Final

USRDOM Development, Calibration, and Application

Prepared for

U.S. Bureau of Reclamation

Mid-Pacific Region

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USRDOM Appendices (on DVD-ROM)

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Acronyms and Abbreviations

ACID	Anderson Cottonwood Irrigation District
ADEIRS	Administrative Draft Environmental Impact Report and Statement
AFRP	Anadromous Fish Restoration Program
CACMP	Common Assumption Common Model Package
CBWQM	Colusa Basin Water Quality Model
CDEC	California Data Exchange Center
cfs	cubic feet per second
COA	Coordinated Operation Agreement
Comp Study	Sacramento and San Joaquin River Basins Comprehensive Study
Corps	U.S. Army Corps of Engineers
CVO	Central Valley Operations Office
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
DEM	digital elevation model
DSOD	Division of Safety of Dams
DWR	California Department of Water Resources
EOP	end-of-period
GCC	Glenn-Colusa Canal
HEC-DSS	Hydrologic Engineering Center's Data Storage System
IBU	In-basin Use
IOS	Interactive Object-oriented Salmonid Simulation
MAF	million acre-feet
NHD	National Hydrography Dataset
NMFS	National Marine Fisheries Service
NODOS	North-of-Delta Off-stream Storage
PG&E	Pacific Gas & Electric
PSC	Project Settlement Contractors

QA/QC	quality control and quality assurance
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Bureau of Reclamation
RHEM	Riparian Habitat Establishment Models
ROD	Record of Decision
Sac-EFT	Sacramento Ecological Flow Tool
SALMOD	Salmon Mortality Model
SRH-lbv	Sedimentation and River Hydraulics and Vegetation 1-Dimensional
SWP	State Water Project
TAF/yr	thousand acre-feet per year
TCC	Tehama-Colusa Canal
USGS	U.S. Geological Survey
USRDOM	Upper Sacramento River Daily Operations Model
USRWQM	Upper Sacramento River Water Quality Model
WDL	Water Data Library
WRCLCM	Winter-Run Chinook Life Cycle Model
WY	water year

SECTION 1

Introduction

1.1 Background

The U.S. Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR) are conducting feasibility-level engineering and environmental studies for the Surface Storage Investigations Program. Modeling of hydrologic, regulatory, and operational conditions on a daily timestep is needed to support the evaluation of potential benefits and impacts of the North-of-Delta Off-stream Storage (NODOS) program alternatives. A modeling tool capable of simulating both low flow (water supply) and high flow (flood) operations is necessary. The Upper Sacramento River Daily Operations Model (USRDOM) is designed to model the flows and related operations of the Sacramento River and existing and proposed facilities related to the operation of proposed NODOS alternatives. USRDOM also can assess temperature and flow regime impacts and benefits. The model includes the streams and facilities in the upper portion of Sacramento River from Shasta Reservoir to Knights Landing and the Trinity River section of the Central Valley Project (CVP). Figure 1.1 shows the spatial scope of this model.

1.2 Purpose of USRDOM Development

USRDOM allows the user to establish bounds on availability and operating criteria for diversion of excess flows to NODOS. It simulates realistic daily flow conditions in the Sacramento River based on the operations specified by CALSIM II under projected conditions (future) or historical operations for use in river morphology and fisheries analyses for NODOS. It also can be used to evaluate NODOS performance for ecosystem restoration objectives. Finally, it can be used to demonstrate incremental environmental impacts of various NODOS scenarios.

1.3 Scope of USRDOM Development

The scope of USRDOM development includes hydrology development, model setup and testing, model calibration and verification, 82-year full-period simulation capability, development of model linkages, model application and documentation. A brief description of the scope of each task is provided below.

- Hydrology Development—A hydrology dataset including reservoir inflows and tributary flows was developed for the 82-year period from water year (WY) 1922 to WY 2003 using the available historical gage records and operations data for the streams and facilities in the geographical area of interest.

- Model Setup and Testing—This task included selecting software to model the daily operations, identifying the spatial and temporal extents of the model, identifying spatial and temporal resolution, preparing the schematic, preparing the input datasets using the historical hydrology and operations data, and testing the model.

- Model Calibration and Verification—This task included calibrating and verifying the simulation of reservoir operations during flood conditions, assessing the quality of the hydrology dataset, and simulating the flow routing using the observed reservoir operations data and gage records as the reference.
- 82-year Full-period Simulation Capability—This task included enhancing the calibrated USRDOM to simulate full-period operations on a daily timestep for projected level conditions. It also included the developing CAL2DOM to downscale monthly CALSIM II operations to daily USRDOM inputs and developing an example full-period simulation.
- Development of Model Linkages—Flow outputs from USRDOM are used by several water quality, habitat, and biological models. The spatial representation of the Sacramento River in each model varies from USRDOM. Therefore, in this task, USRDOM output locations that are appropriate for each individual model were identified and documented.
- Model Application—As part of this task, USRDOM was extended to include NODOS-related conveyance features. In addition, CAL2DOM was modified to include downscaling of CALSIM II operations related to NODOS and develop an example full-period projected level simulation.

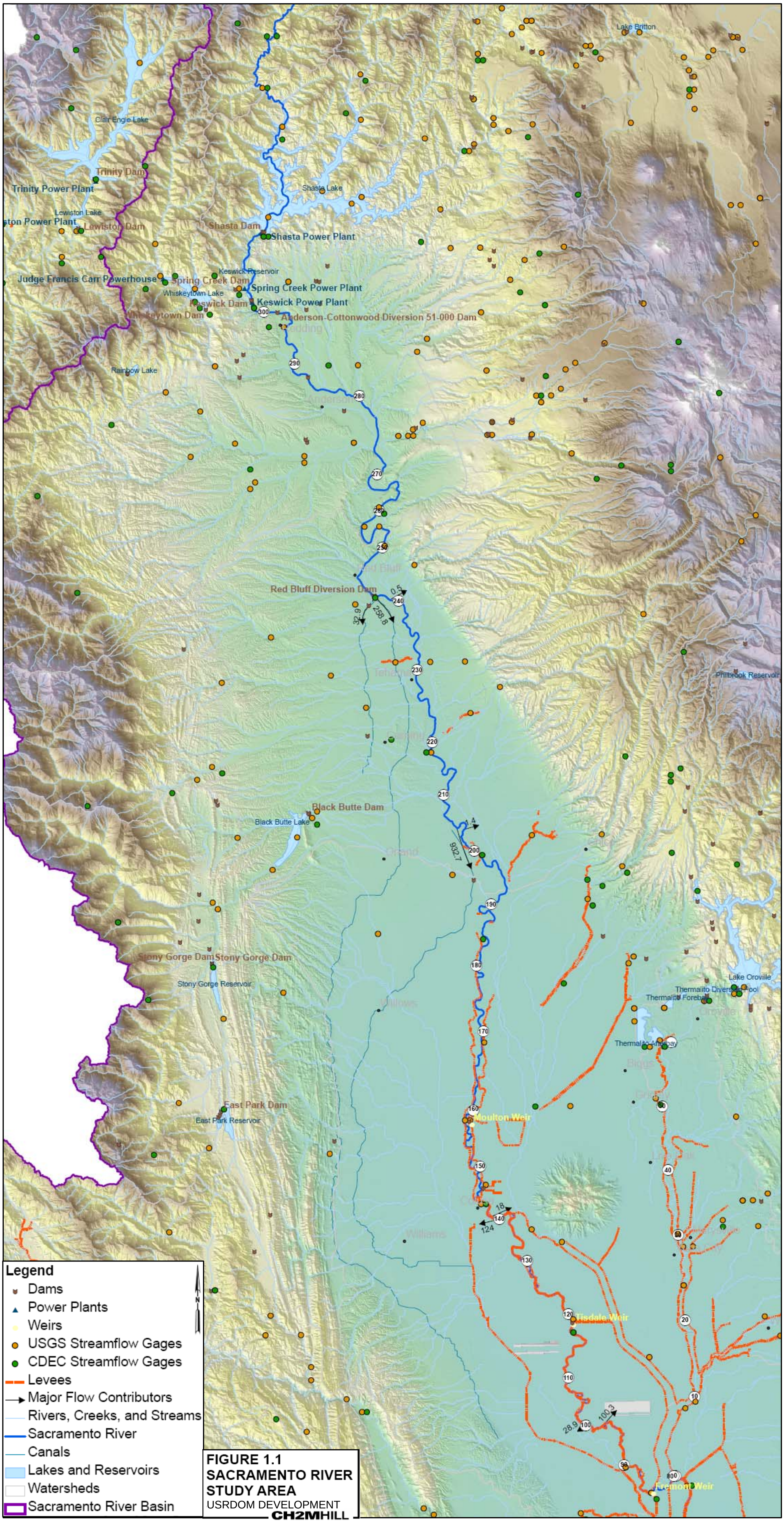

FIGURE 1.1
SACRAMENTO RIVER STUDY AREA
USRDOM DEVELOPMENT

SECTION 2

Hydrology Development

2.1 Overview

The development of a daily hydrology dataset for the Upper Sacramento River for the 82-year period (WY 1922 to WY 2003) was the first task performed as part of USRDOM development. Input time series were developed for inflows into the reservoirs and for tributaries along the Sacramento River. Available historical reservoir inflows and tributary flows were compiled for the entire 82-year period and used where available. Various methods were developed and applied to estimate flows during the periods with missing data.

2.2 Historical Data Available

An historical dataset was assembled to aid in developing the hydrology for the upper Sacramento River and in verifying the operations and routing capabilities of USRDOM. The dataset contains daily average Sacramento River flows and its tributary inflows where gaged. Historical reservoir operation data also were collected, including end-of-day storage; total release; and computed daily inflows for Trinity, Lewiston, Whiskeytown, Shasta, and Keswick reservoirs.

Sources for the historical daily data collected included the U.S. Geological Survey (USGS), Reclamation, and DWR's California Data Exchange Center (CDEC) and Water Data Library (WDL). Table 2.1 lists the source of each data record, which generally is the agency maintaining the gage, USGS gage identification number or CDEC short name, location of the measurement, the parameters measured, and the period of available daily data for every record in the historical dataset.

TABLE 2.1
Collected Historical Data

Location	Agency/ID	Parameter	Period Available
Trinity River above Coffee Creek	USGS/11523200	Flow	10/01/1957 - 10/01/2007
Sacramento River at Antler	USGS/11342500	Flow	10/01/1910 - 09/30/1941
McCloud River at Baird	USGS/11369000	Flow	10/01/1910 - 09/30/1943
Pit River near Ydalpom	USGS/11366500	Flow	10/01/1910 - 09/30/1943
Trinity River at Lewiston	USGS/11525500	Flow	10/01/1911 - 09/23/2007
Trinity Reservoir	Reclamation	Storage-EOP	11/01/1962 - 09/12/2007
Trinity Reservoir	Reclamation	Release-Total	11/01/1962 - 09/12/2007
Trinity Lake	CDEC/CLE	Outflow	11/01/1962 - 09/23/2007
Shasta Reservoir	Reclamation	Storage-EOP	12/31/1943 - 12/06/2006
Shasta Reservoir	Reclamation	Inflow	12/31/1943 - 09/12/2007
Shasta Reservoir	Reclamation	Release-Total	12/31/1943 - 09/12/2007
Shasta Dam	CDEC/SHA	Outflow	01/05/1987 - 09/30/2006
Shasta Dam	CDEC/CLE	Storage	01/01/1985 - 09/23/2007

TABLE 2.1
Collected Historical Data

Location	Agency/ID	Parameter	Period Available
Lewiston Reservoir	Reclamation	Storage-EOP	04/01/1964 - 09/30/2005
Lewiston Reservoir	Reclamation	Inflow	04/01/1964 - 09/30/2005
Lewiston Reservoir	Reclamation	Release-to-River	04/01/1964 - 09/30/2005
Lewiston Reservoir	Reclamation	Release-Total	04/01/1964 - 09/30/2005
Sacramento River at Kennett	USGS/11369500	Flow	10/01/1925 - 09/30/1942
Clear Creek at French Gulch	USGS/11371000	Flow	10/01/1950 - 09/30/1993
Judge Francis Carr Powerplant near French Gulch	USGS/11525430	Diversion	04/16/1963 - 09/30/2006
Whiskeytown Reservoir	Reclamation	Storage-EOP	04/01/1964 - 08/30/2007
Whiskeytown Reservoir	Reclamation	Release-to-SCT	04/01/1964 - 08/30/2007
Whiskeytown Reservoir	Reclamation	Inflow	04/01/1964 - 08/30/2007
Whiskeytown Reservoir	Reclamation	Release-Total	04/01/1964 - 08/30/2007
Whiskeytown Dam	CDEC/WHI	Diversion	4/01/2000 - 09/23/2007
Whiskeytown Dam	CDEC/WHI	Outflow	04/01/2000 - 09/23/2007
Spring Creek at Keswick	USGS/11371600	Diversion	01/01/1964 - 09/30/2006
Keswick Reservoir	Reclamation	Storage-EOP	10/01/1974 - 08/30/2007
Keswick Reservoir	Reclamation	Inflow	10/01/1974 - 08/30/2007
Keswick Reservoir	Reclamation	Release-Total	10/01/1974 - 08/30/2007
Keswick Reservoir	CDEC/KES	Outflow	10/02/1993 - 09/23/2007
Sacramento River at Keswick	USGS/11370500	Flow	10/01/1938 - 09/23/2007
ACID Canal at Sharon Ave Redding	USGS/11370700	Flow	04/01/1991 - 09/23/2007
Clear Creek near Igo	USGS/11372000	Flow	10/01/1940 - 09/23/2007
Churn Creek below Newtown Creek near Redding	USGS/11372060	Flow	10/01/1965 - 10/05/1972
Churn Creek near Redding	USGS/11372050	Flow	10/01/1960 - 09/30/1966
Cow Creek near Millville	USGS/11374000	Flow	10/01/1949 - 09/23/2007
Bear Creek near Millville	USGS/11374100	Flow	10/01/1959 - 09/30/1967
Cottonwood Creek near Cottonwood	USGS/11376000	Flow	10/01/1940 - 09/23/2007
Battle Creek near Cottonwood	USGS/11376500	Flow	10/01/1940 - 09/30/1961
Battle Creek near Coleman Fish Hatchery near Cottonwood	USGS/11376550	Flow	10/01/1961 - 09/23/2007
Paynes Creek near Red Bluff	USGS/11377500	Flow	10/01/1949 - 10/31/1966
Antelope Creek near Red Bluff	USGS/11379000	Flow	10/01/1940 - 09/30/1982
Red Bank Creek near Red Bluff	USGS/11378800	Flow	10/01/1959 - 09/30/1982
Red Bank Creek near Rawson Road Bridge near Red Bluff	USGS/11378860	Flow	10/01/1964 - 09/30/1967
Sacramento River above Bend Bridge near Red Bluff	USGS/11377100	Flow	10/01/1891 - 09/23/2007
Sacramento River at Bend Bridge near Red Bluff	USGS/11377200	Flow	10/01/1967 - 09/30/1970
Sacramento River near Red Bluff	USGS/11378000	Flow	10/01/1902 - 09/30/1968

TABLE 2.1
Collected Historical Data

Location	Agency/ID	Parameter	Period Available
Deer Creek near Vina	USGS/11383500	Flow	10/01/1911 - 09/24/2007
Elder Creek near Paskenta	USGS/11379500	Flow	10/01/1948 - 09/23/2007
Mill Creek near Los Mollinos	USGS/11381500	Flow	10/01/1928 - 09/23/2007
Thomes Creek at Paskenta	USGS/11382000	Flow	10/01/1920 - 09/30/1996
Thomes Creek at Rawson Road Bridge near Richfield	USGS/11382090	Flow	10/01/1977 - 11/04/1980
Big Chico Creek near Chico	USGS/11384000	Flow	10/01/1930 - 09/30/1986
Stony Creek near Hamilton City	USGS/11388500	Flow	01/01/1941 - 09/30/1973
Black Butte	CDEC/BLB	Outflow	10/01/1993 - 09/23/2007
Sacramento River at Vina Bridge near Vina	USGS/11383730	Flow	04/13/1945 - 09/30/1978
Sacramento River at Vina Bridge Near Corning	WDL/A02700	Flow	10/01/1975 - 09/30/2004
Sacramento River near Hamilton City	USGS/11383800	Flow	04/21/1945 - 10/2/1980
Sacramento River at Hamilton City	WDL/A02630	Flow	10/01/1975 - 09/30/2005
Sacramento River at Ord Ferry	WDL/A02570	Flow	10/01/1975 - 09/30/2004
Sacramento River at Butte City	USGS/1138900	Flow	10/01/1938 - 06/30/1995
Sacramento River at Butte City	WDL/A02500	Flow	10/01/1997 - 09/30/2006
Sacramento River opposite Moulton Weir	USGS/11389390	Flow	10/01/1972 - 05/02/1973
Moulton Weir Spill to Butte Basin	USGS/11389350	Flow-Spill	01/01/1943 - 09/30/1977
Moulton Weir Spill to Butte Basin near Colusa	WDL/A02986	Flow-Spill	10/01/1997 - 09/30/2004
Colusa Weir Spill to Butte Basin near Colusa	USGS/11389470	Flow-Spill	01/01/1943 - 09/30/1980
Colusa Weir Spill to Butte Basin near Colusa	WDL/A02981	Flow-Spill	10/01/1997 - 09/30/2004
Sacramento River at Colusa	USGS/11389500	Flow	04/11/1921 - 09/23/2007
Tisdale Weir near Grimes	USGS/11390480	Flow-Spill	01/01/1943 - 09/30/1980
Tisdale Weir near Grimes	WDL/A02960	Flow-Spill	10/01/1977 - 09/30/2004
Sacramento River below Wilkins Slough near Grimes	USGS/11390500	Flow	10/01/1938 - 09/23/2007
Sacramento River at Knights Landing	USGS/11391000	Flow	10/01/1940 - 04/29/1981
Colusa Basin Drain at Knights Landing	WDL/A02945	Flow	10/01/1975 - 09/30/2004

2.3 Reservoir Inflows

The mean daily inflows to Trinity and Shasta reservoirs and local flow components of the inflows to Lewiston and Whiskeytown reservoirs were estimated for the 82-year period as part of the hydrology development process. These four inflows were computed using

Reclamation operations data when available. Reclamation computed the reservoir inflow data based on the releases and other operational information. The Reclamation data were smoothed by doing a 3-day running average to eliminate mass balance errors found in the observed data from the Reclamation. Further, the inflow data were corrected for any negative values and adjusted to maintain minimum daily flows by scaling down the flows on days with higher flows to maintain the same overall monthly volume. For the periods with missing data, other historical gage data were used to synthesize the inflows. A brief description of the process and the gages that were used to synthesize the missing data is provided below. Table 2.2 summarizes this information.

TABLE 2.2
Historical Data Used for Compiling the Reservoir Inflows

Reservoir Inflow	Historical Data Source: Gage Location	Historical Data Source: Agency/ID	Period the Adjacent Historical Data Source Was Used	Reservoir Inflow Synthesis Process and Parameters
Trinity	Trinity River at Lewiston	USGS/11525500	10/1/1921 - 9/30/1960	Corrected for Lewiston local flow
	Trinity River above Coffee Creek	USGS/11523200	10/1/1960 - 9/30/1962	Scaled using the ratio of average Trinity inflow (Trinity release corrected for 50 cubic feet per second [cfs] evaporation) and average Trinity River at Coffee Creek flow for the same periods (4/1/1964 to 9/30/2003)
	Trinity Reservoir	Reclamation CVO	10/1/1962 - 9/30/2003	3-day running average and a minimum inflow of 150 cfs
Lewiston	Trinity River at Lewiston	USGS/11525500	10/1/1921 - 9/30/1960	Scaled using the ratio of average Lewiston local inflow to average Trinity River flow at Lewiston. The average Lewiston local flow was estimated by performing mass-balance based on the average observed releases at Trinity and Lewiston reservoirs for 4/1/1964 to 9/30/2003 period.
	Synthesized Trinity Reservoir inflow based on the Trinity River above Coffee Creek gage	USGS/11523200	10/1/1960 - 9/30/1962	Scaled using the ratio of average Lewiston local inflow to average Trinity River inflow. The average Lewiston local flow was estimated by performing mass-balance based on the average observed releases at Trinity and Lewiston reservoirs for 4/1/1964 to 9/30/2003 period.
	Trinity Reservoir	Reclamation CVO	10/1/1962 - 9/30/2003	

TABLE 2.2
Historical Data Used for Compiling the Reservoir Inflows

Reservoir Inflow	Historical Data Source: Gage Location	Historical Data Source: Agency/ID	Period the Adjacent Historical Data Source Was Used	Reservoir Inflow Synthesis Process and Parameters
Whiskeytown	Thomes Creek at Paskenta	USGS/11382000	10/1/1921 - 9/30/1940	Using Method 4 as described in Section 2.5, with reference baseflow of 50 cfs to compute Clear creek at French Gulch flow
	Clear Creek near Igo	USGS/11372000	10/1/1940 - 9/30/1950	Scaled using a ratio of average flow of Clear Creek at French Gulch to that of Clear Creek at Igo after a 50 cfs baseflow was removed from Igo flow to compute Clear Creek at French Gulch flow
	Clear Creek at French Gulch	USGS/11371000	10/1/1950 - 3/31/1964	Scaled using ratio of average Whiskeytown inflow to that of average flow at Clear Ck at French Gulch after a 50 cfs baseflow was removed from Whiskeytown inflow
	Whiskeytown Reservoir	Reclamation CVO	4/1/1964 - 9/30/2003	3-day running average and a minimum inflow of 50 cfs
Shasta	Sacramento River at Antler	USGS/11342500	10/1/1921 - 9/30/1925	Used to compute Sacramento River flow at Kennett by scaling it to the volume at Kennett
	McCloud River at Baird	USGS/11369000	10/1/1921 - 9/30/1925	Used to compute Sacramento River flow at Kennett by scaling it to the volume at Kennett
	Pit River near Ydalpom	USGS/11366500	10/1/1921 - 9/30/1925	Used to compute Sacramento River flow at Kennett by scaling it to the volume at Kennett
	Sacramento River at Kennett	USGS/11369500	10/1/1925 - 9/30/1938	Used to compute Sacramento River flow at Keswick by scaling it to the flow at Keswick using simple linear regression
	Sacramento River at Keswick	USGS/11370500	10/1/1938 - 12/30/1943	NA
	Shasta Reservoir	Reclamation CVO	12/31/1943 - 9/30/2003	3-day running average and a minimum inflow of 2000 cfs

Notes:

CVO = Central Valley Operations Office
NA = not applicable

Trinity Reservoir inflow for the missing period was estimated using historical records from the USGS gage on Trinity River at Lewiston. The flow at this gage was corrected for a local inflow component of Lewiston Reservoir because the gage was located downstream. The Trinity Reservoir inflow was assumed to equal this corrected flow for the period when Reclamation operations data were unavailable. For the period between 10/1/1960 and 9/30/1962, which was part of the period of construction of the Trinity and Lewiston reservoirs, the synthesized inflow from this USGS gage was found to be far lower than the rest of the period. Therefore, for these two water years, the flow data from the USGS gage on Trinity River above Coffee Creek were used to synthesize Trinity Reservoir inflows. Lewiston Reservoir local inflow for the 82-year period was computed as a fraction of Trinity River inflow. Based on the source of the observed data, different ratios of flow volumes were used to estimate Lewiston local flow as reported in Table 2.2.

Whiskeytown Reservoir local inflow for the missing period was estimated using three historical records. These data were taken from the USGS gages on Clear Creek at French Gulch, Clear Creek at Igo, and Thomes Creek at Paskenta. The inflow was estimated in two steps. The first step involved synthesizing Clear Creek at French Gulch flow since it was unavailable for the entire period, using the Clear Creek at Igo and Thomes Creek flows. The second step included synthesizing Whiskeytown local inflow using the synthesized and measured Clear Creek at French Gulch flow.

Shasta Reservoir inflow for the missing period was synthesized based on the historical data from the gage on the Sacramento River at Keswick. Because this record is not complete, data from the gage on the Sacramento River at Kennett were used to synthesize the missing Sacramento River at Keswick flow record. Because the gage at Kennett was missing some data, the combined measured flows of the Sacramento River at Antler, McCloud River at Baird, and Pit River at Ydalpom were used to synthesize the Sacramento River at Kennett flow. The periods during which each of the gages was used to synthesize Shasta inflow are summarized in Table 2.2. During the period (10/1/1938 to 12/30/1943) when Shasta Dam was under construction, the observed flow from Sacramento River at Keswick gage was used as the inflow into Shasta Reservoir.

2.4 Sacramento River Tributary Inflows

The Sacramento River Basin extending from Shasta Reservoir to Knights Landing comprises several tributaries throughout the watershed. The basin area can be divided into sub-watersheds that contribute to their respective streams and ultimately drain into the Sacramento River. These watersheds resulted from the well-defined topography in the upper regions of the area. The inflow contribution of these watersheds to the Sacramento River is observed in the form of runoff through their respective streams. Runoff through the tributary streams depends on the orientation and extent of the stream. Seasonal runoff patterns can be observed for the streams that depend purely on the precipitation for flow. Continuous flow patterns throughout the year are observed for the streams that extend high into the mountains, for which snowmelt is the source of runoff.

The Sacramento River Basin also includes other contributing areas, usually flatlands, that do not have well-defined structures to form a stream. These areas also drain into the river, but usually in the form of overland flow or groundwater inflow. The flow patterns of these areas are strongly correlated to rainfall patterns and result in flashy hydrographs.

To accurately estimate the total inflow to the Sacramento River, all streams in the basin that contribute to the river were identified. Figure 2.1 shows all 37 streams, along with their

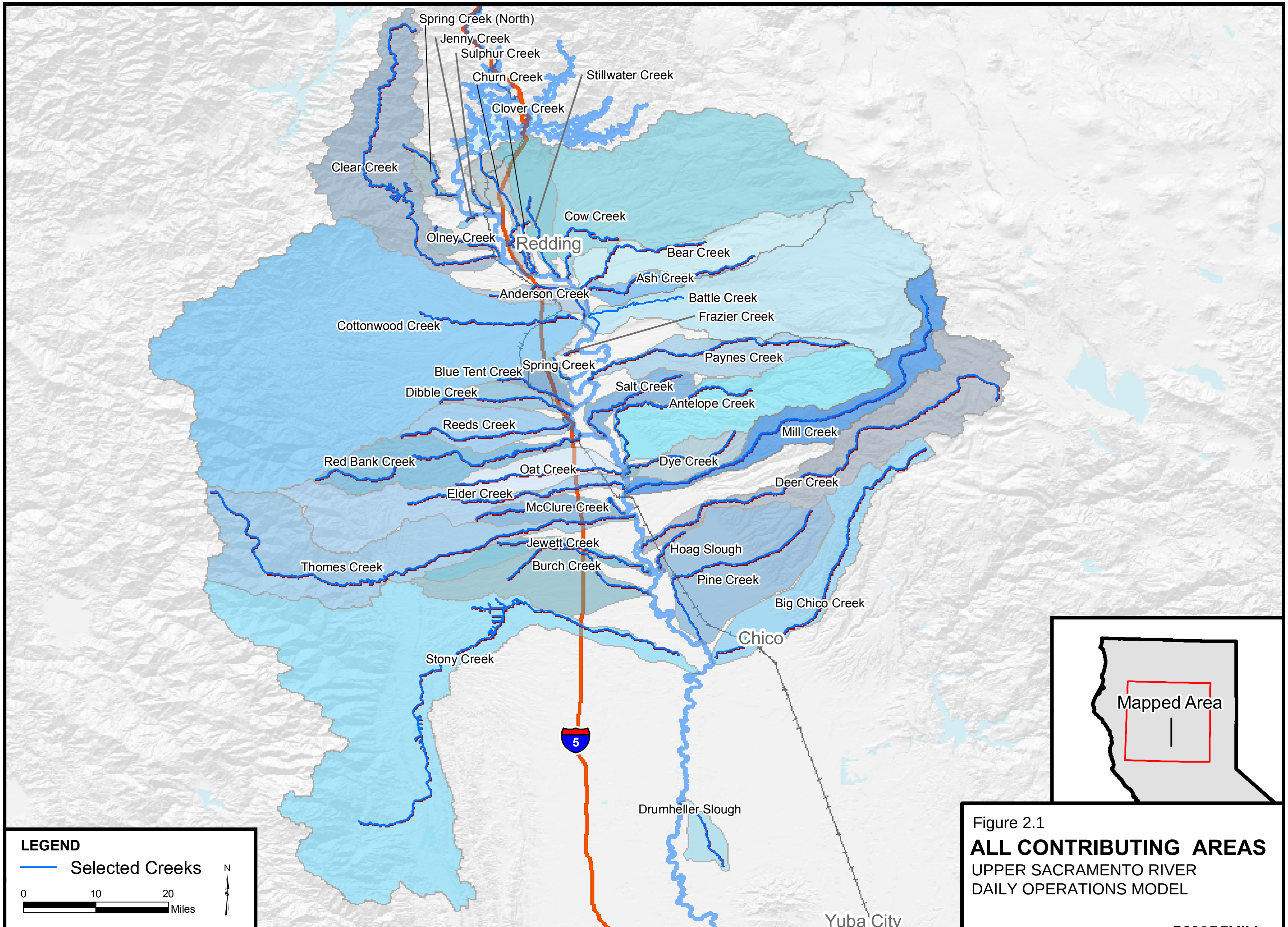

Figure 2.1

ALL CONTRIBUTING AREAS

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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contributing watersheds, that flow into the river. The grey spaces in between the watersheds are the areas that do not fall in any of the sub-watersheds but contribute directly to the river (Figure 2.1).

All streams that contribute to the river were categorized based on gage availability. The streamflow information for the gaged tributaries is known, but streamflows for ungaged tributaries were estimated using synthesis methods.

2.4.1 Contributing Area Estimation

To estimate the contributing watershed areas of all the identified tributaries of the Sacramento River, a high-resolution National Hydrography Dataset (NHD) was obtained from USGS. NHD is a comprehensive set of digital spatial data that contains information about surface water features. Surface water features are combined to form 'reaches,' which provide the framework for linking water-related data to the NHD surface water drainage network. These linkages enable the analysis and display of these water-related data in upstream and downstream order. NHD data were obtained in a combined format that covered the study area in one dataset.

2.4.1.1 Stream Tracing

For each of the identified creeks, ArcGIS ArcInfo version 9.2 software was used to trace upstream from the confluence of the creek and the Sacramento River. Using the NHD network, an attempt was made to identify all contributing streams to the main stem. Results of the tracing were visually inspected. In most cases, the NHD data yielded satisfactory results. In some cases, the stream network was not correct and tracing was performed manually. Using a 30-meter digital elevation model (DEM) raster dataset, a hill-shaded relief image was created to allow visual identification of slope direction, ridge lines, and other topography to improve estimates of stream connectivity. Finally, subsets of NHD were created consisting of all streams contributing to each of the creeks under consideration.

2.4.1.2 Watershed Delineation

CalWater version 2.2.1 was used to identify watershed boundaries. CalWater is the State of California's working definition of watershed boundaries.[1] CalWater 2.2.1 most accurately delineates true watersheds in mountainous terrain, but does not provide accurate information in the valley areas closest to the Sacramento River. In some cases, watershed boundaries within CalWater are based on administrative boundaries rather than physical geography.

For areas surrounding the NHD subsets where inaccuracies were found and additional watershed delineation was needed to calculate the contributing areas. The contributing areas were manually delineated using a combination of the NHD and CalWater data sets and the DEM hill-shaded images.

2.4.1.3 Contributing Area Calculations

Contributing areas were calculated by visually inspecting each upstream tracing and, where appropriate, using CalWater watershed boundaries to define the surface area associated with each of the contributing streams. In cases where watershed definitions were not

[1] More information about CalWater can be found at: http://gis.ca.gov/casil/hydrologic/watersheds/calwater/.

accurate, the contributing areas were manually delineated. The manual process required a visual examination of topography, slope direction, stream locations, and watershed boundaries to derive surface area contribution. In some cases (because of agricultural diversion structures such as canals), creating an accurate estimate was difficult. However, using a combination of the three data sets mentioned above provided sufficient accuracy for the delineation and area calculations for the purposes of this study.

2.4.2 Gaged Tributaries

Historical streamflow data for the gaged tributaries shown in Figure 2.1 were obtained from USGS. From the analysis described above, the contributing watershed areas of the streams up to the mouth of the stream and the gage locations were estimated. These estimated areas were verified using drainage area data from USGS. The watersheds have distinct shapes and orientations that result in varied inflow magnitudes and varied timing of flow to the Sacramento River. Inflows from the tributaries on each side of the river correlate well with other tributaries on the same side. Minimum correlation was observed between the tributaries on opposite banks of the river. When considering the correlations on same side of the bank, tributaries with watershed areas similar in shape and size were found to be well correlated. For example, Deer Creek and Mill Creek are similar in shape and have inflows approximately equal to the ratio of their watershed areas.

In most cases, watersheds at lower elevations show good correlation with similar creeks because the source of runoff is mostly rainfall. For example Cottonwood Creek is very well correlated with Elder Creek and Red Bank Creek. Table 2.3 lists the gaged tributaries and their contributing watershed areas up to the confluence with the Sacramento River.

TABLE 2.3
Gaged Tributaries and Contributing Watershed Areas

Tributary	Bank (Left = Eastside, Right = Westside)	Contributing Watershed Area up to the gage (mi^2)	Total Contributing Watershed Area (mi^2)
Clear Creek	Right	228	244
Churn Creek	Left	11.9	36
Cow Creek	Left	425	428
Bear Creek	Left	75.7	122
Cottonwood Creek	Right	927	944
Battle Creek	Left	357	372
Paynes Creek	Left	92.8	92
Red Bank Creek	Right	109	111
Antelope Creek	Left	123	197
Elder Creek	Right	136	150
Mill Creek	Left	133	142
Thomes Creek	Right	284	292
Deer Creek	Left	210	227
Big Chico Creek	Left	72.4	150
Stony Creek	Right	773	795

Note:
mi^2 = square miles

This section provides a brief description of each gaged tributary in terms of hydrographic characteristics, location (origin and confluence), and information about the reference tributary used to develop the time series for the 82-year period. A more detailed description of some locations can be found in the reference document (CH2M HILL, 1998). The attributes of the gaged streams in terms of flow magnitudes, period of data available, and confluence with river are shown in Table 2.4. Table 2.5 summarizes the reference tributaries used to develop missing data in the 82-year flow record for the gaged tributaries. The 82-year daily flow time series were not developed for Churn Creek, Clear Creek, Bear Creek, and Stony Creek.

