 taf; Tudor Mutual, 210 acre-feet (af); and Oswald, 150 af. “Drought” criteria are defined in the contracts.

Total south-of-Delta SWP deliveries are determined based upon spring storage conditions at Lake Oroville and SWP San Luis and forecasted runoff available to the SWP. Based upon the annual delivery determined, the annual delivery is allocated as a percentage of contractual entitlement that is equal for all SWP contractors. A similar logic is used for North Bay Aqueduct contractor deliveries.

The CVP and SWP share the burden and benefits of compliance and excess flows as dictated in the 1986 Coordinated Operations Agreement (COA). Based upon the rules in the COA, specifically the definition of “Balanced Condition,” the project shares of responsibility for In-Basin-Use are 75 percent for the CVP, and 25 percent for the SWP when storage is being drawn. In-Basin-Use includes project storage withdrawals (including Trinity River imports into the Sacramento River) for maintaining Delta water quality requirements. Also, based upon the rules in the COA, the project shares of surplus flows are 55 percent for the CVP and 45 percent for the SWP. A project’s share of surplus flows includes project storage increase (after accounting for Trinity River imports into the Sacramento River) and Delta exports. The 1986 COA was negotiated in the context of SWRCB D-1485.

D-1485 required export reductions for striped bass, and through agreements CVP provided support for these export reductions. In turn SWP wheeled, at priority at a later time, replacement water for the CVP. This replacement pumping was accounted for as a CVP export. No other wheeling is accounted for under the COA.

CALSIM II uses a simplified accounting of the COA. CALSIM II operates to the COA, sharing formulas to the extent possible within each time step. Outstanding imbalances in this sharing are ignored. In actuality, CVP and SWP operators will similarly allow an imbalance to occur during periods of the year, but will track and frequently attempt to reconcile these imbalances throughout the year. Because of the need to account more closely for CVP and SWP actions that require and are based on project-specific accounting techniques, it is anticipated that “annual” COA accounting is required.

The 1986 COA does not specify project obligations for reducing export under D-1641 export restrictions. Under informal operating arrangements, USBR and DWR have shared the remaining allowable export capacity. A 50 percent–50 percent split of export capacity sharing is assumed.

CALSIM II provides a reasonable planning level simulation of existing project operations, recognizing that the operating environment and regulatory requirements for the projects are in a constant state of transition and change. CALSIM II is best used in a comparative mode. The results from an "alternative" simulation are compared to the results of a "base" simulation to determine the incremental effects of a project. The results from a single simulation may not necessarily represent the exact operations for a specific month or year, but should reflect long-term trends. The model developers advise caution when using CALSIM II to prescribe seasonal operations or to guide real-time operations, or predict flows or water deliveries for any real-time operations.

Table C.4-2 is a general summary and Tables C.4-3 and C.4-4 are more detailed summaries of CALSIM II assumptions for the Future No-Action, Proposed Action, and Alternative 2 conditions.

Table C.4-2. Summary of assumptions for CALSIM II studies.

	Existing Conditions	**Future No-Action, Proposed Action, and Alternative 2**
Period of Simulation	73 years (1922-1994)	Same
HYDROLOGY		
Level of Development (Land Use)	2001 level, DWR Bulletin 160-98 [1]	2020 level, DWR Bulletin 160-98
DEMANDS		
North of Delta (except American River)		
CVP	Land use based, limited by full contract	Same
SWP (FRSA)	Land use based, limited by full contract	Same
Nonproject	Land use based	Same
CVP Refuges	Firm level 2	Same
American River Basin		
Water rights	Fixed annual demands	Fixed annual demands as projected for 2020 by Water Forum analysis
CVP	Fixed annual demands	Fixed annual demands as projected for 2020 by Water Forum analysis, but modified with 35 taf CVP contract supply for the Placer County Water Agency (PCWA) diverted at the new PCWA American River pump station
San Joaquin River Basin		
Friant Unit	Regression of historical	Same
Lower Basin	Fixed annual demands	Same
Stanislaus River Basin	New Melones Interim Operations Plan	Same
South of Delta		
CVP	Full contract	Same
Contra Costa Water District	124,000 acre-feet per year (afy) [2]	158,000 afy [2]
SWP (w/North Bay Aqueduct)	3.0–4.1 maf/yr	3.3–4.1 maf/yr

Table C.4-2. Summary of assumptions for CALSIM II studies.

	Existing Conditions	Future No-Action, Proposed Action, and Alternative 2
SWP Article 21 Demand	Metropolitan Water District of Southern California (MWD) up to 50,000 month/month, Dec-Mar; others up to 84,000 month/month	Same
FACILITIES		
Freeport Regional Water Project	None	Included [3]
Banks Pumping Capacity	6,680 cfs	8,500 cfs
Tracy Pumping Capacity	4,200 cfs + deliveries upstream of Delta-Mendota Canal constriction	4,600 cfs w/ intertie
REGULATORY STANDARDS		
Trinity River		
Minimum Flow below Lewiston Dam	368,600–452,600 afy	Trinity EIS Preferred Alternative (368,600–815,000 afy)
Trinity Reservoir End-of-September Minimum Storage	Trinity export-to-inflow Preferred Alternative (600,000 af as able)	Same
Clear Creek		
Minimum Flow below Whiskeytown Dam	Downstream water rights, 1963 USBR proposal to USFWS and the National Park Service, and USFWS use of CVPIA Section 3406(b)(2) water	Same
Upper Sacramento River		
Shasta Lake End-of-September Minimum Storage	SWRCB 1993 Biological Opinion for winter-run Chinook salmon (1.9 million acre-feet [maf])	Same
Minimum Flow below Keswick Dam	Flows for SWRCB 1990 Order 90-5 and 1993 Biological Opinion on temperature control for winter-run Chinook salmon, and USFWS use of CVPIA Section 406(b)(2) water	Same
Feather River		
Minimum Flow below Thermalito Diversion Dam	1983 DWR/DFG agreement (600 cfs)	Same
Minimum Flow below Thermalito Afterbay Outlet	1983 DWR/DFG agreement (1,000–1,700 cfs)	Same
American River		
Minimum Flow below Nimbus Dam	SWRCB D-893 (see accompanying Operations Criteria), and USFWS use of CVPIA Section 3406(b)(2) water	Same
Minimum Flow at H Street Bridge	SWRCB D-893	Same
Lower Sacramento River		
Mokelumne River		
Minimum Flow below Camanche Dam	FERC 2916-029, 1996 (joint settlement agreement) (100–325 cfs)	Same

Table C.4-2. Summary of assumptions for CALSIM II studies.

	Existing Conditions	Future No-Action, Proposed Action, and Alternative 2
Minimum Flow below Woodbridge Diversion Dam	FERC 2916-029, 1996 (joint settlement agreement) (25–300 cfs)	Same
Stanislaus River		
Minimum Flow below Goodwin Dam	1987 USBR/DFG agreement, and USFWS use of CVPIA Section 406(b)(2) water	Same
Minimum Dissolved Oxygen	SWRCB D-1422	Same
Merced River		
Minimum Flow below Crocker-Huffman Diversion Dam	Davis-Grunsky (180–220 cfs, Nov–Mar), and Cowell Agreement	Same
Minimum Flow at Shaffer Bridge	FERC 2179 (25–100 cfs)	Same
Tuolumne River		
Minimum Flow at Lagrange Bridge	FERC 2299-024, 1995 (settlement agreement) (94,000–301,000 afy)	Same
San Joaquin River		
Maximum Salinity near Vernalis	SWRCB D-1641	Same
Minimum Flow near Vernalis	SWRCB D-1641, and Vernalis Adaptive Management Program per San Joaquin River Agreement	Same
Sacramento–San Joaquin River Delta		
Delta Outflow Index (Flow and Salinity)	SWRCB D-1641	Same
Delta Cross Channel Gate Operation	SWRCB D-1641	Same
Delta Exports	SWRCB D-1641, USFWS use of CVPIA Section 3406(b)(2) water	Same
OPERATIONS CRITERIA		
Subsystem		
Upper Sacramento River		
Flow Objective for Navigation (Wilkins Slough)	3,250–5,000 cfs based on Lake Shasta storage condition	Same
American River		
Folsom Dam Flood Control	Sacramento Area Flood Control Agency, Interim Reoperation of Folsom Dam, Variable 400/670 (without outlet modifications)	Same
Flow below Nimbus Dam	Operations criteria corresponding to SWRCB D-893 required minimum flow	Same
Sacramento Water Forum Mitigation Water	None	Sacramento Water Forum (up to 47,000 afy in Water Forum Agreement drier and driest years) [4]
Feather River		

Table C.4-2. Summary of assumptions for CALSIM II studies.

	Existing Conditions	Future No-Action, Proposed Action, and Alternative 2
Flow at Mouth	Maintain the DFG/DWR flow target above Verona or 2,800 cfs for April–September dependent on Oroville inflow and FRSA allocation	Same
Stanislaus River		
Flow below Goodwin Dam	1997 New Melones Interim Operations Plan	Same
San Joaquin River		
Flow near Vernalis	San Joaquin River Agreement in support of the Vernalis Adaptive Management Program	Same
Systemwide		
CVP Water Allocation		
CVP Settlement and Exchange	100% (75% in Shasta critical years)	Same
CVP Refuges	100% (75% in Shasta critical years)	Same
CVP Agriculture	100%–0% based on supply	Same
CVP Municipal & Industrial	100%–50% based on supply	Same
SWP Water Allocation		
North of Delta (FRSA)	Contract specific	Same
South of Delta	Based on supply; Monterey Agreement	Same
CVP/SWP Coordinated Operations		
Sharing of Responsibility for In-Basin-Use	1986 Coordinated Operations Agreement	Same
Sharing of Surplus Flows	1986 Coordinated Operations Agreement	Same
Sharing of Restricted Export Capacity	Equal sharing of export capacity under SWRCB D-1641; use of CVPIA Section 3406(b)(2) only restricts CVP exports; EWA use restricts CVP and/or SWP exports as directed by CALFED fisheries agencies	Same
Transfers		
Dry Year Program	None	Same
Phase 8	None	Same
MWD/CVP Settlement Contractors	None	Same
CVP/SWP Integration		
Dedicated Conveyance at Banks	None	SWP to convey 100,000 af of Level 2 refuge water each year at Banks Pumping Plant
Notice of Determination Accounting Adjustments	None	CVP to provide the SWP a maximum of 75,000 af of water to meet in-basin requirements through adjustments in COA accounting

Table C.4-2. Summary of assumptions for CALSIM II studies.

