Appendix H Reclamation Temperature Model and SRWQM Temperature Model

Introduction

Specific temperature compliance objectives, in past Biological Opinions, were established for the protection of the salmon fishery. Two tools were developed to assist in the planning and operational compliance of these objectives. One is the Reclamation (or USBR) Temperature model and another is the upper Sacramento River Water Quality Model (SRWQM). The Reclamation Temperature model simulates monthly mean vertical temperature profiles and release temperatures for Trinity, Whiskeytown, Shasta, Folsom, New Melones, and Tulloch Reservoirs. The SRWQM application was developed using the HEC-5Q model to simulate mean daily (using 6-hour meteorology) reservoir and river temperatures at Shasta, Trinity, Lewiston, Whiskeytown, Keswick and Black Butte Reservoirs and the Trinity River, Clear Creek, the upper Sacramento River from Shasta to Knights Landing, and Stony Creek. The objective is to find temperature variability in these the reservoirs and streams, given CVP/SWP operations, and compare between existing and assumed future scenarios.

Key Processes

The following processes are simulated in the temperature models:

- Long-term operational scenarios (i.e., using CalSim-II results)
- Reservoir storage given flood control, hydropower, and reservoir release requirements
- Mean monthly and mean daily downstream temperatures (using monthly and 6-hour meteorology data)
- Accommodate selective withdrawals (Shasta and Folsom reservoir)

The simulated temperature processes is generally described in an excerpt from the SRWQM (RMA, 2003):

> *The external heat sources and sinks that were considered in HEC-5Q were assumed to occur at the air-water interface, and at the sediment-water interface. The method used to evaluate the net rate of heat transfer utilized the concepts of equilibrium temperature and coefficient of surface heat exchange. The equilibrium temperature is defined as the water temperature at which the net rate of heat exchange between the water surface and the overlying atmosphere is zero. The coefficient of surface heat exchange is the rate at which the heat transfer process progresses. The total heat flux is a function of the difference between the equilibrium temperature and ambient temperature. All heat transfer mechanisms, except short-wave solar radiation, are applied at the water surface. Short-wave radiation penetrates the water surface and may affect water temperatures several meters below the surface. The depth of penetration is a function of adsorption*

and scattering properties of the water as affected by particulate material (e.g., phytoplankton and suspended solids). Since no particulate parameters are simulated, the seasonal definition of light attenuation must include the effect of all particulate parameters. The heat exchange with the bottom is a function of conductance and the heat capacity of the bottom sediment.

Models and Applications

The Reclamation Temperature Model was created and developed exclusively for CVP and SWP systems in the Central Valley. The reservoir temperature model simulates monthly mean vertical temperature profiles and release temperatures. The temperature models consist of two basic model elements: a reservoir component, and a downstream river component.

Reclamation Reservoir Model Description

The reservoir component of the Reclamation Temperature model simulates one-dimensional, vertical distribution of reservoir water temperature using monthly input data on initial storage and temperature conditions, inflow, outflow, evaporation, precipitation, radiation, and average air temperature. The reservoir is divided into horizontal layers of uniform thickness. Each layer is assumed to be isothermal (i.e., the same temperature throughout its volume).

The energy exchange between the reservoir and the atmosphere is assumed to affect only the top layers of water except for energy transferred by diffusion. The energy exchange is assumed to affect water temperature linearly from a maximum effect at the surface to a minimum at the depth of energy penetration. Solar radiation, evaporation, and a combination of conduction and long-wave radiation are expressed as functions of the difference between air and water temperatures. These energy exchanges are computed before the stability and diffusion computations are made. The model used five calibration coefficients in calculating the various energy exchange functions. The Reclamation reservoir temperature model simulates monthly mean vertical temperature profiles and release temperatures for Trinity, Whiskeytown, Shasta, Folsom, New Melones and Tulloch Reservoirs based on hydrologic and climatic input data. The temperature control devices (TCD) at Shasta and Folsom Dams can selectively withdraw water from different reservoir levels to provide downstream temperature control. The TCD's are generally operated to conserve cold water for the summer and fall months when river temperatures become critical for fisheries. The model simulates the TCD operations by making upper level releases in the winter and spring, mid-level releases in the late spring and summer, and low level releases in the late summer and fall. To accomplish this function, the Shasta and Folsom temperature models operate to meet mean monthly tail-water temperature targets that function as a surrogate for downstream temperature compliance.