TABLE 2.4
Attributes of Gaged Tributaries

Tributary Name	River Mile at Confluence with River	Agency/ID	Data Availability Period	Mean Flow for the Gaged Period (cfs)	Annual Volume Avg (TAF/yr)
Clear Creek	289	USGS/11372000	10/01/1940 - 09/12/2007	261.70	189.60
Churn Creek	284	USGS/11372060	10/01/1965 - 10/05/1972	23.75	17.20
Cow Creek	280	USGS/11374000	10/01/1949 - 09/12/2007	687.30	497.90
Bear Creek	277.5	USGS/11374100	10/01/1959 - 09/30/1967	81.57	59.10
Cottonwood Creek	273	USGS/11376000	10/1/1940 - 09/12/2007	886.90	642.50
Battle Creek	271.5	USGS/11376500	10/01/1940 - 09/30/1961	448.20	324.70
Paynes Creek	253	USGS/11377500	10/01/1949 - 10/31/1966	70.30	50.90
Red Bank Creek	243	USGS/11378800	10/01/1959 - 09/30/1982	48.60	35.20
Antelope Creek	235	USGS/11379000	10/01/1940 - 09/30/1982	150.70	109.20
Elder Creek	230	USGS/11379500	10/01/1948 - 09/12/2007	104.00	75.40
Mill Creek	230	USGS/11381500	10/01/1928 - 09/12/2007	304.90	220.90
Thomes Creek	226	USGS/11382000	10/01/1920 - 09/30/1996	289.70	209.90
Deer Creek	220	USGS/11383500	10/01/1911 - 09/12/2007	320.50	232.20
Big Chico Creek	193	USGS/11384000	10/01/1930 - 09/30/1986	149.50	108.30
Stony Creek	190	USGS/11388500	01/01/1941 - 09/30/1973	437.24	316.80

Note:

TAF/yr = thousand acre-feet per year

TABLE 2.5
Historical Data Used for Developing Tributary Inflow Hydrology

Tributary	Data Source: Location	Data Source: Agency/ID	Period the Corresponding Data Were Used in the Combined Time Series
Cow Creek	Big Chico Creek	USGS/11384000	10/01/1921 - 09/30/1949
	Cow Creek	USGS/11374000	10/01/1949 - 09/30/2003
Cottonwood Creek	Elder Creek	USGS/11379500	10/01/1921 - 09/30/1940
	Thomes Creek	USGS/11382000	10/01/1921 - 09/30/1940
	Red Bank Creek	USGS/11378800	10/01/1921 - 09/30/1940
	Cottonwood Creek	USGS/11376000	10/01/1940 - 09/30/2003
Battle Creek	Mill Creek	USGS/11381500	10/01/1921 - 09/30/1940
	Battle Creek	USGS/11376500	10/01/1940 - 09/30/1961
	Battle Creek	USGS/11376550	10/01/1961 - 09/30/2003
Paynes Creek	Big Chico Creek	USGS/11384000	10/01/1921 - 09/30/1949
	Paynes Creek	USGS/11377500	10/01/1949 - 10/31/1966
	Big Chico Creek	USGS/11384000	11/01/1966 - 09/30/2003
Red Bank Creek	Elder Creek	USGS/11379500	10/01/1921 - 09/30/1959
	Red Bank Creek	USGS/11378800	10/01/1959 - 09/30/1982
	Elder Creek	USGS/11379500	10/01/1982 - 09/30/2003
Antelope Creek	Mill Creek	USGS/11381500	10/01/1921 - 09/30/1940
	Antelope Creek	USGS/11379000	10/01/1940 - 09/30/1982
	Mill Creek	USGS/11381500	10/01/1982 - 09/30/2003
Elder Creek	Thomes Creek	USGS/11382000	10/01/1921 - 09/30/1948
	Elder Creek	USGS/11379500	10/01/1948 - 09/30/2003
Mill Creek	Deer Creek	USGS/11383500	10/01/1911 - 09/30/1928
	Mill Creek	USGS/11381500	10/01/1928 - 09/30/2003
Thomes Creek	Thomes Creek	USGS/11382000	10/01/1921 - 09/30/1996
	Elder Creek	USGS/11379500	10/01/1996 - 09/30/2003
Deer Creek	Deer Creek	USGS/11383500	10/01/1921 - 09/30/2003
Big Chico Creek	Deer Creek	USGS/11383500	10/01/1911 - 09/30/1930
	Big Chico Creek	USGS/11384000	10/01/1930 - 09/30/1986
	Deer Creek	USGS/11383500	10/01/1986 - 09/30/2003

2.4.2.1 Clear Creek

Clear Creek originates in the Trinity Mountains west of Shasta Reservoir at an elevation of about 6,200 feet and flows east for about 50 miles to the Sacramento River near the town of Anderson, California, at river mile 289 (Figure 2.2). Total contributing area of the watershed up to the mouth of the stream is about 244 square miles. Runoff is usually observed year-long because of snowmelt from the Trinity Mountains. Clear Creek has been heavily affected by regulation in Whiskeytown Reservoir, which was completed in 1963. The contributing area of the watershed below the reservoir down to the mouth of the stream is only 44 square miles, while the region above the reservoir is 200 square miles. The USGS gage at Igo has the longest period of record for the Clear Creek streamflow, covering October 1940 to present. The drainage area of the watershed above this gage is 228 square miles.

2.4.2.2 Churn Creek

Churn Creek originates just below the ridge line of the mountains surrounding Shasta Reservoir. It flows north to south, parallel to the Sacramento River from Lake Shasta to the point of confluence below Redding (Figure 2.3). Churn Creek is partly influenced by snowmelt. The USGS gage located closest to the confluence is at Redding and has records from 1965 to 1972.

2.4.2.3 Cow Creek

Cow Creek flows southeast from the Cascade Range, entering the Sacramento River approximately 4 miles east of Anderson, California. It drains 428 square miles, with many tributaries. The main stream system is approximately 66 miles long, flowing from an elevation of about 6,500 feet near Huckleberry Mountain to about 350 feet at the confluence with the Sacramento River. Although there is no significant water storage Dam on Cow Creek, there are numerous small agricultural diversions in the watershed. Figure 2.4 shows the Cow Creek watershed with measurement gages and contributing areas.

USGS gage Cow Creek at Millville (11374000) is the closest gage to the confluence of the river. Records are available from October 1949 to present. To have a complete data set for WY 1922 to WY 2003, Cow Creek data prior to October 1949 were synthesized using Big Chico Creek flow patterns and flow magnitudes as references. The contributing areas of watersheds and flow averages are used to compute different synthetic parameters such as Reference Area Multiplier, Reference Base Flow Multiplier, Runoff Factor, and Reference-based Runoff Multiplier. A detailed description of the synthesis methods is provided later in this report. Cow Creek is mostly dependent on spring runoff and has no baseflow. Big Chico Creek is dependent on snowmelt and has a consistent baseflow. Therefore, for computing the runoff factor, the baseflow of Big Chico Creek was removed.

2.4.2.4 Cottonwood Creek

Cottonwood Creek originates on the western side of the Sacramento Valley, draining the eastern side of the Trinity and North Yola Bolly mountains of the interior Coast Range into the Sacramento River at a point near the town of Cottonwood, about midway between Redding and Red Bluff (Figure 2.5). The 944-square-mile watershed has numerous tributaries, flowing from an elevation of 7,863 feet to about 350 feet at the confluence of the Sacramento River. There are no major regulating reservoirs in the Cottonwood Creek watershed. Cottonwood Creek is mainly influenced by heavy winter precipitation runoff.

Cottonwood Creek flow is measured by a gage near Cottonwood (USGS 11376000). The gage is located below all local development and has flow records for WY 1941 through WY 2007. Data from this gage are used as tributary inflow for the available period. For WY 1921 to WY 1940, the data were estimated using the combined historical and synthesized records of Elder, Thomes, and Red Bank creeks. The reference creeks were chosen because the combined watershed areas of the three creeks are similar in shape to the watershed area of Cottonwood Creek.

2.4.2.5 Battle Creek

Battle Creek originates on the eastern slopes of Lassen Peak at an elevation of 10,457 feet. Draining about 372 square miles, Battle Creek travels west, entering the Sacramento River near the town of Cottonwood at an elevation of 350 feet. The stream is 41 miles long and has north and south forks that meet about 16 miles above the Sacramento River. Battle Creek is regulated by McCumber Reservoir, located on the north fork, and by several hydroelectric facilities owned by Pacific Gas & Electric (PG&E).

Battle Creek flow is measured by USGS gages 11376500 and 11376550, which are close to each other (Figure 2.6). The historical data combined from two gages are available from October 1940 to September 2007. Data from WY 1921 to WY 1940 were estimated from the combined historical and synthesized data of Mill Creek.

2.4.2.6 Paynes Creek

Paynes Creek originates in the mountains of Lassen National Forest and flows west to the Sacramento River to join the river above Red Bluff. Paynes Creek drains about 92 square miles, forming a narrow leaf-shaped watershed (Figure 2.7). Because of its narrow shape, runoff times are usually short during precipitation events. USGS gage (11377500) on Paynes Creek near Red Bluff measures the daily mean flow. The historical streamflow data are available for WY 1949 to WY 1966. Data prior to 1949 and after 1966 for Paynes Creek were estimated using the combined records of Big Chico Creek.

2.4.2.7 Red Bank Creek

Red Bank Creek originates on Ball Mountain west of the Sacramento River and is formed by numerous tributaries from the mountains joining in the main stream. Red Bank Creek flows east to the Sacramento River, meeting just upstream of the Red Bluff Diversion Dam (Figure 2.8). USGS gage (11378800) measures the daily mean flow of the creek. The period of record available for this gage is WY 1959 to WY 1982. Missing period inflow data for the creek were estimated using the combined flow records of Elder Creek.

2.4.2.8 Antelope Creek

The headwaters of the Antelope Creek watershed are located on Turner Mountain in the Cascade Range. Antelope Creek drains about 197 square miles flowing southwest from an elevation of about 6,890 feet through the Lassen National Forest to an elevation of about 230 feet at the Sacramento River confluence, about 9 miles south of Red Bluff, California.

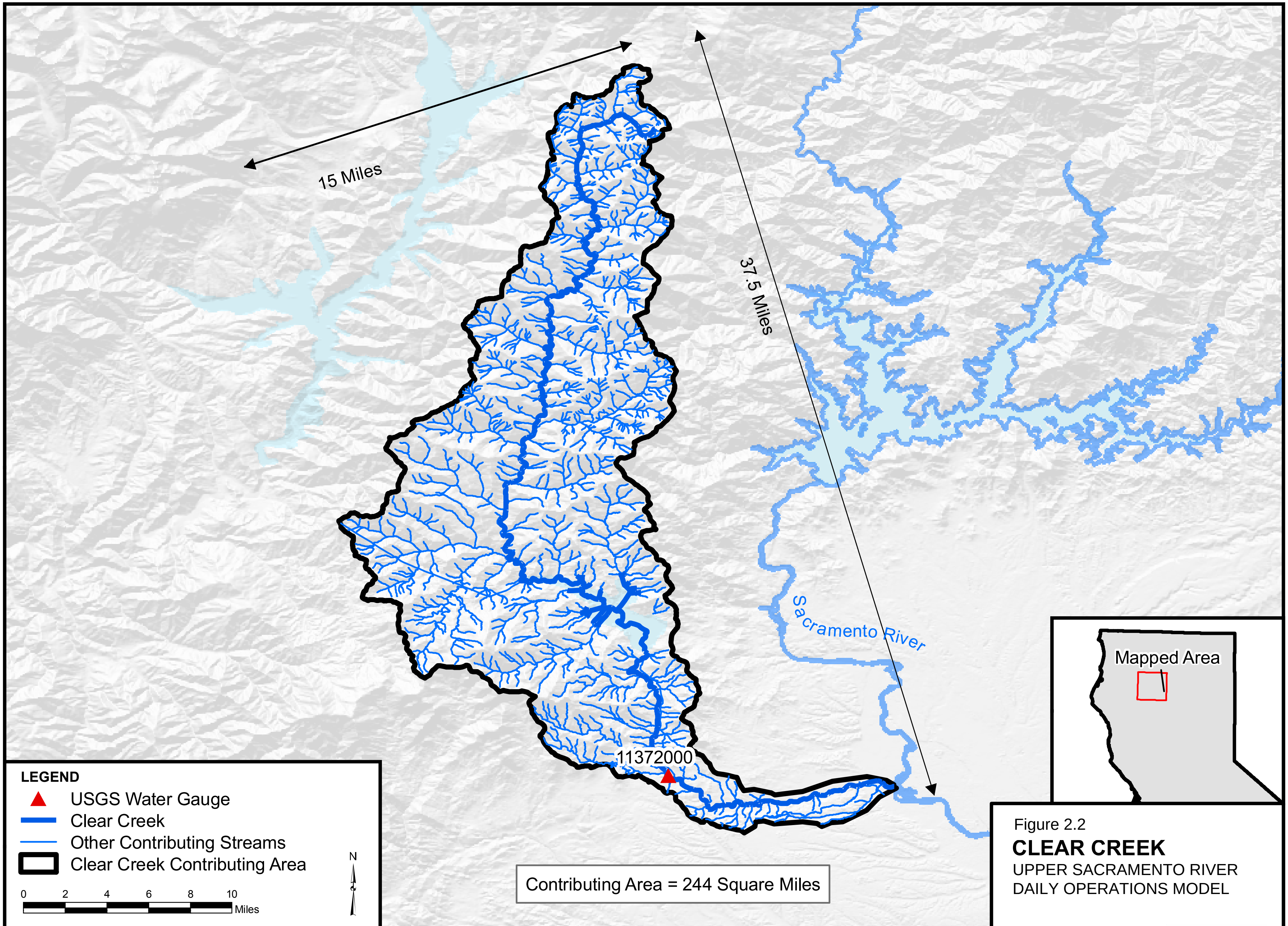

Figure 2.2
CLEAR CREEK
UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

CH2MHILL

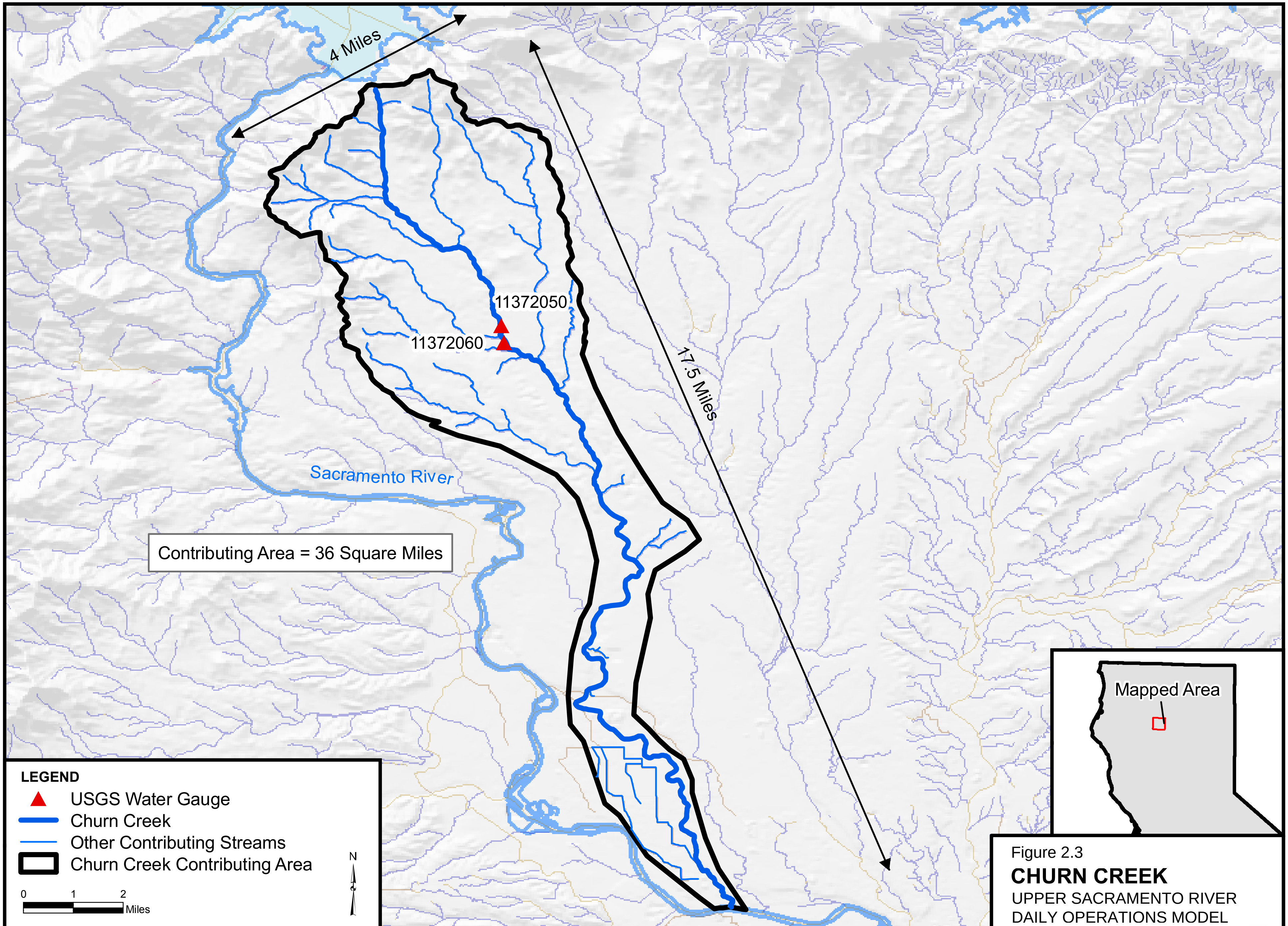

Figure 2.3
CHURN CREEK
UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL
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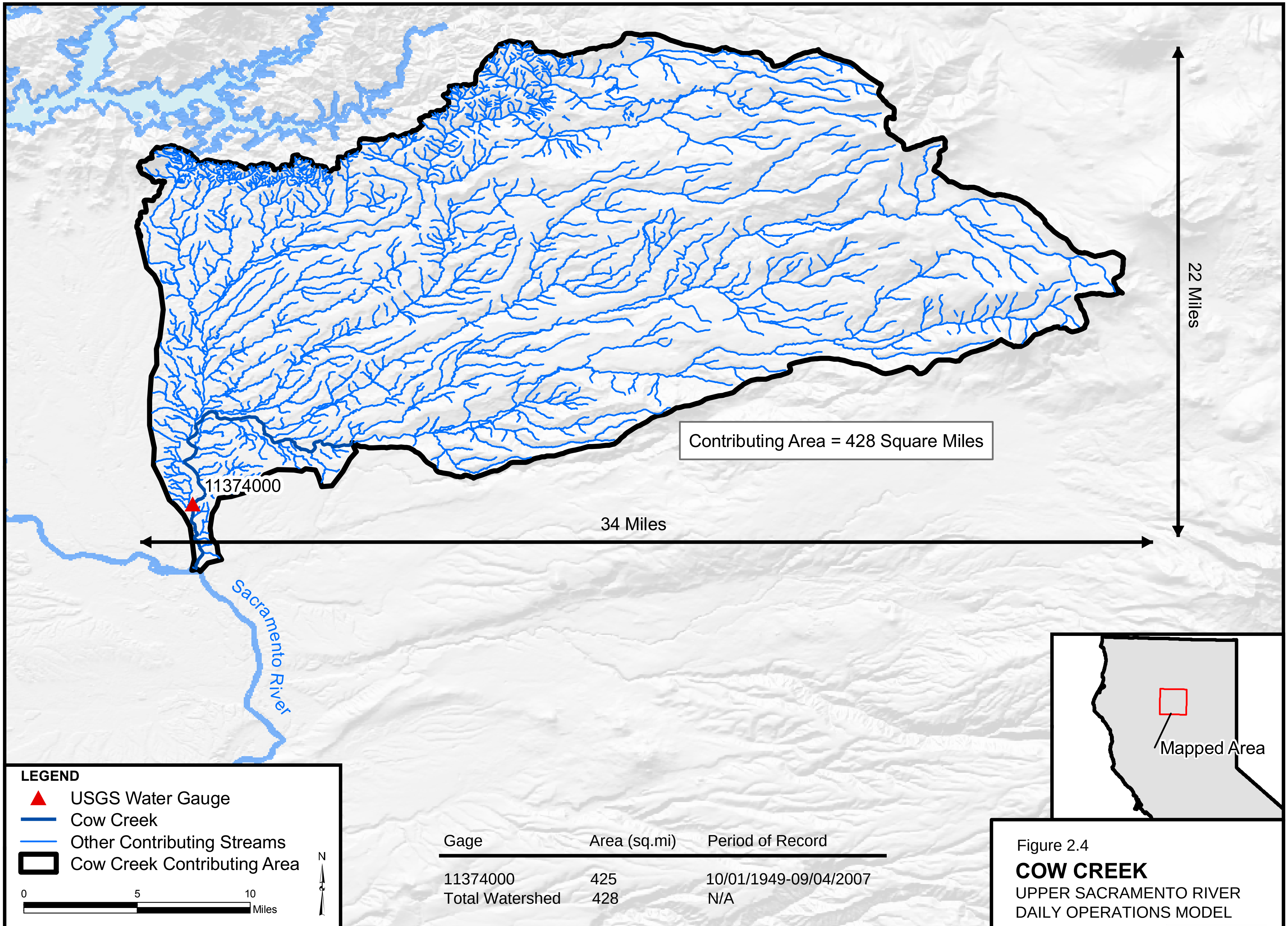

Gage	Area (sq.mi)	Period of Record
11374000	425	10/01/1949-09/04/2007
Total Watershed	428	N/A

Figure 2.4

COW CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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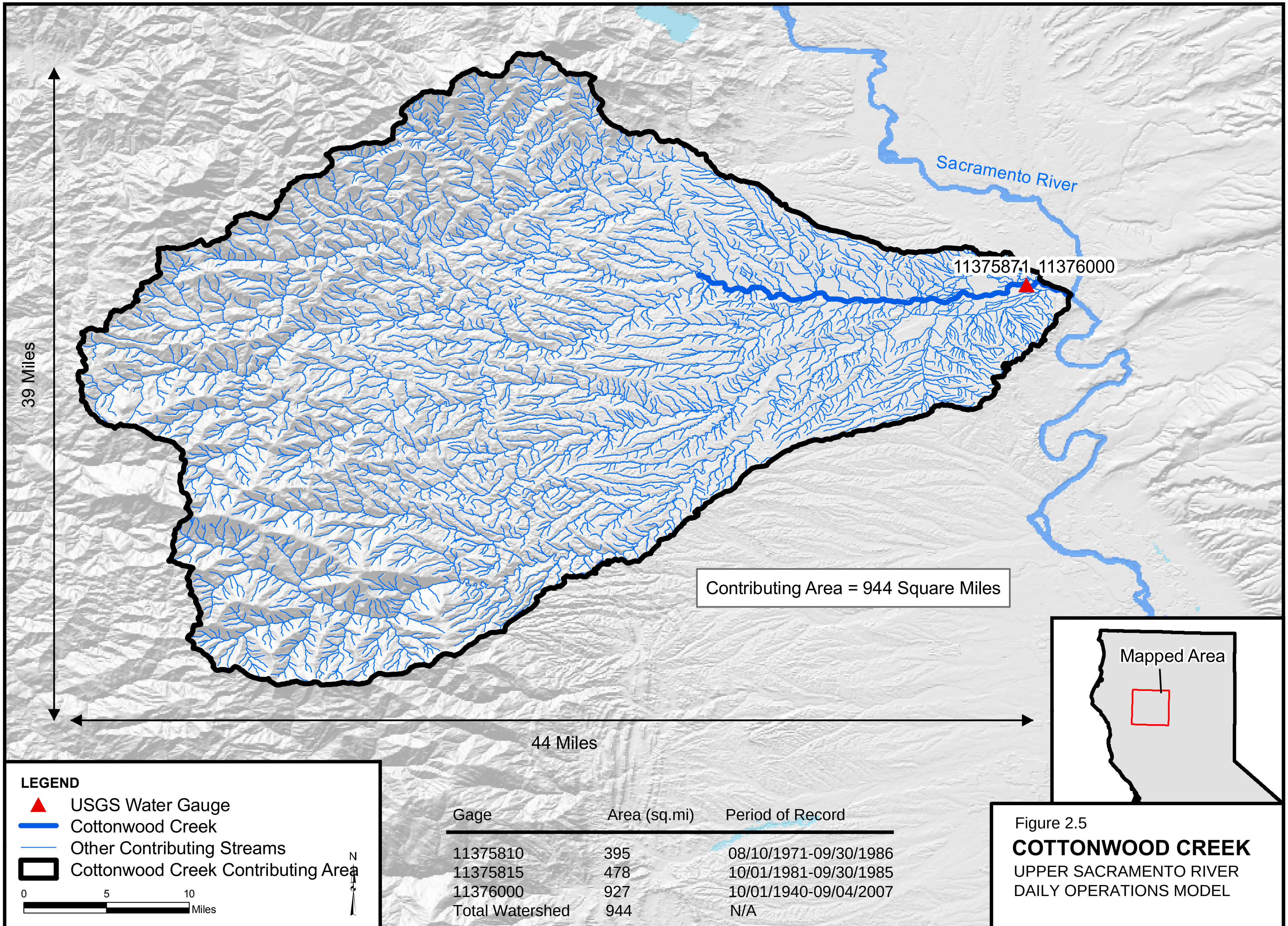

Gage	Area (sq.mi)	Period of Record
11375810	395	08/10/1971-09/30/1986
11375815	478	10/01/1981-09/30/1985
11376000	927	10/01/1940-09/04/2007
Total Watershed	944	N/A

Figure 2.5

COTTONWOOD CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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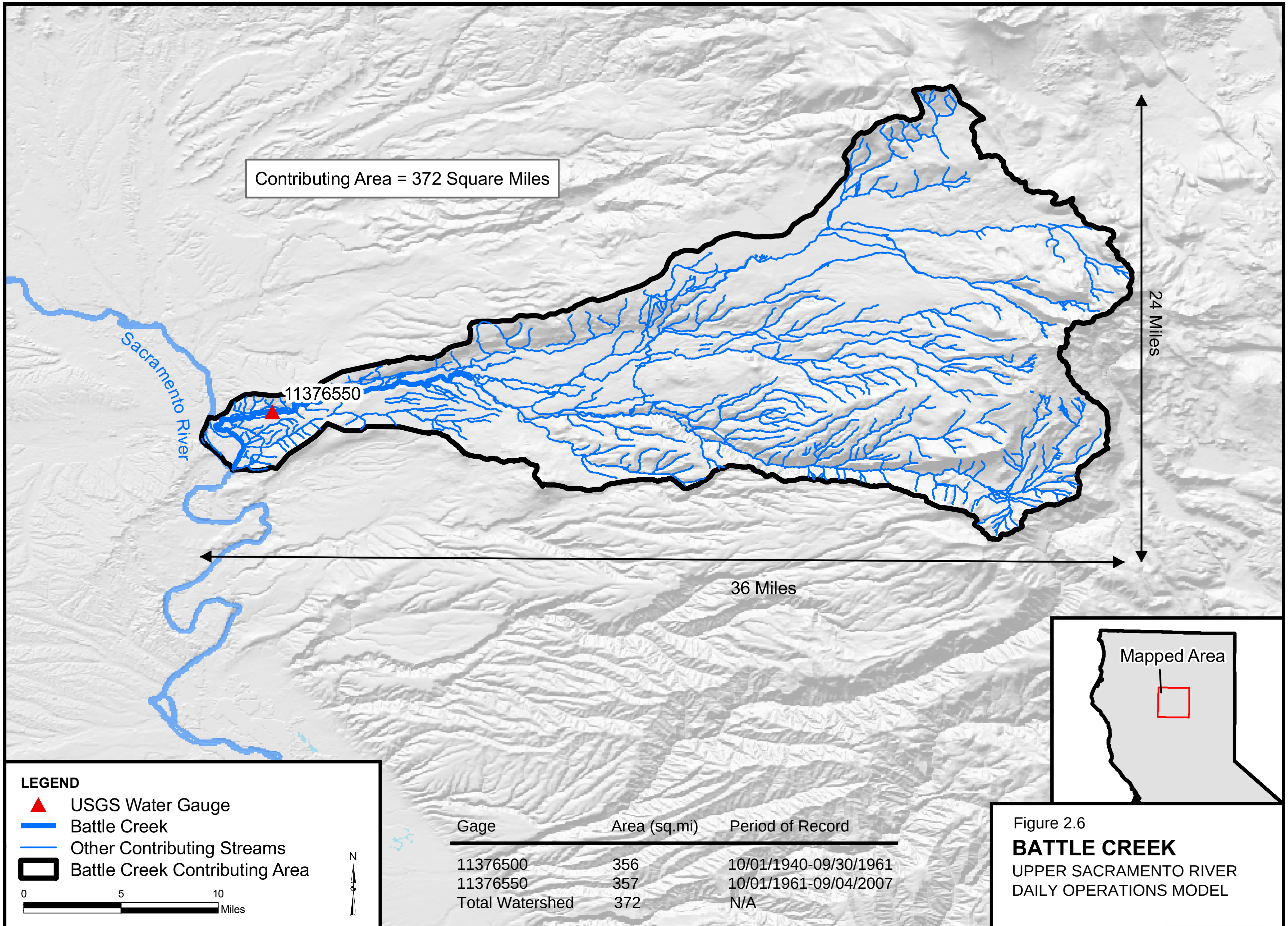

Gage	Area (sq.mi)	Period of Record
11376500	356	10/01/1940-09/30/1961
11376550	357	10/01/1961-09/04/2007
Total Watershed	372	N/A

Figure 2.6
BATTLE CREEK
UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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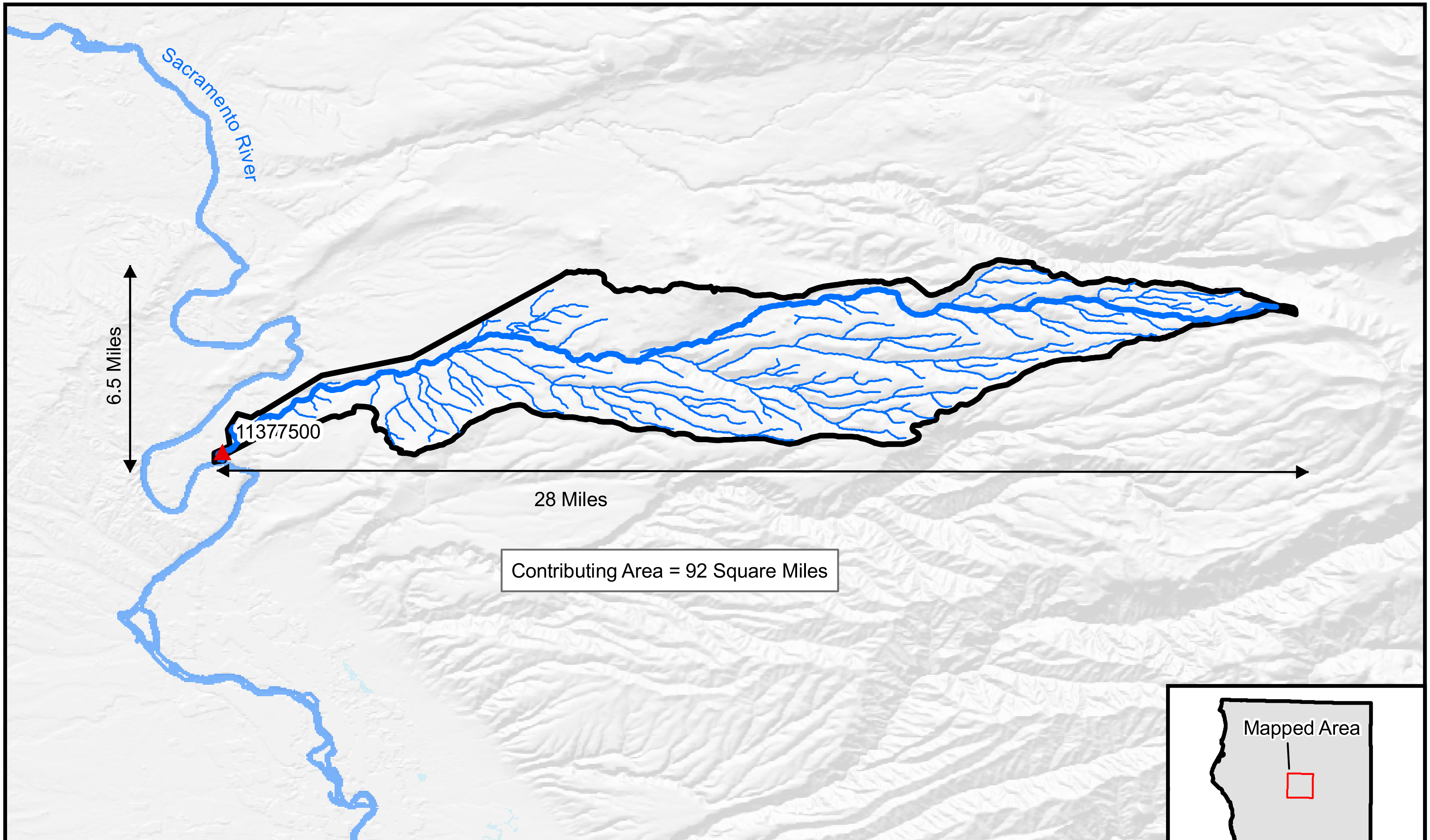

LEGEND

- USGS Water Gauge
- Paynes Creek
- Other Contributing Areas
- Paynes Creek Contributing Area

Gage	Area (sq.mi)	Period of Record
11377500	92	10/01/1949-10/31/1966
Total Watershed	92	N/A

Figure 2.7

PAYNES CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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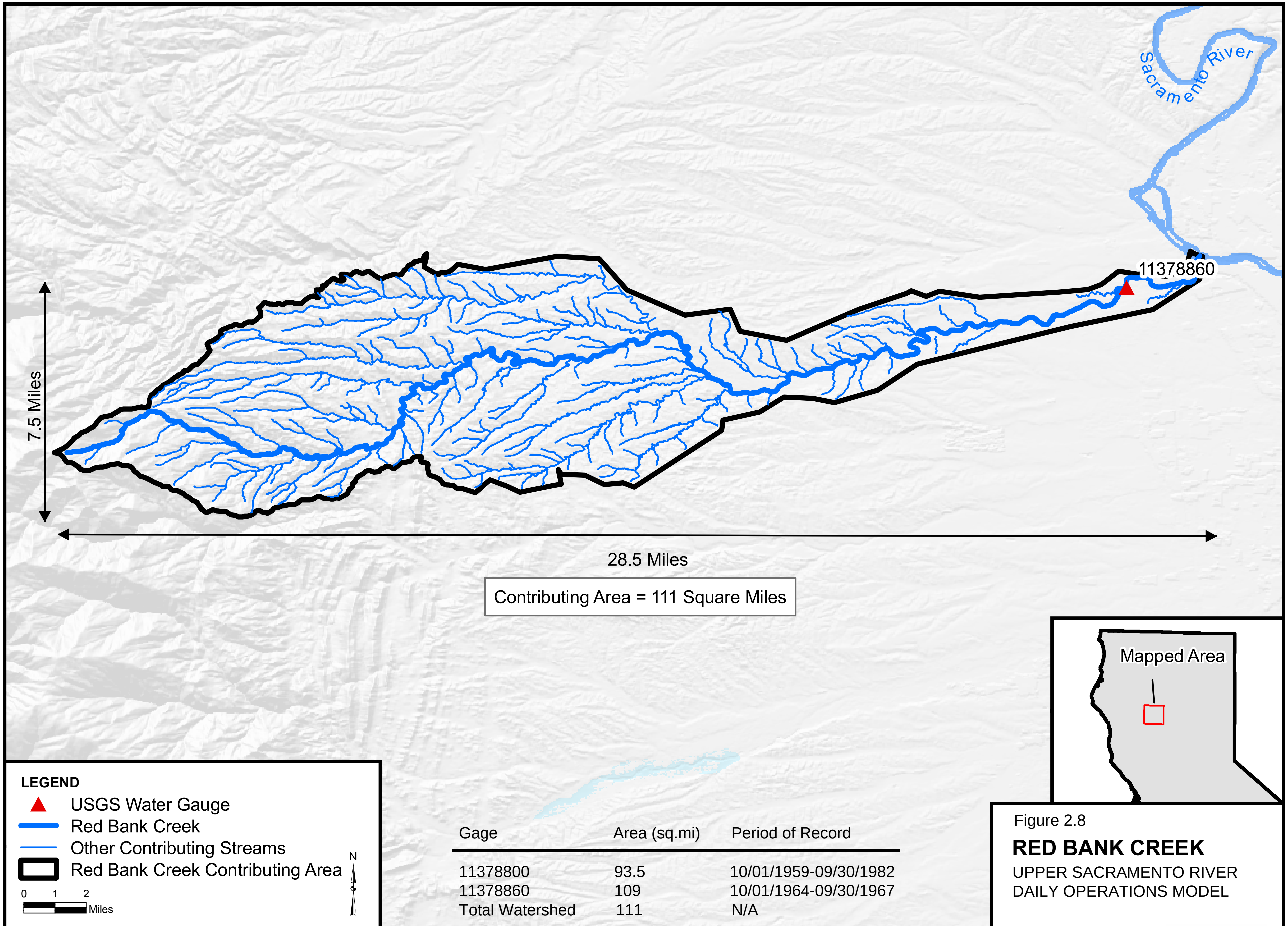

Gage	Area (sq.mi)	Period of Record
11378800	93.5	10/01/1959-09/30/1982
11378860	109	10/01/1964-09/30/1967
Total Watershed	111	N/A

Figure 2.8

RED BANK CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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Antelope Creek daily flow is measured by USGS gage (11379000) located near Red Bluff (Figure 2.9). This gage has historical data from WY 1940 to WY 1982. Inflow data before 1940 and after 1982 for the creek were estimated using the combined inflow data from Mill Creek.

2.4.2.9 Elder Creek

Elder Creek originates west of the Sacramento River and flows east to join the river near Tehama City. Tributaries from Ball Mountain combine and flow as a single stream through Tehama County toward the Sacramento River. The total watershed area draining to the creek is about 150 square miles. Figure 2.10 shows the Elder Creek watershed and USGS gages located on the creek. The gage with the longest record is USGS 11379500, which is about halfway to the river and drains approximately 92.5 square miles. The historical streamflow data for this gage are available from WY 1948 to WY 2007. Inflow data before 1948 were estimated using historical data from Thomes Creek.

2.4.2.10 Mill Creek

Mill Creek originates high on the western side of Lassen Peak at an elevation of 10,457 feet. It flows west, draining about 142 square miles and entering the Sacramento River near the town of Los Molinos, just south of Red Bluff at an elevation of 230 feet (Figure 2.11).

Mill Creek flow is measured by USGS 11381500 for WY 1928 to WY 2007. Data prior to WY 1928 were estimated using the historical gage records from Deer Creek.