	Existing Conditions	Future No-Action, Proposed Action, and Alternative 2
CVPIA Section 3406(b)(2)	U.S. Department of the Interior 2003 decision	Same
Allocation	800,000 afy, 700,000 afy in 40-30-30 dry years, and 600,000 afy in 40-30-30 critical years	Same
Actions	1995 Water Quality Control Plan for the San Francisco Bay/San Joaquin Delta Estuary, fish flow objectives (Oct–Jan); VAMP (Apr 15–May 16) CVP export restriction; 3,000 cfs CVP export limit in May and June (D-1485 striped bass continuation); post-VAMP (May 16-31) CVP export restriction; ramping of CVP export (Jun); upstream Releases (Feb–Sep)	Same
Accounting Adjustments	Per May 2003 Interior decision, no limit on responsibility for D-1641 requirements, no reset with the storage metric and no offset with the release and export metrics.	Same
CALFED Environmental Water Account	None	None

Notes:

[1] *2000 level of development defined by linearly interpolated values from the 1995 level of development and 2020 level of development from DWR Bulletin 160-98.*

[2] *Delta diversions include operations of Los Vaqueros Reservoir and represent average annual diversion.*

[3] *Includes modified EBMUD operations of the Mokelumne River.*

[4] *This is implemented only in the PCWA Middle Fork Project releases used in defining the CALSIM II inflows to Folsom Lake.*

Table C.4-3. CALSIM II assumptions for Existing Conditions.

	ALLOCATION TYPE (MAXIMUM)									
Location/Purveyor	**CVP AG**	**CVP MI**	**CVP Settle-ment/ Exchg**	**Water Rights/ Non-CVP/ No Cuts**	**CVP Refuge**	**Total**	**FUI (Mar–Sep +60 taf)**			**Notes**
							> 1,600	**> 950**	**< 400**	
Auburn Dam Site (D300)										
PCWA	0	0	0	8,500	0	8,500	8,500	8,500	8,500	1, 2, 3, 12
Total, Auburn Dam Site	***0***	***0***	***0***	***8,500***	***0***	***8,500***	***8,500***	***8,500***	***8,500***	
Folsom Lake (D8)										
Sacramento Suburban	0	0	0	0	0	0	0	0	0	4, 5, 11
City of Folsom (includes Public Law [PL] 101-514)	0	0	0	20,000	0	20,000	20,000	20,000	20,000	1, 2, 3
Folsom Prison	0	0	0	2,000	0	2,000	2,000	2,000	2,000	
San Juan Water District (Placer County)	0	0	0	10,000	0	10,000	10,000	10,000	10,000	1, 2, 3, 11
San Juan Water District (Sacramento County) (includes PL 101-514)	0	11,200	0	33,000	0	44,200	44,200	44,200	44,200	1, 2, 3
El Dorado Irrigation District	0	7,550	0	0	0	7,550	5,000	5,000	5,000	1, 2, 3
El Dorado Irrigation District (PL 101-514)	0	0	0	0	0	0	0	0	0	1, 2, 3
City of Roseville	0	32,000	0	0	0	32,000	26,633	26,633	26,633	1, 2, 3, 11, 12
PCWA	0	0	0	0	0	0	0	0	0	11
Total, Folsom Lake	***0***	***50,750***	***0***	***65,000***	***0***	***115,750***	***107,833***	***107,833***	***107,833***	
Folsom South Canal (D9)										
Southern California WC/Arden Cordova WC	0	0	0	3,500	0	3,500	3,500	3,500	3,500	
California Department of Parks and Recreation	0	100	0	0	0	100	100	100	100	

Table C.4-3. CALSIM II assumptions for Existing Conditions.

	ALLOCATION TYPE (MAXIMUM)									
Location/Purveyor	**CVP AG**	**CVP MI**	**CVP Settle-ment/ Exchg**	**Water Rights/ Non-CVP/ No Cuts**	**CVP Refuge**	**Total**	**FUI (Mar–Sep +60 taf)**			**Notes**
							> 1,600	**> 950**	**< 400**	
Sacramento Municipal Utility District (SMUD) (export)	0	0	0	15,000	0	15,000	15,000	15,000	15,000	1, 2, 3
South Sacramento County Agriculture (export, SMUD transfer)	0	0	0	0	0	0	0	0	0	1, 2, 3
Canal Losses	0	0	0	1,000	0	1,000	1,000	1,000	1,000	
Total, Folsom South Canal	***0***	***100***	***0***	***19,500***	***0***	***19,600***	***19,600***	***19,600***	***19,600***	
Nimbus to Mouth (D302)										
City of Sacramento	0	0	0	63,335	0	63,335	63,335	63,335	63,335	6, 7, 8
Arcade Water District	0	0	0	2,000	0	2,000	2,000	2,000	2,000	13
Carmichael Water District	0	0	0	8,000	0	8,000	8,000	8,000	8,000	
Total, Nimbus to Mouth	0	0	0	73,335	0	73,335	73,335	73,335	73,335	
Sacramento River (D162)										
PCWA	0	0	0	0	0	0	0	0	0	
Total, Sacramento River (D162)	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	
Sacramento River (D167/D168)										
City of Sacramento	0	0	0	38,665	0	38,665	38,665	38,665	38,665	8
SCWA (SMUD transfer)	0	0	0	0	0	0	0	0	0	10
SCWA (PL 101-514)	0	15,000	0	0	0	15,000	7,200	7,200	7,200	10
EBMUD (export)	0	0	0	0	0	0	0	0	0	
Total, Sacramento River (D167/D168)	***0***	***15,000***	***0***	***38,665***	***0***	***53,665***	***45,865***	***45,865***	***45,865***	
TOTAL	**0**	**50,850**	**0**	**166,335**	**0**	**217,185**	**209,268**	**209,268**	**209,268**	

Table C.4-3. CALSIM II assumptions for Existing Conditions.

	ALLOCATION TYPE (MAXIMUM)									
Location/Purveyor	**CVP AG**	**CVP MI**	**CVP Settle-ment/ Exchg**	**Water Rights/ Non-CVP/ No Cuts**	**CVP Refuge**	**Total**	**FUI (Mar–Sep +60 taf)**			**Notes**
							> 1,600	**> 950**	**< 400**	

Notes:
AG = Agricultural; FUI = Folsom Unimpaired Index; MI = Municipal & Industrial; WC = Water Company
1. *Wet/average years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is greater than 950,000 af.*
2. *Drier years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is less than 950,000 af but greater than 400,000 af.*
3. *Driest years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is less than 400,000 af.*
4. *Wet/average years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is greater than 1,600,000 af.*
5. *Drier years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is less than 1,600,000 af.*
6. *Wet/average years as they apply to the City of Sacramento are time periods when flows bypassing the E. A. Fairbairn Water Treatment Plant diversion exceed the "Hodge flows."*
7. *Drier years are time periods when the flows bypassing the City's E.A. Fairbairn Water Treatment Plant diversion do not exceed the "Hodge flows."*
8. *For modeling purposes, it is assumed that the City of Sacramento's total annual diversions from the American and Sacramento Rivers in year 2030 would be 130,600 af.*
10. *The total demand for the SCWA would be up to 78,000 af. The 45,000 af represents firm entitlements; the additional 33,000 af of demand is expected to be met by intermittent surplus supply. The intermittent supply is subject to USBR reduction (50%) in dry years.*
11. *Water Rights water provided by releases from PCWA's Middle Fork Project; inputs into the upper American River model must be consistent with these assumptions.*
12. *Demand requires "replacement water" as indicated below.*
13. *Arcade Water District demand modeled as step function: one demand when FUI > 400, another demand when FUI < 400.*

Table C.4-4. CALSIM II assumptions for Future No-Action, Proposed Action, and Alternative 2.

	ALLOCATION TYPE (MAXIMUM)									
Location/Purveyor	**CVP AG**	**CVP MI**	**CVP Settle-ment/ Exchg.**	**Water Rights/ Non-CVP/ No Cuts**	**CVP Refuge**	**Total**	**FUI (Mar–Sep +60 taf)**			**Notes**
							> 1,600	**> 950**	**< 400**	
Auburn Dam Site (D300)										
PCWA	0	35,000	0	35,500	0	70,500	70,500	70,500	70,500	1, 2, 3, 12
Total, Auburn Dam Site	**0**	**35,000**	**0**	**35,500**	**0**	**70,500**	**70,500**	**70,500**	**70,500**	
Folsom Lake (D8)										
Sacramento Suburban	0	0	0	29,000	0	29,000	29,000	0	0	4, 5, 11
City of Folsom (includes PL 101-514)	0	7,000	0	27,000	0	34,000	34,000	34,000	20,000	1, 2, 3
Folsom Prison	0	0	0	5,000	0	5,000	5,000	5,000	5,000	
San Juan Water District (Placer County)	0	0	0	25,000	0	25,000	25,000	25,000	10,000	1, 2, 3, 11
San Juan Water District (Sacramento County) (includes PL 101-514)	0	24,200	0	33,000	0	57,200	57,200	57,200	44,200	1, 2, 3
El Dorado Irrigation District	0	7,550	0	17,000	0	24,550	24,550	24,550	22,550	1, 2, 3
El Dorado Irrigation District (PL 101-514)	0	7,500	0	0	0	7,500	7,500	7,500	0	1, 2, 3
City of Roseville	0	32,000	0	30,000	0	62,000	54,900	54,900	39,800	1, 2, 3, 11, 12
Placer County Water Agency	0	0	0	0	0	0	0	0	0	11
Total, Folsom Lake	0	78,250	0	166,000	0	244,250	237,150	208,150	141,550	
Folsom South Canal (D9)										
Southern California WC/Arden Cordova WC	0	0	0	5,000	0	5,000	5,000	5,000	5,000	

Table C.4-4. CALSIM II assumptions for Future No-Action, Proposed Action, and Alternative 2.