Temperature changes in the downstream regulating reservoirs: Lewiston, Keswick, Natomas, and Goodwin are computed from equilibrium temperature decay equations in the reservoir models, which are similar to the river model equations. The river temperature models output temperatures at 3 locations on the Trinity River from Lewiston Dam to the North Fork, 12 locations on the Sacramento River from Keswick Dam to Freeport, 9 locations on the American River from Nimbus Dam to the mouth, and 8 locations on the Stanislaus River from Goodwin Dam to the mouth (Table 1).

Reclamation River Model Description

The river component of the Reclamation Temperature model calculates temperature changes in the regulating reservoirs, below the main reservoirs. With regulating reservoir release temperature as the initial river temperature, the river model computes temperatures at several locations along the rivers. The calculation points for river temperatures generally coincide with tributary inflow locations. The model is one-dimensional in the longitudinal direction and assumes fully mixed river cross sections. The effect of tributary inflow on river temperature is computed by mass balance calculation.

The river temperature calculations are based on regulating reservoir release temperatures, river flows, and climatic data. Monthly mean historical air temperatures for the 82-year period and other long-term average climatic data for Trinity, Shasta, Whiskeytown, Redding, Red Bluff, Colusa, Marysville, Folsom, Sacramento, New Melones, and Stockton were obtained from National Weather Service records and used to represent climatic conditions for the four river systems.

Table 1 Reclamation Temperature Model nodes.

RIVER OR CREEK SYSTEM	LOCATION
TRINITY RIVER	Trinity Dam
	Lewiston Dam
	Douglas City
	North Fork
CLEAR CREEK	Whiskeytown Dam
	Above Igo
	Below Igo
	Mouth
AMERICAN RIVER	Folsom Dam
	Nimbus Dam
	Sunrise Bridge
	Cordova Park
	Arden Rapids
	Watt Avenue Bridge
	American River Filtration Plant
	H Street
	16th Street

RIVER OR CREEK SYSTEM	LOCATION
	Mouth
SACRAMENTO RIVER	Shasta Dam
	Keswick Lake above Spring Creek Tunnel
	Spring Creek Tunnel
	Keswick Dam
	Balls Ferry
	Jellys Ferry
	Bend Bridge
	Red Bluff
	Vina
	Butte City
	Wilkins Slough
	Colusa Basin Drain
	Feather River
	American River
	Freeport
STANISLAUS RIVER	New Melones Dam
	Tulloch Dam
	Goodwin Dam
	Knights Ferry
	Orange Blossom
	Oakdale
	Riverbank
	McHenry Bridge
	Ripon
	Mouth

SRWQM Reservoir Model Description

The SRWQM is developed using the HEC-5Q model. It is designed for long-term planning simulation of temperature at key locations on the Sacramento River at a mean daily time step (using 6-hour meteorology) that captures diurnal fluctuations and is sensitive to fishery management objectives. The geographical scope of the model ranges from Shasta Dam and Trinity Dam to Knights Landing and includes the features listed in Table 2. Monthly flows, simulated by the CalSim-II model for an 82 year period (WY 1922-2003), are used as input to the SRWQM.

The SRWQM reservoir component consists of Shasta, Trinity, Whiskeytown and Black Butte Reservoirs are represented as a series of one-dimensional vertically stratified elements. The after bays at Lewiston and Keswick are represented as vertically layered and longitudinally segmented layers. More specific details can be found in the Calibration and Validation report (RMA, 2003).