2.4.2.11 Thomes Creek

Thomes Creek originates in the Mendocino National Forest at Ball Mountain. Numerous tributaries in the mountains combine and flow as Thomes Creek east to the Sacramento River. The main source of runoff is snowmelt from Ball Mountain. Its total watershed area is about 292 square miles (Figure 2.12). Two USGS gages measure the streamflow. USGS gage 11382000 has the longest record, from WY 1920 to WY 1996, and is located halfway to the river. Data after WY 1996 were estimated using historical records from Elder Creek.

2.4.2.12 Deer Creek

Deer Creek originates high on the northern slope of Butt Mountain and drains about 227 square miles, entering the Sacramento River at Woodson Bridge State Recreation Area. Deer Creek flow is measured by USGS 11383500, which has a complete record from WY 1911 to WY 2007 (Figure 2.13).

2.4.2.13 Big Chico Creek

Big Chico Creek originates on Colby Mountain in the Cascade Range at an elevation of 6,000 feet. It drains a 150-square-mile watershed into the Sacramento River 5 miles west of Chico (Figure 2.14). Flow in Big Chico Creek is measured by USGS 11384000, which has records from WY 1930 to WY 1986. Data prior to 1930 and after 1986 were estimated using historical records from Deer Creek.

2.4.2.14 Bear Creek

Bear Creek originates on the eastern side of the Sacramento Valley and drains 122 square miles of watershed. Bear Creek flow is measured by USGS 11374100 near Millville (Figure 2.15). This gage has flow records for WY 1959 through WY 1967.

2.4.2.15 Stony Creek

Stony Creek originates on the west side of the Sacramento Valley. The total contributing area of the watershed up to the mouth of the stream is about 795 square miles east to the Sacramento River near Ord, California, at river mile 190 (Figure 2.16). Stony Creek flows are affected by regulation in the Black Butte Reservoir. USGS 11388500 near Hamilton City has the longest period of record (from January 1941 to September 1973) for Stony Creek streamflow. The drainage area of the watershed above this gage is 773 square miles.

2.4.3 Ungaged Tributaries and Areas

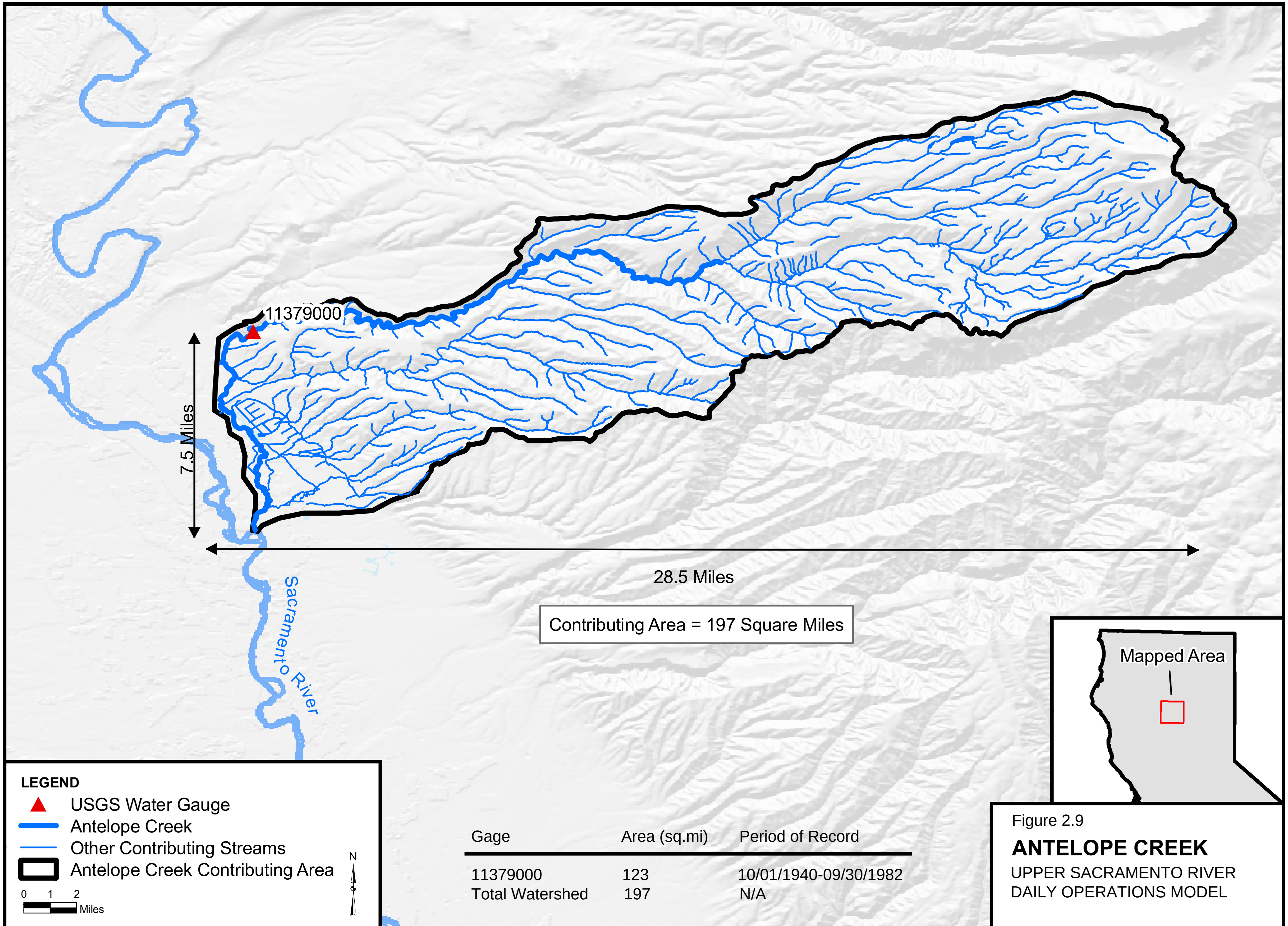
In addition to the flows from the above described gaged tributaries, the Sacramento River receives flows from the ungaged tributaries and the valley floor areas. These flows are generally intermittent and strongly dependent on the rainfall. In developing the hydrology, flows were not estimated for these individual ungaged areas. Instead the flow contributions from these areas were lumped into “closure terms” for modeling purposes as described Section 3.3. Since some of the gages on the tributaries described in Section 2.4.2 were not necessarily located at the mouth of each stream, the additional contributing areas from the gage location to the mouth of the stream were also lumped with the other ungaged areas.

2.5 Data Synthesis Methods

Historical data prior to the 1940s were unavailable for most of the tributaries and the main rivers flowing into the reservoirs. Therefore, several methods for synthesizing tributary flows and reservoir inflows were developed for filling the missing flow data in the 82-year period hydrology.

In general, the data synthesis for any tributary was based on one or more reference streams. Initial selection of a reference stream was based on the correlation between the historical flows in the tributary with missing data and the reference stream. Factors such as contributing watershed areas, average runoff volumes, and baseflows of the two streams were also considered. Tributaries were found to be well correlated with streams on the same side of the Sacramento River, which may be because of the similar hydrologic characteristics in the respective watersheds.

The missing data for the tributaries and reservoir inflows were estimated based on streamflow in a reference tributary using one of the synthesis methods described below. The selection of the method was based on the quality of the synthesized tributary flow in comparison to the observed flow for the same tributary. Histograms were plotted for the gaged tributary flow and the combined (synthesized and historical) tributary flow to prevent the synthesized flow from altering the natural variability in the tributary flows. For each method, a reference stream was identified based on the available gage data and how well it correlated with the tributary being synthesized.



Gage	Area (sq.mi)	Period of Record
11379000	123	10/01/1940-09/30/1982
Total Watershed	197	N/A

Figure 2.9

ANTELOPE CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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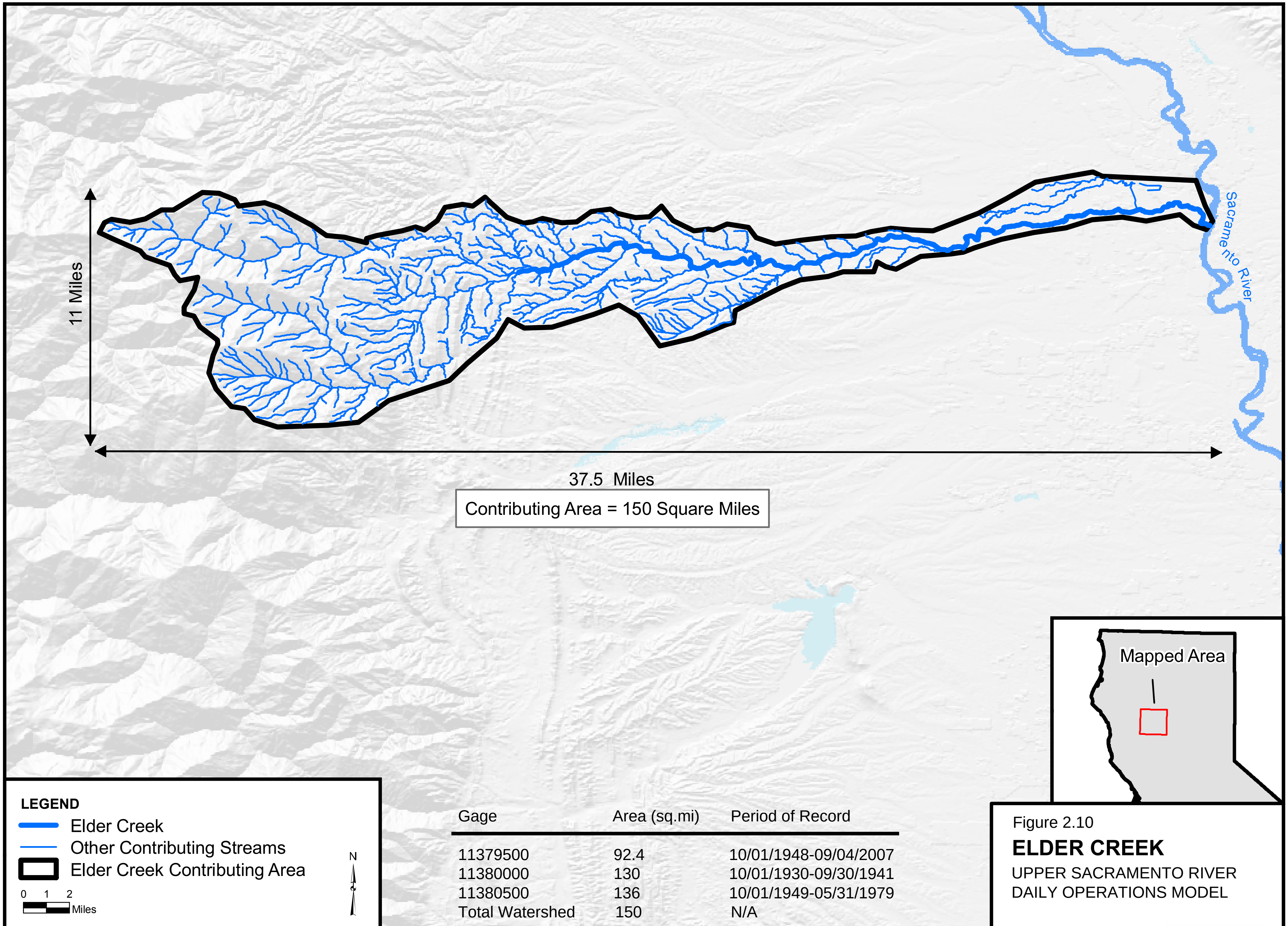

Gage	Area (sq.mi)	Period of Record
11379500	92.4	10/01/1948-09/04/2007
11380000	130	10/01/1930-09/30/1941
11380500	136	10/01/1949-05/31/1979
Total Watershed	150	N/A

Figure 2.10
ELDER CREEK
UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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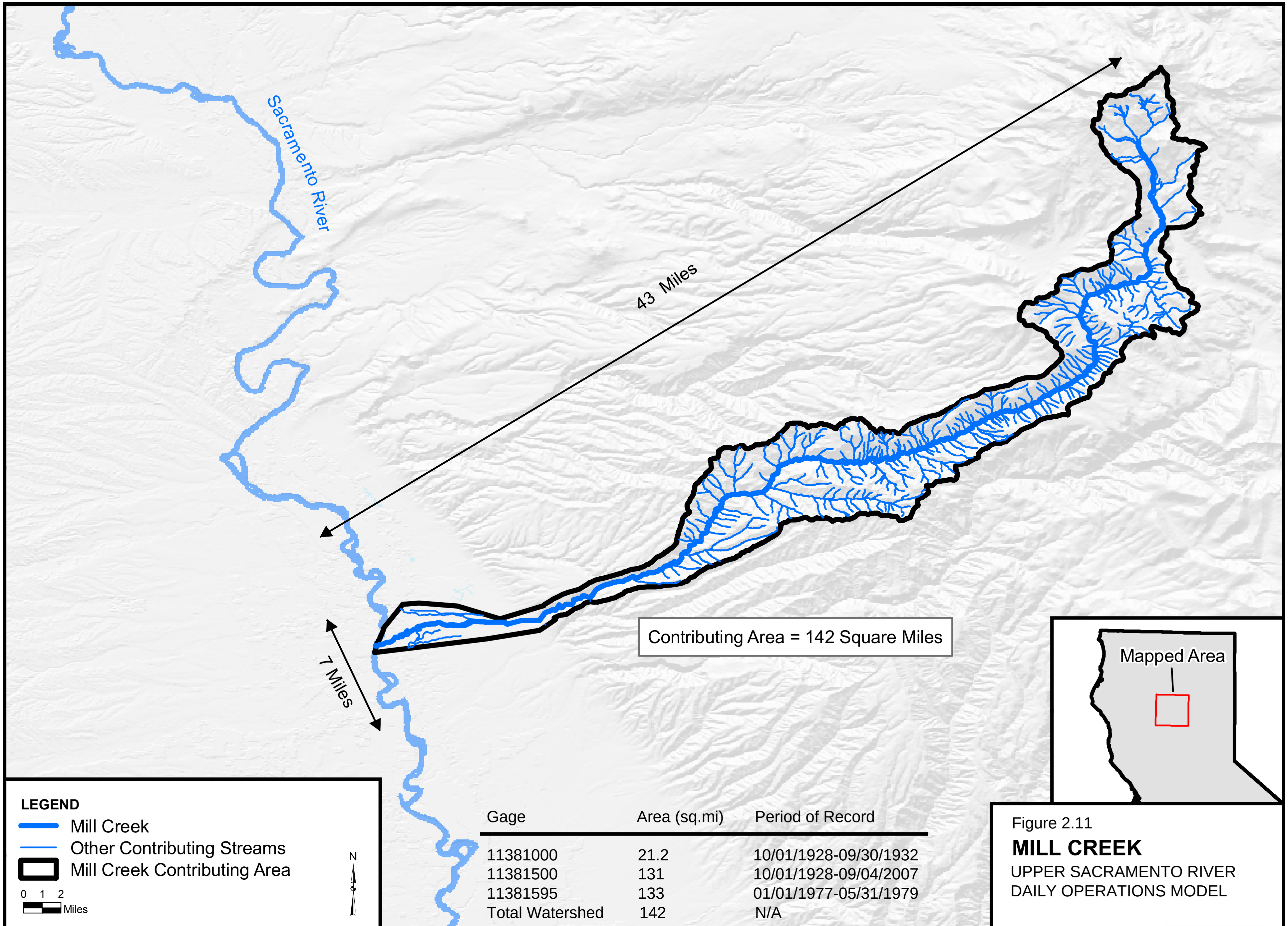

Gage	Area (sq.mi)	Period of Record
11381000	21.2	10/01/1928-09/30/1932
11381500	131	10/01/1928-09/04/2007
11381595	133	01/01/1977-05/31/1979
Total Watershed	142	N/A

Figure 2.11
MILL CREEK
UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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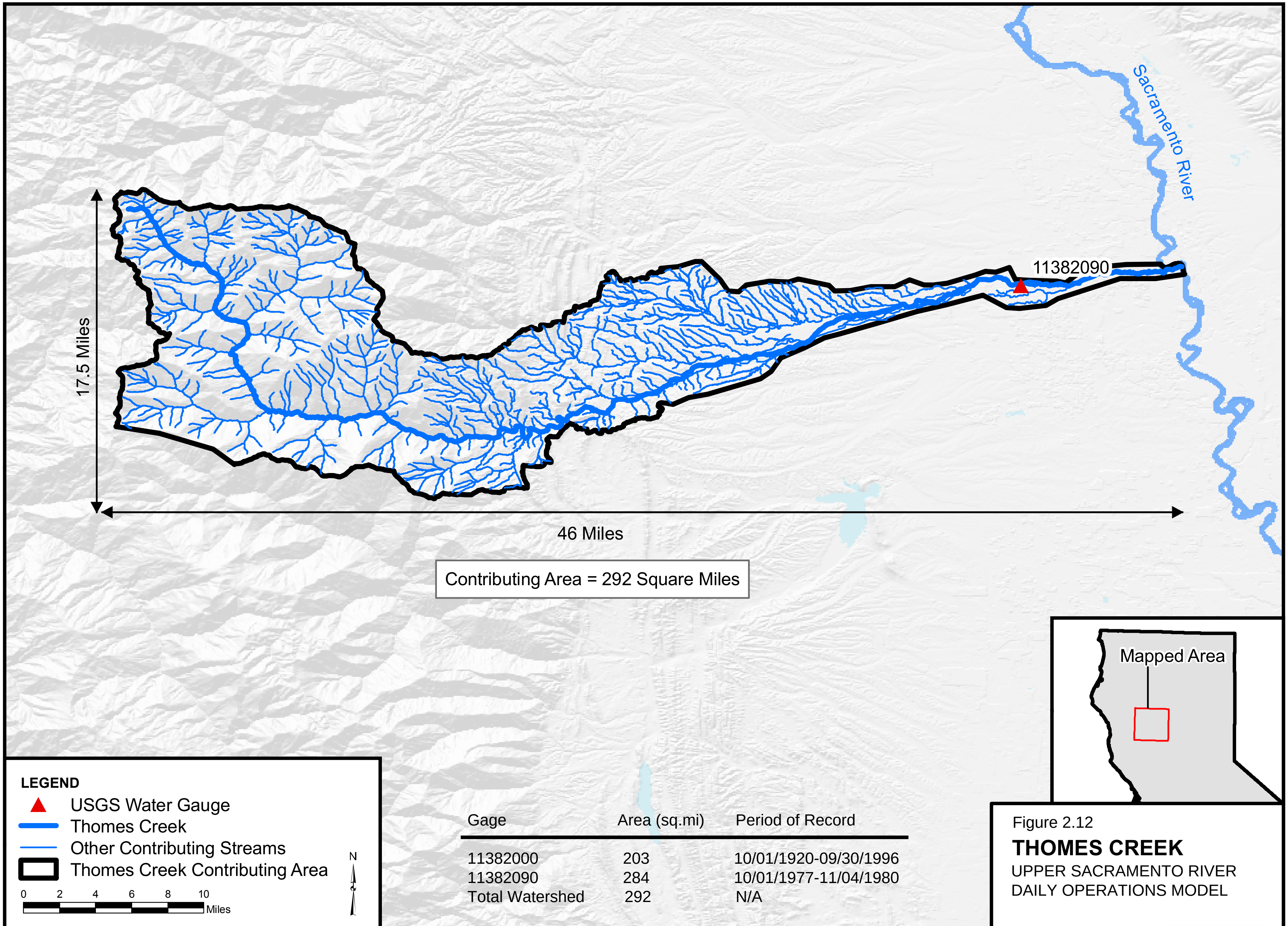

Gage	Area (sq.mi)	Period of Record
11382000	203	10/01/1920-09/30/1996
11382090	284	10/01/1977-11/04/1980
Total Watershed	292	N/A

Figure 2.12

THOMES CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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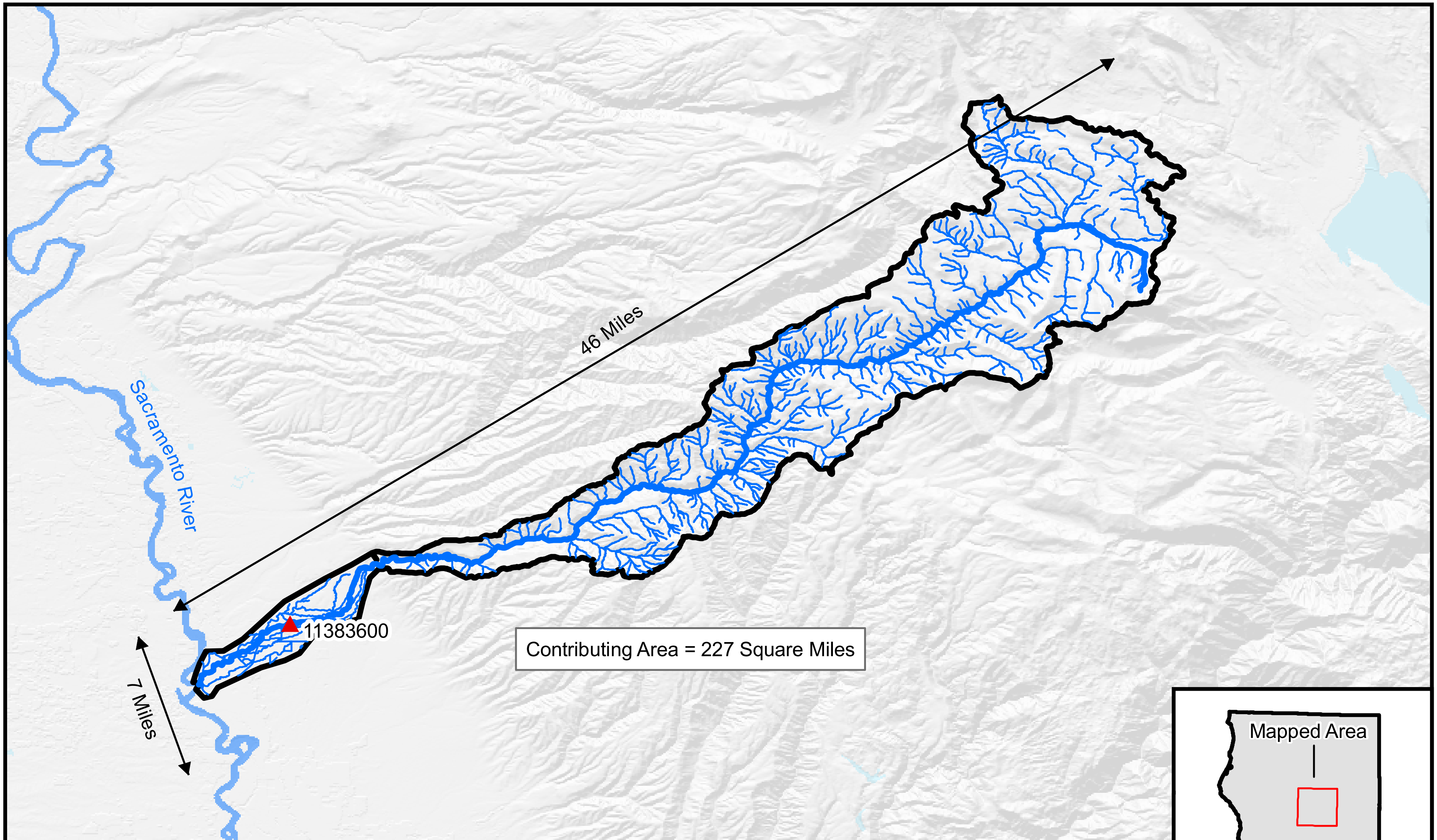

Gage	Area (sq.mi)	Period of Record
11382550	69.4	08/01/1961-10/08/1970
11383500	208	10/01/1911-10/01/2007
11383600	210	01/01/1977-05/31/1977
Total Watershed	227	N/A

Figure 2.13

DEER CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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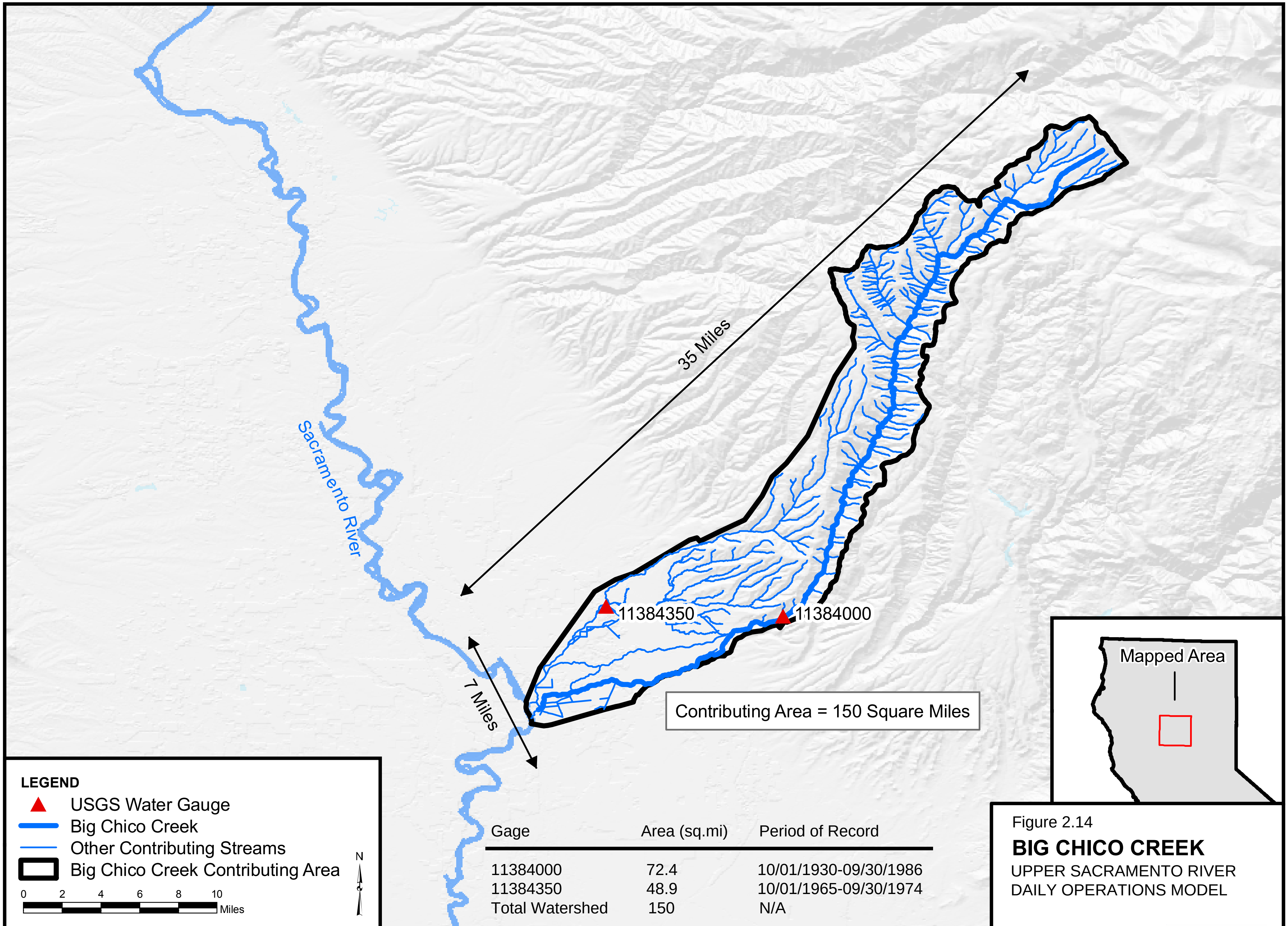

Gage	Area (sq.mi)	Period of Record
11384000	72.4	10/01/1930-09/30/1986
11384350	48.9	10/01/1965-09/30/1974
Total Watershed	150	N/A

Figure 2.14

BIG CHICO CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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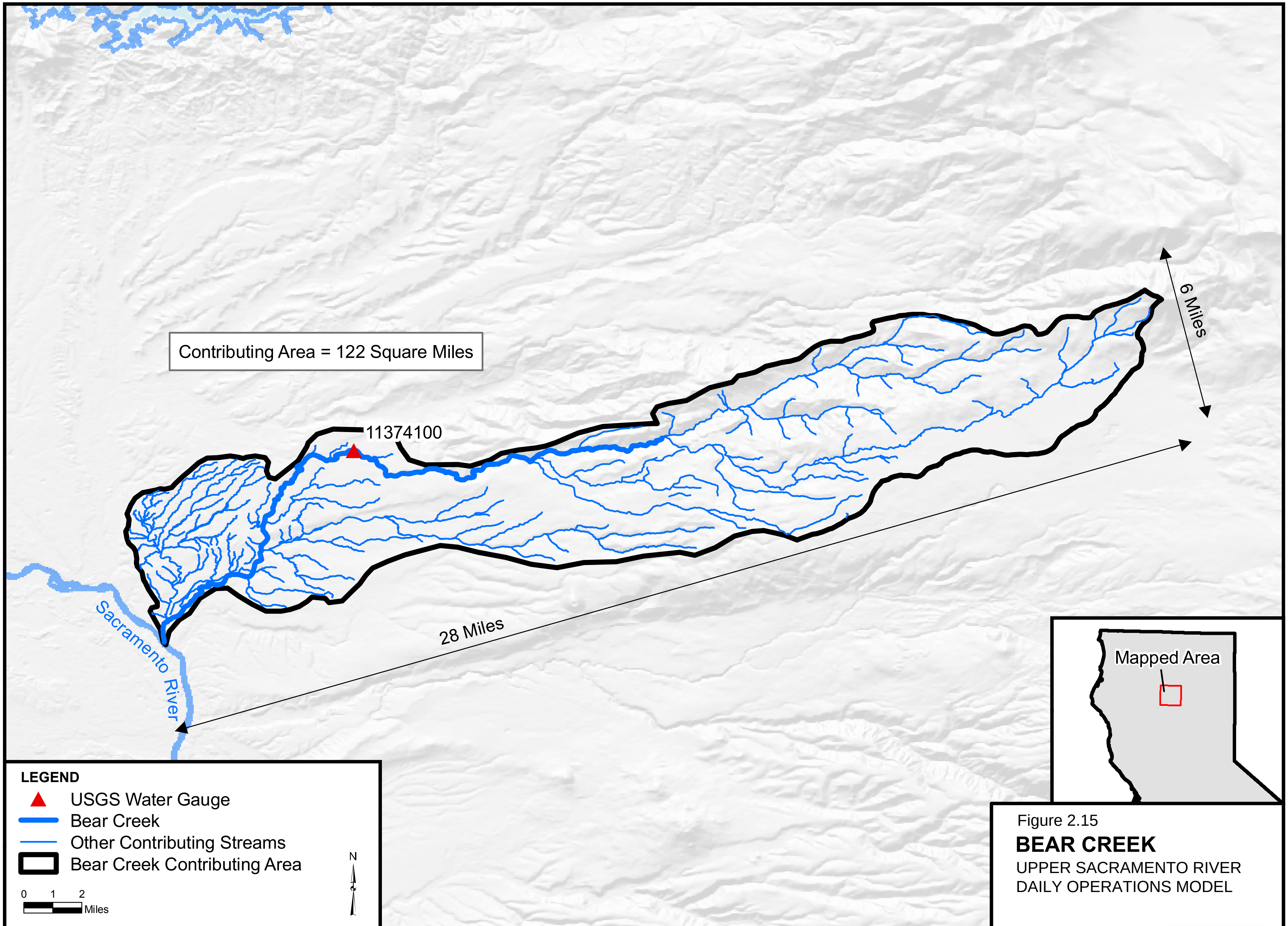

Figure 2.15

BEAR CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

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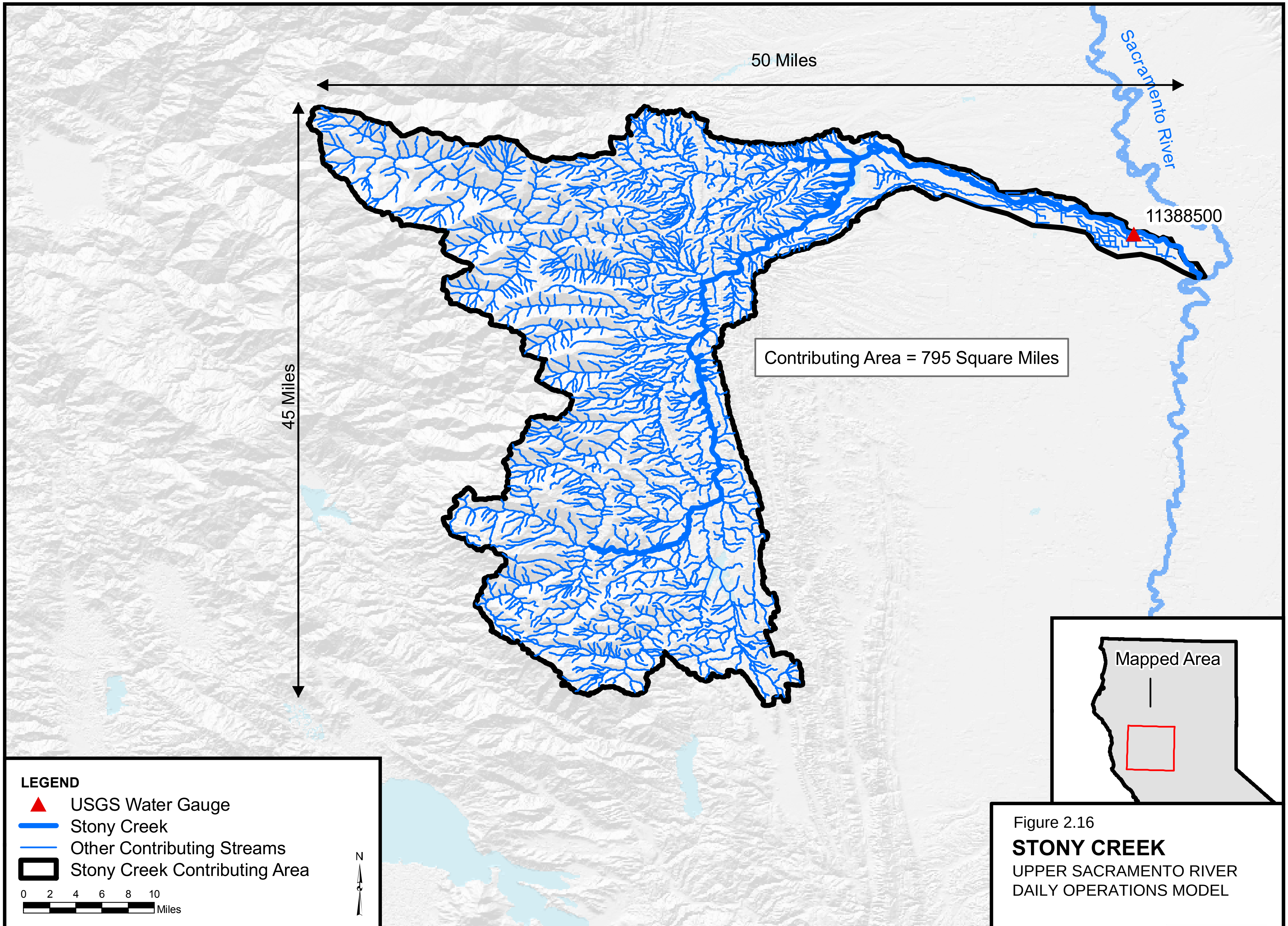


Figure 2.16

STONY CREEK

UPPER SACRAMENTO RIVER
DAILY OPERATIONS MODEL

Method 1: Basin Area Multiplier Method

This method estimates the synthesized tributary flow during the periods with missing gage data by scaling the flow from a reference tributary using a factor computed based on the contributing watershed areas for the two streams. A non-dimensional multiplier called 'Basin Area Multiplier,' reflecting the variability in the contributing watershed areas of the synthesized tributary and the reference stream, was computed by taking the ratio of the contributing area of the tributary to the contributing area of the reference stream. Finally, the flow from the reference stream was scaled using the multiplier to estimate the flow in the synthesized tributary.

$$Q_{synTrib} = K_{area} * Q_{refTrib}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}$$

$Q_{synTrib}$ = Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib}$ = Reference Tributary flow in cubic feet per second (cfs)

K_{area} = Basin Area Multiplier

$A_{synTrib}$ = Contributing Area of Synthesized Tributary in square miles (mi^2)

$A_{refTrib}$ = Contributing Area of Reference Tributary in square miles (mi^2)

Method 2: Basin Area and Runoff Multiplier Method

This method synthesizes the missing flow in a tributary by scaling the flow from the reference stream using two multipliers related to the contributing areas and average runoff. The Basin Area Multiplier, representing the variability in the contributing areas, was computed using Method 1. Another non-dimensional multiplier, "Reference-based Runoff Multiplier," representing the variability of the runoff characteristics between the two watersheds, was computed by taking the ratio of average annual runoff volumes per square mile for the synthesized tributary and the reference stream. Finally, the reference tributary flow was scaled using the two multipliers to estimate the synthesized tributary flow.

$$Q_{synTrib} = K_{area} * K_{runoff} * Q_{refTrib}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}, \quad K_{runoff} = \frac{q_{synTrib}}{q_{refTrib}}$$

$$q_{synTrib} = \frac{V_{synTrib}}{A_{synTrib}}, \quad q_{refTrib} = \frac{V_{refTrib}}{A_{refTrib}}$$

$Q_{synTrib}$ = Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib}$ = Reference Tributary flow in cubic feet per second (cfs)

K_{area} = Basin Area Multiplier

K_{runoff} = Runoff Multiplier

$A_{synTrib}$ = Contributing area of synthesized tributary in square miles (mi^2)

$A_{refTrib}$ = Contributing area of reference tributary in square miles (mi^2)

$q_{synTrib}$ = Runoff factor for synthesized tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$q_{refTrib}$ = Runoff factor for reference tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$V_{synTrib}$ = Average annual runoff volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refTrib}$ = Average annual runoff volume for reference tributary in thousand acre-feet per year (TAF/YR)

<u>Method 3: Basin Area and Runoff Multiplier with Separate Baseflow Method</u>

This method is similar to Method 2, except it separates the flow values that are exceeded during most periods, or the "baseflow" in the reference stream and the synthesized tributary. It is appropriate use this method when baseflows exist in both the reference and synthesized tributaries. In addition to the multipliers defined in Methods 1 and 2, a new scaling factor called the "Reference-based Baseflow Multiplier" was computed as a ratio of the synthesized tributary baseflow to reference stream baseflow. This multiplier was used to scale flows less than or equal to the baseflow in the reference stream to estimate the baseflow in the synthesized tributary.