	ALLOCATION TYPE (MAXIMUM)									
Location/Purveyor	**CVP AG**	**CVP MI**	**CVP Settle-ment/ Exchg.**	**Water Rights/ Non-CVP/ No Cuts**	**CVP Refuge**	**Total**	**FUI (Mar–Sep +60 taf)**			**Notes**
							> 1,600	**> 950**	**< 400**	
California Department of Parks and Recreation	0	5,000	0	0	0	5,000	5,000	5,000	5,000	
SMUD (export)	0	15,000	0	15,000	0	30,000	30,000	30,000	15,000	1, 2, 3
South Sacramento County Agriculture (export, SMUD transfer)	0	0	0	0	0	0	0	0	0	1, 2, 3
Canal Losses	0	0	0	1,000	0	1,000	1,000	1,000	1,000	
Total, Folsom South Canal	***0***	***20,000***	***0***	***21,000***	***0***	***41,000***	***41,000***	***41,000***	***26,000***	
Nimbus to Mouth (D302)										
City of Sacramento	0	0	0	96,300	0	96,300	96,300	96,300	50,000	6, 7, 8
Arcade Water District	0	0	0	11,200	0	11,200	11,200	11,200	3,500	13
Carmichael Water District	0	0	0	12,000	0	12,000	12,000	12,000	12,000	
Total, Nimbus to Mouth	0	0	0	119,500	0	119,500	119,500	119,500	65,500	
Sacramento River (D162)										
Placer County Water Agency	0	0	0	0	0	0	0	0	0	
Total, Sacramento River (D162)	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	
Sacramento River (D167/D168)										
City of Sacramento	0	0	0	34,300	0	34,300	34,300	34,300	80,600	8
Sacramento County Water Agency (SMUD transfer)	0	30,000	0	0	0	30,000	30,000	30,000	30,000	10
Sacramento County Water Agency (PL 101-514)	0	15,000	0	0	0	15,000	15,000	15,000	15,000	10

Table C.4-4. CALSIM II assumptions for Future No-Action, Proposed Action, and Alternative 2.

	ALLOCATION TYPE (MAXIMUM)									
Location/Purveyor	CVP AG	CVP MI	CVP Settle-ment/ Exchg.	Water Rights/ Non-CVP/ No Cuts	CVP Refuge	Total	FUI (Mar–Sep +60 taf)			Notes
							> 1,600	> 950	< 400	
Sacramento County Water Agency—assumed appropriated water	0	0	0	28,900	0	28,900				
EBMUD (export)	0	133,000	0	0	0	133,000				
Total, Sacramento River (D167/D168)	***0***	***178,000***	***0***	***63,200***	***0***	***241,200***	***79,300***	***79,300***	***125,600***	
TOTAL	**0**	**133,250**	**0**	**342,000**	**0**	**475,250**	**468,150**	**439,150**	**303,550**	

Notes:
AG = Agricultural; FUI = Folsom Unimpaired Index; MI = Municipal & Industrial; WC = Water Company
1. Wet average years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is greater than 950,000 af.
2. Drier years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is less than 950,000 af but greater than 400,000 af.
3. Driest years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is less than 400,000 af.
4. Wet/average years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is greater than 1,600,000 af.
5. Drier years for this diverter are defined as those years when the projected March-through-November unimpaired inflow to Folsom Lake is less than 1.60 maf.
6. Wet average years as they apply to the City of Sacramento are time periods when the flows bypassing the E. A. Fairbairn Water Treatment Plant diversion exceed the "Hodge flows."
7. Drier years are time periods when the flows bypassing the City's E.A. Fairbairn Water Treatment Plant diversion do not exceed the "Hodge flows."
8. For modeling purposes, it is assumed that the City of Sacramento's total annual diversions from the American and Sacramento River in year 2030 would be 130,600 af.
10. The total demand for SCWA would be up to 78,000 af. The 45,000 af represents firm entitlements; the additional 33,000 af of demand is expected to be met by intermittent surplus supply. The intermittent supply is subject to USBR reduction (50%) in dry years.
11. Water Rights water provided by releases from PCWA's Middle Fork Project; inputs into upper American River model must be consistent with these assumptions.
12. Demand requires "replacement water" as indicated below.
13. Arcade Water District demand modeled as step function: one demand when FUI > 400, another demand when FUI < 400.

C.4.5 Disaggregation of CALSIM II Output for HYDROPS™

The need for data disaggregation derived from the differences in temporal resolution between CALSIM II and HYDROPS™.

CALSIM II simulates the operations of the SWP and CVP on a monthly time step over a synthetic 73-year hydrology based on water years 1922 through 1994. Because of its coarse temporal resolution, CALSIM II does not include flow ramping and stability criteria that are important considerations in daily operations. HYDROPS™, by contrast, simulates weekly local operations of the Oroville Facilities, including power generation, on an hourly basis using the monthly water supply conditions from CALSIM II as the boundary conditions. Because of its refined temporal resolution, HYDROPS™ directly incorporates flow ramping and stability criteria as operational constraints. Therefore, there could have been a discrepancy between the monthly water budget simulated by CALSIM II and the weekly water budget required for HYDROPS™.

The potential discrepancy is illustrated in Figure C.4-1, which shows a comparison of Feather River flows below the Thermalito Afterbay Outlet in the period of June–October 1949. The CALSIM II–simulated monthly flow has a significant reduction between August and September; the reduction during the week of August 29–September 5, 1949, exceeds the allowable ramping criterion (up to 1,400 cfs per week; for more details, see discussion later in this appendix). When possible, DWR prefers a smoother change in flow throughout the year to reduce potential adverse effects on fishery and other natural resources. Therefore, adjusting the flow for the week of August 29–September 5, 1949, for the ramping criterion would require accompanying adjustments in other periods to preserve water budgets on a long-term basis.

Flow in the Feather River below the Thermalito Afterbay Outlet is a key parameter for data disaggregation. This parameter is one of the common elements in CALSIM II and HYDROPS™ and is controlled largely by downstream water supply and regulatory needs; that is, it is mostly insulated from local operations for power generation, the Feather River Fish Hatchery, and agricultural diversions within the Thermalito Complex.

Because the water budget between the simulated operations of CALSIM II and HYDROPS™ on a weekly basis is not preserved, the data disaggregation process was based on water budget preservation for a longer period (more than 1 month; likely 2–3 months).

In addition, the data disaggregation incorporated additional operational criteria such as flow ramping and stabilization criteria, and DWR's preference in controlling flow fluctuations if possible.

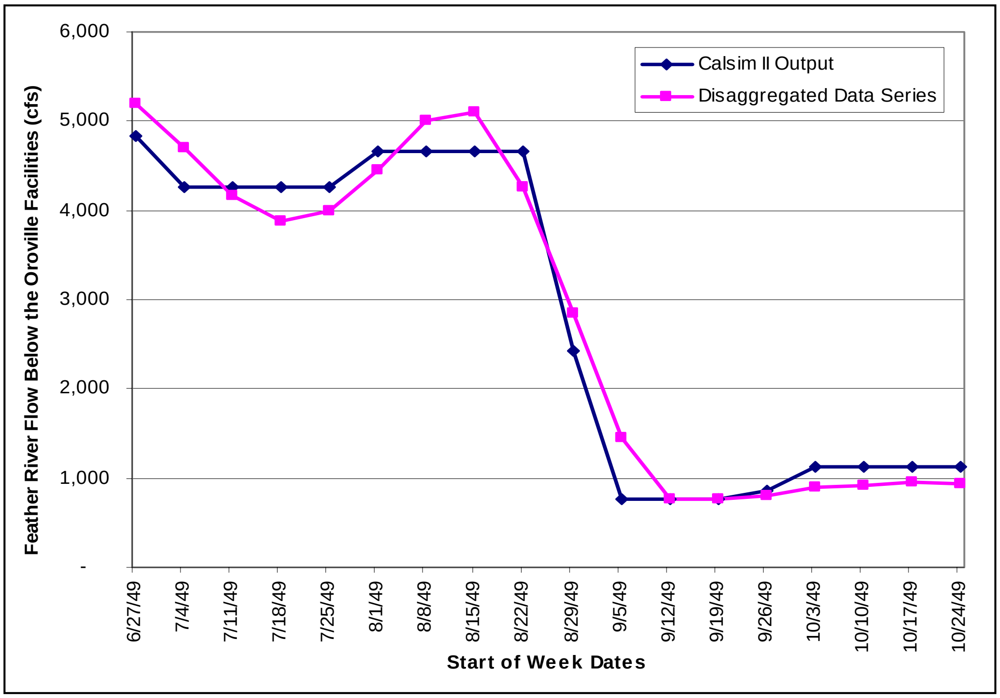


Figure C.4-1. Comparison of simulated weekly Feather River flows below the Thermalito Afterbay Outlet before and after the data disaggregation process.

The data disaggregation process can be detailed in four major steps, described below.