SRWQM River Model Description

River or stream reaches are represented as a linear network of volume segments, where cross-sectional area and flow-depth relationships define the elements (original development and calibration was done by UC Davis and refinements were completed by the USGS) (RMA, 2003).

Shasta Dam is also represented in this model with a Temperature Control Device (TCD) to improve the flexibility of release temperatures. To accommodate for the TCD the HEC-5Q code was modified and temperatures adjusted to include this operational flexibility (RMA, 2003). Detailed relationships developed to account for TCD efficiency at various outflow release rates and reservoir elevations were also implemented (Reclamation, 1999).

Table 2 SRWQM model nodes.

RIVER OR CREEK SYSTEM	LOCATION
Shasta Dam	Tailwater
Lewiston	Fish Hatchery
Spring Creek	Powerhouse
Sacramento River	Below Keswick Dam
	Clear Creek Confluence
	Balls Ferry
	Jellys Ferry
	Bend Bridge
	Red Bluff Diversion Dam
	Tehama
	Woodson Bridge

RIVER OR CREEK SYSTEM	LOCATION
	Hamilton City
	Butte City
	Colusa
	Above Colusa Basin Drain
Black Butte Dam	Black Butte Dam
Stony Creek	Tehama Colusa Canal

Model Documentation

The temperature models for the Sacramento and American Rivers are documented in a 1990 USBR report (Rowell, 1990). The Trinity River temperature model is documented in a 1979 USBR report (Rowell, 1979). The Stanislaus River temperature model is documented in a 1993 USBR report (Rowell, 1997). The models are also described in Appendix IX of the 1997 USBR Draft CVPIA-PEIS (Reclamation, 1997).

The SRWQM calibration and validation report documents model assurance (RMA, 2003) and a review of the model is also provided by Watercourse Engineering, Inc. (2003).

Model Mathematics

The Reclamation Temperature model mechanics are described in Rowell, (1979, 1990, and 1997). HEC-5Q mathematics is described in USACE's Appendix on Water Quality Analysis (1986).

Rationale

The Reclamation Temperature Model has been applied to past CVP and SWP system operational performance evaluations (Reclamation 1994 and 2004). Sub-monthly temperature results from the SRWQM for the upper Sacramento, Trinity, and Clear Creek reaches were developed to approximate diurnal temperature variability. Historical temperature observations are provided as complementary information in addition to the monthly and mean daily (using 6-hour meteorology) temperature results.

Quality Assurance and Data Quality Assessment

No formal process documented the quality assurance and data quality of the Reclamation Temperature Model. This model was developed at a time where specific documentation requirements were less stringent. A peer review of the Reclamation Temperature model has not been performed.

Also, no formal quality assurance and data quality assessment document exists for the SRWQM. However, the SRWQM was technically reviewed by Watercourse Engineering, Inc. in 2003. This review found "[a]lthough several facets of the Temperature Modeling System (TMS) have been postponed to future phases, it is clear that the approach is valid and that the end-product would be a powerful tool." (Watercourse Engineering, Inc., 2003).

Assumptions

The available cold water (in the reservoirs) is utilized efficiently depending on the month in the monthly model and storage levels in any given year in the mean daily model. These targets are developed for facilities that can modify releases for temperature control. The Reclamation Temperature Model Shasta and Folsom reservoir temperature targets are listed in Table 3.

Table 3 Reclamation Temperature Model Tailwater Targets (° F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shasta	80	80	56	48	46	45	47	47	40	40	40	80
Folsom	80	80	80	63	63	63	63	63	63	55	40	80

For the SRWQM, multiple seasonal patterns depending on the End-of-May storage conditions were developed to use the coldwater. End-of-May storage provides information on whether the year is wet, dry or critical etc. and is a reasonable indicator of the available cold water.

For the SRWQM Shasta reservoir temperature targets, a set of seasonally varying temperature schedules were also developed. Each schedule varies from other ones based on two things – when the target temperature is lowered and how much should it be lowered by in order to meet the downstream temperature requirements. Based on the storage levels in each tier, a new target temperature schedule was assigned to the years in that tier. Four tiers were established based on the End-of-May storage conditions for Shasta. Table 4 provides end-of-May Shasta storage thresholds for each tier and the temperature schedules used in the corresponding tier.