Because a separate scaling factor was estimated for estimating the baseflow in the synthesized tributary, while computing the Reference-based Runoff Multiplier (Method 2), the respective baseflows were deducted from the average annual runoff volume computation for the synthesized tributary and the reference stream. The final synthesized tributary flow under this method was the sum of the scaled baseflow from reference tributary using the baseflow multiplier and the scaled reference tributary flow in excess of its baseflow, using the Basin Area Multiplier and the Reference-based Runoff Multiplier.

$$Q_{synTrib} = K_{base} * Min\{Q_{refTrib}, Q_{refBase}\} + K_{area} * K_{runoff} * Max\{0, (Q_{refTrib} - Q_{refBase})\}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}, \quad K_{runoff} = \frac{q_{synTrib}}{q_{refTrib}}, \quad K_{base} = \frac{\left(Q_{synBase} / Q_{refBase}\right)}{K_{area}}$$

$$q_{synTrib} = \frac{\left(V_{synTrib} - V_{synBase}\right)}{A_{synTrib}}, \quad q_{refTrib} = \frac{\left(V_{refTrib} - V_{refBase}\right)}{A_{refTrib}}$$

$Q_{synTrib} =$ Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib} =$ Reference Tributary flow in cubic feet per second (cfs)

$Q_{synBase} =$ Base-flow for synthesized tributary in cubic feet per second (cfs)

$Q_{refBase} =$ Base-flow for reference tributary in cubic feet per second (cfs)

$K_{area} =$ Basin Area Multiplier

$K_{runoff} =$ Runoff Multiplier

$K_{base} =$ Reference based base-flow multiplier

$A_{synTrib} =$ Contributing area of synthesized tributary in square miles (mi^2)

$A_{refTrib} =$ Contributing area of reference tributary in square miles (mi^2)

$q_{synTrib} =$ Runoff factor for synthesized tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$q_{refTrib} =$ Runoff factor for reference tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$V_{synTrib} =$ Average annual runoff volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refTrib} =$ Average annual runoff volume for reference tributary in thousand acre-feet per year (TAF/YR)

$V_{synBase} =$ Average annual base-flow volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refBase} =$ Average annual base-flow volume for reference tributary in thousand acre-feet per year (TAF/YR)

Method 4: Basin Area and Runoff Multiplier with Baseflow Removal Method

Method 4 is a variation of Method 3 in which the synthesized tributary baseflow ($V_{synBase}$) is zero, while the reference baseflow is not. This method helps improve the correlation between the tributary flows and the reference streamflows by separating the baseflow from the reference stream.

Method 5: Basin Area and Runoff Multiplier with Baseflow Addition Method

Method 5 is similar to Method 2 and was appropriate when a baseflow component was observed in the synthesized tributary while not in the reference streamflow. Under this method, prior to calculating the Runoff Multiplier (Method 2), the volume corresponding to the estimated baseflow is subtracted from the total volume for the synthesized tributary. Finally, the synthesized tributary flow under this method was computed as the sum of the estimated baseflow and the reference streamflow scaled with the Basin Area Multiplier and the Reference-based Runoff Multiplier.

$$Q_{synTrib} = Q_{synBase} + K_{area} * K_{runoff} * Q_{refTrib}$$

$$K_{area} = \frac{A_{synTrib}}{A_{refTrib}}, \quad K_{runoff} = \frac{q_{synTrib}}{q_{refTrib}}$$

$$q_{synTrib} = \frac{(V_{synTrib} - V_{synBase})}{A_{synTrib}}, \quad q_{refTrib} = \frac{V_{refTrib}}{A_{refTrib}}$$

$Q_{synTrib}$ = Synthesized Tributary flow in cubic feet per second (cfs)

$Q_{refTrib}$ = Reference Tributary flow in cubic feet per second (cfs)

$Q_{synBase}$ = Base-flow for synthesized tributary in cubic feet per second (cfs)

K_{area} = Basin Area Multiplier

K_{runoff} = Runoff Multiplier

$A_{synTrib}$ = Contributing area of synthesized tributary in square miles (mi^2)

$A_{refTrib}$ = Contributing area of reference tributary in square miles (mi^2)

$q_{synTrib}$ = Runoff factor for synthesized tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$q_{refTrib}$ = Runoff factor for reference tributary in thousand acre-feet per year per square mile (TAF/YR/mi^2)

$V_{synTrib}$ = Average annual runoff volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

$V_{refTrib}$ = Average annual runoff volume for reference tributary in thousand acre-feet per year (TAF/YR)

$V_{synBase}$ = Average annual base-flow volume for synthesized tributary in thousand acre-feet per year (TAF/YR)

Table 2.6 lists the synthesized tributaries and summarizes the synthesis method used and parameters for each tributary. The process of synthesizing missing tributary flows retained seasonable variability in addition to preserving daily variability for a tributary. The latter was verified using frequency histograms. For retaining the observed seasonal variability in each synthesized tributary, the fraction of average annual volume within each month were computed for both the period with available gaged data and the period with the synthesized data for that tributary. Based on these fractional volumes from the observed and synthesized data, monthly ratios were computed. These monthly ratios were adjusted iteratively until the fraction of average annual volume within each month was the same for both the observed and synthesized periods. For the tributaries that required baseflow adjustment (Cow Creek, Battle Creek, and Cottonwood Creek) the baseflow volume was removed from the average annual volume before computing the monthly fractions of the annual volume.

TABLE 2.6
Synthesized Tributaries, Period and Method of Synthesis, and Parameters Used

Tributary	Period of Synthesis	Reference Stream (Gaged or Combined)	Method of Synthesis	Synthesis Parameters: Contributing Area (mi^2) Tributary	Contributing Area (mi^2) Reference Stream	Basin Area Multiplier	Runoff Factor (TAF/yr)/mi^2 Tributary	Runoff Factor (TAF/yr)/mi^2 Reference Stream	Reference-based Runoff Multiplier	Baseflow (cfs) Tributary	Baseflow (cfs) Reference Stream	Reference-based Baseflow Multiplier
Cow Creek	10/01/1921 - 09/30/1949	Big Chico Creek (Combined)	Method 4	425.0	72.4	5.8702	1.17	1.13	1.0338	0	30	0
Cottonwood Creek	10/01/1921 - 09/30/1940 10/01/1982 - 09/30/2003	Sum of Elder, Thomes and Red Bank Creeks (Combined)	Method 5	927.0	388.9	2.3836	0.65	0.85	0.7570	60	NA	NA
Battle Creek	10/01/1921 - 09/30/1940	Mill Creek (Combined)	Method 3	357.0	131.0	2.7252	0.53	1.21	0.4412	225	95	2.3684
Paynes Creek	10/01/1921 - 09/30/1949 11/01/1966 - 09/30/2003	Big Chico Creek (Combined)	Method 2	92.8	72.4	1.2818	0.55	1.48	0.3716	NA	NA	NA
Red Bank Creek	10/01/1921 - 09/30/1959 10/01/1982 - 09/30/2003	Elder Creek (Combined)	Method 2	93.5	92.4	1.0119	0.38	0.78	0.4857	NA	NA	NA
Antelope Creek	10/01/1921 - 09/30/1940 10/01/1982 - 09/30/2003	Mill Creek (Combined)	Method 2	123.0	131.0	0.9389	0.89	1.77	0.5027	NA	NA	NA
Mill Creek	10/01/1921 - 09/30/1928	Deer Creek (Gaged)	Method 2	131.0	208.0	0.6298	1.69	1.14	1.4817	NA	NA	NA
Elder Creek	10/01/1921 - 09/30/1948	Thomes Creek (Gaged)	Method 2	92.4	203.0	0.4552	0.79	1.13	0.6949	NA	NA	NA
Thomes Creek	10/01/1996 - 09/30/2003	Elder Creek (Gaged)	Method 1	203.0	92.4	2.1970	NA	NA	NA	NA	NA	NA
Big Chico Creek	10/01/1921 - 09/30/1930 10/01/1986 - 09/30/2003	Deer Creek (Gaged)	Method 1	72.4	208	0.3481	NA	NA	NA	NA	NA	NA

Note:
NA = not applicable

SECTION 3

Model Development

3.1 Overview

The capabilities of USRDOM include simulating the physical and operational processes of the hydrologic features in the Sacramento River system on a daily time scale. The processes include reservoir operations and hydrologic stream routing in the main stem Sacramento River and its tributaries and diversions. The model accounts for the inflows, diversions, accretions, and depletions occurring in the river and is constrained by daily assumptions based on the regulatory and operational details consistent with the Common Assumptions Common Model Package CALSIM II model (CACMP CALSIM II). The solution is constrained by the delivery flow targets and the downstream flow targets from CACMP CALSIM II. USRDOM was developed using the U.S. Army Corps of Engineers' (Corps') HEC-5 software, the same software used by the Upper Sacramento River Water Quality Model (USRWQM), which is part of the CACMP. Using the same software for USRDOM development allowed for easy linkage between the two models.

3.2 Model Schematic

The spatial domain of USRDOM includes the Upper Sacramento River from Shasta Reservoir to Knights Landing, including the facilities and tributaries in the region. It also includes the Trinity River section of the CVP and the Sutter Bypass region. The spatial resolution of USRDOM relies on many factors, including location of reservoirs and diversion control structures and confluence points with major tributaries. Spatial resolution also is influenced by the information needs for other models, such as the NODOS Winter Run Life Cycle Model. A few control points were included to maintain consistency with USRWQM. A complete list of the control points used in the model, along with a description of the control point locations and their river mile on the Sacramento River, are provided in Table 3.1. Figure 3.1 shows the model schematic for USRDOM. An information table with detailed reach by reach descriptions of USRDOM schematic is included in Appendix A with the schematic. This table helps in understanding how the model schematic and some of the modeling parameters were developed.

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
340	Trinity Reservoir	Trinity River	340-TRINITYRES
330	Trinity River above Lewiston Reservoir	Trinity River	330-ABVLEWISTN
320	Lewiston Reservoir	Trinity River	320-LEWISTNRES
300	Dummy reservoir[a] for Trinity River downstream of Lewiston Reservoir	Trinity River	300-BLWLEWISTN

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
244	(Clear Creek Tunnel Flow + Trinity River Spills) at Lewiston Reservoir	Trinity River	244-TRINMINREL
242	Clear Creek Powerplant	Trinity River	242-CLEARCKTUN
240	Whiskeytown Dam	Clear Creek	240-WHSKYTWNDAM
214	(Spring Creek Tunnel Flow + Clear Creek Spills) at Whiskeytown Reservoir	Clear Creek	214-WHISKMINREL
2112	Spring Creek Powerplant	Clear Creek	212-SPRINGCRTUN
230	Dummy reservoir[a] for Clear Creek downstream of Whiskeytown Reservoir	Clear Creek	230-CLRCKBLWWSK
220	Shasta Dam/Reservoir	310.6	220-SHASTADAM
210	Sacramento River Above Keswick Reservoir	302.0	210-ABVKESWICK
200	Keswick Reservoir	302.0	200-KESWICKDAM
197	Sacramento River at ACID Diversion	298.5	197-ACID-DIV
195	Sacramento River at Clear Creek Confluence	289.0	195-CLEARCKINF
192	Sacramento River at Churn and Clover Creek Confluence	284.0	192-CHURCLOVINF
191	Sacramento River at Stillwater Creek Confluence	281.0	191-STILLWATINF
1901	Dummy reservoir[a] representing Cow Creek	Cow Creek	1901-COWCK
190	Sacramento River at Cow Creek Confluence	280.0	190-COWCKINF
188	Sacramento River at Bear and Ash Creek Confluence	277.5	188-BEAR-ASHINF
1861	Dummy reservoir[a] representing Cottonwood Creek	Cottonwood Creek	1861-COTTONWDCK
186	Sacramento River at Cottonwood Creek Confluence	273.0	186-COTTONWDINF
1851	Dummy reservoir[a] representing Battle Creek	Battle Creek	1851-BATTLECK
185	Sacramento River at Battle Creek Confluence	271.5	185-BATTLECKINF
1801	Dummy reservoir[a] representing Paynes Creek	Paynes Creek	1801-PAYNESCK
182	Sacramento River at Bend Bridge	260.0	182-BENDBR-GAGE
180	Sacramento River at Paynes Creek Confluence	253.0	180-PAYNESCKINF
1751	Dummy reservoir[a] representing Red Bank Creek	Red Bank Creek	1751-RDBANKCK

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
175	Sacramento River at Red Bluff Diversion Dam	243.0	175-RDBLFDIVDAM
1701	Dummy reservoir[a] representing Antelope Creek	Antelope Creek	1701-ANTELOPECK
170	Sacramento River at Antelope Creek Confluence	235.0	170-ANTELOPEINF
1652	Dummy reservoir[a] representing Mill Creek	Mill Creek	1652-MILLCK
1651	Dummy reservoir[a] representing Elder Creek	Elder Creek	1651-ELDERCK
165	Sacramento River at Mill Creek Confluence	230.0	165-MILLCKINF
1621	Dummy reservoir[a] representing Thomes Creek	Thomes Creek	1621-THOMESCK
162	Sacramento River at Thomes Creek Confluence	226.0	162-THOMESCKINF
1601	Dummy reservoir[a] representing Deer Creek	Deer Creek	1601-DEERCK
160	Sacramento River at Deer Creek Confluence	220.0	160-DEERCKINF
155	Sacramento River Below Woodson Bridge	214.0	155-BLW-WOODSON
150	Sacramento River at Glenn-Colusa Diversion	206.0	150-GCC-DIV
1451	Dummy reservoir[a] representing Big Chico Creek	Big Chico Creek	1451-BIGCHICOCK
145	Sacramento River at Big Chico Creek Confluence	193.0	145-BIGCHICOINF
1136	Black Butte Reservoir	Stony Creek	1136-BLKBUTTEDM
1134	Stony Creek at Tehama-Colusa Canal	Stony Creek	1134-STONYCR-TC
142	Sacramento River at Stony Creek Confluence	190.0	142-STONYCKINF
140	Sacramento River at Ord Ferry Overflow	189.0	140-ORDFERRY
135	Sacramento River at Butte City	169.0	135-BUTTE-CITY
132	Sacramento River above Moulton Weir	160.0	132-ABVMOULTONW
130	Sacramento River at Moulton Weir	159.0	130-MOULTONWEIR
129	Sacramento River at NODOS Diversion	159.0	129-NODOS-DIV
127	Sacramento River at above Colusa Weir	147.0	127-ABVCOLUSAWR
125	Sacramento River at Colusa Weir	146.0	125-COLUSA-WEIR
120	Sacramento River at Butte Slough Confluence	138.0	120-BUTTE-SL
117	Sacramento River above Tisdale Weir	121.0	117-ABV-TISDALE
115	Sacramento River at Tisdale Weir	119.0	115-TISDALEWEIR

TABLE 3.1
USRDOM Schematic Information

Control Point Number	Description of Control Point Location	Sacramento River Mile	Control Point ID in HEC-5
110	Sacramento River at D129A and D128 Diversions	100.0	110-LOW-SAC-DIV
105	Sacramento River at Knights Landing	84.0	105-KNIGHTSLNDG
1184	Dummy reservoir[a] to route Ord Ferry Overflow to Butte Basin	Sutter Bypass	1184-ORD-ROUTE
1158	Dummy reservoir[a] to route Moulton Weir Diversion through sub-Butte Basin	Sutter Bypass	1158-MWEIR-ROUTE
1146	Dummy reservoir[a] to route Colusa Weir Diversion through sub-Butte Basin	Sutter Bypass	1146-CWEIR-ROUTE
1119	Dummy reservoir[a] to route Tisdale Weir Diversion through sub-Butte Basin	Sutter Bypass	1119-TWEIR-ROUTE
2119	Tisdale Weir spills flowing into Sutter Bypass	Sutter Bypass	2119-TWEIR-END
2184	Ord Ferry spills flowing into Butte Basin	Sutter Bypass	2184-ORD-END
2158	Moulton Weir spills flowing into Butte Basin	Sutter Bypass	2158-MWEIR-END
2146	Colusa Weir spills flowing into Butte Basin	Sutter Bypass	2146-CWEIR-END
2222	Dummy reservoir[a] for Butte Basin Total Flow	Sutter Bypass	2222-B-BASIN
2000	Sutter Bypass at Meridian	Sutter Bypass	2000-MERIDIAN
1500	Sutter Bypass at junction with Tisdale Weir	Sutter Bypass	1500-SUTRBYPASS
1400	Dummy node[b] representing end of Sutter Bypass	Sutter Bypass	1400-SB-OUTLET

[a]HEC-5 requires the most upstream location on each tributary to be a reservoir. If no reservoir exists, a dummy reservoir with no storage is used.

[b]A dummy node is a HEC-5 control point sometimes used to represent a given location more than once in the model or to represent an end point to route all the streams in the model schematic.

3.3 Modeling of Tributary Inflows and Diversions

A critical element of upper Sacramento River flood operations is the local runoff entering the Sacramento River between Keswick Reservoir (control point 210) and Bend Bridge (control point 182). The unregulated creeks (major creek systems are Cottonwood Creek, Cow Creek, and Battle Creek) in this reach of the Sacramento River can be sensitive to large rainfall events and can produce large rates of runoff into the Sacramento River in short time periods. During large rainfall or flooding events, the local runoff between Keswick Reservoir and Bend Bridge can exceed 100,000 cfs. The tributaries that contribute significant flow to the main stem and have flow gage data or that are necessary as part of NODOS reporting metrics were included in USRDOM. Table 3.2 lists tributaries that were explicitly modeled in USRDOM. It also includes the control point numbers where each tributary inflow meets the main stem, the contributing area for each inflow, and the HEC-5 identification of the dummy reservoir where each inflow is included in USRDOM.

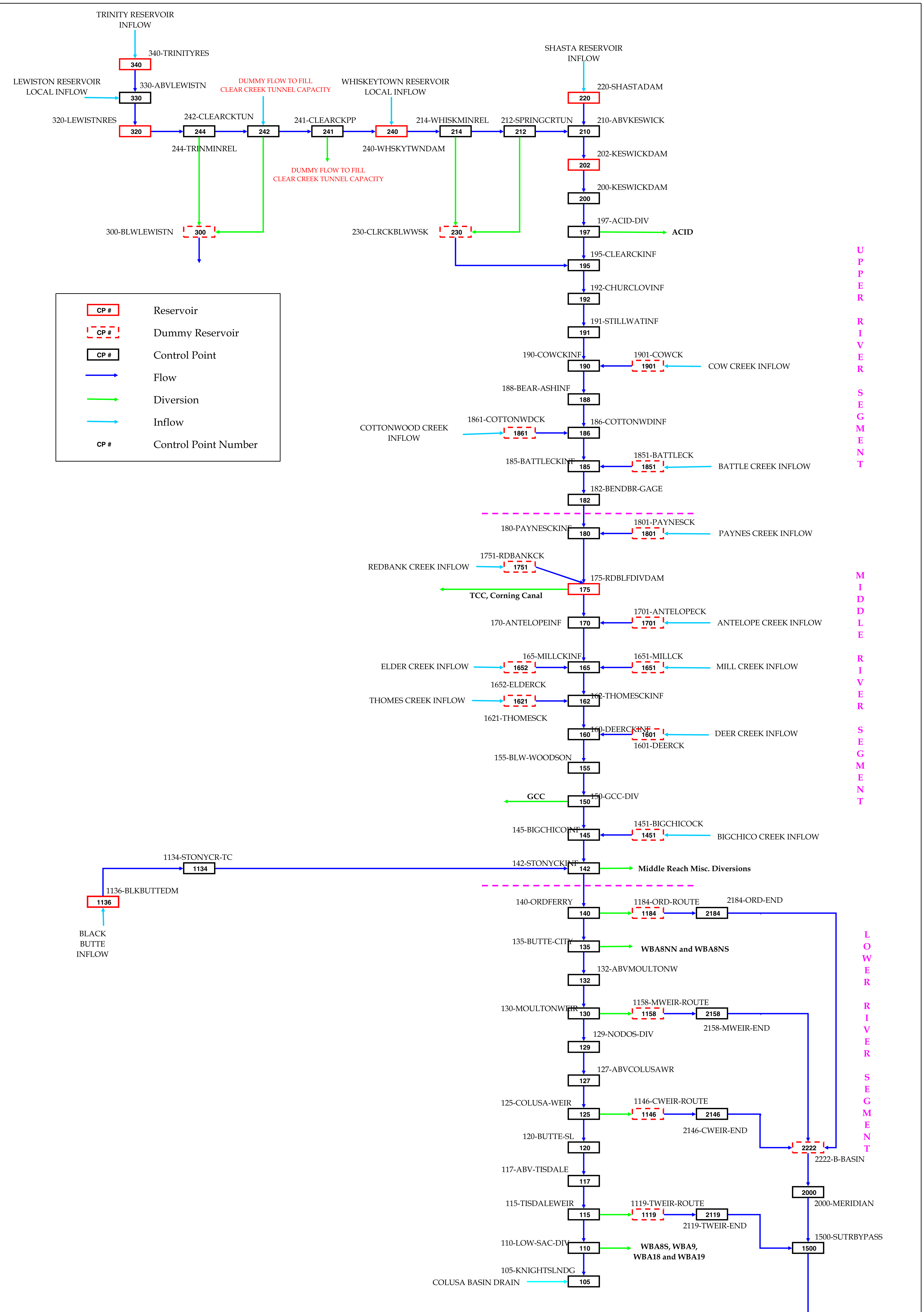


FIGURE 3.1
USRDOM CALIBRATION/VERIFICATION SCHEMATIC

TABLE 3.2
Tributaries Explicitly Modeled in USRDOM

Tributary	Control Point Number at Confluence with Sacramento River	Contributing Area (mi^2)	Dummy Reservoir for Tributary Inflow
Cow Creek	190	425	1901-COWCKINF
Cottonwood Creek	186	927	1861-COTTONWDCK
Battle Creek	185	357	1851-BATTLECK
Paynes Creek	180	92.8	1801-PAYNESCK
Red Bank Creek	175	109	1751-RDBANKCK
Antelope Creek	170	123	1701-ANTELOPECK
Mill Creek	165	133	1652-MILLCK
Elder Creek	165	136	1651-ELDERCK
Thomes Creek	162	284	1621-THOMESCK
Deer Creek	160	210	1601-DEERCK
Big Chico Creek	145	72.4	1451-BIGCHICOCK

The major diversions along the Sacramento River that were modeled in USRDOM include Anderson Cottonwood Irrigation District (ACID), Tehama-Colusa Canal (TCC), Glenn-Colusa Canal (GCC), and the flood bypass overflows downstream of Hamilton City. Other diversions in the Colusa Basin area and the lower river diversions were aggregated into a few locations and were modeled as diverted from the nearest control point. The diversion data for calibration and verification of USRDOM was derived from the CACMP V8 CALSIM II Existing Condition Simulation when the historical data were unavailable. Monthly CALSIM II data were downscaled using the CALSIM25Q utility. CALSIM25Q is used for disaggregating monthly CALSIM II output to daily time step for using as input to the USRWQM model (RMA, 2003). The diversions modeled explicitly in USRDOM are listed in Table 3.3, along with the corresponding definition in CALSIM II, the control point number at which the diversion is simulated, and the HEC-5 identifier for the Hydrologic Engineering Center's Data Storage System (HEC-DSS) time series.

Other Sacramento River diversions, accretions, depletions, and inflows from tributaries not explicitly included in the model were accounted for as part of two closure terms. One covers the upper Sacramento River from Keswick to Bend Bridge, and the other covers its middle stretch from Bend Bridge to Ord Ferry. Details on the closure terms are provided in Sections 4 and 5.

TABLE 3.3
Diversions Explicitly Modeled in USRDOM

Diversions	Corresponding Values in CALSIM II	Control Point Number at the Location of Diversion	Name for Diversion's Time Series
Anderson Cottonwood Irrigation District and other depletions	D104_PSC	197	**QD197**
Tehama-Colusa Canal and Corning Canal	D112	175	**QD175**
Glenn-Colusa Canal	D114	150	**QD150**
Miscellaneous above Ord	D113A+D113B+GS61	142	**QD142**
West Bank (D122A and D122B)	D122A+D122B	135	**QD135**
Lower River (D128 and D129A)	D128+D129A	110	**QD110**

Table 3.4 lists tributaries not explicitly modeled in USRDOM at each control point. It also includes respective areas of contribution for each tributary and any ungaged areas; the control point number where the inflows are accounted for; and a fraction called the 'C1 ratio,' which corresponds to the contributing watershed area at each control point, runoff from which was not explicitly modeled in USRDOM. To compute this fraction, the total contributing watershed areas for the inflows that were not accounted for in USRDOM were estimated for the upper (Keswick to Bend Bridge) and the middle (Bend Bridge to Ord Ferry) segments of the Sacramento River. The C1 ratio for each control point is estimated as the ratio of the lumped ungaged contributing area located along the River reach up to the upstream control point to the total ungaged watershed area for the segment in which the control point is present. The total ungaged watershed area in the upper segment of the Sacramento River is 515.2 sq. mi. and in the middle segment of the Sacramento River is 1556.9 sq. mi. C1 ratio is used to distribute the closure flows along the River for each segment. Closure flow computation and implementation is described in Sections 4 and 5.

TABLE 3.4
Contribution Areas for Ungaged Tributaries and Areas along Sacramento River

Ungaged Tributary or Area	Contributing Area (mi^2)	Control Point Number at Confluence with Sacramento River	C1 Ratio
Clear Creek below Whiskeytown	44	230	0.0854
Spring Creek (N)	17	195	0.1799
Jenny Creek	1.7		
Olney Creek	14		
Sulphur Creek	4		
Other Ungaged Areas	56		
Churn Creek	36	192	0.0992
Clover Creek	6		

TABLE 3.4
Contribution Areas for Ungaged Tributaries and Areas along Sacramento River

Ungaged Tributary or Area	Contributing Area (mi^2)	Control Point Number at Confluence with Sacramento River	C1 Ratio
Other	9.1		
Stillwater Creek	67	191	0.1374
Other Ungaged Areas	3.8		
Cow Creek (ungaged)	3	190	0.0113
Other Ungaged Areas	2.8		
Bear Creek	122	188	0.2995
Ash Creek	31		
Other Ungaged Areas	1.3		
Cottonwood Creek (ungaged)	17	186	0.1403
Anderson Creek	26		
Other Ungaged Areas	29.3		
Battle Creek (ungaged)	15	185	0.0353
Other Ungaged Areas	3.2		
Frazier Creek	1.6	182	0.0116
Other Ungaged Areas	4.4		
Paynes Creek (ungaged)	0	180	0.0392
Spring Creek	3.3		
Other Ungaged Areas	57.7		
Red Bank Creek (ungaged)	17.5	175	0.0652
Reeds Creek	18		
Blue Tent Creek	18		
Dibble Creek	33		
Other Ungaged Areas	15		
Antelope Creek (ungaged)	74	170	0.0897
Salt Creek	43		
Other Ungaged Areas	22.6		
Mill Creek (ungaged)	11	165	0.0938
Dye Creek	47		
Oat Creek	63		
Elder Creek (ungaged)	14		
Other Ungaged Areas	11		
Thomes Creek (ungaged)	89	162	0.0903
McClure Creek	42		
Other Ungaged Areas	9.6		

TABLE 3.4
Contribution Areas for Ungaged Tributaries and Areas along Sacramento River

Ungaged Tributary or Area	Contributing Area (mi^2)	Control Point Number at Confluence with Sacramento River	C1 Ratio
Deer Creek (ungaged)	19	160	0.0844
Other Ungaged Areas	112.4		
Jewett Creek	42	155	0.0342
Hoag Slough	7.4		
Other Ungaged Areas	3.9		
Burch Creek	377	150	0.2495
Other Ungaged Areas	11.4		
Pine Creek	215	145	0.1965
Big Chico Creek (ungaged)	77.6		
Other Ungaged Areas	13.3		
Stony Creek below Black Butte	35	142	0.0573
Other Ungaged Areas	54.2		

3.4 Stream Routing

Accurate stream routing is an essential component of proper simulation of reservoir operations. For example, the travel time required for changes in releases at Keswick Reservoir to affect Bend Bridge flows is approximately 8 to 10 hours. If this travel time were not modeled accurately, then in a likely event where the channel capacity is projected to exceed at Bend Bridge, the releases from Keswick Reservoir would not be ramped down in time to protect Bend Bridge location from flooding.

3.4.1 Description of Routing Methods

Stream routing in USRDOM was simulated using coefficient methods. These methods compute outflow from a routing reach as a linear function. Equation (1) is the basic routing equation. For the direct input of coefficients, the series of 'C' values are input and their sum should equal 1 to maintain continuity.

$$O_n = C_1 I_n + C_2 I_{n-1} + C_3 I_{n-2} + \ldots\ldots\ldots \qquad (1)$$

where:

O_n = ordinate of outflow hydrograph at time 'n'

I_n, I_{n-1}, etc. = ordinates of inflow hydrograph at times n, n-1, etc.

C_1, C_2, etc. = routing coefficients, as coefficients of inflow

Two coefficient methods were used in USRDOM: the Attenuation of Hydrographs method and the Muskingum Routing method. The Attenuation of Hydrographs method was used for the stream routing in the main stem Sacramento River. This method requires user-specified ‘C’ values. Muskingum Routing was used in the Sutter Bypass reaches. The ‘C’ values for this method are computed based on the travel time in hours (K) and the dimensionless routing parameter between 0 and 0.5 (X) specified for each reach. In addition to specifying K and X values in Muskingum Routing, the number of sub-reaches within a routing reach is required. To avoid computing negative coefficients, the K value must be greater than or equal to [t/(2*(1-X)] and less than or equal to [t/(2*X)], where ‘t’ is the timestep used in the model.

3.4.2 Development of Routing Coefficients

The routing coefficients for the main stem Sacramento River were developed based on the travel times and routing coefficients used in the USRWQM. When the USRDOM schematic was developed, control points consistent with USRWQM in terms of location were included. Table 3.5 shows the routing coefficient computation process for USRDOM using the information from USRWQM for the Clear Creek confluence to Cow Creek confluence reach of the Sacramento River.

The information in columns 3 through 8 corresponds with USRWQM. According to the information from USRWQM, the Clear Creek to Cow Creek reach was 9 miles long and the travel time was 2.05 hours. The routing coefficient C_1 was 0.91 and C_2 was 0.09. Columns 9 to 14 correspond with USRDOM. According to this information, Clear Creek to Cow Creek reach now has three sub-reaches, Clear Creek to Churn and Clover creeks, Churn and Clover creeks to Stillwater Creek, and Stillwater Creek to Cow Creek. The lengths of the sub-reaches were 5 miles, 3 miles, and 1 mile, respectively. These lengths add up to 9 miles, which is the same value in USRWQM. In column 12, the travel time within each sub-reach was estimated based on the ratio of sub-reach length to the total reach length from USRWQM. Thus, for Clear Creek to Churn and Clover creeks, the travel time was five/ninths of 2.05 hours, or 1.14 hours. Column 14 has the routing coefficient C_2 values for each sub-reach in USRDOM. These values were estimated based on the ratio of travel time for individual sub-reaches to the total travel time for the reach in USRWQM. Thus, for the first sub-reach in USRDOM, C_2 was (1.14/2.05) times 0.09 (value of C_2 for the reach in USRWQM). Finally, C_1 values were estimated simply by subtracting C_2 values from 1. The routing coefficients in Columns 6 and 7 are verified by computing a cumulative value of routing coefficients for Clear Creek to Cow Creek, which are shown in columns 15 and 16. The equivalent C_1 and C_2 values are the same as the routing coefficients for Clear Creek to Cow Creek reach in USRWQM, or 0.91 and 0.09, respectively. Travel times and routing coefficients were estimated for other sub-reaches in similar fashion. Table 3.6 lists the routing coefficients used in USRDOM for all routed reaches in the main stem Sacramento River.

TABLE 3.5
An Example of Routing Coefficients Estimation for the Main Stem Sacramento River

		USRWQM						USRDOM							
					Routing Coefficient							Routing Coefficient			
Location Name & Description (1)	River Mile (2)	Control Point (3)	Length of d/s Reach (4)	Routed To CP (5)	C_1 (6)	C_2 (7)	Travel Time [hr] (8)	CP (9)	Length of d/s Reach (10)	Routed To CP (11)	Travel Time [hr] (12)	C_1 (13)	C_2 (14)	Equiv C_1 (15)	Equiv C_2 (16)
Sacramento River at Clear Creek Confluence	289.0	180	9.0	178	0.91	0.09	2.05	195	5.0	192	1.14	0.9500	0.0500		
Sacramento River at Churn and Clover Creek Confluence	**284.0**							**192**	**3.0**	**191**	**0.68**	**0.9701**	**0.0299**	**0.92**	**0.08**
Sacramento River at Stillwater Creek Confluence	**281.0**							**191**	**1.0**	**190**	**0.23**	**0.9899**	**0.0101**	**0.9100**	**0.0900**
Sacramento River at Cow Creek Confluence	280.0	178						190							

Notes:

Rows in bold represent new control points added in the USRDOM model within the same reach in USRWQM.

d/s = downstream

TABLE 3.6
Routing Coefficients Used in USRDOM for the Reaches in the Main Stem Sacramento River

Upstream Control Point	Downstream Control Point	Travel Time (hrs)	Routing Coefficients C1	Routing Coefficients C2
200	197	0.80	0.9650	0.0350
197	195	2.16	0.9050	0.0950
195	192	1.14	0.9500	0.0500
192	191	0.68	0.9700	0.0300
191	190	0.23	0.9900	0.0100
190	188	0.50	0.9821	0.0179
188	186	0.90	0.9679	0.0321
186	185	0.30	0.9885	0.0115
185	182	2.30	0.9115	0.0885
182	180	1.24	0.9382	0.0618
180	175	1.76	0.9118	0.0882
175	170	2.21	0.9172	0.0828
170	165	1.38	0.9483	0.0517
165	162	1.10	0.9586	0.0414
162	160	1.66	0.9379	0.0621
160	155	1.66	0.9379	0.0621
155	150	2.00	0.9000	0.1000
150	145	3.25	0.8781	0.1219
145	142	0.75	0.9719	0.0281
1136	1134	Not Available	0.7500	0.2500
1134	1132	Not Available	0.6500	0.3500
142	140	0.29	0.9881	0.0119
140	135	5.71	0.7619	0.2381
135	132	2.70	0.8650	0.1350
132	130	0.30	0.9850	0.0150
130	129	0.00	1.0000	0.0000
129	127	4.62	0.8154	0.1846
127	125	0.38	0.9846	0.0154
125	120	2.96	0.8815	0.1185
120	117	6.30	0.7481	0.2519
117	115	0.74	0.9704	0.0296
115	110	6.51	0.7286	0.2714
110	106	5.49	0.7714	0.2286

The routing coefficients for the reaches in the Sutter Bypass region were obtained from the Sacramento and San Joaquin River Basins Comprehensive Study (Comp Study) (California Reclamation Board and Corps, 2002). Because the Comp Study is an hourly timestep model and USRDOM is a daily timestep model, the number of sub-reaches and K values specified for a few routed reaches were modified in USRDOM to avoid negative routing coefficients by checking the criteria described in the Section 3.4.1. Comp Study included higher number of sub-reaches and smaller K values. When using this information in USRDOM, the number of sub-reaches was reduced and K values were increased such that the negative routing coefficients were avoided. Table 3.7 lists the X and K values used in USRDOM for all routed reaches in Sutter Bypass region.