C.4.5.1 Step 1. Curve-Fitting the CALSIM II Data

As shown in Figure C.4-1, the weekly flows derived directly from CALSIM II results are jagged; therefore, the first step in disaggregation was to smoothen the CALSIM II data with a curve-fitting routine. Although other methods for generating a relatively smooth operation from CALSIM II data were evaluated, curve-fitting proved the most useful because it yields results that are easily implemented. Highly accurate results were not yet necessary because this step only jump-starts the process, which includes additional corrections for refining the flow schedule.

The following equation was used for curve-fitting by Microsoft Excel's built-in tool for regression analysis:

$$Y = A + Bx + Cx2 + Dx3 + Ex4 + Fx5 + Gx6 + Hx7$$

Y is the weekly flow derived from CALSIM II results, *x* is the plotting position for a series of Y values, and *A* through *H* are regression parameters.

The minimum number of data points analyzed using this curve-fitting process matches the number of parameters. The maximum number of periods analyzed in a single regression depends on the variation of the data and the similarity in simulated operations throughout the period. The actual length of the period used in a single curve-fitting process was from trial and error. Typically the periods were about 18 weeks.

The fitness of the resulting curve for weekly flows from the CALSIM II results was reviewed visually. If there were significant violations of minimum flow requirements, or the regression curve missed or exaggerated inflections in weekly flows from the CALSIM II results, adjustments were made to the number of periods analyzed and to the number of variables used, and the regression analysis was revised accordingly. Continuity was preserved by overlapping in data points between fitted curves. Long-term mass balance of the flow was generally preserved, but reinforced in the following steps.

C.4.5.2 Step 2. Correcting the Smoothed Curve for Operational Rules

The applicable operational rules include regulatory requirements and physical limitations. The regulatory requirements include minimum instream flow requirements, flow stability criteria, and flow ramping criteria; the physical limitations include the maximum and minimum storage capacity of Lake Oroville. The following describes these corrections.

Correction for Minimum Flow Requirements

This correction was to adjust the curve-fitted flows for minimum flow requirements, which were simulated in CALSIM II. The curve-fitted flows were compared against the minimum flow requirements, and the greater of these two was used.

Correction for Flow Stability Through the Fall Season

If Feather River flows rise above 2,500 cfs between October 15 and November 30, the flows must be maintained through the spring. This flow stability criterion is designed to protect the spawning habitat on the Feather River. Typically, operators maintain flow below 2,500 cfs in this period, except for flood control. Thus, the disaggregated flows were limited to a maximum of 2,500 cfs during this period unless the storage of Lake Oroville exceeds 2,760 taf.

Correction for Ramping Criteria

The ramping criteria for changing the flows on the Feather River are flow-rate dependent. These ramping criteria are to protect fishery habitat from rapid dewatering and to protect the river channel from erosion and scour resulting from high flow fluctuation.

Table C.4-5. Feather River ramping criteria for reducing flow (cfs).

Feather River Flow below Thermalito Afterbay Outlet	Maximum Weekly Reduction
Less than 2,500	1,400
From 2,500 to 3,500	3,500
From 3,500 to 6,500	7,000
Greater than 6,500	14,000

Note: For increasing the flows, the hourly limit is 5,000 cfs regardless of flow rate in the previous hour. However, this ramping criterion is not applicable if the storage of Lake Oroville is above 2,780 taf, i.e., flooding conditions.

Correction for Physical Constraint: Maximum Reservoir Storage

The resulting reservoir storage was computed using the modified releases and was compared to the maximum reservoir storage level. If the flows had been decreased to the point that the resulting storage of Lake Oroville was greater than its gross storage, an appropriate increase in release was made to keep the reservoir storage within the physical maximum.

Correction for Physical Constraint: Minimum Reservoir Storage

Similar to the correction for maximum reservoir storage described above, a physical minimum storage was used to ensure that releases did not draw the reservoir below its dead pool.

C.4.5.3 Step 3. Correction for Long-term Volumetric Consistency

Throughout the operational rule implementation process described in Section C.4.5.2, the reservoir accumulated a volumetric difference when compared to the original CALSIM II–derived storage. Incremental corrections for this difference were added back in subsequent periods. The goal of the disaggregation was to have a correct mass balance over the course of a month, but because of limitations in flow changes with the previously mentioned operational rules, this was not necessarily possible. The volumetric difference was accumulated until the time when the rules allow for it to be balanced.

C.4.5.4 Step 4. Review by SWP Operations Staff

The entire disaggregation process and the resulting disaggregation flows were reviewed and approved by the SWP Operations staff for use by HYDROPS™.

C.4.6 Inputs

CALSIM II inputs fell into several major categories:

- *Natural system:* Rivers and connectivity;
- *Facilities:* Reservoirs, canals, and pumps;

- *Hydrology:* Inflows, in-basin accretions and depletions, and evaporation;
- *Operation rules:* Reservoir rule curves, exports, delivery allocation logic, COA, contractual requirements, and priorities (weights); and
- *Regulatory requirements:* Minimum flows, water quality, export limits, operational limits, and flood control limits.

C.4.7 Outputs

CALSIM II outputs fell into the following major categories:

- Reservoir operations;
- Flows throughout the system; and
- Deliveries.

C.4.8 Appraisal

CALSIM II cannot be calibrated in the traditional sense of the term because the model does not mimic any real-time data. The conditions in the model are not historic; the modeling conditions represented a planning level analysis with varied precipitation. The model underwent a rigorous review process with CVP/SWP operations and modeling experts from DWR, USBR, and consultants. This process resulted in a version of the model and simulations that are acceptable to both USBR and DWR for use in the Oroville Facilities relicensing process.

C.5 LOCAL OPERATIONS MODEL—HYDROPS™

C.5.1 Description

HYDROPS™ was developed by Powel Technology, Inc., formerly Charles Howard and Associates, Inc. HYDROPS™ has been used by power utilities in the United States and Canada for operation, planning, and relicensing purposes.

HYDROPS™ has both long-term and short-term study models. The long-term model has a 1-year time horizon with weekly time steps, and the short-term model runs for 1 week at hourly time steps. For simulating detailed, short, time-step operations of the Oroville Facilities, only the short-term model (hourly optimization with a 1-week time horizon) was needed.

For the Oroville Facilities, HYDROPS™ was set up to run continuously for an entire 73-year period. Operational boundary conditions within each week were provided with disaggregated monthly results from the CALSIM II model. These boundary conditions were the weekly starting and ending levels at Lake Oroville, and the weekly average flow at the Feather River node right below Thermalito Afterbay.

Given the boundary conditions set by CALSIM II as targets, the HYDROPS™ model optimized hourly operations of the Oroville-Thermalito Complex while meeting all facilities constraints and operational requirements.

Hourly outputs from HYDROPS™ (including flow, generation, and reservoir levels) were used by the WQRRS model to simulate the temperature at various locations within, and downstream of, the Oroville Facilities. The temperature control actions, which included various operational measures on spill, generation, and pumpback, were applied to meet temperature criteria, and these operational changes were then fed back to HYDROPS™ for reoptimization.

The Oroville HYDROPS™ model included all details of this hydroelectric power complex, from engineering data of the facilities to the operational constraints.

Figure C.5-1 illustrates how the Oroville-Thermalito Complex was modeled in Oroville HYDROPS™. The gray triangles represent reservoirs, the green squares are power plants, and the blue circles are river nodes.

The relationship between reservoir storage and level is described as the stage-storage curve. It could be an equation or a table of storage values versus level values. This relationship was stored in the database and used by the HYDROPS™ model to keep track of the amount of water coming in and going out of the reservoirs at any time step. Storage volume and level were updated every hour and head was calculated accordingly for the power equation.

A spillway is the main component of a dam. The spillway crest elevation and spillway rating curve information were used to calculate the amount of spill.

The generating and hydraulic capacities of a plant were used to set upper bounds for plant generation and discharge, respectively. The tailwater of each plant—a function of plant discharge—was used to calculate head for the power equation.

Each turbine/pump unit has efficiency that varies with the head and unit output. These units may also have a rough zone, at which the operation is not desirable for various reasons (vibration, noise, cavitation, etc.).

The Thermalito Power Canal was modeled in HYDROPS™ to connect the Diversion Pool with Thermalito Forebay. Water in the Thermalito Power Canal flows in either direction, depending on whether the plants are generating or pumping.

Three river nodes were included in the Oroville HYDROPS™ model: the Feather River Fish Hatchery, the Low Flow Channel, and the Feather River below Thermalito Afterbay. Constraints on minimum and maximum flow could be set at these nodes.