Table 4 Definition of tiers and corresponding temperature schedules for Shasta releases

Tier	End of May Shasta Storage (TAF)	Target Temperatures	
		Date	Temperature (° C)
Tier I	< 3100	1-Jan	16
		7-Apr	12
		31-Jul	9
		7-Dec	16
Tier II	< 3500	1-Jan	16
		7-Apr	12

Tier	End of May Shasta Storage (TAF)	Target Temperatures	
		Date	Temperature (^{o} C)
		7-Jul	9
		7-Dec	16
		1-Jan	16
		7-Apr	12
Tier III	< 4100	14-Jun	9
		15-Sep	7
		7-Dec	16
		1-Jan	16
		7-Apr	12
Tier IV	> 4100	10-May	9
		15-Sep	5
		7-Dec	16

Model Testing

Calibration and Validation

A discussion of the Reclamation Temperature reservoir and river model verification is presented in references: Rowell (1990) and Rowell (1993 and 1997). The predicted temperatures were generally within 1-2° F of measured temperature.

The following is an excerpt describing the calibration of the SRWQM from the report: Upper Sacramento River Water Quality Modeling with HEC-5Q: Model Calibration and Validation (RMA, 2003):

> *HEC-5Q was calibrated for the period of January 1998 through November 2002 using temperature time series field observations at numerous locations in the Upper Sacramento River; tailwater temperature time series at Shasta, Lewiston, Keswick and Black Butte Dams; temperature time series at Spring Creek Powerhouse and Stony Creek at Tehama Colusa Canal; and temperature profile observations in Shasta, Trinity, Lewiston and Whiskeytown Reservoirs. The following temperature data sets were utilized. CDEC water temperature time series; DWR water temperature time series; Reservoir temperature profiles (Shasta, Trinity, Lewiston and Whiskeytown) provided by USBR; and US Army Corps of Engineers Black Butte Reservoir temperature profiles. The*

hydrology, meteorology, and inflow water quality conditions described in Chapter 2 [RMA 2003 report: Upper Sacramento River Water Quality Modeling with HEC-5Q: Model Calibration and Validation] were assumed.

The intent of the model calibration exercise was to adjust the model parameters to minimize the differences between the daily average computed and observed data, and demonstrate that the model adequately represents the thermal responses of the Upper Sacramento River stream and reservoir system. Calibration emphasized warmer periods.

The results of the calibration effort are presented as plots of computed and observed temperature time series and reservoir temperature profiles. The model is spinning up during 1998, and TCD operation to meet downstream temperature targets did not begin until the spring of 1999, therefore reservoir temperature profile plots are provide from 1999 on.

The SRWQM was also validated using a summer and fall comparison for each year 1990 through 1997. Dates were selected near July 1^{st} and September 15^{th} for Shasta. Comparisons between observed vertical reservoir temperature profiles are reported to closely match. Surface temperature deviates in some instances from 2° F to 7° F. It is observed however, that the deviation is does not affect computed reservoir temperatures at greater depths or tailwater temperatures (RMA, 2003).

Computed and observed temperature time series for selected locations throughout the Upper Sacramento River system are plotted in Figures 4-18 through 4-24. Computed values are plotted at 6- hour intervals at times 00:00, 06:00, 12:00 and 18:00. Observed data are plotted as daily average values. Computed temperatures are generally within 3° F or less of average observed data at each of the locations plotted. Computed temperatures tend to be slightly cooler than observed. The higher summertime temperatures of the 1990 – 1992 relative to the 1993 – 1997 temperatures show that the model adequately represents ambient temperature conditions during wet and dry years. Validation results are summarized in Table 4.1.

Additional details of the validation analysis are available in the same report.

Sensitivity and Uncertainty of Model Inputs

Sensitivity and uncertainty analyses were not conducted for the Reclamation Temperature or the SRWQM applications.