TABLE 3.7
Routing Parameters Used in USRDOM for Reaches in the Sutter Bypass Region

Upstream Control Point	Downstream Control Point	Routing Parameters	
		X	K (hr)
1184	2184	0.10	20
1158	2158	0.10	20
1146	2146	0.10	16
1119	2119	0.20	16
2000	1500	0.20	20

As noted earlier, the routing coefficients used in USRDOM for the main stem Sacramento River were developed based on USRWQM model data. To verify the accuracy of these routing coefficients, it was necessary to double check with other sources. This process is described in Section 4.

3.5 Modeling **of Flood Bypass Weirs**

Flood bypass weirs downstream of Hamilton City, Ord Ferry, Moulton Weir, Colusa Weir, and Tisdale Weir were modeled in USRDOM. Table 3.8 shows the control point numbers where these bypass diversions are located. The operation of the weirs in USRDOM was based on the Comp Study. Diversion flows through Ord Ferry, Moulton, Colusa, and Tisdale weirs along the Sacramento River were defined as a relationship between the flows in the river and flows over the weirs.

TABLE 3.8
USRDOM Control Points and Flood Bypass Weir Locations

Control Point at Confluence with River	Weir
140	Ord Ferry to Sutter Bypass
130	Moulton Weir
125	Colusa Weir
115	Tisdale Weir

The relationships used in the Comp Study were verified using the historical flow data through the river and through diversions. Historical data were obtained at three locations on Sacramento River (near Colusa, Tisdale, and Moulton weirs). The gage locations were chosen in such a way that flow through the weir and flow in the river immediately downstream of the weir were captured.

Figures 3.2 through 3.5 show the comparison of the diversion relationships used in the Comp Study and the historical data. Mean daily flow over a weir was plotted on the x-axis and the river flow upstream of a weir is plotted on the y-axis. The relationships between the flows for different years were plotted as separate series to check the patterns during the high flood and low flood events. The corresponding flow relationship used by the Comp Study for each weir is also plotted, along with the historical flow values.

Figure 3.2 shows the relationship between flow through Moulton Weir and flow in the Sacramento River just upstream of Moulton Weir. The black line on the graph indicates the relationship used by the Comp Study, and scatterpoints represent historical flow values from USGS and WDL gages. The blue scatterpoints are the flow values for high flood events from 1980 to 2000.

Figure 3.3 and Figure 3.4 show the flow relationship curves for Colusa and Tisdale weirs, respectively. By observing the curves for the weirs using historical data and comparing them with the values used by the Comp Study, it is evident that the relationships used in the Comp Study agree with historical observations.

Figure 3.5 shows the relationship used for Ord Ferry in the Comp Study. Because the historical flow data were not available for the Sutter Bypass, this relationship was not verified.

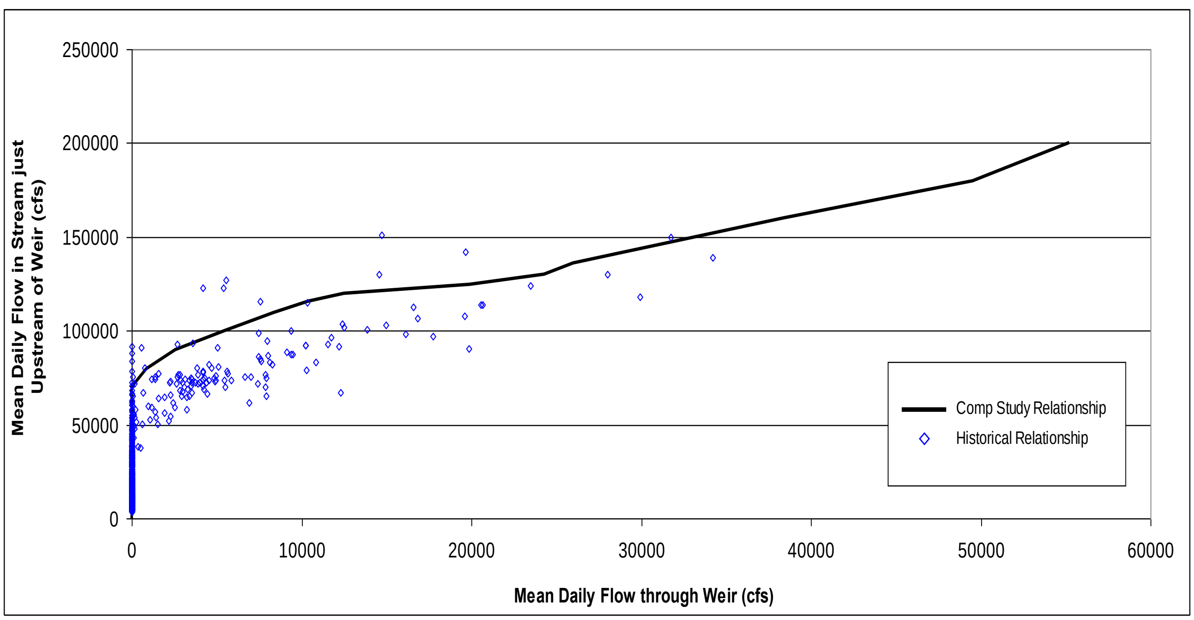


FIGURE 3.2
Flow Relationship Curve for Moulton Weir

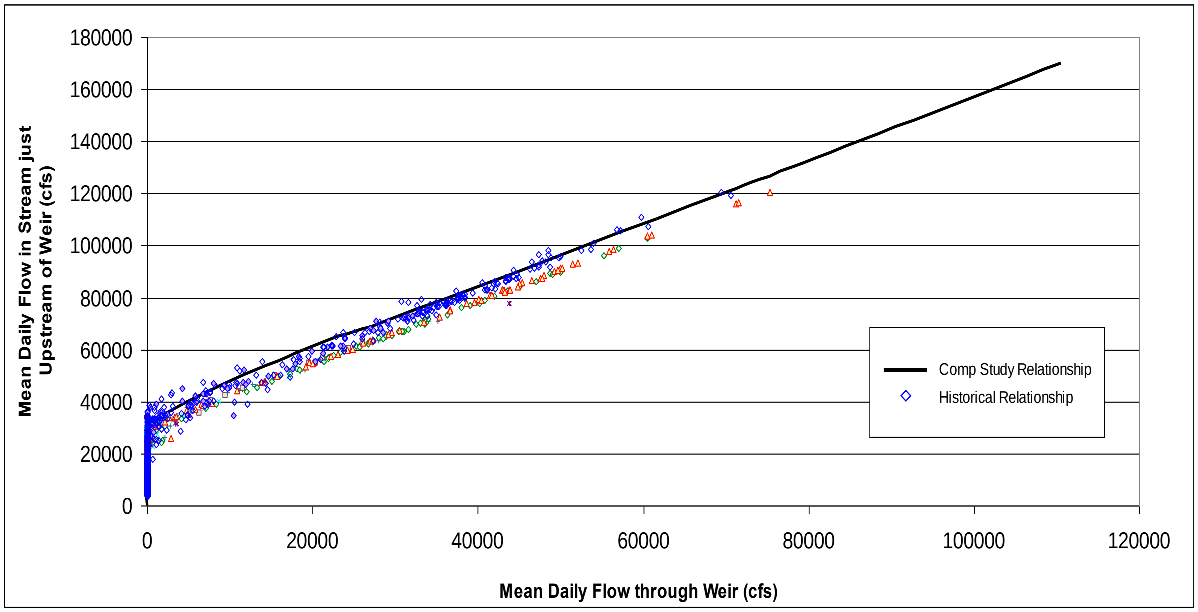


FIGURE 3.3
Flow Relationship Curve for Colusa Weir

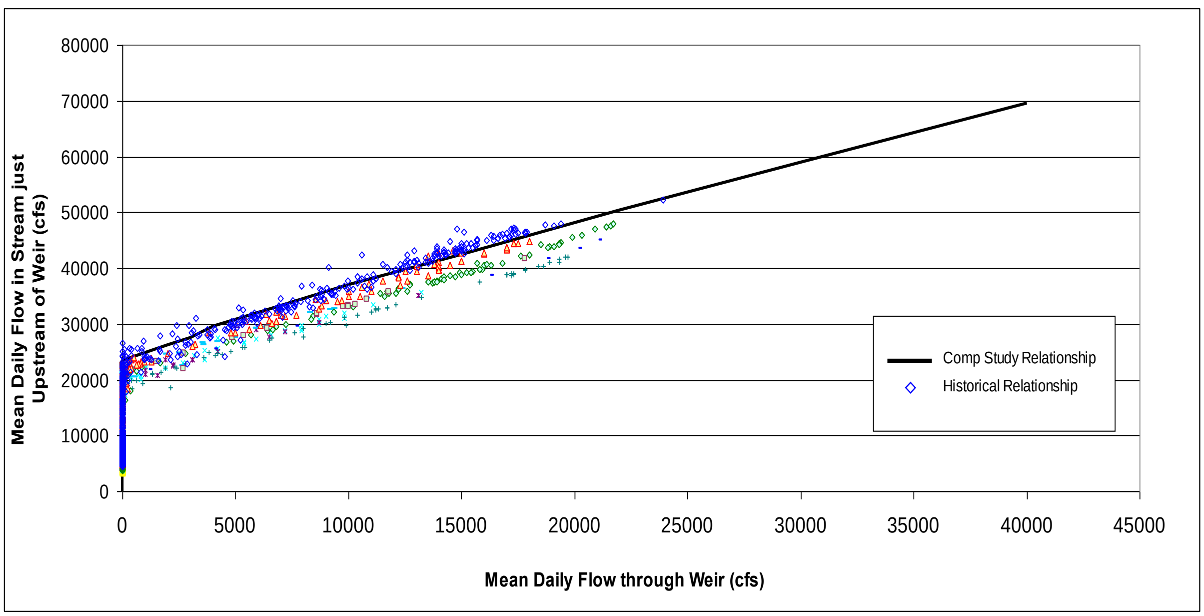


FIGURE 3.4
Flow Relationship Curve for Tisdale Weir

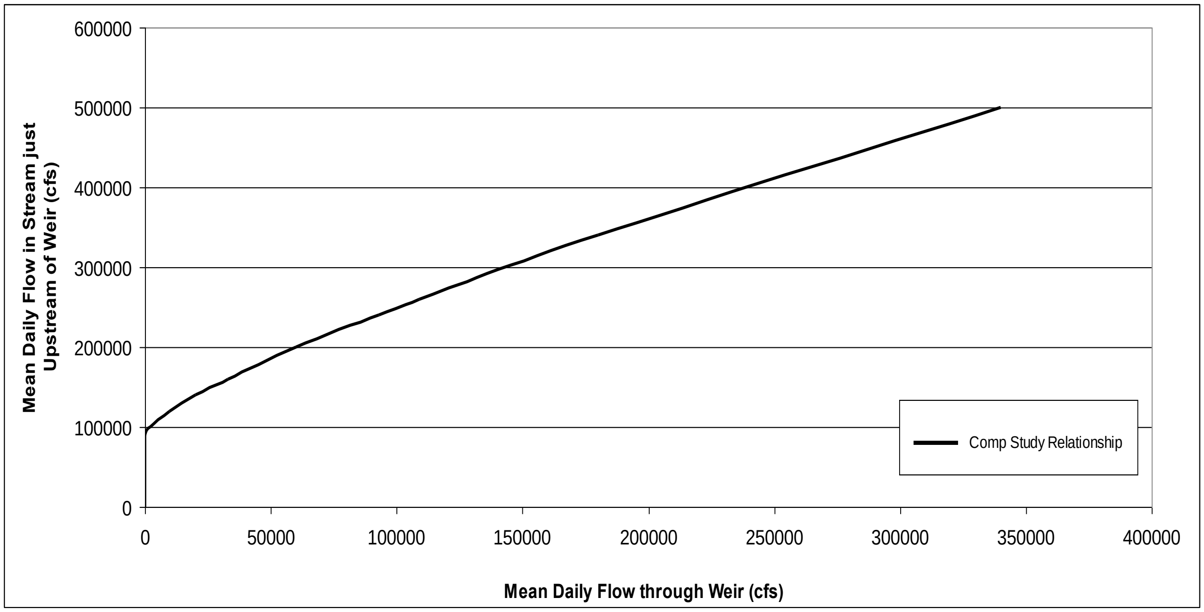


FIGURE 3.5
Flow Relationship Curve for Ord Ferry Spills

3.6 Modeling of Reservoir Operations

USRDOM includes the five CVP reservoirs at the upstream end of Sacramento River: Trinity Reservoir, Lewiston Reservoir, Whiskeytown Reservoir, Shasta Reservoir, and Keswick Reservoir. It also includes the Black Butte Reservoir on Stony Creek. This section provides a brief description of the operation criteria used and how each reservoir operation was simulated in USRDOM.

3.6.1 Trinity and Lewiston Operations

Trinity Dam is on the Trinity River and regulates the flow from a drainage area of approximately 720 square miles. The dam was completed in 1962, forming Trinity Reservoir, which has a maximum storage capacity of approximately 2.4 million acre-feet (MAF). The mean annual inflow to Trinity Reservoir from the Trinity River is about 1.2 MAF. Historically, an average of about two-thirds of the annual inflow has been diverted to the Sacramento River Basin. Trinity Reservoir stores water for release to the Trinity River and for diversion to the Sacramento River via Lewiston Reservoir, Carr Tunnel, Whiskeytown Reservoir, and Spring Creek Tunnel where it mixes in Keswick Reservoir with Sacramento River water released from Shasta Dam and water released from Spring Creek Debris Dam.

Flood control is not an authorized purpose of the Trinity River Division, but flood control benefits are provided by implementing the California Division of Safety of Dams (DSOD) requirement that storage does not exceed 2.1 MAF from November through March. Therefore, the top of the conservation level was modeled as at 2.1 MAF from November through March in USRDOM.

Trinity Dam operates to the capacity constraints and minimum release requirements at Lewiston Reservoir and Judge Francis Carr Powerplant. The minimum release requirements for Trinity River below Lewiston are based on the fish and wildlife requirements on Trinity River as specified in the Record of Decision (ROD) (USFWS and Hoopa Valley Tribe, 1999). The minimum required releases from Lewiston Reservoir to the Trinity River in USRDOM were specified based on historical Trinity River releases from Lewiston while calibrating the model. In USRDOM, the necessary downstream control points were added to the RO record for Trinity Reservoir in the model code. A daily varying minimum release requirement was also included for Trinity Reservoir using MR record in the model code. This minimum flow was computed as sum of the minimum flow requirement for Trinity River below Lewiston and the minimum flow requirement to Clear Creek Tunnel.

Trinity imports are constrained based on whether the Sacramento River is spilling at Tisdale Weir and whether Whiskeytown is nearing spill condition or spilling. Trinity releases for import are reduced so that the flood risk on the Sacramento River and Clear Creek downstream of Whiskeytown is not increased. The channel capacity of Clear Creek Tunnel and the Trinity minimum release is reduced to 300 cfs when Tisdale Weir is spilling.

The storage-capacity curves and other facility data for the Trinity Reservoir were derived from USRWQM.

Lewiston Reservoir is on the Trinity River, 7 miles downstream from Trinity Dam. Lewiston Reservoir functions as a regulating reservoir to control flow fluctuations downstream for the Trinity Powerplant and as a forebay for the Carr Powerplant. Lewiston Reservoir was set as a flow-through reservoir in USRDOM so that all constraints for minimum releases and Clear Creek Tunnel capacity are relayed to Trinity Reservoir. The buffer and conservation levels (Levels 2 and 3) for the Lewiston Reservoir were bound to 14,000 acre-feet to reflect the average operating condition. Lewiston Reservoir facility data were taken from USRWQM. In USRDOM, all Lewiston Reservoir releases are reflected at control point 320; therefore, downstream channel capacity for Lewiston Reservoir includes Clear Creek Tunnel capacity.

Total river release is limited to 6,000 cubic feet per second (cfs) below Lewiston Reservoir under DSOD requirements because of local high water concerns and local bridge flow capacities. Because only 3,200 cfs of flow can be conveyed through the Clear Creek Tunnel, USRDOM allows no more than 6,000 cfs below Lewiston when the total inflow to Lewiston is less than or equal to 9,200 cfs. This is true until the total inflow to Lewiston Reservoir, including local flow and Trinity Reservoir releases, exceeds 9,200 cfs, at which time the excess flows are spilled downstream into the river.

3.6.2 Whiskeytown Operations

As part of the CVP since 1964, a portion of the flow from the Trinity River Basin has been exported to the Sacramento River Basin through Whiskeytown Reservoir on Clear Creek. From Whiskeytown Reservoir, water is released through the Spring Creek Power Conduit to the Spring Creek Powerplant and into Keswick Reservoir. All the water diverted from the Trinity River and a portion of Clear Creek flows, are conveyed through the Spring Creek Tunnel into Keswick Reservoir. From 1964 to 1992, an average annual quantity of 1,269,000 acre-feet of water was diverted from Whiskeytown Reservoir to Keswick Reservoir. This annual quantity is approximately 17 percent of the flow measured in the Sacramento River at Keswick.

Whiskeytown is normally operated to regulate inflows for power generation and recreation, support upper Sacramento River temperature objectives, and provide for releases to Clear Creek consistent with Central Valley Project Improvement Act (CVPIA) Anadromous Fish Restoration Program (AFRP) objectives. Whiskeytown Reservoir is drawn down approximately 35,000 acre-feet per year of storage space during November through April to regulate flows for power generation. Heavy rainfall events occasionally result in spillway discharges to Clear Creek.

To reflect this operating criteria in USRDOM, Whiskeytown Reservoir operates under the constraints from Spring Creek Tunnel capacity (4,200 cfs) and a minimum required release downstream into Clear Creek. The buffer level was reduced to 27,542 acre-feet and the conservation level was varied between 206,000 acre-feet (November through April) and 238,500 acre-feet to reflect the average operating conditions. The minimum required release for Clear Creek below Whiskeytown was computed based on historical operations data so that a flow between 50 cfs and 250 cfs was ensured. In addition to the minimum required releases, Whiskeytown releases greater than 4,200 cfs are routed down Clear Creek.

3.6.3 Shasta and Keswick Operations

Shasta Dam is located on the Sacramento River just below the confluence of the Sacramento, McCloud, and Pit rivers. The dam regulates the flow from a drainage area of approximately 6,649 square miles. Shasta Dam was completed in 1945, forming Shasta Reservoir, with a maximum storage capacity of 4,552,000 acre-feet. Water in Shasta Reservoir is released through or around the Shasta Powerplant to the Sacramento River, where it is re-regulated downstream by Keswick Reservoir.

Flood control objectives for Shasta Reservoir require releases to be restricted so that the flow at the tail water of Keswick Reservoir does not exceed 79,000 cfs and a stage of 39.2 feet is not exceeded in the Sacramento River at the Bend Bridge gaging station, which corresponds to a flow of approximately 100,000 cfs. Therefore, in USRDOM, Shasta Reservoir operates to the channel capacity constraints at Keswick Reservoir and Bend Bridge (control point 182). To ensure the 79,000 cfs criterion was met, QS and CC records from the Comp Study were used in the model code to specify channel capacity as a function of inflow for Shasta Reservoir.

According to the regulating criteria developed by the Corps for Shasta flood control operations, maximum flood space reservation is 1.3 MAF, with variable storage space requirements based on an inflow parameter. For USRDOM, this inflow parameter was estimated based on the Shasta daily inflows. Daily top of the conservation storage pool was estimated based on the flood control diagram in the Shasta flood control manual (Corps, 1977). Daily conservation level (Level 3) values were specified in USRDOM using the ST record in the model code to regulate the flood control space in Shasta Reservoir on a daily basis.

Flood control criteria for Keswick releases specify that releases should not be increased more than 15,000 cfs or decreased more than 4,000 cfs in a 2-hour period. In USRDOM, this was implemented using the R2 records for Shasta Reservoir.

Another operational criterion is to meet the navigation flow requirement of 5,000 cfs to Wilkins Slough (gaging station on the Sacramento River) under all but the most critical water supply conditions to facilitate pumping. Moreover, the 1993 National Marine

Fisheries Service (NMFS) winter-run Biological Opinion requires a minimum release of 3,250 cfs for normal years from September 1 through the end of February. In USRDOM, Shasta Reservoir was operated to meet a daily varying minimum required flow forced using the MR record. This daily minimum requirement was computed based on the historical Shasta releases so that a minimum flow of 3,250 cfs is released between November and April 15, and 15,000 cfs is released the rest of the year.

Storage, capacity, area, and elevation curves are a combination of the data from USRWQM and the Comp Study. For Shasta storage less than 3.7 MAF, the data from USRWQM were used. For storage greater than 3.7 MAF, the Comp Study data were used. Table 3.9 lists the control points that constrain the operation of each reservoir.

TABLE 3.9
Reservoirs and Corresponding Control Points on the RO Card

Reservoir/Control Point	Operating Control Point Numbers	Channel Capacity (cfs)
Trinity/340	340	9,200
	330	9,200
	320	9,200
	244	9,200
Whiskeytown/240	240	53,600
	214	53,600
	212	3,600
Shasta/220	220	15,000 to 79,000
	210	79,000
	202	15,000 to 79,000
	186	100,000
	180	100,000
	142	260,000
	132	160,000
	127	135,000
	117	66,000
	110	30,000
Black Butte/1136	1134	5,000

Keswick Reservoir was formed by the completion of Keswick Dam in 1950. It has a capacity of approximately 23,800 acre-feet and serves as an afterbay for releases from Shasta Dam and for discharges from the Spring Creek Powerplant. In USRDOM, Keswick is operated as a flow-through reservoir. To reflect the historical operations, the buffer and conservation levels are set to vary seasonally so that 22,250 acre-feet of storage is available from July 15 through October 31 and 21,250 acre-feet for the rest of the year. The facility data were obtained from USRWQM. The CL and CC records from the Comp Study were used to provide variable channel capacity with Shasta storage level, which ensures that Shasta operates to the maximum flow constraint of 79,000 cfs at Keswick.

3.6.4 Red Bluff Diversion Dam Operations

The Red Bluff Diversion Dam (RBDD), located on the Sacramento River approximately 2 miles southeast of Red Bluff, is a gated structure with fish ladders at each abutment. Construction of the RBDD was completed in 1964. When the gates are lowered, the impounded water rises about 13 feet, creating Lake Red Bluff and allowing gravity diversions through a set of drum screens into a stilling basin serving the Tehama-Colusa and Corning canals. The gates are lowered June 5 to impound water for diversion and raised September 25 to allow river flow through. In USRDOM, RBDD was operated as a flow-through reservoir. The buffer and conservation levels were varied seasonally to reflect the gate closure dates.

3.6.5 Black Butte Operations

Black Butte operations specified in USRWQM were used in USRDOM.

SECTION 4

Model Calibration

4.1 Overview

The calibration and verification process used a three-phase approach to evaluate the performance of the individual components of USRDOM and the full model. The process also allowed for identifying and understanding any inherent biases in the results.

The three calibration and verification phases used to evaluate the performance of USRDOM are:

1. Calibration/Verification of Hydrologic Inputs and Stream Routing
2. Calibration/Verification of Reservoir Operations
3. Calibration/Verification of Full Model

The following sections provide details for each phase.

4.2 Calibration/Verification of Hydrologic Inputs and Stream Routing (1964–2003)

4.2.1 Approach

In this first step, the goal was to calibrate and verify the hydrologic inputs and river processes, such as stream routing in the upper Sacramento River from Keswick to Knights Landing in the USRDOM. USRDOM was used to simulate the flow conditions in the upper Sacramento River over a 40-year period from WY 1964 to WY 2003. Observed tributary inflows and Keswick releases were used as the boundary conditions for this simulation. This 40-year USRDOM run allowed for hindcasting of the River flows at different locations where flow observations were unavailable, historically. It provides a synthesis of river flows at all control points in USRDOM downstream of Keswick based on the historical inflows and operations.

The 40-year hindcast run was developed to verify the ability of USRDOM to simulate flow routing, tributary inflows, weir overflows, diversions, and other closure flows in the model. To isolate and assess the uncertainty in the modeled flows with respect to these parameters, the effects of reservoir operations and import mechanisms were not included in the hindcast simulation by specifying the Keswick Reservoir outflow to be equal to the observed data (USGS 11370500). Clear Creek inflows into the Sacramento River were also forced to be equal to the historical data (Reclamation – Whiskeytown Reservoir Release). In addition, the tributary inflows and diversions were set equal to historical data as described in Section 3.3. Two closure flow time series were developed to account for accretions and depletions that were not explicitly modeled in USRDOM for the upper and the middle segments of the Sacramento River. The development of these two closure flow terms is described in the following sections.

4.2.2 Closure Terms

The USRDOM hydrology was developed based on historical flow data. However, not all the tributaries were gaged for the entire simulation period, which were synthesized as described in Section 2. A closure term represents the uncertainty between the synthesized and observed flow data, which results from incomplete flow data, and assumptions involved in estimating the missing data. In addition, the closure term also represents the flows that were not explicitly modeled in USRDOM such as ungaged stream flows, valley-floor runoff, groundwater interactions and minor diversions. Closure terms were developed for the calibration process to bring closure between the observed flow at a location in the river and the model inflows and diversions upstream of that location.

The closure term was computed by estimating the differences between the observed flows at a location and all known inflows and diversions modeled in USRDOM upstream of that location. For ease of computation, the upper Sacramento River was divided into three river segments, an upper segment extending from Keswick to Bend Bridge, a middle segment from downstream of Bend Bridge to Ord Ferry, and a lower segment downstream of Ord Ferry to Knights Landing. Closure terms were computed separately for the upper and middle segments but not for the lower segment because of incomplete data records available downstream of Ord Ferry. However, the USRDOM hindcast simulation still resulted in a satisfactory performance for the lower segment. This may be attributed to the fact that most of the River in this segment has been constrained by levees and hence the accretions and depletions, apart from those represented in the model explicitly, are minor.

Additional diversion and groundwater interaction data from CALSIM II hydrology were used for closure term computation for the upper and middle segments, when observed data was unavailable. Ungaged tributary inflow data were estimated using known inflows from the hydrology development and outflows for each river segment represented by a gage measurement. The computed closure terms were patterned to fit the observed river flows and are distributed based on the fraction of ungaged area at each control point in USRDOM. Detailed computation information for the upper and middle segment closure terms is provided below.

4.2.2.1 Upper Segment

As mentioned before, the closure term was computed by estimating the differences between the observed flows at a location and all known inflows and diversions modeled in USRDOM upstream of that location. Upper segment flow closure computation included following flow information for the river stretch from Keswick to Bend Bridge:

1. Main-stem river flows
2. Gaged tributary flows
3. Stream diversions
4. Miscellaneous flows
5. Ungaged tributary flows

Main-stem river flows for the upper segment closure term computation include Sacramento River flow at Keswick, Clear Creek flow below Whiskeytown, and Sacramento River flow at Bend Bridge. All these flows were obtained from historical gage and operational records. Gaged tributary flows used in this closure term computation include flows from Cow Creek, Cottonwood Creek, and Battle Creek. The daily flows for these tributaries were developed using the observed data as part of the hydrology development for USRDOM as described Section 2.

Stream diversions included in the computation of upper segment closure term were those to ACID, City of Redding, and miscellaneous CVP Settlement Contractors; various municipal and industrial diversions; agricultural use diversions; and non-project diversions. Flow delivery information for these components was obtained from the CACMP CALSIM II V8B Existing Condition Simulation. Since the observed data for these diversions were sparse, monthly data from CALSIM II were translated to daily diversion flows.

In CALSIM II, USRWQM, and USRDOM, the ACID diversion is explicitly modeled as a point diversion. However, in CALSIM II and USRWQM, in addition to the flows conveyed through the ACID canal, the modeled ACID diversion includes miscellaneous diversions along the Sacramento River between the Keswick and Clear Creek confluences. In USRDOM, these two sets of diversions are separated and only the diversion flows that are actually conveyed through ACID canal are simulated explicitly as a point diversion. The rest is distributed as part of the upper segment closure term. The ACID diversion in USRDOM is assumed equal to the D104_PSC flow from the CACMP CALSIM II V8B Existing Condition Simulation up to the ACID canal capacity of 315 cfs. The daily values are assumed to equal the monthly values from CALSIM II.

Miscellaneous flows include groundwater interactions, additional accretions, and return flows within the upper river segment, for which observed data was unavailable. Any data available for these types of flows were obtained from the CACMP CALSIM II V8B Existing Condition Run. Monthly timestep values are converted to daily format and separated as inflows and outflows.

Ungaged tributary flows represent the flows from ungaged streams or diversions that were not modeled explicitly. In USRDOM, these flows are modeled as distributed inflows as part of the closure term. The difference between the daily known outflows and inflows in the segment is used to compute the ungaged tributary flow. The negative differences are zeroed out, and the positive differences were adjusted to get the right pattern, while maintaining the total volume of the difference between the known outflows and known inflows for each water year.

Table 4.1 shows the categorization and source of the flow information used to compute the closure term for the upper segment of the Sacramento River.

4.2.2.2 Middle Segment

Similar to the upper segment closure computation, the middle segment closure is computed using the flow information from the above-mentioned types of flows for the river stretch downstream of Bend Bridge to Ord Ferry.

Main-stem river flows for this segment include observed data for the Sacramento River at Bend Bridge and synthesized data for Sacramento River below Stony Creek. Gaged

TABLE 4.1
Flow Information Used to Compute the Historical Upper Segment River Flow Closure Terms

Flow Data	Inflows	Outflows
Main-Stem River Flows	Sac River at Keswick (Combined Impaired [USGS 11370500] and Unimpaired [Shasta Inflow*] flow) Clear Creek below Whiskeytown (Combined Impaired [Whiskeytown Release*] and Unimpaired [Whiskeytown Inflow*] flow)	Sacramento River at Bend Bridge (USGS 11377100).
Gaged Tributary Flows	Cow Creek (Combined Observed/Synthesized Data) Cottonwood Creek (Combined Observed/Synthesized Data) Battle Creek (Combined Observed/Synthesized Data)	
Stream Diversions		ACID, City of Redding, Miscellaneous Settlement Contractors (CALSIM II D104_PSC) Municipal and Industrial Use (CALSIM II D104_PMI) Agricultural Use (CALSIM II D104_PAG)
Miscellaneous Flows	Negative Groundwater/Streamflow Interaction (CALSIM II GS60) Accretions Adjustments (CALSIM II D109) Return Flow (CALSIM II R109)	Positive Groundwater/Streamflow Interaction (CALSIM II GS60)
Ungaged Tributary Flows	Inflow computed based on the difference between the known inflows and outflows	

*Observed data obtained from Reclamation operations records

tributary flows for this segment include Paynes Creek, Antelope Creek, Mill Creek, Deer Creek, Red Bank Creek, Big Chico Creek, Elder Creek, and Thomes Creek. The daily flows for these tributaries were developed using the observed data as part of the hydrology development for USRDOM as described in Section 2.

Stream diversions include diversions to Sacramento River miscellaneous users; Thomes, Mill, Deer, and Antelope creek users; Corning, Tehama-Colusa, and Glenn-Colusa canal users; and Stony Creek users. Delivery flow information for these components was obtained from the CACMP CALSIM II V8B Existing Condition Simulation. Monthly data from CALSIM II were translated to daily diversion flows.

Miscellaneous flows in the segment include groundwater interactions and return flows. This information was obtained from the CACMP CALSIM II V8B Existing Condition Simulation. Monthly timestep values were converted to daily format and separated as inflow and outflows. All the ungaged tributary flows in the segment are computed based on the difference between known outflows and known inflows in the reach, similar to the upper segment closure term.

Table 4.2 shows the categorization and source of the flow information used to compute the closure term for the middle segment of Sacramento River.

4.2.3 Hydrologic Routing

The model development section of this document describes the methodology and development of routing coefficients for USRDOM. Two coefficient methods were used in USRDOM: the Attenuation of Hydrographs method and the Muskingum Routing method. Attenuation of Hydrographs method was used for the stream routing in the main stem Sacramento River. This method requires user specified 'C' values. Muskingum Routing was used in the Sutter Bypass reaches. The 'C' values for this method are computed based on the travel time in hours (K) and the dimensionless routing parameter between 0 and 0.5 (X) specified for each reach.

For the main-stem Sacramento River, the routing coefficients and the travel times are obtained from the USRWQM calibration document (RMA, 2003). USRDOM routing coefficients were obtained by modifying the USRWQM routing coefficients to account for the differences in the reach lengths in the two models as described in Section 3.4. To validate routing coefficients, USRDOM based travel times are compared with the travel times computed in the Comp Study. They are also compared with another independent source (Jones, 1999) to check the validity of the travel times.

Table 4.3 shows the comparison of USRDOM-based travel times with travel times computed from the Comp Study and Jones.

USRDOM travel times agreed well with the Comp Study and Jones' travel times from Keswick to Moulton Weir. The travel times deviate slightly downstream of Moulton Weir to Knights Landing. Total difference in the travel time at Knights Landing is less than 20 hours, which would result in a day offset in the modeled results compared to the Comp Study. However, USRDOM travel time values are closer to those estimated by Jones.

4.2.4 Verification Metrics

To quantify the quality of USRDOM hydrologic inputs and performance of stream routing, the following metrics were defined using the results from the USRDOM hindcast simulation.