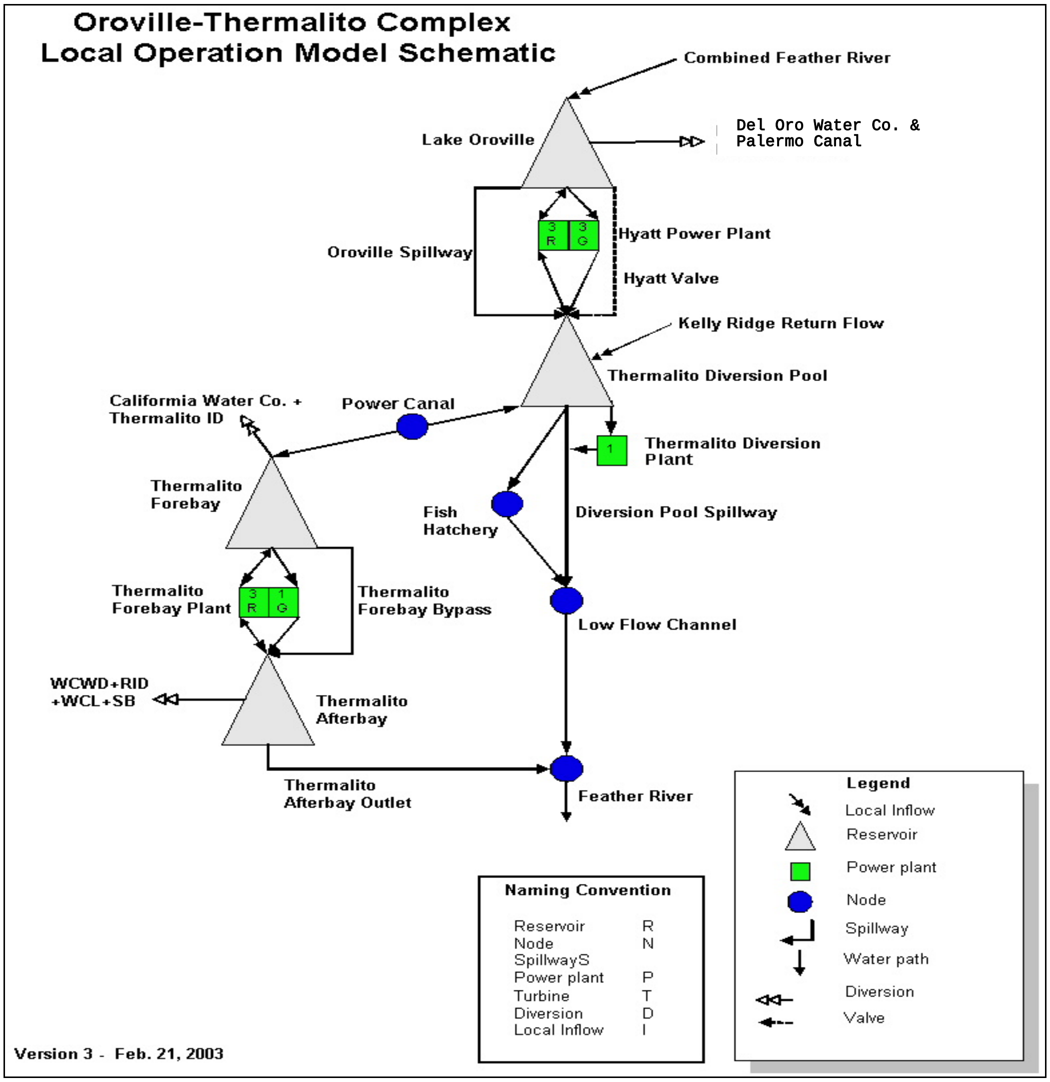


Figure C.5-1. Schematic for Oroville HYDROPS™ model.

C.5.2 Usage

HYDROPS™ was used to simulate hourly operations of the Oroville Facilities using a weekly modeling horizon. The weekly timeframe was used because power production optimization is completed over the same period.

Operational boundary conditions were provided from the CALSIM II statewide operations modeling; these boundary conditions were imposed as targets on the local operations model. HYDROPS™ then optimized the Oroville Facilities' hydroelectric power operations while striving to meet the many operational targets imposed on such operations. In addition to the boundary targets provided by CALSIM II, the model considered localized facility constraints and targets, as well as operation requirements that could not be captured accurately in the monthly time-step model.

Model output was used to provide information on the Oroville Facilities' hydroelectric power operations within the other operational limit assumptions, and within the seasonal water supply operation boundaries from the statewide modeling. Potential changes in the operational policy, requirements, or facilities and any associated impacts could then be evaluated based on the modeling results. The optimization function of the selected local operations model is essential to adequately model the hydroelectric power operations.

Like CALSIM II, HYDROPS™ was used as a planning model; that is, each scenario simulated was compared to a base condition for subsequent analyses. It was not used for flood control or real-time operation decisions based on hourly flow predictions for the entire period of record. The model could be used to route specific flood events through the Oroville Facilities if desired.

C.5.3 Limitations

The local operations modeling was based on the results of the CALSIM II simulations; therefore, the results are subject to the accuracy of those simulations. The reasonableness of the local operations modeling was continually evaluated during the simulation process.

The local operations model used a synthetic hydrologic flow sequence that contains the same volume of flows as CALSIM II on a monthly basis. The monthly hydrology used from the CALSIM II modeling was disaggregated into weekly or daily data using a process designed to preserve the monthly volumes while accounting for shorter term ramping restrictions not included in the monthly CALSIM II modeling. The resulting hydrology does not reproduce historical flood events.

The Oroville HYDROPS™ model had two types of constraints: hard constraints that could not be violated (i.e., physical limits and strict operating constraints), and soft constraints with associated penalty coefficients that could be traded off with other objective function coefficients (i.e., constraints that could be violated depending on the value of the penalty coefficients relative to other coefficients in the objective function).

C.5.3.1 Minimum/Maximum Constraints

The desirable range of operations could be set by defining minimum/maximum constraints on reservoir levels, flows at various locations, plant generation and discharge, and spill.

C.5.3.2 Conditional Constraints

Conditional constraints under HYDROPS™ were as follows:

- *Ramping constraints:* The rate of change (level or flow) was conditioned upon flow at the Feather River node.

- *Flow constraints:* Minimum/maximum flows at the Feather River node were conditioned upon Lake Oroville inflow.

C.5.3.3 Special Constraints

Special constraints under HYDROPS™ are described below.

Hyatt Valve Operation

The valve at the Hyatt Pumping-Generating Plant operates only when insufficient head exists for the plant or as specified as a temperature control action. The valve capacity is a function of head and is described in a rating table.

Hyatt Plant Shutdown

Different turbine and pump units at the Hyatt Pumping-Generating Plant are shut down when the level of Lake Oroville drops to various thresholds.

Thermalito Power Canal Flow

Water in the Thermalito Power Canal can flow in either direction, depending on whether the plants are generating or pumping. To ensure that the water flowing in the Thermalito Power Canal is hydraulically correct without making the models complicated, a special constraint was used to set water levels at the Diversion Pool the same as those at Thermalito Forebay at all times.

C.5.4 Assumptions

HYDROPS™ was used to simulate the Oroville Facilities and the Feather River to a point just downstream of the Thermalito Afterbay Outlet. Figure C.5-1 is a schematic of the Oroville Facilities features that were modeled.

C.5.5 Inputs

HYDROPS™ inputs fell into several major categories:

- *Natural system:* Rivers and connectivity;
- *Facilities:* Reservoirs, canals, pumps, and generators;
- *Hydrology:* Inflows, evaporation, and diversions;
- *Operation rules:* Reservoir rule curves, contractual requirements, and priorities (weights); and
- *Regulatory requirements:* Instream minimum flows, instream water quality requirements (these must be estimated as flow constraints for simulation in the local operations model process), operational limits, and flood control limits.

Monthly results from the CALSIM II model were disaggregated to weekly values, which became inputs to HYDROPS™. These weekly values included:

- Inflow to Lake Oroville;
- Inflow at Kelly Ridge;
- Lake Oroville evaporation;
- Thermalito Forebay and Afterbay evaporation;
- Palermo Canal diversion;
- Butte County diversion;
- Thermalito Irrigation District diversion;
- Western Canal diversion;
- Joint Canal diversion;
- Feather River flow below the Oroville-Thermalito Complex;
- Lake Oroville release;
- Feather River Fish Hatchery diversion;
- Lake Oroville end-of-week storage; and
- Lake Oroville flood control limit.

The inflows, evaporation, and diversions were used by HYDROPS™ as basic inputs. Lake Oroville levels and Feather River flow were used as weekly targets. The Lake Oroville flood control limit became a soft constraint for the maximum level at Lake Oroville.

Other inputs, described below, included energy price, pumpback trigger price, and maintenance schedule.

C.5.5.1 Energy Price

Hourly energy price indices from the California Energy Commission were used as the likely projection for future energy prices. These hourly prices were used by HYDROPS™ in the optimization to maximize expected power revenues.

C.5.5.2 Pumpback Trigger Price

DWR's pumpback procedures were based mainly on the pumpback trigger price, which includes 15 percent markup and $2 per megawatt (MW) startup cost. These procedures were incorporated into a simple multiplier factor that was applied to the energy price for pumpback decision.

C.5.5.3 Maintenance Schedule

The user may specify when the units are out of service.

C.5.6 Outputs

HYDROPS™ outputs fell into the following major categories:

- Storage in Lake Oroville, Thermalito Forebay, and Thermalito Afterbay;
- Flows throughout the system;
- Diversions;
- Power generation; and
- Pumpback power requirements.

C.5.7 Appraisal

While the simulations produced by the local operations model could be verified using recent historical data, the simulations depended on the CALSIM II model to provide operational boundaries. As such, the results of the simulations are subject to the same limitations as the results of the CALSIM II models.

When used in a comparative mode as envisioned in this process, this model provides results compatible with the needs of the relicensing process.

In addition to the engineering data and CALSIM II inputs mentioned above, operating constraints for the modeling scenarios are described as shown in Tables C.5-1 through C.5-9 below.

Table C.5-1. Starting levels.

Location	Long-Term Average Level (ft)
Lake Oroville	From CALSIM II
Diversion Pool	223.31
Thermalito Forebay	223.31
Thermalito Afterbay	128.40

Table C.5-2. Ending target levels.

Location	End-of-Week Target Level (ft)
Lake Oroville	From CALSIM II
Diversion Pool	223.31
Thermalito Forebay	223.31
Thermalito Afterbay	128.40

Table C.5-3. Level constraints.

Location	Hard Minimum (ft)	Soft Minimum (ft)	Soft Maximum (ft)	Hard Maximum (ft)
Lake Oroville	340	N/A	From CALSIM II	901
Diversion Pool	180	222	224	225
Thermalito Forebay	180	222	224	225
Thermalito Afterbay	124	N/A	N/A	136.26

Table C.5-4. Flow constraints.