Limitations

The main limitation of CALSIM II and the Reclamation temperature model is the time-step. Mean monthly flows and temperatures do not define daily variations that could occur in the rivers due to dynamic flow and climatic conditions. However, monthly results are still useful for general comparison of alternatives. The temperature models are also unable to accurately simulate certain aspects of the actual operations strategies used when attempting to meet temperature objectives, especially on the upper Sacramento River. In the monthly model, to account for the short-term variability and the operational flexibility of the system to respond to changing conditions, cooler water than that indicated by the model is released in order to avoid exceeding the required downstream temperature target. However, results capturing diurnal temperature variability is available with the mean daily (using 6-hour meteorology) SRWQM for the upper Sacramento River.

For both models, there is also uncertainty regarding performance characteristics of the Shasta TCD. Due to the hydraulic characteristics of the TCD, including leakage, overflow, and performance of the side intakes, the model releases are cooler than can be achieved in real-time operations; therefore, a more conservative approach is taken in real-time operations that is not fully represented by the models.

Future Development

The treatment of temperature analysis amongst all of the OCAP BA reaches evaluated is inconsistent. Future development to incorporate diurnal temperature variability, similar to the efforts made on the upper Sacramento with SRWQM, will be considered. These efforts will focus on the application of the American and the Stanislaus Rivers. Although sub-monthly models do exist for both of the American and Stanislaus River, they are not configured as the SRWQM model is, to perform long-term planning simulation to maintain the same level of consistency.

References

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U.S. Bureau of Reclamation, 2004. Long-Term Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment. June 30, 2004.

Watercourse Engineering, Inc., 2003. Upper Sacramento Temperature Model Review: Final Report Summary. December 31, 2003.

Attachment H-1 Temporal Downsizing of CALSIM II Flows

Temporal downscaling was performed on the CALSIM II monthly average tributary flows to convert them to daily average flows for HEC5Q input. Monthly average flows are converted to daily tributary inflows based on 1921 through 1994 daily historical record for the following aggregated inflows.

1) Trinity River above Lewiston.
2) Sacramento River above Keswick.
3) Incremental inflow between Keswick and Bend Bridge.
4) Cottonwood Creek (regression with bend Bridge local flow for 1921-1940)
5) Inflows below Butte City (Seven-day trailing average of Bend Bridge daily inflow. i.e., inflow attenuated uniformly over the following week. This distribution was assumed due to lake of gauge data in the lower Sacramento River drainage).

Each of the total monthly inflows specified by CALSIM II is scaled proportional to one of these four historical records.

Trinity Reservoir inflows were proportioned based on historical record #1. Whiskeytown and Shasta were proportioned by historical record #2. (Keep in mind that the Whiskeytown inflow refers to Clear / Whiskey Creek unregulated flow and not the inflow from the Clear Creek Tunnel.) The downscaled reservoir inflows occasionally result in minor violation of normal reservoir operation constraints. Since the violations occurred infrequently and were less than 2% of the reservoir volume constraint, they were ignored.

Incremental local inflows above Bend Bridge have two components. The Cottonwood Creek flow (Explicitly defined in CALSIM II as I108) is proportioned by historical record #4. All other projects gains (I109) are distributed by #3. Within HEC-5Q, these project gains are partitioned as shown in Table 5.

Tributaries between Bend Bridge and the confluence with Stony Creek are combined (CALSIM I110, I113a & I113b) and proportioned by historical record #3. The rational for not treating Paynes Creek and Thomes Creek separately is that these two tributaries constitute less than 20 percent of the total incremental inflow (I110 +I113A = 18,475 TAF; I113B = 83,421 TAF). The use of historical record #3 for these tributaries was due to insufficient stream flow data to distinguish differences in flow patterns between tributaries above and below Bend Bridge. Table 6 also contains aggregated inflows below Stony Creek that are represented as inflows at Butte Creek and the Colusa Basin Drain.