1. Cumulative probability exceedance plots showing the scatter of daily modeled flows at each rank of daily historical observed flows in high (October–March) and low (April-September) flow seasons

2. Average daily residuals (simulated minus historical observed flows) for each of the following flow ranges for high and low flow seasons

    - 0 to 15,000 cfs
    - 15,000 to 45,000 cfs
    - 45,000 cfs
    - Full range

TABLE 4.2
Flow Information Used to Compute the Historical Component of Middle Segment River Flow Closure Terms

Flow Data	Inflows	Outflows
Main-Stem River Flows	Sacramento River at Bend Bridge (USGS 11377100)	Sacramento River below Stony Creek (Combined Observed/Synthesized Data)
Gaged Tributary Flows	Paynes Creek (Combined Observed/Synthesized Data) Antelope Creek (Combined Observed/Synthesized Data) Mill Creek (Combined Observed/Synthesized Data) Deer Creek (Combined Observed/Synthesized Data) Big Chico Creek (Combined Observed/Synthesized Data) Red Bank Creek (Combined Observed/Synthesized Data) Elder Creek (Combined Observed/Synthesized Data) Thomes Creek (Combined Observed/Synthesized Data)	
Stream Diversions		Sacramento River, Thomes, Elder, Deer, Mill and Antelope Misc. Users (CALSIM II D11301+D105+D11305) Corning Canal Historical Diversion (DWR Monthly Historical) Tehama-Colusa Historical Diversion (DWR Monthly Historical) Glenn-Colusa Historical Diversion (DWR Monthly Historical) Stony Creek Historical Diversion (DWR Monthly Historical)
Miscellaneous Flows	Negative Groundwater/Streamflow Interaction (CALSIM II GS61) Return Flow (CALSIM II R113+R114A+R114B+R114C)	Positive Groundwater/Streamflow Interaction (CALSIM II GS61)
Ungaged Tributary Flows	Inflow computed based on the difference between the known inflows and outflows	

TABLE 4.3
Comparison of USRDOM-based Travel Times

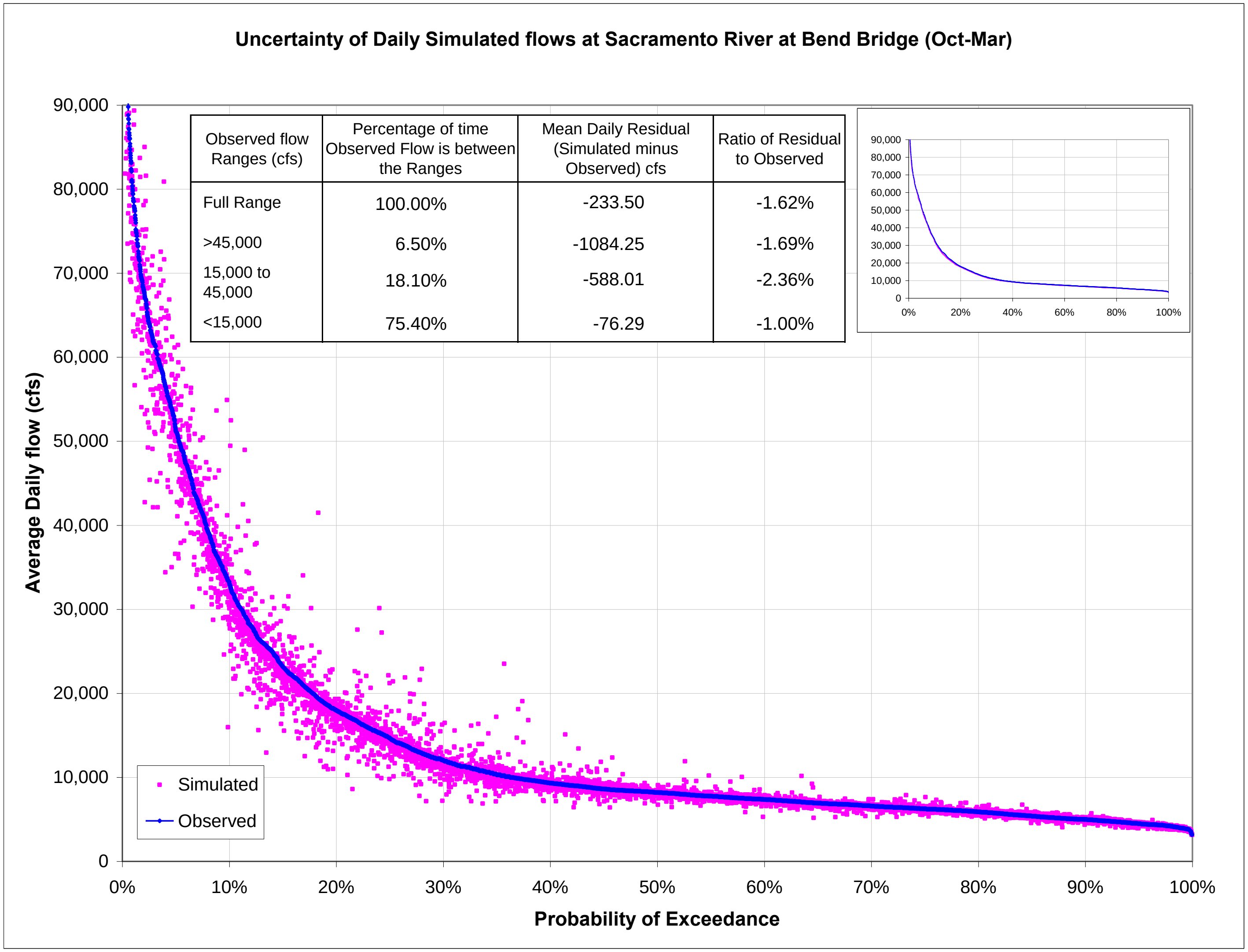
	Travel Time (Hours)		
Location	**USRWQM/USRDOM**	**Comp Study**	**Jones, 1999**
Keswick Reservoir	0	0	0
Cow Creek	5	5.2	-
Bend Bridge	9	10.2	12
Red Bluff Diversion Dam	12	-	-
Woodson Bridge	20	19.8	22
GCID intake	22	-	-
Stony Creek	26	26.5	-
Butte City	32	26.5	-
Moulton Weir	35	34.5	38
Colusa Weir	40	34.5	39
Tisdale Weir	50	42.5	47
Wilkins Slough	-	-	65
Knights Landing	62	42.5	-

Cumulative probability exceedance plots show the uncertainty in daily simulated flows with respect to the observed daily flows for the full range of flows for high flow and low flow seasons. Separate seasonal data sets (October–March and April–September) of observed and simulated mean daily flows were used to compare the uncertainty in simulated flows. The mean daily paired data sets were then sorted by observed data to obtain the cumulative probability of exceedance of daily flows.

4.2.5 Comparison of Model Results with Observed Data

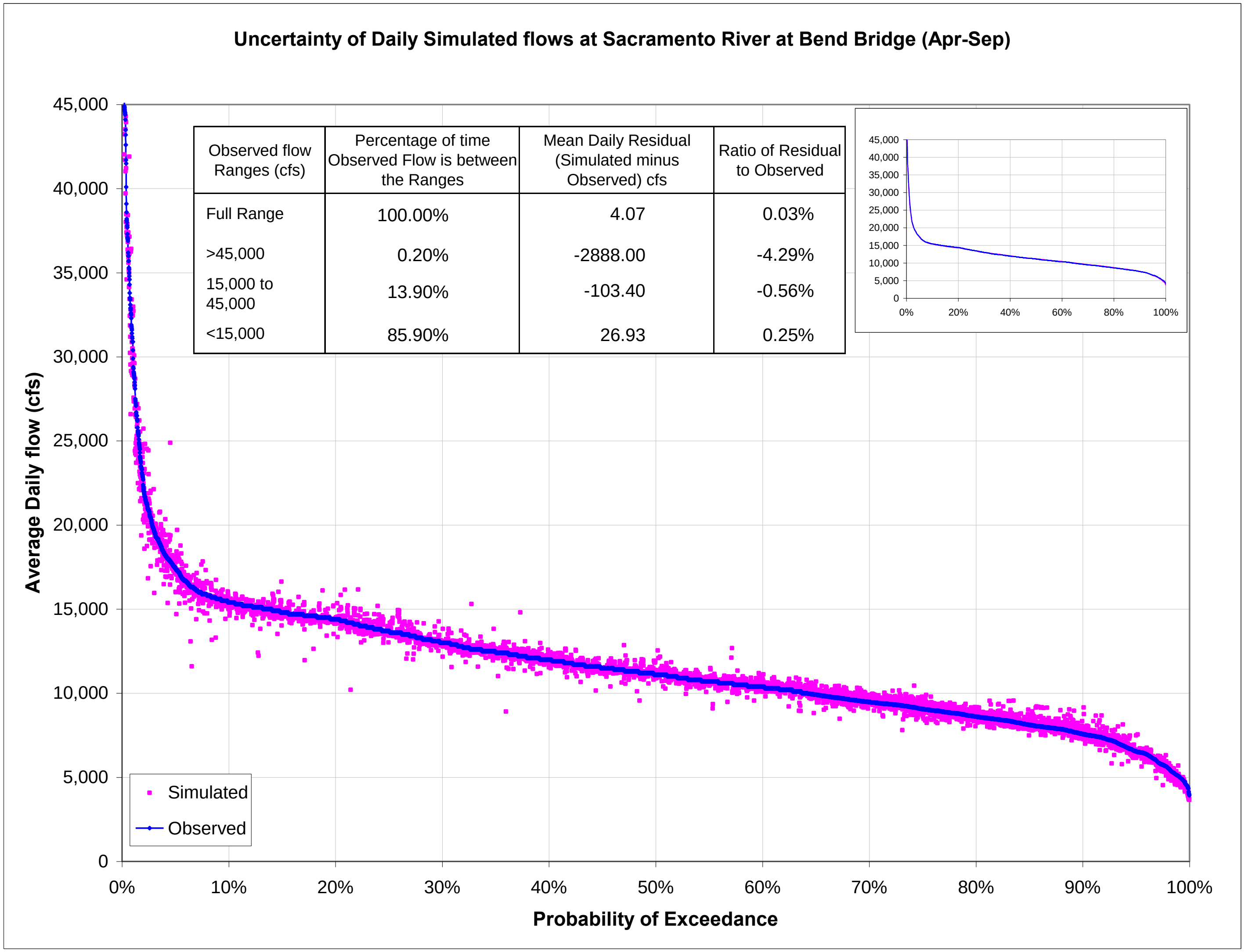
Cumulative probability exceedance plots for the full range of flows for the high flow and low flow seasons and average daily residual tables for different flow ranges are presented for the Sacramento River at Bend Bridge. Exceedance plots for other locations are presented in Appendix A.

Figure 4.1 is a cumulative probability of exceedance plot showing the uncertainty of daily simulated Sacramento River flows at Bend Bridge for the high flow season, October through March. Probability of exceedance (percent) is shown on the x-axis and the daily flows (cfs) are shown on the y-axis. The solid blue line represents the observed flow and the magenta scatter points represent the simulated flow on the same day. If the model is able to emulate the observed flows exactly both in terms of the timing and magnitude, the magenta scatter points should fall on top of the blue curve. Therefore, the uncertainty in the simulated flows for a given observed flow value can be measured based on the vertical scatter of simulated flow around it. Figure 4.2 shows a similar plot for Sacramento River at Bend Bridge for the low flow season (April–September). In both Figures 4.1 and 4.2 a probability of exceedance



Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	-233.50	-1.62%
>45,000	6.50%	-1084.25	-1.69%
15,000 to 45,000	18.10%	-588.01	-2.36%
<15,000	75.40%	-76.29	-1.00%

FIGURE 4.1
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (October – March)



Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	4.07	0.03%
>45,000	0.20%	-2888.00	-4.29%
15,000 to 45,000	13.90%	-103.40	-0.56%
<15,000	85.90%	26.93	0.25%

FIGURE 4.2
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (April – September)

plot is shown as inset where the observed and simulated data are sorted independently. These plots show that the probability of exceedance for observed and simulated flows show good agreement indicating that the variability in the observed flow magnitudes over the calibration period is accurately represented in the USRDOM results.

The average daily residuals for the high flow and low flow seasons are summarized in Tables 4.4 and 4.5, respectively. (They are also shown as insets in Figures 4.1 and 4.2). Mean daily residuals (average of simulated minus observed daily flows) and relative difference in the simulated flows with respect to the observed mean are computed for the flow ranges defined in Section 4.2.4. Column 1 describes the flow range for which the residuals have been computed. Column 2 shows the percentage of time for which the observed flow is within the ranges described in column 1. The sum of the percentages for different flow ranges should equal 100 percent. Columns 3 and 4 show the mean daily residual in cfs and the relative difference between simulated and observed flows, respectively. The summary tables help to clarify the uncertainty in simulated daily flows for different flow ranges, which is helpful in assessing the performance of the model for purposes such as temperature modeling, diversion analysis, and flood control.

TABLE 4.4
Average Daily Residuals between Simulated and Observed Daily Flows along the Sacramento River for Oct – Mar Using Results from USRDOM Hindcast Model

Locations	Observed Flow Ranges (cfs)	% of Time Observed Flow within Range	Mean Daily Residual (Simulated minus Observed) (cfs)	Ratio of Residual to Observed (%)
Sacramento River at Bend Bridge	Full Range	100.0	-233.5	-1.6
	>45,000	6.5	-1084.3	-1.7
	15,000 to 45,000	18.1	-588.0	-2.4
	<15,000	75.4	-76.3	-1.0
Sacramento River at Hamilton city	Full Range	100.0	-591.5	-3.5
	>45,000	8.8	-4010.7	-5.7
	15,000 to 45,000	20.4	-1331.9	-5.3
	<15,000	70.8	46.9	0.6
Sacramento River at Colusa	Full Range	100.0	-333.1	-2.3
	>45,000	0.9	-604.1	-1.3
	15,000 to 45,000	30.4	-804.4	-2.8
	<15,000	68.7	-122.5	-1.6
Sacramento River at Knights Landing	Full Range	100.0	-693.0	-4.9
	>45,000	0.0	-	-
	15,000 to 45,000	35.6	-852.9	-3.7
	<15,000	64.4	-605.5	-6.6

TABLE 4.5
Average Daily Residuals between Simulated and Observed Daily Flows along the Sacramento River for Apr – Sep Using Results from USRDOM Hindcast Model

Locations	Observed Flow Ranges (cfs)	% of Time Observed Flow within Range	Mean Daily Residual (Simulated minus Observed) (cfs)	Ratio of Residual to Observed (%)
Sacramento River at Bend Bridge	Full Range	100.0	4.1	0.0
	>45,000	0.2	-2888.0	-4.3
	15,000 to 45,000	13.9	-103.4	-0.6
	<15,000	85.9	26.9	0.3
Sacramento River at Hamilton city	Full Range	100.0	380.6	3.7
	>45,000	0.3	-3795.2	-5.6
	15,000 to 45,000	9.3	-177.8	-0.8
	<15,000	90.4	451.6	5.1
Sacramento River at Colusa	Full Range	100.0	266.8	2.7
	>45,000	0.0	-	-
	15,000 to 45,000	9.2	-984.7	-4.4
	<15,000	90.8	391.3	4.5
Sacramento River at Knights Landing	Full Range	100.0	-207.3	-2.2
	>45,000	0.0	-	-
	15,000 to 45,000	8.8	-1239.1	-6.4
	<15,000	91.2	-111.8	-1.3

Figure 4.1 shows that the uncertainty in the simulated flows at Bend Bridge is higher at times when the observed flow is greater than 15,000 cfs, with better agreement between the simulated and observed flows below 15,000 cfs. The summary table shows that observed flows are less than 15,000 cfs 75.4 percent of the time, and the average daily residual in that range is -76.29 cfs, which is approximately 1 percent of the mean observed flows in that range. This flow statistic supports the conclusion that USRDOM simulates the river flows accurately when the river flows are below 15,000 cfs for the high flow season.

For flows of 15,000 to 45,000 cfs, the mean simulated flow is 2.4 percent lower than the observed flows. However, the observed flows are in this range only 18 percent of the time. Similarly, for flows greater than 45,000 cfs, the mean daily residual is about 1.7 percent of the mean observed flows in this range, but observed flows fall in this range only 6.5 percent of the time. For the full range of flows, the mean simulated flow is 1.6 percent lower than the observed flows. Therefore, USRDOM is capable of accurately simulating the full range of flows during the high flow season when the reservoirs are under the flood operations.

Figure 4.2 shows the cumulative probability of exceedance plot for daily simulated flows at the Sacramento River at Bend Bridge for the low flow season (April through September). The daily residuals of different flow ranges show agreement between the simulated and observed flows. This implies that USRDOM performs better in simulating the full range of flows for the low flow season likely because the reservoirs mainly release to meet specific downstream demands and the influence of local tributary flows is insignificant.

The cumulative probability of exceedance plots shown as insets in Figures 4.1 and 4.2 represent the frequency of daily observed and simulated flows sorted independently. Both datasets appear nearly identical, which means the model is capable of simulating all the flow ranges accurately in terms of magnitude.

The higher discrepancy seen between the simulated and observed data when the river flow is higher than 15,000 cfs may be a combination of various factors. One factor may be the uncertainty associated with the assumed ungaged flows in USRDOM, in terms of magnitude, timing, and inflow location. Another factor may be the constant monthly demands used in the hindcast simulation for the major diversions and the lumped diversions in certain reaches. Finally, the hydrology development process used for USRDOM does not capture valley-floor dynamics associated with flood routing. In other words, the representation of storm driven, intermittent high runoff events that occur on the valley floor have not been fully resolved in the hydrology development process.

4.3 Calibration/Verification of Reservoir Operations (1996-2003)

4.3.1 Approach

USRDOM includes Trinity, Lewiston, Whiskeytown, Shasta, Keswick, and Black Butte reservoirs. The model is equipped with operating rules to simulate the daily operations at each of the reservoirs as close to the observed conditions as possible. The quality of the simulated daily operations in comparison to the observed data was evaluated. The focus of the calibration/verification was mainly on the three CVP reservoirs: Trinity, Shasta, and Whiskeytown.

The performance of USRDOM in simulating daily reservoir operations was assessed by running eight separate simulations for WY 1996 through WY 2003. In each simulation, the initial storage of Trinity, Whiskeytown, and Shasta reservoirs is set equal to the observed data at the start of the run. Simulation of daily reservoir operations was verified by comparing the end-of-day simulated reservoir storage and releases for each separate run with the observed data during the period when the reservoirs were not operating under downstream control.

4.3.2 Definition of Control Periods

Reservoir storage and release operations in the Trinity River system and Sacramento River system are influenced primarily by the upstream flood control operations during the high flow season and by the downstream control for the low flow season. During the downstream control periods, the releases from the reservoirs are made to meet the demands for the diversions and other minimum requirements along the Sacramento River. Therefore, during this period, each reservoir operates based on a specified downstream release requirement.

The beginning of the downstream control periods was identified by locating the timestep where the observed reservoir releases just meet the minimum release requirements for the reservoir following the last major flood of the season. The period prior to this timestep was assumed as the period of upstream control. Performance of the reservoir operations of

USRDOM were evaluated by comparing the simulated storages and reservoir releases with the observed operations during the upstream control period.

4.3.3 Changes to Reservoir Operating Criteria

Reservoir operating criteria for the Trinity, Whiskeytown, and Shasta reservoirs were refined to achieve better agreement with the observed data. Some of the operating rules were evaluated and implemented in the model as part of the calibration/verification process. Minimum required releases for Shasta and Trinity reservoirs were updated to account for the isolated X2 related releases that rarely occurred historically during the upstream control periods. Evaporation was included at Shasta, Trinity, Whiskeytown, and Black Butte reservoirs using the monthly evaporation rates from the CACMP V9 CALSIM II Existing Condition Run. The sensitivity of the simulated operations to the specified release ramping rates was tested for Trinity and Shasta reservoirs.

Trinity River releases in USRDOM are determined based on the Trinity River flow schedules and Clear Creek Tunnel flows. Observed data for Clear Creek Tunnel flows show that Trinity River imports to the Sacramento River are reduced to 300 cfs when flood conditions begin to occur in the Sacramento River. To simulate this condition, when the Tisdale Weir (control point 115) is spilling, the Trinity import to the Sacramento River is reduced to 300 cfs. Further, to reduce the flooding risk of Clear Creek below Whiskeytown, the Trinity import to the Sacramento River is also reduced when Whiskeytown (control point 240) is near spilling.

In order to modify Trinity imports dynamically in USRDOM, Clear Creek Tunnel (control point 242) channel capacity needs to change between full capacity (3,200 cfs) and the limited capacity (300 cfs). However, in HEC-5 channel capacity cannot be modified based on the flows at downstream control points. Therefore, to implement the above Trinity import logic few deliberate changes were implemented in USRDOM. The first change was to add a dummy inflow to the Clear Creek Tunnel control point (242) in the USRDOM, which is diverted out of the system at the next downstream control point (241). This dummy flow allows in artificially changing the available channel capacity for the Trinity imports.

The second change was to run USRDOM in two iterations. The first USRDOM iteration is simulated without limiting the Trinity imports. The dummy inflow at control point 242 is set to zero throughout the simulation, keeping full channel capacity available for the Trinity imports. The results from the first iteration are used to determine the days when Tisdale Weir spills and Whiskeytown is ready to spill or spills. On the identified days, the Trinity import utility changes the dummy flow value to 2,900 cfs, which fills the channel capacity of Clear Creek Tunnel (3,200 cfs) and thereby reducing the available tunnel capacity for the Trinity imports to 300 cfs. This dummy flow is diverted just upstream of Whiskeytown Reservoir. The utility also reduces Trinity releases for imports. Using the modified dummy flow and the Trinity release requirements, the second and final iteration of USRDOM is simulated to produce the final results. Testing has verified that this Trinity import logic reasonably limits the Trinity flows to Sacramento River.

4.3.4 Verification Metrics

To quantify the performance of USRDOM in simulating the reservoir operations, the following metrics were defined.

1. Annual time series plots showing simulated and observed storage with a delineation of conservation and flood storage capacity, and modeled and historical observed flow releases with a delineation of releases associated with identified downstream requirements
2. Tables showing modeled, observed, and residual (modeled minus observed) and annual average ending storage conditions associated with the date at which the reservoir begins to operate each year for downstream requirements exclusively

4.3.5 Comparison of Model Results with Observed Data

Annual time series plots comparing the simulated and observed storage and reservoir releases are presented for Trinity, Whiskeytown, and Shasta reservoirs.

The storage residuals at the end of the upstream control period for Trinity and Shasta reservoirs are presented in Tables 4.6 and 4.7.

Figures 4.3 and 4.4 show the time series comparison plot between observed and simulated storage and reservoir releases for Shasta Reservoir for WY 1998 and WY 2003, respectively. Plots for other water years are provided in Appendix A.

The beginning of the period for which the operations are based on the downstream control in the observed data is shown by a vertical solid black line. The period before this line is the upstream control period during which the performance of USRDOM reservoir operations is being assessed. In some years, brief cases of downstream control occur before the date indicated by the solid black line. The numerical difference in observed and simulated storage at the end of the upstream control period is computed for each water year. This information is provided for Trinity and Shasta reservoirs in Tables 4.6 and 4.7, respectively.

The simulated Shasta storage closely follows the observed storage in the upstream control period. Because the initial storage for the simulation is reset to the observed storage, the simulated storage at the beginning of the water year matches the observed data. The difference in the storage is seen when a high flow event occurs in the observed data. During this period, the storage in the reservoir encroaches into the flood storage pool (above the top of conservation storage pool level) to accommodate the increased inflows to the reservoir. As the event recedes, USRDOM releases more water compared to the observed data, until the simulated reservoir storage level equals the top of the conservation storage pool. The observed storage during this period, however, shows encroachment for a longer period, resulting in a difference between the simulated and observed releases. The difference in the storage is carried until the end of the upstream operations control period. The cause of this difference in operation is that the model is not informed about the forecast information that the operators may have had and, therefore, the release decisions in the model and the field are different.

The storage residuals at the end of upstream control period for Shasta Reservoir for all the water years are provided in Table 4.7. The percentage difference in simulated storages for

TABLE 4.6
Comparison of Simulated and Observed Storage at Beginning of Downstream Control for Trinity Reservoir

Simulated Water Year	Date at the Beginning of Downstream Control	Trinity Reservoir Storage (TAF)				Remarks
		Simulated	Observed	Difference (Simulated minus Observed)	Ratio of Difference to Observed	
1996	04/04/1996	2,106	2,185	-79	-3.6%	Observed storage did not follow the flood diagram and encroached on the flood storage pool by releasing lower flows, but simulated releases were higher and the storage followed the flood diagram.
1997	04/04/1997	2,101	2,114	-13	-0.6%	Observed releases were lower compared to the simulated, resulting in higher storage.
1998	07/12/1998	2,448	2,447	0	0.0%	Higher observed releases than simulated in February 1998 caused the storage difference, which continued until few days prior to 07/12/1998.
1999	03/31/1999	2,100	2,096	4	0.2%	Observed releases were higher from 11/16/1998 until 03/31/1999, and observed storage did not follow the flood diagram. Simulated storage followed the flood diagram.
2000	05/31/2000	2,424	2,384	40	1.7%	Higher observed releases at the end of April 1999 caused the storage difference between observed and simulated storages and continued until 05/31/2000.
2001		-	-	-	-	There were no flood events during this year.
2002		-	-	-	-	There were no flood events during this year.
2003	06/10/2003	2,373	2,407	-35	-1.4%	Observed releases were lower from December 2002, resulting in higher observed storage than the simulated storage.
Average:				-14	-0.6%	

TABLE 4.7
Comparison of Simulated and Observed Storage at the Beginning of Downstream Control for Shasta Reservoir

Simulated Water Year	Date at the Beginning of Downstream Control	Shasta Reservoir Storage (TAF)				Remarks
		Simulated	Observed	Difference (Simulated minus Observed)	Ratio of Difference to Observed	
1996	04/01/1996	3,738	3,904	-166	-4.3%	Because of an event on 02/06/1996, storage encroached into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas observed storage did not.
1997	02/16/1997	3,442	3,438	4	0.1%	Even though the difference is very small, events from 12/06/1996 led to the encroachment into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas observed storage receded slowly.
1998	04/13/1998	3,873	3,734	139	3.7%	Because of events in January and February, storage encroached into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas the observed storage continued to drop below the flood diagram.
1999	03/30/1999	3,937	3,842	95	2.5%	Observed releases were lower than simulated, resulting in higher storage; however, simulated storage followed the flood diagram, causing higher releases.
2000	03/25/2000	3,590	3,659	-68	-1.9%	Because of events in January and February, storage encroached into the flood storage pool. After the event, the simulated storage dropped quickly to follow the flood diagram, whereas observed storage receded from the flood pool slowly.
2001	01/17/2002	-	-	-	-	There were no flood events during this year.
2002	05/10/2003	3,446	3,431	15	0.4%	Observed releases on 01/05/2002 were higher than simulated, resulting in lower observed storage.
2003	04/01/1996	4,534	4,459	75	1.7%	Observed releases on 05/04/2003 were higher than simulated, resulting in lower observed storage.
Average:				14	0.3%	

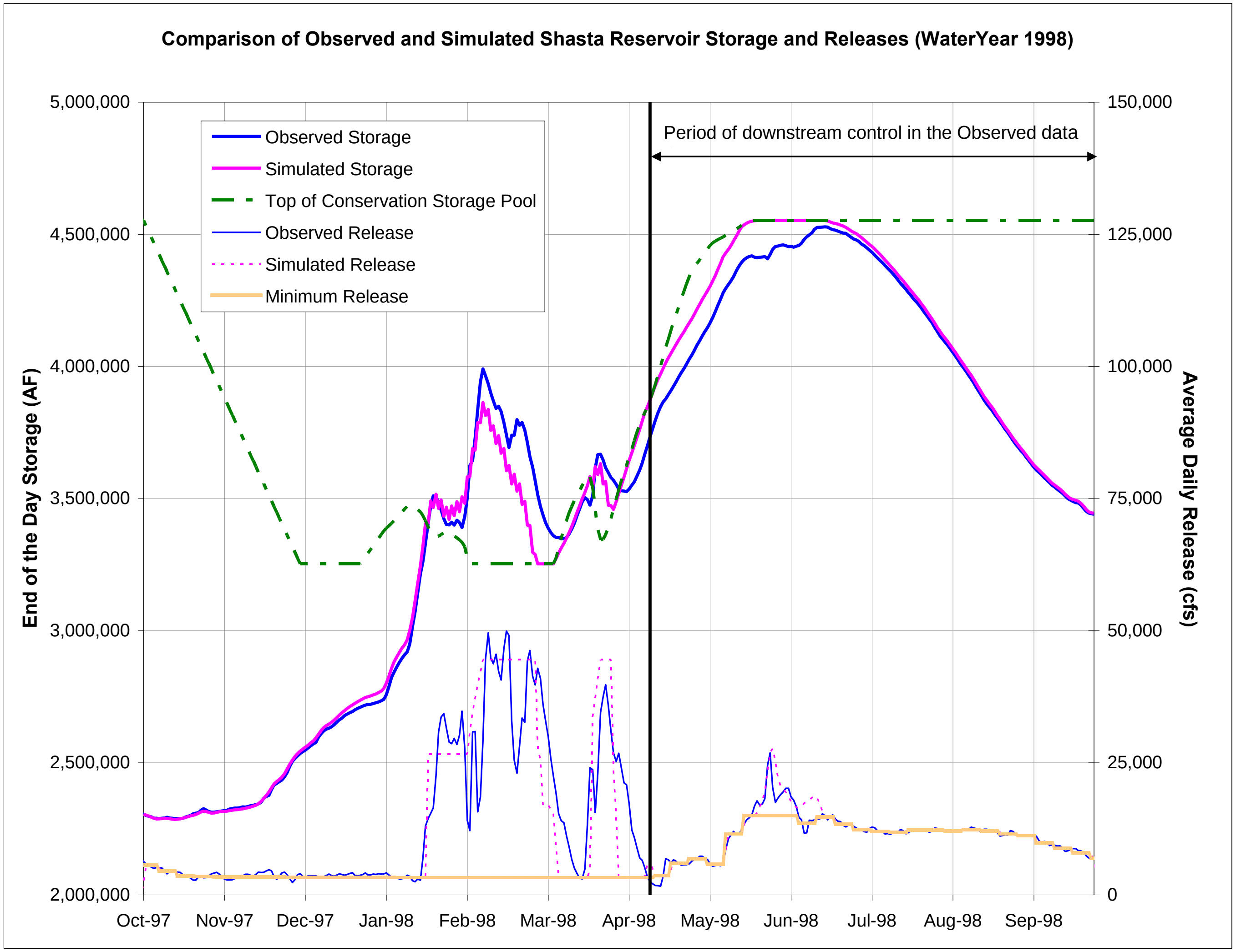


FIGURE 4.3
Comparison of Observed and Simulated Shasta Reservoir Storage and Releases (WY 1998)

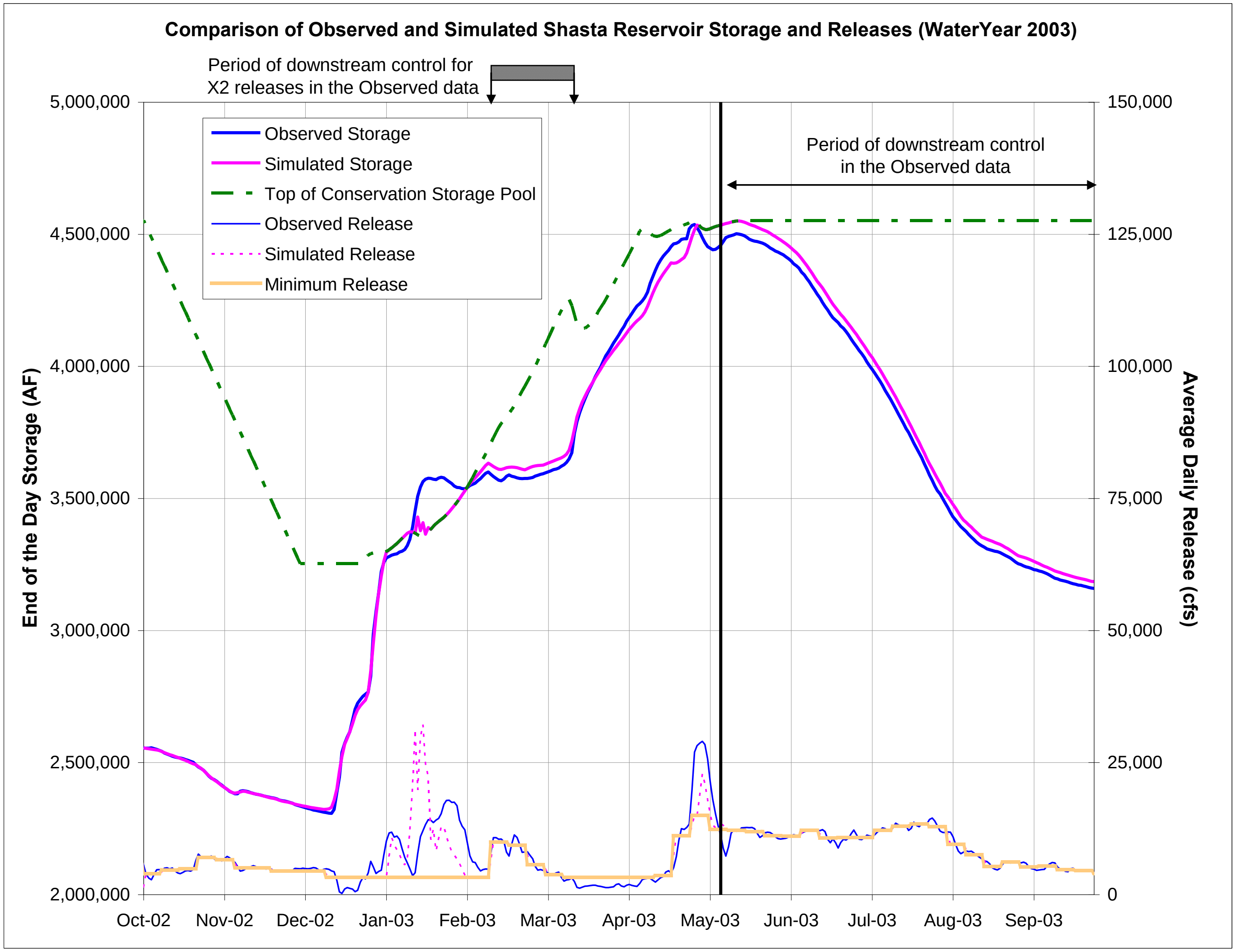


FIGURE 4.4
Comparison of Observed and Simulated Shasta Reservoir Storage and Releases (WY 2003)

the water years is very small and is mostly because of the differences in the encroachment of storage into the flood pool. The results in the table demonstrate that USRDOM simulates Shasta Reservoir operations accurately. Similarly, based on the residuals shown in Table 4.6, USRDOM mimics the observed Trinity operations accurately. For the water years where the residuals were not reported, the year did not have any flood operations.

4.4 Full Verification of USRDOM Simulation (1996–2003)

4.4.1 Approach

This section discusses the process of full verification of USRDOM, including the full extent of the schematic, with the reservoir operations simulated according to the rules described previously and the flow routed from Keswick to Knights Landing. An 8-year simulation with the historical hydrologic inputs for WY 1996 to WY 2003 was used for the full verification of USRDOM. The goal of full verification was to assess the performance of USRDOM in simulating the daily flows in the river and identify uncertainty in the simulated flows when compared to the observed data.

The version of USRDOM used for the full verification contains the same reservoir operations criteria and river flow operations as the reservoir operations verification simulation and hindcast simulation. The model was simulated for WY 1996 to WY 2003 with initial conditions equal to the observed data at the end of September 30, 1995.

4.4.2 Verification Metrics

To evaluate the performance of full verification simulation, the following metrics were defined and reported for several key locations.

- High flow season (October through March) and low flow season (April through September) cumulative probability exceedance plots showing the scatter of daily modeled flows at each rank of daily historical observed flows
- High flow season (October through March), low flow season (April through September), and annual total average of daily residuals (simulated minus historical observed flows) for each of the following flow ranges:
  - 0 to 15,000 cfs
  - 15,000 to 45,000 cfs
  - > 45,000 cfs
- Time series plots showing the simulated and observed daily flows
- Time series plots showing the simulated and observed end-of-the-day storage

4.4.3 Comparison of Model Results with Observed Data

The following locations were selected for the USRDOM full verification simulation:

- River flow verification locations
  - Clear Creek Tunnel
  - Clear Creek below Whiskeytown Dam
  - Spring Creek Tunnel

  - Sacramento River below Keswick Reservoir
  - Sacramento River at Bend Bridge
  - Sacramento River at Hamilton City
  - Sacramento River at Colusa
  - Sacramento River at Knights Landing

- Reservoir storage verification locations
  - Trinity Reservoir
  - Whiskeytown Reservoir
  - Shasta Reservoir

This section presents the storage results for three reservoirs and the flow results for the Bend Bridge location. All other verification results are presented in Appendix A.

Figure 4.5 shows the cumulative probability of exceedance plot showing the uncertainty of daily simulated flows at Sacramento River at Bend Bridge for October through March. Figure 4.6 shows a similar plot for Sacramento River at Bend Bridge for April through September.

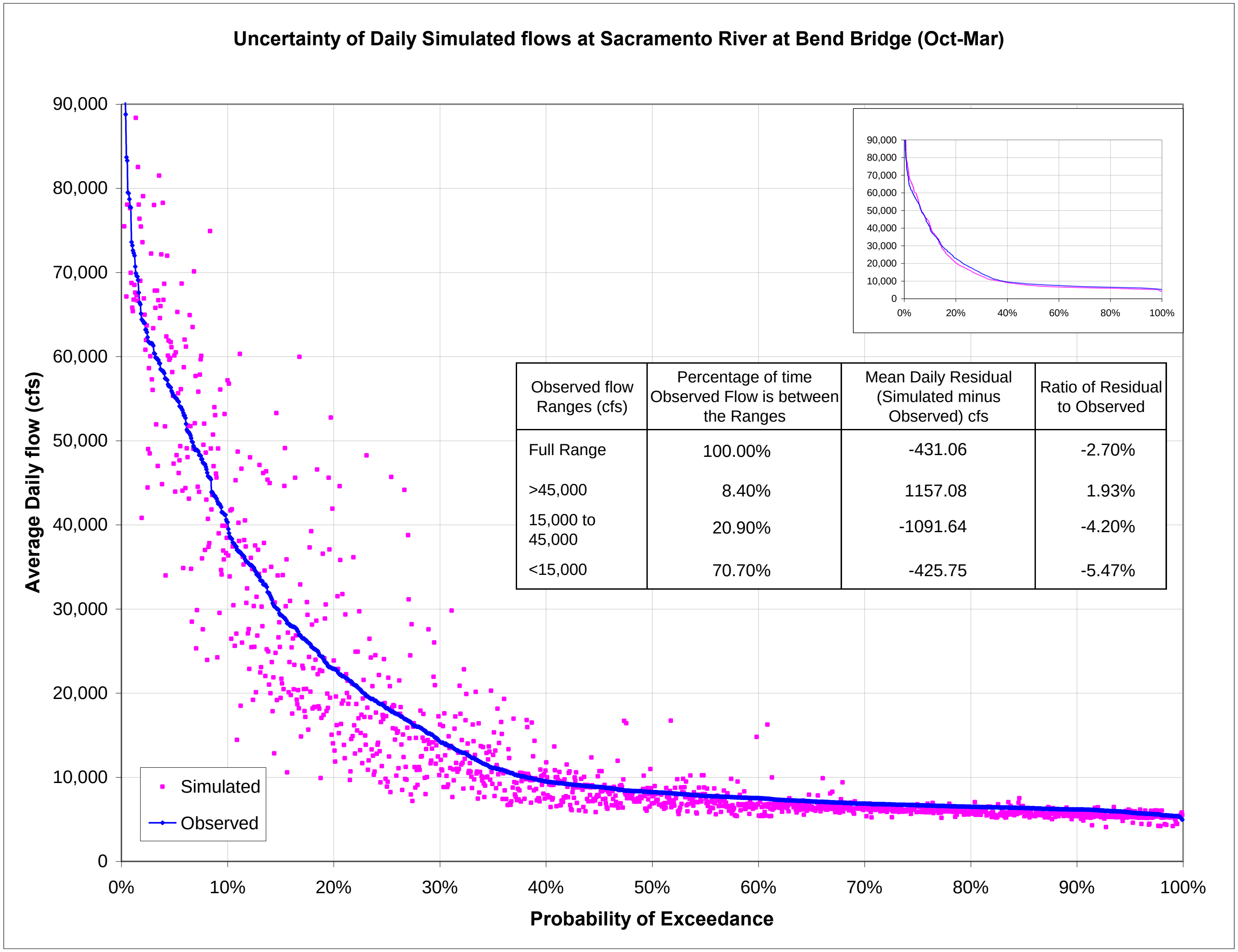
A summary table of the average daily residuals is provided as an inset in Figure 4.5. Mean daily residuals (average of simulated minus observed daily flows) and ratios of average daily residual to the observed mean are computed for the flow ranges defined in the verification metrics section.