Location	Hard Minimum (cfs)	Soft Minimum (cfs)	Soft Maximum (cfs)	Hard Maximum (cfs)
Hyatt Pumping-Generating Plant Valve	0	N/A	N/A	5,000
Feather River Fish Hatchery	100	N/A	N/A	100
Low Flow Channel	600	N/A	N/A	180,000
Feather River	700	*	*	180,000
Thermalito Power Canal	0	N/A	N/A	17,000

**The soft minimum/maximum flow constraints at the Feather River node were calculated based on the weekly flow values from CALSIM II. These constraints ensure constant flow as much as possible at this location.*

Table C.5-5. Generation constraints.

Plants	Hard Minimum (MW)	Soft Minimum (MW)	Soft Maximum (MW)	Hard Maximum (MW)
Hyatt Pumping-Generating Plant	0	N/A	N/A	819
Thermalito Diversion Dam Power Plant	0	N/A	N/A	3
Thermalito Pumping-Generating Plant	0	N/A	N/A	121

Table C.5-6. Generating flow constraints.

Plants	Hard Minimum (cfs)	Soft Minimum (cfs)	Soft Maximum (cfs)	Hard Maximum (cfs)
Hyatt Pumping-Generating Plant	0	N/A	N/A	17,715
Thermalito Diversion Dam Power Plant	0	N/A	N/A	615
Thermalito Pumping-Generating Plant	0	N/A	N/A	17,800

Table C.5-7. Pumpback flow constraints.

Plants	Hard Minimum (cfs)	Soft Minimum (cfs)	Soft Maximum (cfs)	Hard Maximum (cfs)
Hyatt Pumping-Generating Plant	0	N/A	N/A	5,000
Thermalito Pumping-Generating Plant	0	N/A	N/A	7,000

Table C.5-8. Spill constraints.

Location	Hard Minimum (cfs)	Soft Minimum (cfs)	Soft Maximum (cfs)	Hard Maximum (cfs)
Lake Oroville	0	N/A	100,000	720,000
Diversion Pool	0	N/A	100,000	646,000
Thermalito Forebay	0	N/A	50,000	10,000
Thermalito Afterbay	0	N/A	N/A	17,000

Table C.5-9. Conditional ramping constraints for the Feather River node and flow levels at which they apply.

Ramping Rate (cfs/day)	Applicable Flow Level (cfs)
-200	0–2,500
-500	2,500–3,500
-1,000	3,500–6,500
-2,000	> 6,500
+5,000	> 0

C.5.7.1 Pumpback Trigger Price

The pumpback trigger price was set at 1.21 for the modeling runs. The product of this factor and the hourly energy price became the cost of pumping.

C.5.7.2 Maintenance Schedule

There was no maintenance schedule specified for the modeling scenarios.

C.5.8 Disaggregation of HYDROPS^{TM} and CALSIM for WQRRS

The WQRRS flow and temperature model of the Feather River received input data from CALSIM II and HYDROPS^{TM}. CALSIM II provided monthly values for Feather River, Yuba River, and Bear River flows and depicted accretions and depletions to the Feather River as a single node. HYDROPS^{TM} provided daily flow releases from Thermalito Afterbay and the Thermalito Diversion Dam (headwater inflows). These flows needed to be reconciled or adjusted before they could be used in WQRRS so that flow requirements were properly simulated at the appropriate locations.

C.5.8.1 Accretion and Depletion Adjustment and Distribution

Two things needed to be determined when flows were translated between models. First, the location of accretions and depletions along the river in the WQRRS model needed to be decided. Also, a method was developed to synchronize the monthly tributary inflows (Yuba and Bear Rivers and accretions) and withdrawals (depletions) with the daily varying headwater inflows (Diversion Pool and Thermalito Afterbay releases). Figure C.5-2 presents the four steps of adjusting accretions and depletions to balance flows.

Step 1. Check Flows

The first step was to check net river flows against the minimum required flow for each day of the simulation period using the raw CALSIM II and HYDROPS™ inputs. If minimum flows were met at all locations, no adjustment of accretions and depletions was necessary.

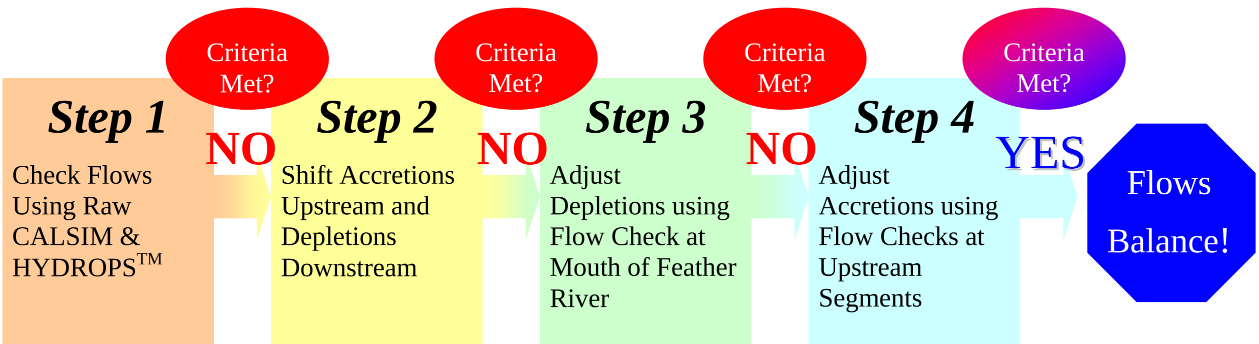


Figure C.5-2. The four steps of adjusting accretions and depletions to balance flows.

Accretions and depletions can be added to the Feather River at any location along three reaches: (1) below the Thermalito Afterbay Outlet to the confluence with the Yuba River, (2) between the Yuba and Bear Rivers, and (3) between the Bear River confluence and the mouth of the Feather River. As a first trial, the monthly CALSIM accretions and depletions were split into three equal components (1/3, 1/3, and 1/3) for the three sections. When this approach was used, minimum flows were not met for numerous periods of the simulation.

There are two reasons why minimum flows were exceeded in WQRRS but not in the CALSIM II budget. CALSIM II treats the river as a single node for which minimum flows are ensured, whereas WQRRS considers the spatial variation of inflows and withdrawals and net flow at each reach of the river. Second, HYDROPS™ flows can vary substantially from the CALSIM II monthly mean flow. Short-term drops in HYDROPS™ headwater flows occasionally coincide with relatively large constant depletions. During times such as these, there is a short-term deficit of water in the river.

Step 2. Shift Accretions and Depletions

The second step was to adjust the initial equal distribution of accretion and depletion flows to reduce the minimum-flow exceedances after the first step. Accretions were shifted upstream, and depletions were shifted downstream to help short-term low flows in the river and large relative depletions. After a few iterations, a suitable distribution was determined to be 60 percent, 20 percent, and 20 percent for accretions, and 0 percent, 50 percent, and 50 percent for depletions (Table C.5-10). Shifting flows in this manner caused a much greater level of compliance. SWP operations staff approved this final distribution.

Table C.5-10. Distribution of accretions and depletions in the Feather River temperature model.

	Relative Amount by River Reach (percent)		
	Reach 1: From the Thermalito Afterbay Outlet to Upstream of the Yuba River Confluence	**Reach 2: Between Confluences of the Yuba and Bear Rivers**	**Reach 3: Downstream of the Bear River**
Accretions	60	20	20
Depletions	0	50	50

Table C.5-11 shows the locations of accretions and depletions in the model. Large inflows and outflows from the model can cause internal numerical instabilities within the hydrodynamic solution. Thus, the specific locations of these inflows and outflows were selected in part to ensure the model's numerical stability.

Table C.5-11. Location of accretions and depletions in the Feather River temperature model.

	Location (River Miles) of Accretions and Depletions by River Reach		
	Reach 1	**Reach 2**	**Reach 3**
Accretions	28.5	13.5	10.5
Depletions	N/A	26.5	11.5 and 9.5

Figure C.5-3 is a schematic of the Feather River that summarizes the location and distribution of accretions and depletions. The Diversion Pool release, Thermalito Afterbay release, and Yuba and Bear River inflows are shown as blue arrows. The accretion inflows are shown in gray, and the depletions are green. The color-shaded regions in the background indicate reaches 1, 2, and 3. The river mile is indicated next to each inflow and withdrawal, and the accretions and depletions also indicate their relative distribution in percent.

Step 3. Adjust Depletions

Because minimum flow requirements were not met at all times after Step 2, a third step was required, to adjust the constant monthly depletions to better align with daily headwater fluctuations. A method was developed to redistribute depletions so that minimum flows were met at the mouth of the Feather River. This method subtracted from depletions when necessary, and later increased depletions when possible with respect to the flow requirement. In each case depletions were conserved over the adjustment period.

An example of Step 3 using data from the modeling scenarios is shown in Figure C.5-4. This plot spans the 3-month period from October to December in 1993. The first line in the legend shows the original, monthly depletion flows from the CALSIM II model (dark green line). Depletions are constant over each month in this period, and they vary from just over 750 cfs to almost 1,000 cfs, and then down to less than 750 cfs. The thin blue line shows the original net flow in the river at its mouth. Net flow was calculated as the sum of the headwater (HYDROPS™ Diversion Pool plus Thermalito Afterbay releases), Yuba River, Bear River, and total accretion inflows minus the total accretion outflows as follows:

$$\text{Net River Flow} = \sum \begin{array}{l} \text{Diversion Pool Release} \\ \text{Afterbay Release} \\ \text{Yuba River Inflow} \\ \text{Bear River Inflow} \\ \text{Accretion Inflow} \end{array} - \text{Depletions}$$

In Figure C.5-4, the net flow is above the minimum flow requirement (dashed red line) in October. No adjustment is necessary during this time. In November, however, it drops below the flow requirement. To increase the net river flow in November, depletions were adjusted. Depletions were reduced such that the net flow would increase to the required flow. The light green line shows the adjusted or decreased depletions in November that are below the original depletions. The light blue line indicates the resulting adjusted net flow. This line lies on top of the dashed red line in November showing that it just reaches the minimum level. The red arrows in Figure C.5-4 indicate that the direction flows changed (depletions down and net flows up) to maintain November flow requirements.