Table 5 Percentage of Flow between Keswick and Bend Bridge

Mile	Tributary	% of flow between Keswick and Bend Bridge (excluding Cottonwood Creek)
		(CALSIM - I109 & R109)
292	Clear Cr. Local	7
285	Churn Creek	7
280	Cow Creek	42
277	Bear+Ash Creek	17
273	Anderson Creek	4
271	Battle Creek	23

Table 6 Percentage of Flow between Bend Bridge and Stony Creek

mile	Tributary	% of flow between Bend Bridge and Stony Creek
		(CALSIM I110, I113a & I113b)
253	Paynes Creek	4
244	Red Bank + Reeds Creek	4
234	Antelope Creek	14
230	Elder Creek	14
230	Mill Creek	14
226	Thomes Creek	15
220	Deer Creek	14
215	Jewett Creek	4
196	Pine Creek	8
193	Big Chico Creek	9
		Flows below Stony Creek
138	Butte Creek + Misc	100% of CALSIM I123 + R129
85	Colusa Drain + Misc,	100% of CALSIM C148A

For inflows (excluding returns) below Stony Creek the monthly flows were distributed as follows.

1) Inflows above Butte City are redistributed based on by historical record #3.
2) Inflows below Butte City (lower valley streams) are redistributed based on the 7-day trailing average of the by historical record #3 (attenuates the peaks to account for delayed runoff within the watershed).

CALSIM II flows for Stony Creek were assumed to reflect operation of Black Butte Reservoir (assumption based on the magnitude of summertime inflows). Since Black Butte Reservoir and Stony Creek (downstream of Black Butte Dam) are simulated in HEC-5Q, it was necessary to approximate operation of the reservoir. The following approach was developed.

1) Defining the CALSIM II flow as the reservoir outflow rate
2) Assuming a typical seasonal volume variation to account for the change in storage
3) Compute resulting inflow rate and proportioned by historical record #3
4) Adjust outflows as necessary to preserve reservoir volume constraints

Figure 1 shows a typical Black Butte Reservoir volume history after imposing this approach.