Figure 4.5 shows that, during the high flow season, the uncertainty in the simulated flows at Bend Bridge is significant when the observed flows are greater than 15,000 cfs. There is comparatively less uncertainty in the simulated flows when the daily observed flows are below 15,000 cfs. Observed flows are less than 15,000 cfs about 70 percent of the time, and the average daily residual is -425.75 cfs. The same parameter for the hydrology verification simulation is only -76.3 cfs. This implies that additional -349.5 cfs of average daily residual is introduced at Bend Bridge because of simulated reservoir operations.

From the daily residuals for the flow ranges 15,000 to 45,000 cfs; above 45,000 cfs; and full range of flows, the relative error in the mean flows is -4.2 percent, 1.9 percent, and -2.7 percent, respectively. Therefore, the USRDOM model performs reasonably well for the high flow ranges during the high flow season, when most diversion and flood control operations occur. Mean daily residuals for the full range of flows show that the modeled flows are 2.7 percent less than the observed flows, meaning that USRDOM is capable of simulating the flows accurately for the full range of flows for the high flow season.

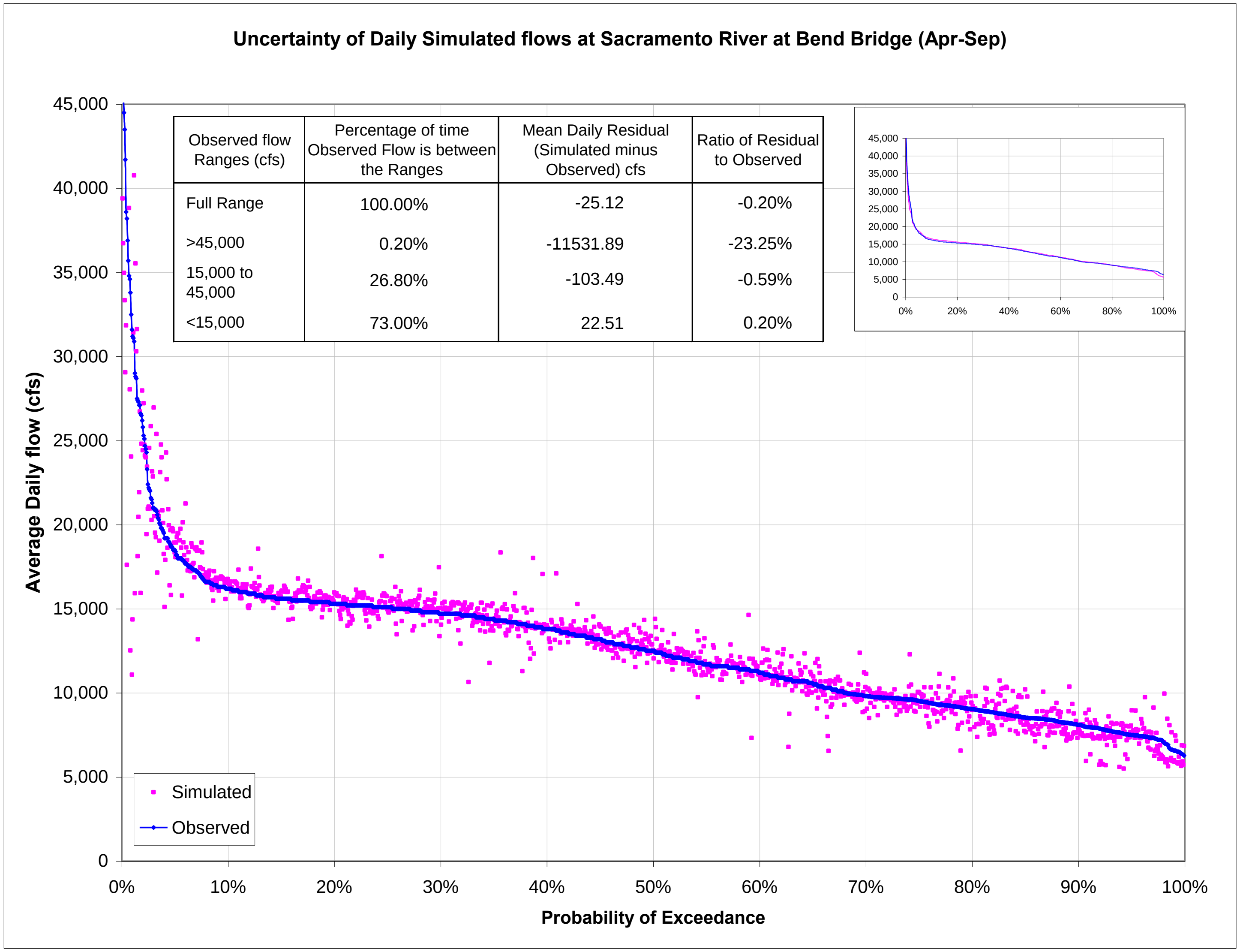
The cumulative probability of exceedance plot provided as an inset in Figure 4.5 represents the frequency of daily observed and simulated flows. Both curves are similar, which means the model is capable of simulating all the flow ranges accurately in terms of magnitude.

Similarly, Figure 4.6 shows the cumulative probability of exceedance plot of the uncertainty in the daily simulated flows at Sacramento River at Bend Bridge for April to September. The daily residuals of different flow ranges show a better agreement between the simulated and observed flows for the low flow season. This implies that USRDOM performs better in simulating flows for the low flow season because the reservoir operations' induced



Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	-431.06	-2.70%
>45,000	8.40%	1157.08	1.93%
15,000 to 45,000	20.90%	-1091.64	-4.20%
<15,000	70.70%	-425.75	-5.47%

FIGURE 4.5
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (October–March)



Observed flow Ranges (cfs)	Percentage of time Observed Flow is between the Ranges	Mean Daily Residual (Simulated minus Observed) cfs	Ratio of Residual to Observed
Full Range	100.00%	-25.12	-0.20%
>45,000	0.20%	-11531.89	-23.25%
15,000 to 45,000	26.80%	-103.49	-0.59%
<15,000	73.00%	22.51	0.20%

FIGURE 4.6
Uncertainty of Daily Simulated Flows at Sacramento River at Bend Bridge (April–September)

uncertainty is significantly lower in this season. Reservoirs only release to meet specified minimum in-stream flow requirements and other downstream demands.

The full verification simulation's reservoir operations can also be assessed by comparing the simulated and observed reservoir storage and outflows. Figures 4.7 through 4.12 show the time series plots of simulated and observed storages and the outflow for Trinity Reservoir, Whiskeytown Reservoir, and Shasta Reservoir, respectively.

The figures show that the storage is simulated accurately to follow the timing and magnitude of the observed data. Overall, the simulated storage in all three reservoirs agrees with the observed data for the entire simulation period. One exception is that during WY 2001 to WY 2003, simulated Trinity storage is higher than the observed data. The Trinity Reservoir release during this period is significantly lower than the observed data. This occurs because the process used to develop the minimum release requirement in the model does not capture all of the operational decisions that led to observed releases during this period.

The uncertainty induced in the river flows because of reservoir operations can be quantified by comparing the average daily residuals at key locations in the system between full verification simulation and hindcast simulation. To facilitate the comparison of the statistics, system diagrams have been developed that indicate the average daily residuals and ratios of these residuals to the observed means at each location. The results of full verification simulation and hindcast simulation are presented in the system diagrams (Figures 4.13, 4.14, and 4.15). Because the full verification simulation is for WY 1996 to WY 2003, the mean daily residuals for the hindcast were also computed only for this period.

Figure 4.13 shows the system diagram with a comparison of mean daily residuals at key locations in the Upper Sacramento River for the full verification simulation and the hindcast simulation for October to March. Figures 4.14 and 4.15 present the summary of mean daily residual in flows for April to September and the full period averages, respectively.

Figure 4.13 shows that, during the high flow season, the ratios of daily residuals to the observed data for Trinity, Clear Creek Tunnel, and Whiskeytown, are 0.46 percent, 2.0 percent, and 1.46 percent, respectively. These ratios indicate that the uncertainty in the simulated flows for the Trinity system is not more than 2.0 percent, which implies that the full verification of USRDOM simulates Trinity import flows reasonably well. The uncertainty in the simulated flows at Spring Creek Tunnel and Clear Creek below Whiskeytown are -8.52 percent and 84.93 percent, respectively. This indicates that there is a mismatch in simulating the imports to the Sacramento River from Clear Creek below Whiskeytown Dam and through Spring Creek Tunnel. Because the flows through Clear Creek are small compared to the Sacramento River, this does not have a significant impact on the results in the Sacramento River.

By observing the uncertainties in the main-stem Sacramento River, we can conclude that Shasta Reservoir outflows are simulated well in USRDOM and have only 0.34 percent uncertainty. The uncertainty goes up to -4.16 percent at Keswick but drops back to -2.7 percent at Bend Bridge, reflecting the small differences in Clear Creek and Spring Creek Tunnel simulated flows. Comparison of uncertainties between full verification and hindcast

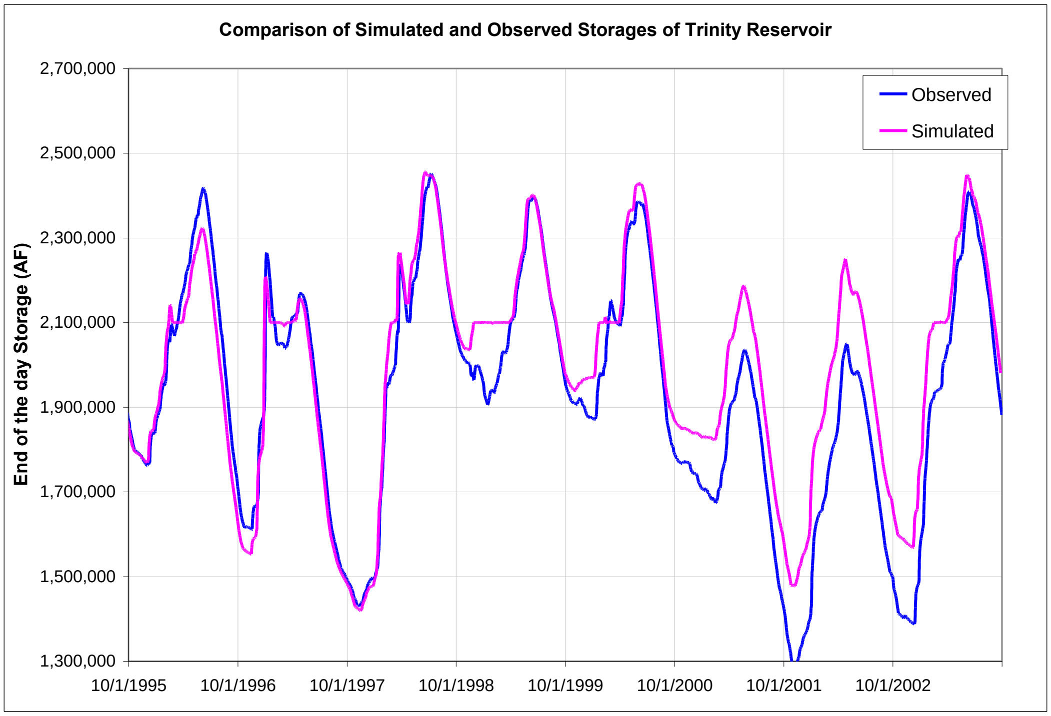


FIGURE 4.7
Comparison of Observed and Simulated Storages at Trinity Reservoir

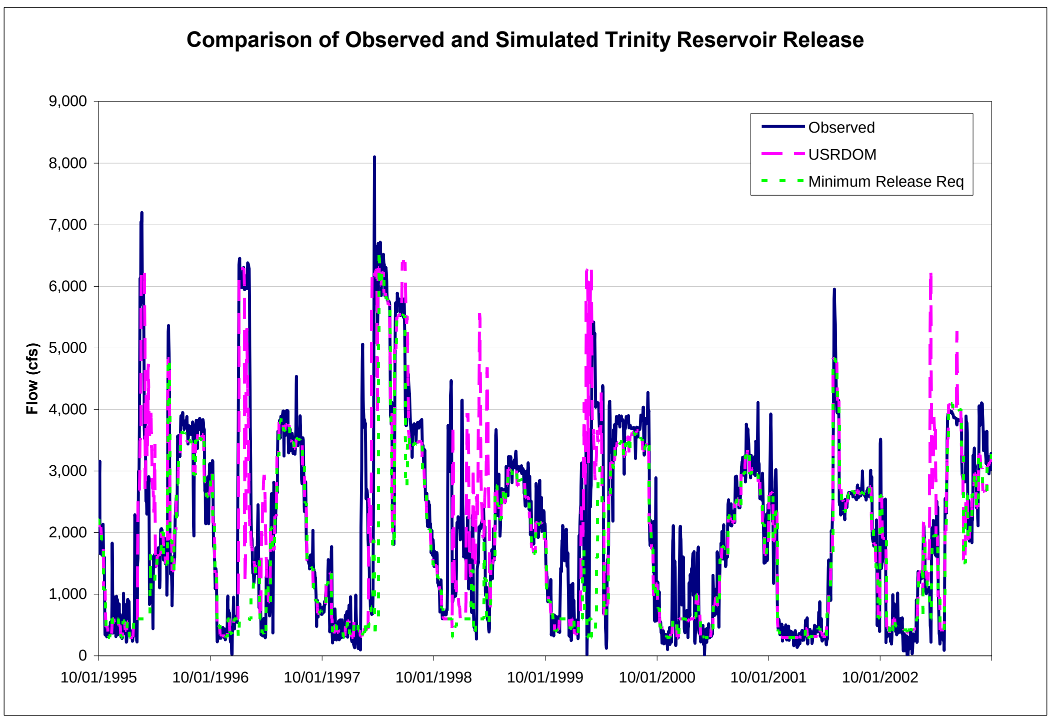


FIGURE 4.8
Comparison of Observed and Simulated Trinity Reservoir Outflow

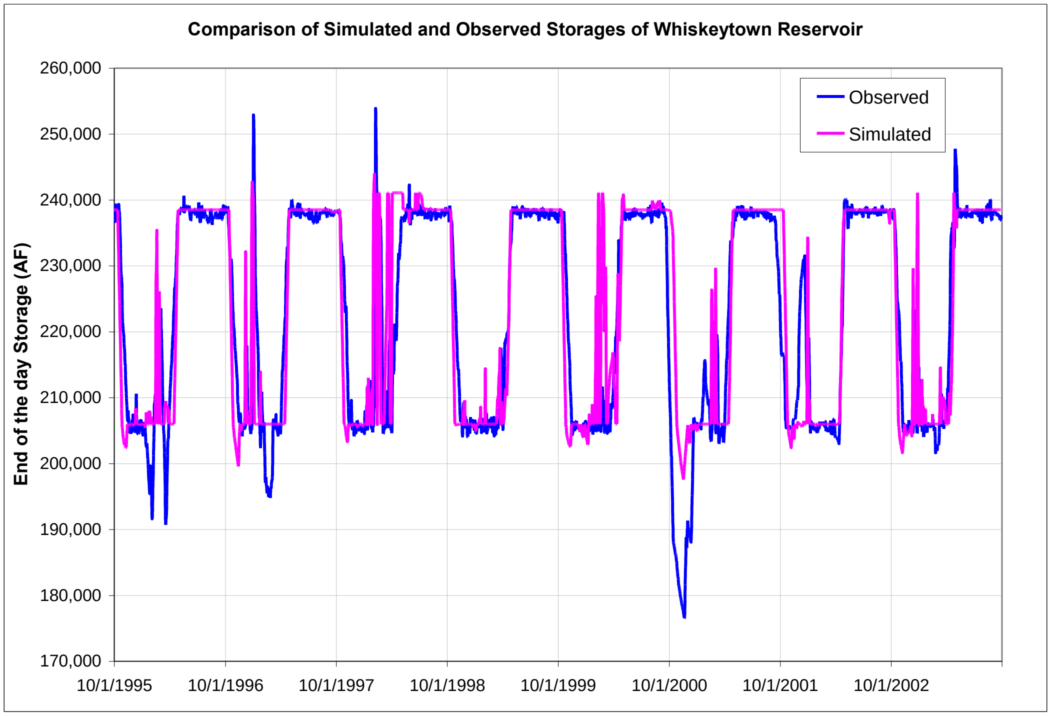


FIGURE 4.9
Comparison of Observed and Simulated Storage at Whiskeytown Reservoir

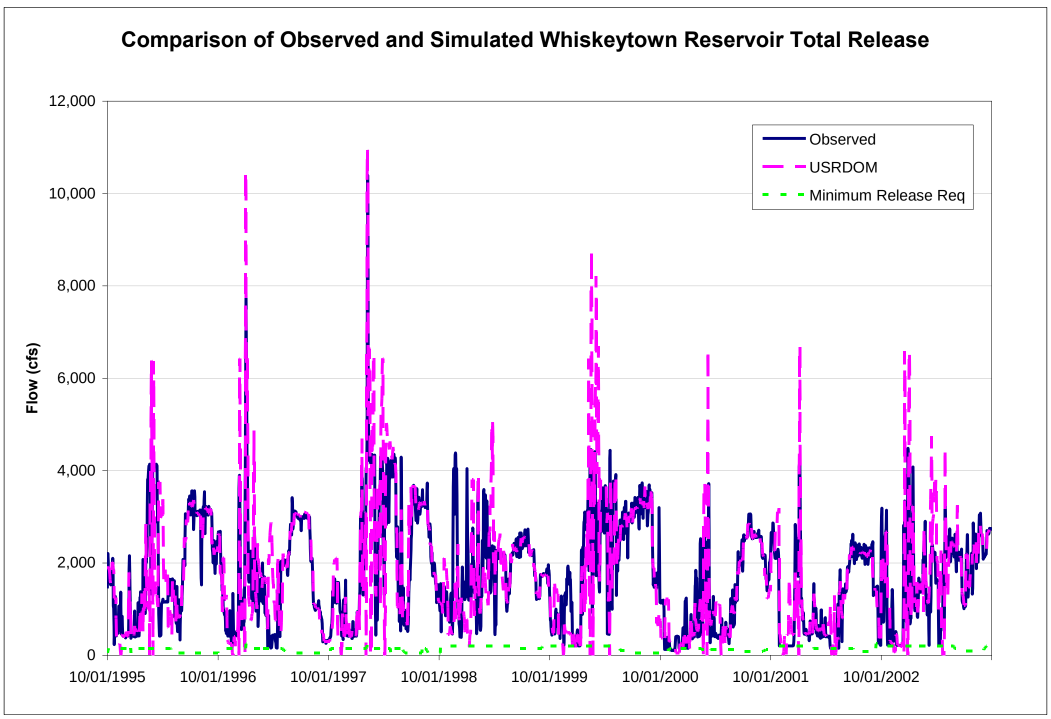


FIGURE 4.10
Comparison of Observed and Simulated Whiskeytown Reservoir Outflow

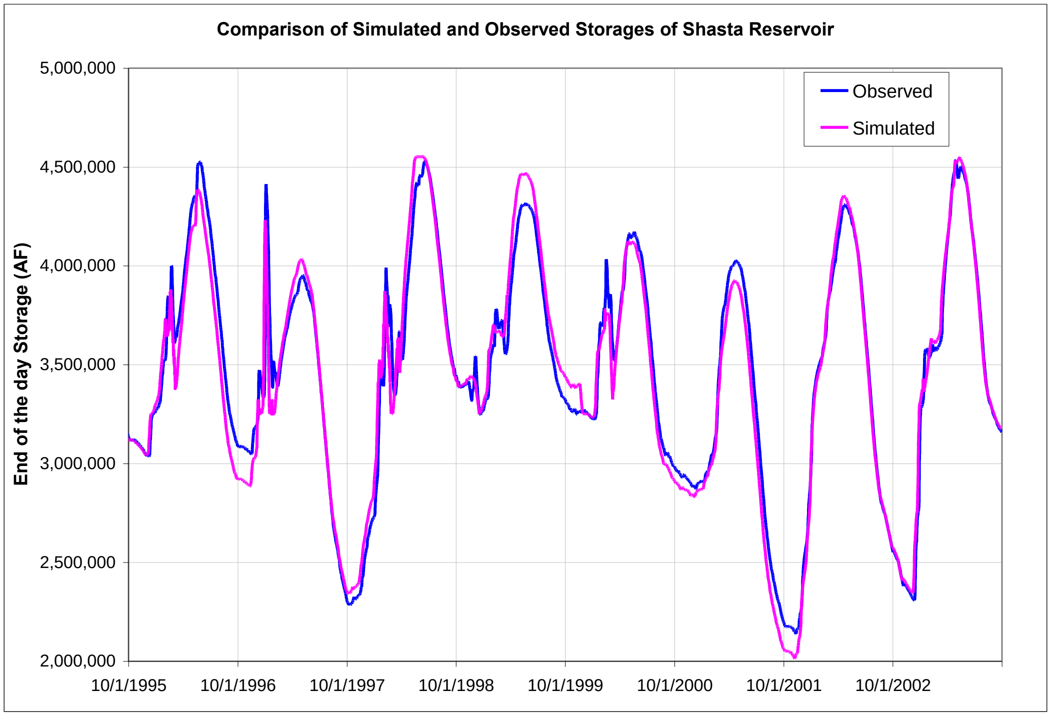


FIGURE 4.11
Comparison of Observed and Simulated Storage at Shasta Reservoir

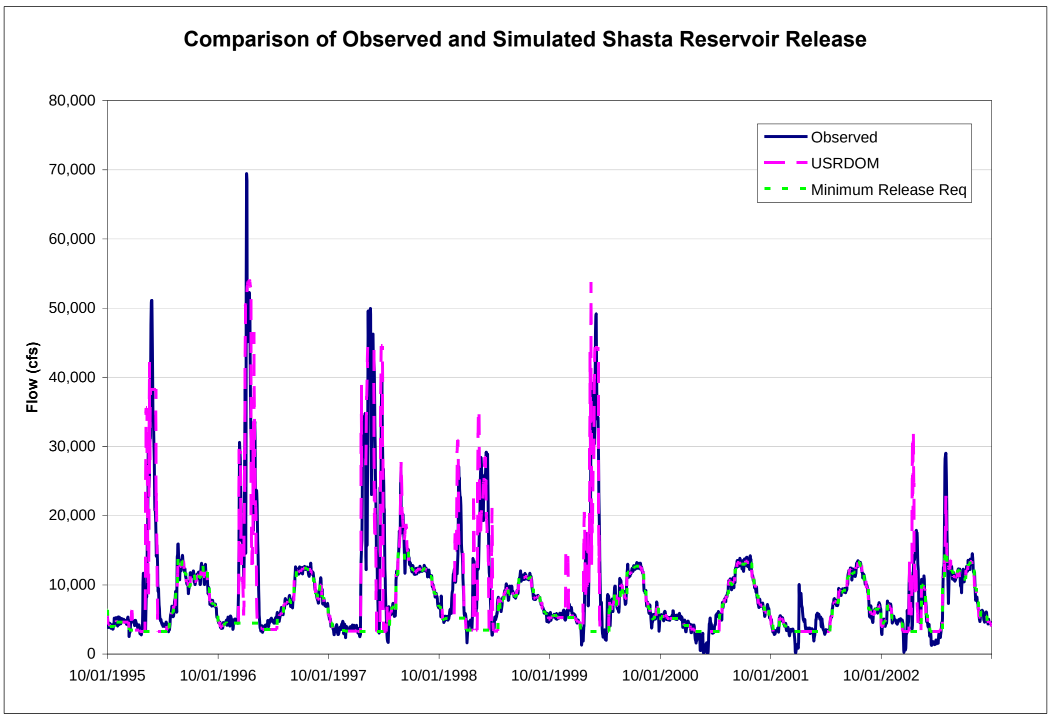


FIGURE 4.12
Comparison of Observed and Simulated Shasta Reservoir Outflow

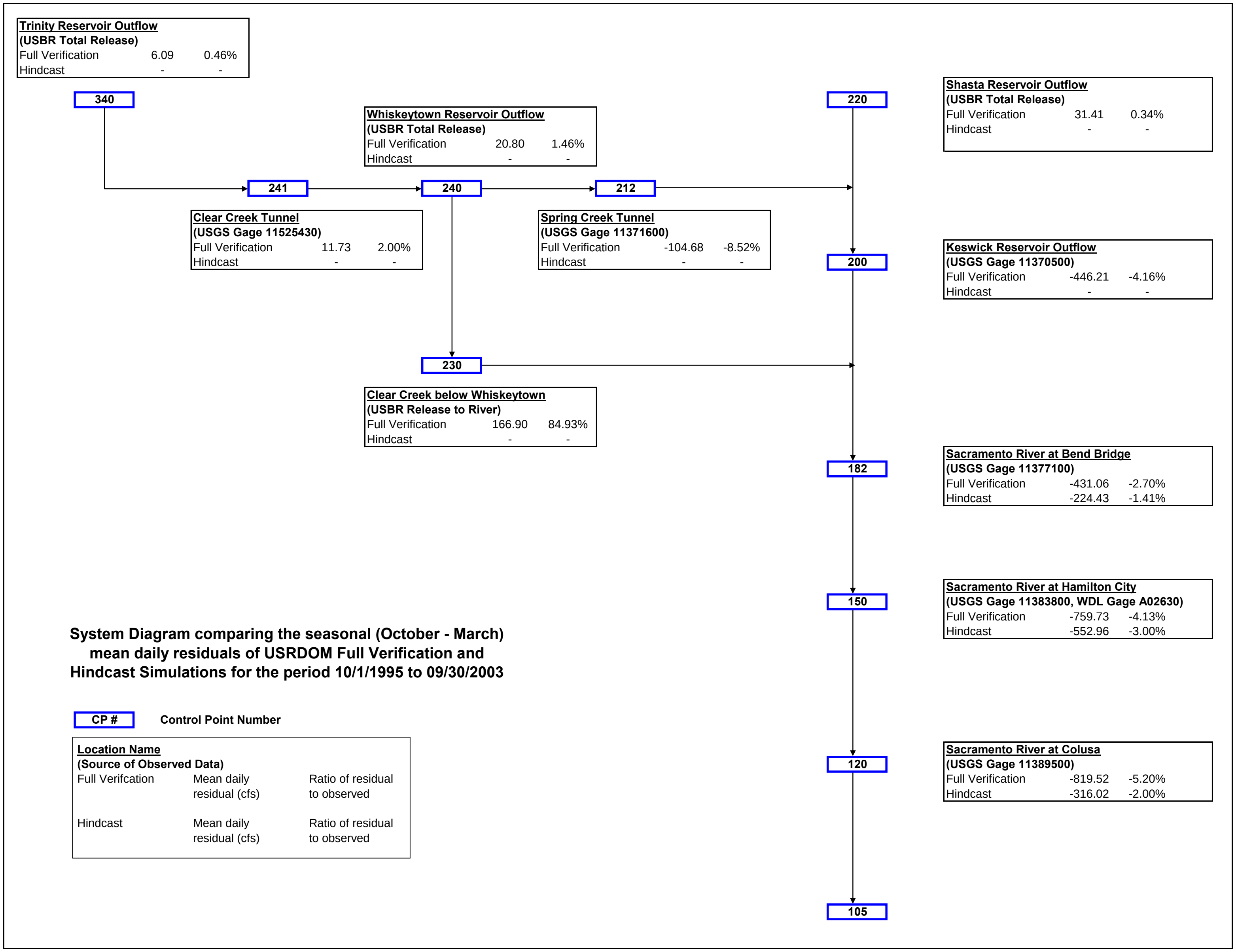


FIGURE 4.13

Comparison of Mean Daily Residuals between Reservoir Operations Verification Run and Hindcast Simulation Run (October–March)

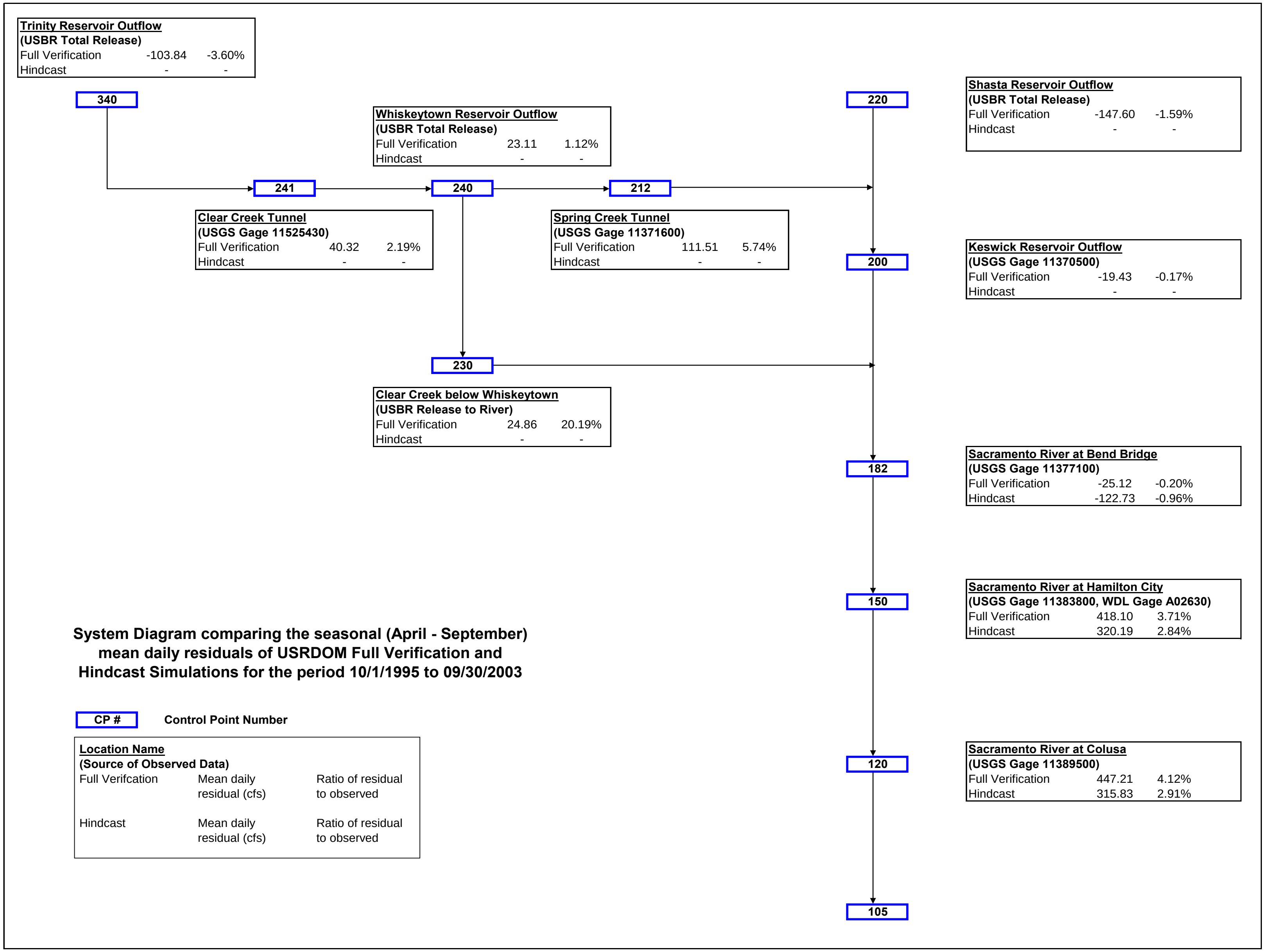


FIGURE 4.14

Comparison of Mean Daily Residuals between Reservoir Operations Verification Run and Hindcast Simulation Run (April–September)

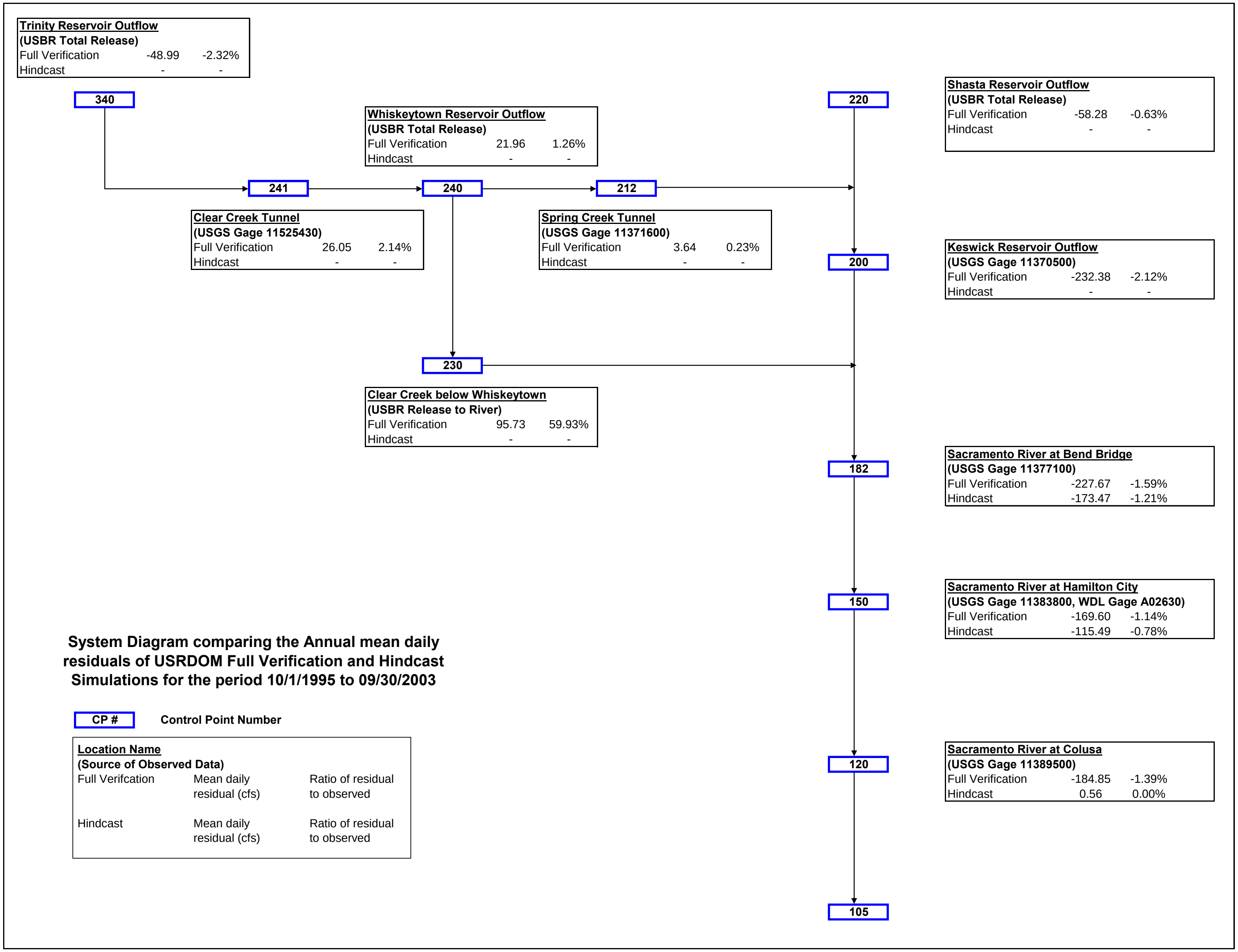


FIGURE 4.15
Comparison of Mean Daily Residuals between Reservoir Operations Verification Run and Hindcast Simulation Run (Annual)

simulation at Bend Bridge shows that there is 1.3 percent higher uncertainty in the river flows caused by the reservoir operations.

The uncertainties increase downstream along the Sacramento River because of the increase in the complexity of river processes downstream of Bend Bridge. The effect of diversions, stream routing, valley floor routing, bypass weirs, and local accretions accumulates and is shown as the net uncertainty at the Sacramento River at Colusa.