For each reduction in depletion, a corresponding increase in depletion was made so that total depletions over the period would not change. In Figure C.5-4, the original net flow (blue line) rises above the minimum level in December. Thus, there is water available to subtract from the river, i.e., depletions can increase. Net river flows are reduced, and depletions are increased until the last week in December, when the deficit of depletions has been made up. Depletions that were lowered in November are added in December so that the overall depletions within the period do not change. The gray arrows in C.5-4 indicate the direction in which flows were changed in December.

Step 4. Adjust Accretions

The third step considered the overall flow requirement at the mouth of the Feather River, but it did not consider requirements upstream of the confluence with the Yuba River, or between the Yuba and Bear Rivers. Step 4 was needed to adjust flows at the segments above the Bear River. A method similar to that of Step 3 was used to rearrange accretions and maintain minimum flows. Adjusting accretions was required only a handful of times in the 73-year modeling period, and adjustments were typically required for a few days. This final step brought flows into compliance for the remaining periods. Thus, flows in each river reach meet flow requirements for all days of the simulation period.

C.6 RESERVOIR–RIVER TEMPERATURE MODEL—WQRRS

C.6.1 Description

WQRRS is a hydrodynamic and water quality simulation model for river and reservoir systems, distributed by the USACE HEC (U.S. Army Corps of Engineers 1978). This model divides reservoirs into stacked layers of water and divides rivers into segments; these layers and segments serve as control volumes for water balance and heat budget calculations. WQRRS is a one-dimensional model; it calculates the temperature profile of a lake in the vertical direction and the temperature profile of a river in the horizontal direction.

To adapt this model to a particular system, geometric data of reservoirs, such as depth-area and depth-volume relationships, are compiled and input to the model. The elevations of intakes and outlets of hydroelectric power plants are specified. Hourly inflow, outflow (power plant releases and spills), and meteorology data are used to drive the model, which performs hourly calculations to predict the lake surface elevations, lake temperature profiles, coldwater volume, and temperatures at various locations specified in the system.

C.6.2 Usage

WQRRS was used to simulate Lake Oroville, the Diversion Pool, Thermalito Forebay, and Thermalito Afterbay as the stratified reservoirs. WQRRS simulated the Feather River from the Diversion Pool to the confluence with Sacramento River as a vertically mixed river. WQRRS provided an integrated simulation of temperatures for various locations in the Oroville Facilities as well as the Feather River and was adapted and calibrated with field data collected in 2002 and 2003.

C.6.3 Limitations

The temperature model did not automatically reoperate the system to meet temperature targets; it simply simulated the temperature from a given set of operational parameters. Simulation of Oroville Facilities reoperation occurred through the modeling process described earlier in this document.

C.6.4 Computational Methods

WQRRS emulated heat transfer processes by breaking the system being modeled into specific areas or control volumes. For each time step of computation, every control volume had an estimate of water inflow (flow from an upstream boundary or control volume), outflow (flow to a downstream boundary or control volume), heat gain from solar energy at the surface of the control volume, and heat loss from evaporation.

C.6.5 Inputs

Temperature model inputs fell into several major categories:

- *Meteorological:* Temperature, solar radiation, cloud cover, and wind;
- *Natural system:* Rivers and connectivity;
- *Facilities:* Reservoirs, canals, and river channel pumps;
- *Hydrology:* Inflow (flow and temperature) in-basin accretions and depletions, and evaporation; and
- *Operational data:* Reservoir storages, reservoir releases, pumpback, and flows throughout the system.

For the hourly simulation, WQRRS accepted hourly input data of meteorological conditions that included short-wave radiation, long-wave radiation, air temperature, dewpoint temperature, atmospheric pressure, and wind speed. These data varied both hourly and daily as a result of the ever-changing weather conditions. During the model calibration, actual meteorological data were used to predict the temperatures measured in real time in the field.

C.6.6 Assumptions

C.6.6.1 Lake Oroville Inflows and Temperatures

The division of the inflow into Lake Oroville from the various forks was estimated from historic flow records. These flow splits are detailed in Table C.6-1.

The table shows that the two largest tributaries of Lake Oroville are the North Branch and the Middle Fork. Their flow fractions appeared to be constant for much of the year, i.e., 54–60 percent for the North Branch and 31–36 percent for the Middle Fork from December and January through June. The patterns changed particularly in August through October, when the North Branch fraction increased to 80 percent and the Middle Fork fraction decreased to 10 percent. This change in the summer and fall may be caused by increased hydroelectric power operation on the North Branch.

The temperature of combined inflow was estimated to vary according to the seasons. However, it was necessary to separate hydroelectric power generation flows, which are relatively cold in the summer and fall, from natural or unimpaired streamflows.

Table C.6-1. Percentage of inflows to Lake Oroville among its tributaries.

Month	Percent of inflow				
	North Fork				
	North Branch	West Branch	Middle Fork	South Fork	Total
January	59	6	31	4	100
February	56	6	34	4	100
March	54	6	35	5	100
April	55	6	35	4	100
May	54	6	36	3	100
June	58	6	31	5	100
July	70	6	18	6	100
August	77	3	12	8	100
September	76	5	11	8	100
October	75	6	16	3	100
November	67	6	25	2	100
December	60	6	31	3	100

Very large temperature fluctuations occur in summer and fall below the Poe Powerhouse on the North Fork. Therefore, the North Fork flow was further split into regular streamflow and hydroelectric power release as shown in Table C.6-2.

Table C.6-2. Estimated flow split for Pacific Gas and Electric Company hydroelectric power release.

	Percent of Flow						
	North Fork		North Branch Split				
Month	North Branch	West Branch	Stream	Hydro. Power Operat'n	Middle Fork	South Fork	Total
January	59	6	59	0	31	4	100
February	56	6	56	0	34	4	100
March	54	6	54	0	35	5	100
April	55	6	55	0	35	4	100
May	54	6	54	0	36	3	100
June	58	6	58	0	31	5	100
July	70	6	18	53	18	6	100
August	77	3	8	68	12	8	100
September	76	5	8	68	11	8	100
October	75	6	11	63	16	3	100
November	67	6	25	42	25	2	100
December	60	6	60	0	31	3	100

This split assumed minimal hydroelectric power operation from December through June, and gradually increasing operation beginning in July and ending in November. The total flow was split such that the instream flow reflected similar flow fractions from other forks in the summer months, i.e., approximately 8 percent of the total inflow during the summer. The remaining portion of the North Branch flow was assumed to be from hydroelectric power operations.

With the separation of Pacific Gas and Electric Company (PG&E) flow releases from the total inflow to Lake Oroville, WQRRS had two temperatures for tributary inflows into Lake Oroville. One represented natural or nonimpaired flow and temperature variations, and the other represented the effects of hydroelectric power operations in the summer and fall.

The natural temperatures of tributary inflows to Lake Oroville were estimated based on a regression with air temperature data. A regression relationship was developed using available observed temperature data for tributary inflows from August 2002 to the end of December 2003, the calibration period. The correlation between air temperatures and inflow temperatures was good, as indicated by an r2 value of 0.875. The following equation shows the relationship between air temperature and natural inflow temperature used in the modeling simulations:

$$T_{\inf low} = 0.7919 \times T_{air} + 0.2609$$

Hydroelectric power inflow temperatures were estimated using observed data in the stream below the PG&E Poe Powerhouse. Data were available for several months when hydroelectric power operation was believed to occur (mainly August through October) of the calibration period in 2002 and 2003.

In 2002, the average minimum daily temperature of inflows from below the Poe Powerhouse from the beginning of September to the end of October was 10.5 degrees Celsius (°C) (51.0 degrees Fahrenheit [°F]) with a minimum of 6.5°C (44.0°F). From August to the end of November 2003, the average minimum daily temperature was 14.5°C (58.1°F) with an absolute minimum of 6.9°C (44.5°F).

The average minimum temperature in the stream below Poe Powerhouse was used as an indicator of hydroelectric power temperatures because these temperature data represent a combination of natural streamflows and powerhouse releases. It is not known how the averages of the observed data were calculated, or whether they are flow-weighted. However, the relatively low average and absolute minimum temperatures in summer and fall indicate coldwater inflows from hydroelectric power operation in otherwise warm-weather periods. From the data with an average of approximately 51–58°F and minimum of 44°F, an estimate of 50°F was applied to the hydroelectric power inflows in the modeling scenarios.

C.6.6.2 Hyatt Intake Shutter Settings

Actual operation records of dry years (1990 and 1991) and wet years (1997 and 1998) were analyzed for the historic shutter settings of the Hyatt Pumping-Generating Plant. These shutter settings were analyzed together with water surface elevations in Lake Oroville to develop the shutter settings for the first pass of WQRRS simulation.

C.6.6.3 River Flows

Actual flows of the Oroville Facilities and Feather River fluctuate hourly and daily. For the 73-year simulation, CALSIM II provided monthly flows of the Yuba River and Bear River, which contribute tributary flows to the Feather River. It also provided the accretions and depletions that occurred along the river. For the modeling simulations, a procedure was developed to disaggregate the monthly flows to weekly flows and then hourly flows. Accretions and depletions were assumed to occur in three points. The accretions occurred at river mile (RM) 28.5 (above the Yuba River), RM 13.5 (above the Bear River), and RM 10.5 (below the Bear River). The depletions occurred at RM 26.5 (below the Yuba River) and RMs 11.5 and RM 9.5 (both below the Bear River). Accretions and depletions were proportioned to maintain minimum flow in the river at all river segments all the time. The majority of accretions occur upstream of the Yuba River, and depletions occur in equal proportion above and below the Bear River.