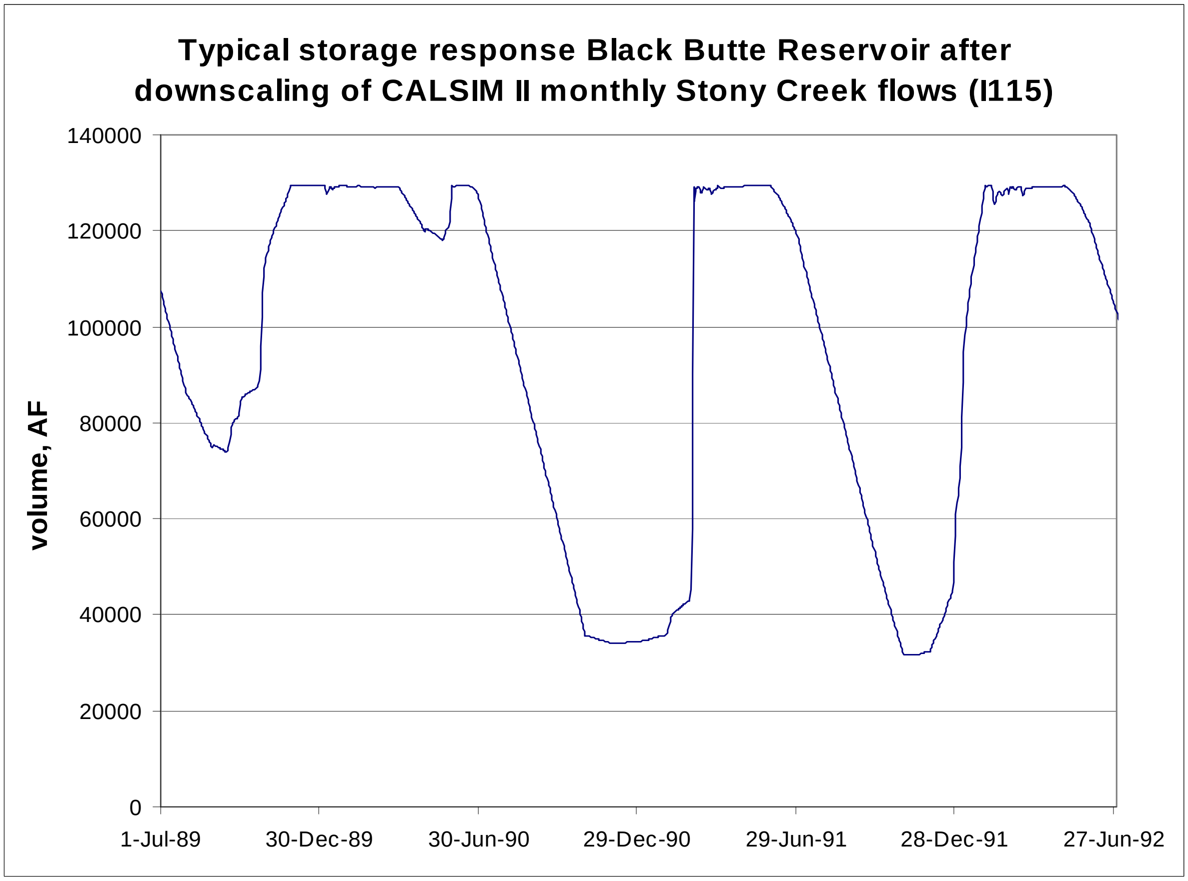

Figure 1 Typical Storage Response, Black Butte Reservoir after downscalling of CalSim-II

Outflows

Since reservoir outflow and diversion rates are a function of the CALSIM II operating assumptions, historical flow patterns are not meaningful. Consequently monthly flows were simply smoothed for a better transition at the end of the month. Initially, flows are defined without regard for reservoir volume constraints or downstream minimum flows.

As flows are redistributed within the month, the minimum flow constraint at Keswick, Red Bluff and Knights Landing may be violated. In such cases, operation modifications are required for daily flow simulation to satisfy minimum flow requirements.

Minimum Sacramento River flow constraints imposed by CALSIM II at Red Bluff and Knights Landing are satisfied by the following.

1) Redistribute TCC and GCC withdrawals up to the capacity of the conveyance facilities.
2) Reallocate Shasta outflows maintaining monthly outflow volume.

3) Increase Shasta release if 1) and 2) cannot meet minimum flow requirements (excess release volumes are made up in later months when Shasta releases are in excess of minimum flows).

This process may violate the minimum flow requirement at Keswick Dam. In such cases, the Shasta Dam release is adjusted by the process described in #3 above.

Diversions such as the ACID, GCID and TCCA were defined as point withdrawals for input to HEC-5Q. Miscellaneous project gains out were combined and assumed as diffuse inflows or withdrawals in HEC-5Q.

During periods of high Sacramento River flow, diversions to Sutter Bypass based on historical weir flows relative to river flows at Butte City. These diversions occasionally occurred when no Moulton, Colusa and Tisdale weir spills were indicated in the CALSIM II output.

The locations of the point diversions are listed in Table 7. The “U/S” designation indicates that the withdrawal is distributed uniformly above the referenced river mile.

Table 7 Percentage of Total Withdrawal from Control Point

Mile	Diversion	% of total withdrawal from Control Point (% and CALSIM ID)
299	ACID	100% of D104 + D109 + GS60
243	TCCA	100% of D112A + D112B + C112A
207	GCID	100% of D114 + C114A
U/S 190	misc abv Ord	100% of D113+D117A+D117B+GS61-R118
160	abv Colusa	100% of D122
159	Moultin Weir	10% of D123 + D124 + D125 + GS63
146	Colusa Weir	90% of D123 + D124 + D125 + GS63
119	Tisdale Weir	100% of D126
110	misc abv Knights Ldg.	100% of D128 + D129