A stage-flow study using the HEC-RAS model in concert with observed data was conducted for the Feather River below the Thermalito Diversion Dam. The study provides a cross section and invert elevation for every segment of the river segment as short as 0.02 mile. The river cross section and invert elevation data were used to determine the cross section and invert elevation of the WQRRS river segments, which vary from 0.25 to 0.5 river mile in the upstream section of the Feather River and 1–2 river miles in the downstream section of the Feather River. WQRRS used the data to route the flow for the Feather River dynamically using St. Venant's equation.

C.6.6.4 Temperatures of Tributary Flows and Accretions

Depletions are assumed to reflect the water at the ambient river temperature. Temperatures were estimated for tributary inflows and accretions. The temperatures for accretions were set at the ambient temperature of the river at the location of the return flow. Thus, accretions do not change the temperature of the river, but only affect the flow volume in the river.

During the model calibration, two relationships between air temperature and inflow temperature for the Yuba River and the Bear River were developed using the 2002 data. These relationships were used to calculate the inflow temperatures.

C.6.7 Outputs

The integrated model produced temperature profiles of Lake Oroville that could be used to calculate the volume of cold water in the reservoir. The model also produced the reservoir surface elevations and temperatures of reservoir releases.

The integrated model produced temperatures of various control volumes and diversion flows for the Oroville Facilities.

C.6.8 Appraisal

The accuracy of the model is measured by the discrepancy between the predicted values and observed values. This discrepancy actually represents the errors of both data and model. However, the discrepancy is commonly attributed to the model error. The degree of accuracy is unknown at this time. Past experience indicates that the error can be within 1°C.

C.7 FLOW-STAGE MODEL—HEC-RAS VERSION 3.1

C.7.1 Description

The HEC-RAS computer program was developed by the USACE HEC to simulate one-dimensional steady (constant) or unsteady (time-varying) flow in a network of natural and constructed water channels. HEC-RAS is also capable of simulating conditions at structures that affect the flow of water such as gated and uncontrolled spillways, weirs, bridges, and culverts.

A HEC-RAS model of the Feather River from the base of Oroville Dam to its confluence with the Sacramento River was developed as part of the USACE Sacramento–San Joaquin Basins Comprehensive Study. Channel geometry data for this model were collected from topographic data approximately every 0.2–0.25 mile (1,000–1,300 feet) along the river. These data are very detailed and provide a good representation of the river at each cross section.

C.7.2 Usage

The HEC-RAS model was used to develop flow-stage relationships at locations along the river where such information is needed for environmental analyses such as riparian recruitment and temperature.

C.7.3 Limitations

The model data were collected in the period 1997–1998; although the river as a whole likely has not changed significantly since that period, it is possible that specific cross sections are significantly different today than they were when the data were collected. The model cross section spacing of 0.25 mile is somewhat larger than the ideal spacing for a low-flow model of the river.

Under low-flow conditions, the upper 25 miles (RM 45–70) of the river may be characterized as a series of pools and riffles that are 1–3 miles in length. At low flows these pools and riffles become hydraulically separated, meaning that the water surfaces in the reaches upstream and downstream of a pool have no effect on the water surface in the pool. This means that the model can accurately simulate conditions at points in the river where data were collected, but it will not be as accurate at locations where data were not collected.

C.7.4 Assumptions

HEC-RAS assumed that the cross section data in the model are representative of the river.

C.7.5 Inputs

HEC-RAS inputs fell into several major categories:

- *Hydrology:* Feather River and tributary inflows for the steady-state model, and Feather River and tributary hydrographs for the unsteady-state model;
- *Geometry:* Cross section data;
- *Facilities:* Bridges, dams, weirs, culverts, etc.; and
- *Hydraulic:* Manning's n value for the river channel and banks.

C.7.6 Outputs

HEC-RAS outputs fell into the following major categories:

- *Figures:* Cross section plots including facilities; profile plots; and rating curve (flow-stage data at a cross section);
- *Tables:* At each cross section, hydraulic data (velocity, water surface, n value); and geometric data (area, invert, bank); and
- *Digital Output:* DSS, ASCII, or spreadsheets.

C.7.7 Appraisal

The HEC-RAS model was calibrated for flows of 2,000, 4,000, and 6,000 cfs. Calibration data were available at six DWR gauging stations on the Feather River. Calibration results are quite good with predicted water surface elevations at the calibration points typically within 0.5 foot of the actual gauge reading. However, as described above under "Limitations," calibration in the upper 25 miles of the river is valid only for short reaches. In uncalibrated reaches the absolute accuracy of the model may be less than desired, but the model should still provide accurate predictions of relative differences in the water surface elevation with a change in flow.

C.8 GEOMORPHIC MODEL—FLUVIAL-12

C.8.1 Description

River channel behavior is studied for its natural state and response to human regulation. Studies of river hydraulics, sediment transport, and river channel changes may be through physical modeling, mathematical modeling, or both. The computer program FLUVIAL-12 is a mathematical model that is formulated and developed for water and sediment routing in natural and human-made channels. The combined effects of flow hydraulics, sediment transport, and river channel changes are simulated for a given flow period. FLUVIAL-12 is capable of modeling changes over time in the following physical parameters:

- Channel scour and fill, aggradation, and degradation;
- Changes in channel cross section, including depth and width;
- Changes in bed material composition, including coarsening or fining (armoring, the condition where the surface layer becomes coarser than the underlying bed material, is also predicted and modeled);
- Changes in cross section location caused by bank erosion, sediment deposition, and meandering;
- Changes in water surface and bed elevation profiles;
- Changes in Manning's n, or the roughness of the channel;
- Changes in sediment transport; and
- Changes in river curvature.

C.8.2 Usage

The model has been developed for water and sediment routing in rivers while simulating river channel changes. River channel changes simulated by the model include channel-bed scour and fill (or aggradation and degradation), width variation, and changes caused by curvature effects. Because changes in channel width and channel-bed profile are closely interrelated, modeling of erodible channels must include both changes. In fact, width changes are usually greater than the concomitant scour and fill in the bed, particularly in ephemeral streams.

While this model is for erodible channels, physical constraints such as bank protection, grade-control structures, and bedrock outcroppings may also be specified. Applications of this model include evaluation of general scour at bridge crossings, sediment delivery, channel responses to sand and gravel mining, channelization, and dams. It has been applied to many designs for bank protection and grade-control structures that must extend below the potential channel bed scour and withstand the design flood.

C.8.3 Limitations

FLUVIAL-12 is an erodible-boundary model that simulates changes in bed elevation, channel width, and bed topography induced by channel curvature. In this way, bank erosion, changes in channel curvature, and river meandering can also be modeled. Channel changes and bank erosion occur in the reach analyzed in SP-G2, *Effects of Project Operations on Geomorphic Processes Downstream of Oroville Dam*. The

FLUVIAL-12 model has the ability to select sediment transport equations that best match river conditions. On studies on the South Fork Trinity River and on Cottonwood Creek, the Parker equation was selected as the most appropriate and this equation was then added to the model. The preliminary analysis of the Feather River indicated that this equation was also the most appropriate available equation for this project.

Model inputs for all four of the geomorphic models do not appear to be compatible with the Operations Model used in SP-E2, *Perform Modeling Simulations*, because the models have different data needs. Discussions with the engineers indicated that sharing hydraulic data such as streamflow was highly improbable. The operations models use monthly data, while FLUVIAL-12 uses hourly and daily data. Hourly and daily flow data are readily available from the California Data Exchange Center and the U.S. Geological Survey. Any cross sections developed for the operations model, however, may be used for FLUVIAL-12.

C.8.4 Assumptions

Some of the assumptions used in the model were the following:

- Cross sections used in the analyses are adequate representations of the stream channel at all flows.
- The roughness coefficient remains static at all levels of flow.
- The geometric mean of the bed material size fractions adequately describes the sediment size distribution.
- The selected sediment transport equation properly represents sediment movement at all discharges.
- The river channel is in dynamic equilibrium at all discharges.
- There is uniformity in sediment discharge, power expenditure, energy gradient, water surface slope, and other elements in the short reaches between cross sections.
- The spatial and temporal variations in flow, sediment transport, and channel geometry, are adequately modeled with iterative time, cross section, and flow data.

C.8.5 Inputs

FLUVIAL-12 inputs fell into several major categories:

- Selection of appropriate sediment transport equations;
- Estimate of bank erodibility factor;

- Estimate of Manning's coefficient of roughness;
- Development of flow data sets for representative cross sections in the study reach;
- Calculation of channel slope;
- Identification of reaches of bank protection;
- Measurement of water temperature;
- Estimate of thickness of erodible bed;
- Measurement of sediment characteristics: Specific gravity, number of size fractions, angle of repose;
- Decision about whether unsteady-flow modeling is appropriate;
- Bed material sampling and determination of bedload sediment size fractions; and
- Location and resurveying of cross sections and determination of their characteristics: Erodible versus nonerodible banks, degree of curvature of centerline of channel (where banks are static), bank erodibility factor, estimated thickness of erodible gravel bed, and size fractions of bed material.

C.8.6 Outputs

FLUVIAL-12 outputs included:

- Changes in channel scour and fill;
- Bedload;
- Roughness;
- Cross section;
- Gradient;
- Sediment transport; and
- Hydraulic conditions: Bottom shear stress, velocity, and wetted hydraulic radius.

C.9 REFERENCES CITED

U.S. Army Corps of Engineers. 1978. WQRRS. Hydrologic Engineering Center. Davis, California.

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