From the system diagram of April to September (Figure 4.14), we can conclude similar results in terms of propagation of uncertainties in the system. The only difference is the magnitude of the uncertainties is less compared to the high flow season. This implies that the model performs better in the low flow season in terms of reservoir operations and hydrology and river processes.

Figure 4.15 shows the performance of the full verification simulation of USRDOM for the full 8-year period. The uncertainties for the annual average scale are relatively better than the high flow season. Overall, the Trinity and Whiskeytown operations are simulated very well in USRDOM, except for the Clear Creek flows below Whiskeytown with a high daily mean residual. Because the flows from Clear Creek are small compared to the Sacramento River, the model is appropriate for analyses of the Sacramento River. However, it should not be used for analyses that solely focus on Clear Creek.

4.5 Development of Full-period Simulation Capability (1922–2003)

For use in planning analyses, USRDOM must be capable of simulating full 82-year daily flow conditions in the upper Sacramento River using the results from CALSIM II simulations. The inputs and the model used in the full verification simulation are the starting point for this full-period model.

4.5.1 Extension of Hydrology (1922–1963)

The calibration/verification process was focused on WY 1964 to WY 2003. The daily hydrology dataset developed for use in the calibration/verification process was extended to the full 82-year period, anticipating the need for it in the projected full-period simulations. The methods described in Section 2 were implemented in estimating the reservoir inflows, tributary flows, and ungaged local flows.

Available gage records were sparse in the pre-1964 water years for the tributary flows and reservoir inflows (pre-1940). Therefore, missing daily flow data for these years were estimated using the methods described in Section 2.

4.5.2 Standard Assumptions and Inputs (Future Conditions)

As part of preparing USRDOM for the full-period projected condition simulations, some of the assumptions used in the full verification simulations were modified to better reflect the future level conditions, including:

- The channel capacity of the Trinity River downstream of Lewiston Reservoir was increased from 6,000 cfs to 11,000 cfs based on the proposed modifications to the bridge capacities and channel widening.

- The Trinity River minimum release requirement that provides the daily release schedule was changed to the projected conditions based on the Trinity River Flow Evaluation Final Report (USFWS and Hoopa Valley Tribe, 1999) recommendation. In the verification simulation, this requirement was estimated based on the observed releases from Lewiston Reservoir.
- All other projected model inputs, such as minimum reservoir release requirements, minimum in-stream flow requirements, downstream diversions, and other demands, were estimated based on the results of the CALSIM II simulations.

4.5.3 Model Schematic Changes

The USRDOM schematic used in the full verification simulation was modified slightly to ensure better conformity between CALSIM II and USRDOM. In the projected conditions schematic, the Stony Creek reach downstream of Black Butte Reservoir was modified to include CALSIM II WBA6 diversions and Stony-TCC intertie flow. Routing remained consistent with the verification simulation in this reach of Stony Creek.

In the main stem Sacramento River, the proposed Delevan pipeline diversion and inflow were added to the schematic just upstream of Moulton Weir. Unlike the full verification simulation, a closure flow was included in the lower river segment from Ord Ferry to Knights Landing. Finally, miscellaneous diversions in the lower river segment were relocated for better agreement between CALSIM II and USRDOM.

Figure 4.16 provides a model schematic for the USRDOM full-period projected condition simulations. The schematic also includes the detailed conveyance features of the proposed NODOS project in the Colusa Basin region. This portion of the model is described in Section 6. The schematic used for the projected conditions simulation and an information table describing the schematic are included in Appendix B.

4.5.4 USRDOM Toolset

The Common Assumptions framework and the models included in it will be used to analyze the feasibility of the proposed NODOS project. It is anticipated that USRDOM would be part of the framework. The USRDOM toolset was developed so that it is ready to be integrated into the Common Assumptions framework. The toolset includes utilities and batch processes to set up and run USRDOM, and to create linkage datasets from the USRDOM output for other models along with the documentation and model protocols.

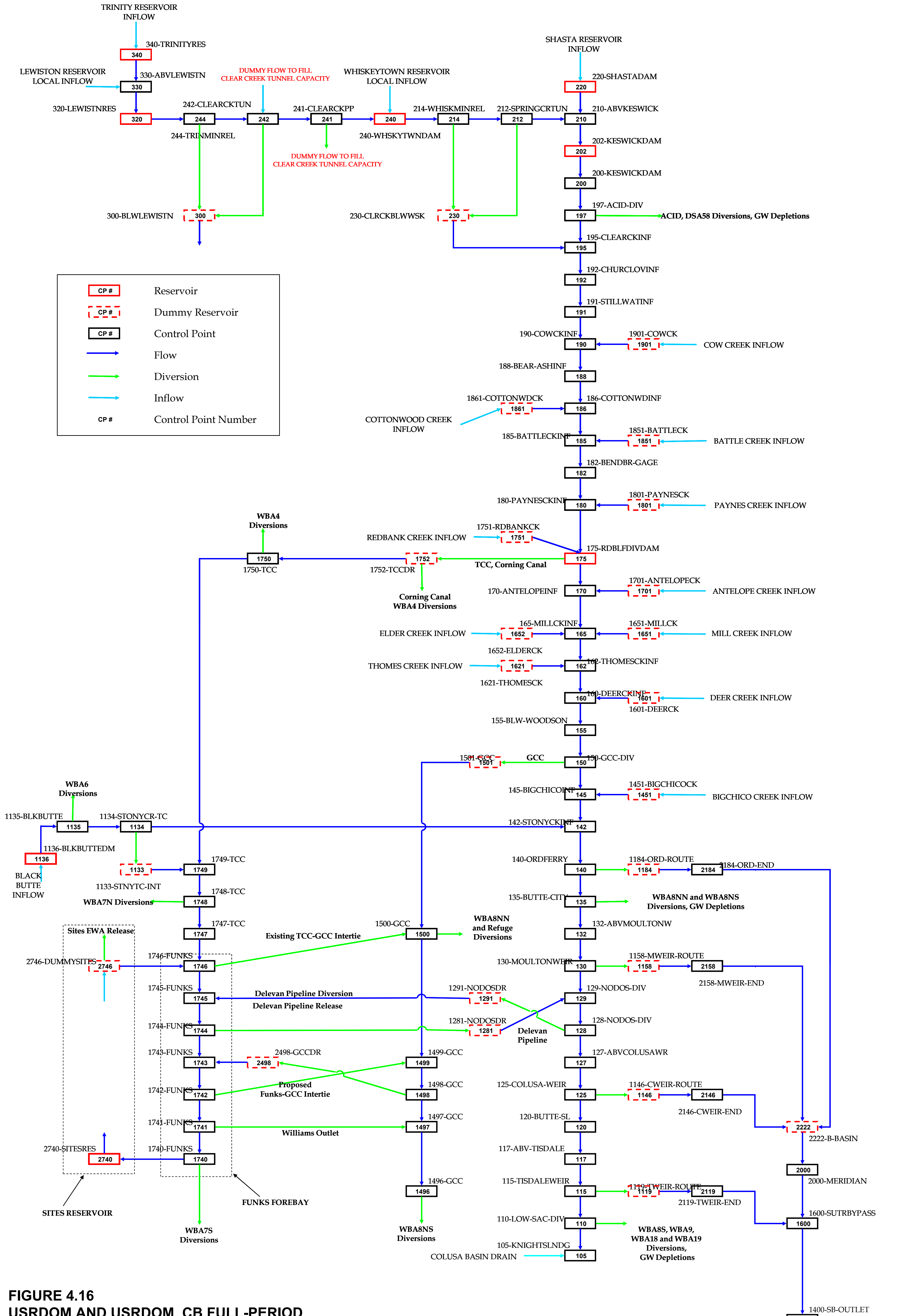


FIGURE 4.16
USRDOM AND USRDOM_CB FULL-PERIOD PROJECTED CONDITIONS SCHEMATIC

SECTION 5

Model Application

5.1 Overview

The main objective of USRDOM development is to simulate daily operations in the Upper Sacramento River to evaluate and compare proposed alternatives in the NODOS feasibility study analysis. This section describes the development of USRDOM to simulate daily flow conditions in Sacramento River for the full 82-year period based on the inputs derived from CASLIM II results. The framework and the utilities developed as part of this application are also described in this section.

5.1.1 Integrated Analysis Framework

The USRDOM model for projected condition simulations includes several pieces. Figure 5.1 shows the process diagram for USRDOM, which identifies the input data sources and the utilities that are part of the USRDOM toolset. Several new utilities and batch files have been created to run USRDOM as part of the Common Assumptions framework.

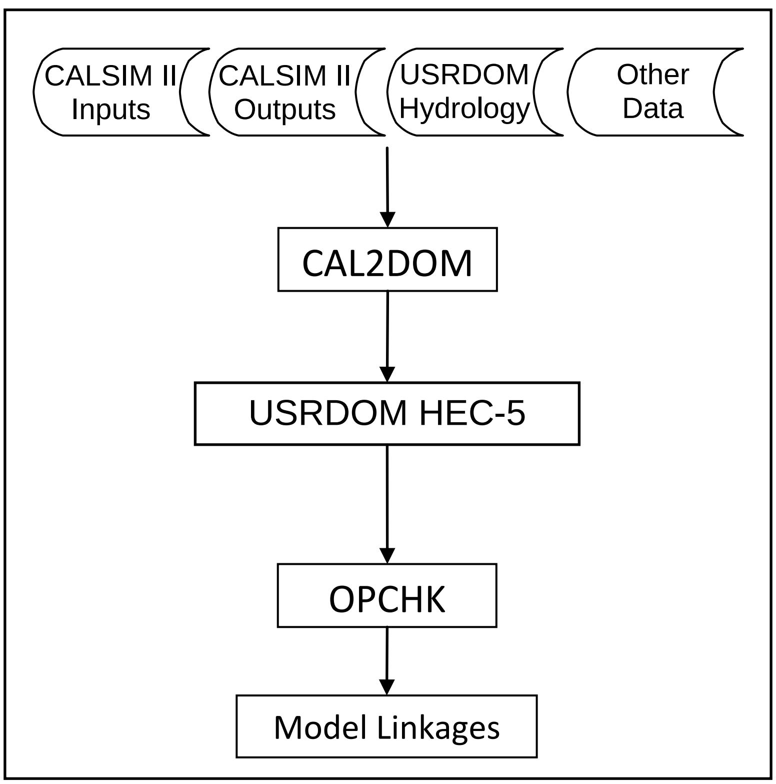


FIGURE 5.1
USRDOM Process

The inputs for USRDOM are derived from the database of daily hydrology time series described in Section 2 and other operational inputs developed as part of the full verification simulation such as the reservoir operation parameters and flow routing data described in Section 3. The projected level inputs for USRDOM such as the reservoir evaporation rates, initial storage conditions, minimum requirements, reservoir releases and storages, deliveries are derived from CALSIM II input and output databases. A full list of CALSIM II variables used and the method used to convert them to USRDOM inputs is provided in the following sections.

A new utility called 'CAL2DOM' was developed to perform quality assurance and prepare the time series inputs for USRDOM from these individual data sources. The processed inputs from CAL2DOM are fed to the HEC-5 model, the core engine of USRDOM. The results from HEC-5 are fed to another new utility called 'OPCHK,' which generates summary results for quick quality assurance check. Utilities that generate input datasets for several habitat and water quality models based on the results from USRDOM are also included in the USRDOM toolset.

5.2 USRDOM and CALSIM II

CALSIM II simulates CVP and State Water Project (SWP) operations on a monthly timestep from WY 1922 through WY 2003. The 82-year hydrology for CALSIM II was developed using historical rainfall and runoff data and has been adjusted for changes in water and land use that have occurred or may occur in the future. The model simulates the operation of the water resources infrastructure in the Sacramento and San Joaquin river basins on a month-to-month basis during this 82-year period. In the model, the reservoirs and pumping facilities of the SWP and CVP are operated to meet the flow and water quality requirements for these systems. The model assumes that facilities, land use, water supply contracts, and regulatory requirements are constant over 82 years from 1922 to 2003, representing a fixed level of development (Reclamation, 2008).

As part of the NODOS feasibility study, CALSIM II is the model of choice for the lead agencies to simulate reservoir operations and river flow conditions. Therefore, for the USRDOM projected conditions simulation, the inputs are taken from CALSIM II for a consistent analysis. Because USRDOM requires inputs on a daily timestep, the monthly inputs and outputs of the CALSIM II model must be downscaled to a daily timestep. Because spatial resolution between USRDOM and CALSIM II is inconsistent, the CAL2DOM utility translates data between the two models, including the disaggregation and consolidation of flow data.

A well-maintained catalog and dataflow record are necessary to track the data and the number of variables that need to be translated between the two models. Appendix D includes a spreadsheet called "*DSS_Catalog_and_DZYMAN_CFGs.xls*" that documents the data catalog and dataflow between various models as part of USRDOM and a few snapshots from it. In the "*Reports*" worksheet of this spreadsheet, by selecting the destination, the data from all the sources to the selected model or utility is shown organized by various categories. For example, to find all the data from CALSIM II that is used as inputs in USRDOM, the user can select the destination as CAL2DOM and the spreadsheet lists all the CALSIM II inputs and outputs. The "*Data Flowpaths*" worksheet shows the sources of data for each model or utility and is helpful for understanding the USRDOM data flow and framework. This spreadsheet is also used to generate configuration files using the DZYMAN utility, which is described in the next section.

5.2.1 DZYMAN

DZYMAN is a generic FORTRAN program that provides fast, automated batch processing of large amounts of HEC-DSS time series data. It requires free-format instruction files, with simple keywords to initiate a computation. It contains a wide variety of commonly used algebraic, time conversion, and smoothing functions to perform data translations and computations on DSS data. It automatically converts the units of the inputs based on the outputs requested. It requires instruction files that are easy to maintain or modify, even with minimal programming skills. DZYMAN standardizes the computation approaches and assures quality control during data processing.

DZYMAN requires a configuration (**.cfg*) file and an instruction file (**.dzy*). The configuration file includes a list of handles or variables with various DSS pathnames assigned to them. This file should include all the DSS data records that are needed in the computation process. The instruction file includes the computation steps using simple keywords representing the DZYMAN functions (e.g., ADD, MAX, ISEQUAL etc.) and the handles (listed in the configuration file) on which the computation has to occur. Appendix E contains an instruction key with the keywords representing the functions in DZYMAN. A brief description of each function is included along with the source code for the utility.

DZYMAN is used to create the intermediate USRDOM utilities such as CAL2DOM, OPCHK, Trinity Import Logic utility (WIDGET) and other utilities that translate USRDOM output as inputs to other fisheries and habitat models. CAL2DOM, OPCHK, WIDGET are applications of DZYMAN. Each utility or a DZYMAN application would have unique configuration (*.cfg) and instruction (*.dzy) files. "*DSS_Catalog_and_DZYMAN_CFGs.xls*" spreadsheet in Appendix D helps in generating the configuration files for the above utilities. Another spreadsheet called "*CAL2DOM_OPCHK_DZYMAN_Instructions.xls*" is used to generate the instruction files for the utilities and is included in the Appendix B. To create a new DZYMAN application, a DSS file with time series data, a configuration file with the list of DSS pathnames with handle names and an instructions file with the computation steps are needed.

5.2.2 CAL2DOM

The CAL2DOM utility translates monthly CALSIM II operations data to a daily time step. It uses the inputs and outputs from CALSIM II, USRDOM hydrology, and other datasets and computes inflows, diversions, and evaporation rates for USRDOM. CAL2DOM performs consistency checks between USRDOM and CALSIM II inputs and outputs. CAL2DOM also identifies operation controls for storage release requirements and computes the minimum release requirements for the reservoirs included in USRDOM. Table 5.1 shows the consolidated list of USRDOM inputs CAL2DOM computes based on the CALSIM II inputs and outputs. Appendix B includes the CAL2DOM instruction file with detailed computations for each of the inputs.

TABLE 5.1
USRDOM Inputs Based on CALSIM II data Using CAL2DOM

Input Type	USRDOM Inputs	USRDOM Nickname

TABLE 5.1
USRDOM Inputs Based on CALSIM II data Using CAL2DOM

Input Type	USRDOM Inputs	USRDOM Nickname
Minimum Reservoir Releases	Trinity Reservoir	MR340
	Whiskeytown Reservoir	QD214
	Shasta Reservoir	MR220
Minimum In-stream Flows	Trinity River flow downstream of Lewiston	QD244
	Sacramento River downstream of Red Bluff Diversion Dam	MR175
	Sacramento River downstream of GCC diversion	MR150
	Sacramento River downstream of Wilkins Slough	MR110
	Sacramento River downstream of Knights Landing	MR105
Diversions	ACID and other lumped upper segment diversions	QD197
	Tehama-Colusa Canal and Corning Canal	QD175
	Lumped middle segment miscellaneous diversions	QD155
	Stony Creek WBA6 Diversions	QD1135
	Stony Creek - TCC Intertie Flow	QD1134
	Glenn-Colusa Canal	QD150
	Lumped WBA8NN and WBA8NS Diversions (Lower Segment)	QD135
	New Delevan Pipeline Diversion to NODOS	QD128
	Lumped WBA8S, WBA9, WBA18, and WBA19 Diversions (Lower Segment)	QD110
Closure terms	Upper segment closure term	IN182
	Middle segment closure term	IN142
	Lower segment closure term	IN132
Evaporation Rate	Trinity Reservoir	EV340
	Whiskeytown Reservoir	EV240
	Shasta Reservoir	EV220
	Black Butte Reservoir	EV1136
Reservoir Outflow	Black Butte Reservoir	QA1136
Reservoir Inflow	Black Butte Reservoir	IN1136

5.2.3 CAL2DOM Methodology

This section provides an overview of the computation methodology in CAL2DOM to develop the daily inputs for the full period USRDOM projected conditions simulation. Different approaches were developed and tested in the process leading to an approach that resulted in USRDOM operations that were fully consistent with CALSIM II results. A brief description of all the approaches that resulted in the final CAL2DOM methodology is provided in this section.

The first approach, Option A, was a simplified approach in which the Shasta Reservoir minimum release requirement in USRDOM was set equal to CALSIM II monthly Shasta releases, if one of the following trigger conditions was true:

1. If the simulation month is June through October
2. If In-Basin Use (IBU) conditions under the Coordinated Operations Agreement (COA) sharing exists
3. Delta Controls—If the Shasta release in CALSIM II is determined based on any of the Delta outflow, export, or salinity control requirements
4. Sacramento River Controls—If the Shasta release in CALSIM II is determined based on the minimum required in-stream flow in Sacramento River at Keswick, Red Bluff Diversion Dam, Wilkins Slough, or Knights Landing

The Option A approach ensures that the end-of-month storage in Shasta Reservoir simulated in USRDOM is equivalent to CALSIM II data. However, under this approach, there may be insufficient flow in the river to fully meet the deliveries and minimum required flow needs along the Sacramento River simulated by CALSIM II. This situation may arise because the daily diversion needs may be higher than the monthly average Shasta releases determined by CALSIM II, which does not account for daily variability in the unregulated tributary inflows along the Sacramento River.

Option B is similar to Option A, except that Sacramento River Controls (trigger 4) are calculated based on daily flow conditions and shortages in every reach, including downstream boundary conditions at Knights Landing. In determining the shortages the daily reach flow is computed based on the unregulated inflows and the CALSIM II demands translated to daily time step. If one of the triggers 1 through 4 exist, then the required Shasta release in USRDOM is set equal to the monthly CALSIM II Shasta release, unless a flow shortage is anticipated in the Sacramento River at Keswick, Red Bluff Diversion Dam, Wilkins Slough, or Knights Landing control locations. In the event of a flow shortage, Shasta release is set to meet the flow required at that control location.

Under the Option B approach, even though the demands and minimum required flows are consistent with CALSIM II, there is a considerable drawdown in Shasta storage in USRDOM. In other words, though this approach addresses the daily flow controls it did not have the benefit of CALSIM II adjusting operations in response to daily varying flow balances (at a monthly level). Therefore, to make the models consistent with each other it was concluded that CALSIM II needed to be informed about daily variability of flows.

The final approach is an improvement to Option B. In the final approach, unregulated flows that are below the monthly average are summed up for the whole month and averaged to come up with a monthly adjustment. Preprocessed time series of the necessary additional flows are added to the CALSIM minimum instream flow requirement as a time series. This allows CALSIM II to dynamically adjust its operations to account for this variability. With this change the CAL2DOM controls to determine Trinity operations based on Sacramento River conditions and Knights Landing control in Option B were no longer necessary and were removed from the shortage computation. The Knights Landing control provided Delta requirements in Option B that are now provided at Keswick in the final approach.

5.2.3.1 Consistency Checks

The hydrology data used in CALSIM II and USRDOM are consistent. CAL2DOM performs checks between CALSIM II inputs and the USRDOM inputs to ensure consistency. The inputs to both models are compared on monthly time step at various locations along the River. Table 5.2 summarizes the list of inflows for which CAL2DOM compares the CALSIM II values to monthly USRDOM inputs. CAL2DOM also compares certain variables computed using the CALSIM II translations with the variables from the USRDOM full verification simulation. These variables are listed in Table 5.3. Daily USRDOM inputs are converted to monthly scale from which the CALSIM II values are then subtracted. The results are stored in a temporary DSS file (TEMP.DSS) using the handle name in the Result column as Part B. Finally, basic statistics are computed and are written to the console.

TABLE 5.2
Data Checks between CALSIM II Inputs and USRDOM Inputs in CAL2DOM

Description	QA/QC (Result)	USRDOM	CALSIM II
Trinity Reservoir Inflow	IN340_CHK	IN340	I1
Lewiston Reservoir Inflow	IN330_CHK	IN330	I100
Lewiston Reservoir Outflow Release	QD244_CHK	QD244	C100_MIF
Whiskeytown Reservoir Inflow	IN240_CHK	IN240	I3
Shasta Reservoir Inflow	IN220_CHK	IN220	I4
Cow Creek Inflow	IN1901_CHK	IN1901	I10801
Cottonwood Creek Inflow	IN1861_CHK	IN1861	I10802
Battle Creek Inflow	IN1851_CHK	IN1851	I10803
Paynes Creek Inflow	IN1801_CHK	IN1801	I11001
Red Bank Creek Inflow	IN1751_CHK	IN1751	I112
Elder Creek Inflow	IN1652_CHK	IN1652	I11303
Thomes Creek Inflow	IN1621_CHK	IN1621	I11304
Antelope Creek Inflow	IN1701_CHK	IN1701	I11307
Mill Creek Inflow	IN1651_CHK	IN1651	I11308
Deer Creek Inflow	IN1601_CHK	IN1601	I11309
Big Chico Creek Inflow	IN1451_CHK	IN1451	I11501

TABLE 5.3
Additional Data Checks between Translated USRDOM Inputs (from CALSIM II) and Verification Inputs in CAL2DOM

Description	QA/QC (Result)	USRDOM	USRDOM Full Verification
ACID, DSA58 Diversions and GW Depletions	QD197_CHK	QD197	QD197_VER
Upper Reach Historical Ungaged Tributary Inflows	IN182_CHK	IN182	IN182_UG_VER
Middle Reach Historical Ungaged Tributary Inflows	IN142_CHK	IN142	IN142_UG_VER

5.2.3.2 CALSIM II Operational Controls

CAL2DOM identifies the operational controls for the storage release requirements for Trinity and Shasta Reservoirs in CALSIM II for each month. It uses these controls to determine the minimum in-stream flow requirements and minimum reservoir release requirements in USRDOM. Table 5.4 shows the list of operational controls computed in CAL2DOM. CALSIM II operational (simulated) and control variables (requirements) are listed in separate columns.

TABLE 5.4
CALSIM II Operational Controls in CAL2DOM

Description	CAL2DOM Ops Controls (Result)	CALSIM II		Method used to determine the control
		Control	Operation	
Trinity River Minimum Flow	C100_CTRL	C100_MIF	C100	C100_CTRL is 1 if C100 = C100_MIF, otherwise is 0
Clear Creek Minimum Flow	C3_CTRL	C3_MIF	C3	C3_CTRL is 1 if C3 = C3_MIF, otherwise is 0
Sacramento River at Keswick Reservoir Minimum Flow	C5_CTRL	C5_MIF	C5	C5_CTRL is 1 if C5 = C5_MIF, otherwise is 0
Red Bluff Diversion Dam Bypass Flow	C112_CTRL	C112_MIF, C112_MIFADJ	C112	C112_CTRL is 1 if C112 = C112_MIF + C112_MIFADJ, otherwise is 0
Glenn-Colusa Canal Diversion Bypass Flow	C114_CTRL	C114_MIF, C114_MIFADJ	C114	C114_CTRL is 1 if C114 = C114_MIF + C114_MIFADJ, otherwise is 0
Sacramento River at Wilkins Slough (NCP) Flow Objective	C129_CTRL	C129_MIF, C129_MIFADJ	C129	C129_CTRL is 1 if C129 = C129_MIF + C129_MIFADJ, otherwise is 0
Sacramento River at Rio Vista Minimum Flow	C405_CTRL	C405_MIF	C405	C405_CTRL is 1 if C405 = C405_MIF, otherwise is 0

TABLE 5.4
CALSIM II Operational Controls in CAL2DOM

Description	CAL2DOM Ops Controls (Result)	CALSIM II		Method used to determine the control
		Control	Operation	
Delta Inflow needed for Delta Export for ANN compliance	C400_CTRL	C400_MIF	C400_ANN	C400_CTRL is 1 if C400 = C400_MIF, otherwise is 0
Delta Outflow needed to comply with Jersey Point salinity standards	JP_CTRL	JP_MRDO	C407, D407	JP_CTRL is 1 if JP_MRDO >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Emmaton salinity standards	EM_CTRL	EM_MRDO	C407, D407	EM_CTRL is 1 if EM_MRDO >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Rock Slough salinity standards	RS_CTRL_1	RS_MRDO_1	C407, D407	RS_CTRL_1 is 1 if RS_MRDO_1 >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Rock Slough salinity standards	RS_CTRL_2	RS_MRDO_2	C407, D407	RS_CTRL_2 is 1 if RS_MRDO_2 >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Rock Slough salinity standards	RS_CTRL_3	RS_MRDO_3	C407, D407	RS_CTRL_3 is 1 if RS_MRDO_3 >= C407 + D407, otherwise is 0
Delta Outflow needed to comply with Collinsville salinity standards	CO_CTRL	CO_MRDO	C407, D407	CO_CTRL is 1 if CO_MRDO >= C407 + D407, otherwise is 0
Sacramento and San Joaquin River Delta Outflow	C407_CTRL	0	C407	C407_CTRL is 1 if C407 = 0., otherwise is 0
Delta Inflow needed to maintain Delta Export/Inflow Ratio	EI_CTRL	EIExpCtrl	D418, D419	EI_CTRL is 1 if EIExpCtrl <= D418 + D419, otherwise is 0
Status of COA Sharing (UWFE or IBU conditions)	IBU_TRUE	0	UWFE_TRUE	IBU_TRUE is 1 if UWFE_TRUE = 0., otherwise is 0
Shasta Reservoir is in Flood Control	S4_FLD_CTRL	S4LEVEL5	S4, S44	S4_FLD_CTRL is 1 if S4LEVEL5 <= S4 + S44, otherwise is 0
Cumulative Sacramento River Control	SACR_CTRL	C5_CTRL, C112_CTRL, C114_CTRL, C129_CTRL	N/A	Take the maximum of all CTRL values

TABLE 5.4
CALSIM II Operational Controls in CAL2DOM

Description	CAL2DOM Ops Controls (Result)	CALSIM II		Method used to determine the control
		Control	Operation	
Cumulative Sacramento/San Joaquin Delta Control	DELTA_CTRL	C400_CTRL, JP_CTRL, EM_CTRL, RS_CTRL_1, RS_CTRL_2, RS_CTRL_3, CO_CTRL, C407_CTRL, EI_CTRL	N/A	Take the maximum of all CTRL values
Set Trinity Reservoir Release Trigger	TRIN_TRUE	1, S4_FLD_CTRL, JUNOCT_TRUE, SACR_CTRL	N/A	Maintain Trinity Reservoir releases if Shasta Reservoir is NOT in flood control (S4_FLD_CTRL is subtracted from the value of 1) or if it is June through October or if Sacramento River controls are in effect
Set Shasta Reservoir Release Trigger (Option A)	SHASTA_TRUE	JUNOCT_TRUE, IBU_TRUE, DELTA_CTRL, SACR_CTRL	N/A	Maintain Shasta Reservoir releases if it is June through October, IBU conditions exist, and Sacramento/San Joaquin Delta controls or Sacramento River controls are in effect
Set Shasta Reservoir Release Trigger (Option B)	SHASTA_TRUE	JUNOCT_TRUE, IBU_TRUE, DELTA_CTRL	N/A	Maintain Shasta Reservoir releases if it is June through October, IBU conditions exist, or Sacramento/San Joaquin Delta controls are in effect (Sacramento River controls are implemented as flow checks)

Notes:

ANN = artificial neural network
N/A = not applicable
NCP = navigation control point
UWFE = unstored water for export

5.2.3.3 Minimum In-stream Flows

Table 5.5 includes the CALSIM II variables and the methodology used in CAL2DOM to compute various minimum in-stream flow requirements used in USRDOM. Minimum in-stream requirements in USRDOM are specified at four Sacramento River locations: Red Bluff Diversion Dam, GCC diversion, Wilkins Slough, and Knights Landing. The minimum in-stream flow requirement for Trinity River is specified as a diversion at the Lewiston Reservoir.

TABLE 5.5
Computation of Minimum In-stream Flow Requirements in CAL2DOM

USRDOM Inputs	USRDOM Nickname	CALSIM II Variables	CAL2DOM Translation
Trinity River flow downstream of Lewiston	QD244	N/A	Estimated based on the Trinity River Flow Evaluation Final Report (USFWS and Hoopa Valley Tribe, 1999) recommendation
Sacramento River downstream of Red Bluff Diversion Dam	MR175	C112_MIF	Converted to daily, ramped 2 days going up and saved the result as average weekly values
Sacramento River downstream of GCC diversion	MR150	C114_MIF	Converted to daily, ramped 3 days going up and saved the result as average weekly values
Sacramento River downstream of Wilkins Slough	MR110	C129_MIF	Converted to daily, ramped 6 days going up and saved the result as average weekly values
Sacramento River downstream of Knights Landing	MR105	C134	If Shasta Reservoir release trigger, SHASTA_TRUE (described in Table 5.4), is 1, then C134 value is used. Checked to make sure at least 3,000 cfs of flow exists, ramped 6 days going up and saved the result as average weekly values.

Note:

N/A = not applicable

5.2.3.4 Diversions

Table 5.6 lists the diversions explicitly modeled in USRDOM, along with the CALSIM II variables and the methodology used by CAL2DOM to compute them. In addition to the diversions modeled in the full verification simulation, Stony Creek – TCC Intertie flow and the new Delevan pipeline diversion to NODOS are included in the projected conditions version of USRDOM.

TABLE 5.6
Diversions in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
ACID Diversion	QD197	D104_PSC	Limited to a maximum of 315 cfs (used the remainder, D104_PSC_REM for estimating upper segment closure term, IN182). Converted to daily and smoothed over 9-day period without conserving the monthly volume and saved as average weekly values
Red Bluff Diversion Dam Diversion (Tehama-Colusa and Corning Canals)	QD175	D112	Converted monthly to daily and smoothed over 21 days while conserving monthly volume and saved as average weekly values
Middle Reach Miscellaneous Diversions	QD155	D11301, D11305, D113B	Converting the sum of the three monthly CALSIM II diversions to daily, smoothed over 21 days while conserving monthly volume and saved as average weekly values

TABLE 5.6
Diversions in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
Hamilton City Diversion (Glenn-Colusa Canal)	QD150	L143, D413A, D143A_WTS, D143A_EWA, D143B, D14401, D145A, D145B, D145A_WTS, D145A_EWA, C17502, C17502A, C17502B	Estimated based on the deliveries and inflows along the Glenn – Colusa canal. Losses and diversions along the GCC are added and the inflows from TCC are subtracted to estimate daily Hamilton City diversion. Converted monthly to daily and smoothed over 21 days while conserving monthly volume and saved as average weekly values for all except for C17502, C17502A and D14401 for which converted monthly to daily values and smoothed over 9 days without conserving monthly volume
Stony Creek WBA6 Diversions	QD1135	D42, L17301, D17301, L173, L142	Converting the sum of the three monthly CALSIM II diversions and two loss terms (L173 and L142 are losses lower down on Stony Creek) to daily, smoothed over 21 days while conserving monthly volume and saved a as average weekly values
Stony Creek - TCC Intertie Flow	QD1134	C173B_STCR	Converting monthly to daily values and smoothed over 9 days without conserving monthly volume
WBA8NN and WBA8NS Diversions	QD135	D122A, D122B, D122A_WTS, D122B_WTS, D122_EWA	Converted the sum of five monthly CALSIM II diversions to daily, smoothed over 21 days while conserving monthly volume and saved as average weekly values (negative diversions are removed)
New Delevan Pipeline Diversion to NODOS	QD128	D124A	Converting monthly to daily values and smoothed over 9 days without conserving monthly volume and saved as average weekly values – ensured the diversion did not exist on the same day as a release from NODOS to the River
WBA8S, WBA9, WBA18, and WBA19 Diversions	QD110	D128, D128_WTS, D128_EWA, D129A	Converted the sum of four monthly CALSIM II diversions to daily, smoothed over 21 days while conserving monthly volume and saved as average weekly values

5.2.3.5 Closure Terms

CAL2DOM computes closure terms for the three river segments in USRDOM. The closure terms for the projected conditions simulation are mainly comprised of ungaged tributary flows, accretions or gains, and depletions within the river segment. The general methodology in estimating these closure terms involved:

1. Removing the volume of ungaged tributary flows estimated in the hydrology development for use in the full verification simulation from the volume of total distributed accretions and depletions within each river segment

2. Separating the remaining volume into gains (positive flows) and depletions (negative flows)

3. Converting the monthly gains to daily and smoothing over a 21-day period while conserving monthly volume

4. Converting the monthly depletions to daily, smoothing over a 21-day period while conserving monthly volume and computing average weekly values
5. Subtracting the smoothed depletions from the smoothed gains and adding the daily ungaged tributary flows estimated in the hydrology development for use in the full verification simulation.

This process preserves the variability and the daily pattern of the ungaged flows used in the full verification simulation, thereby reducing any inconsistency that may result between CALSIM II and USRDOM from the ungaged tributary flows.

To address some outliers within middle and lower segment negative gains, net negative gains over both segments were computed and a portion of the lower segment negative gains were shifted to the middle segment while computing the closure terms for these two segments. Because the lower river segment did not include a closure adjustment in the verification simulation step 1 was not included while computing the closure adjustment for the projected conditions USRDOM simulation. Table 5.7 includes the variables used and the methods used in computing the three closure terms.

TABLE 5.7
Closure Terms in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Methodology used to determine Closure Adjustments
Upper Reach Distributed Accretions and Closure Adjustment	IN182	IN182_UG_VER (monthly), IN182_UG_VER (daily)	I109, R109, GS60, D104_PSC, D104_PAG, D104_PMI, demand_D109	IN182 is distributed over upstream USRDOM nodes from 195 to 182; I109 is separately patterned based on the IN182_UG_VER pattern (by subtracting monthly and adding daily back in); adjustments smoothed over 21 days; conserving monthly volume (GS60, D104_PAG, D104_PMI, demand_D109 and remainder of D104_PSC: D104_PSC_REM are subtracted)
Middle Reach Distributed Accretions and Closure Adjustment	IN142	IN142_UG_VER (monthly), IN142_UG_VER (daily)	I118, R113, R114A, R114B, R114C, GS61, demand_D118, demand_D123 Shift	IN142 is distributed over USRDOM nodes 180 through 142; I118 is separately patterned based on the IN142_UG_VER pattern (by subtracting monthly and adding daily back in); adjustments smoothed over 21 days; conserving monthly volume (GS61 and demand_D118 are subtracted; demand_D123 shift is also subtracted - this is an adjustment for negative gain outliers in the lower segment)

TABLE 5.7
Closure Terms in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Methodology used to determine Closure Adjustments
Lower Reach Distributed Accretions and Closure Adjustment	IN132		GS63, demand_D123 Adjusted, I123	IN132 is located at 132, however may be distributed over upstream nodes from 140 to 105; I123 is separately smoothed to daily; smooth operations are over 21 days; conserving monthly volume (GS63 and demand_D123 are subtracted and demand_D123 is adjusted for negative gain outliers in the lower segment)

5.2.3.6 Reservoir Inflow, Outflow, and Evaporation Rates

Black Butte Reservoir inflow and outflow are specified in USRDOM. CAL2DOM computes these time series based on CALSIM II outputs. The inflows to Trinity, Shasta and Whiskeytown are synthesized for the 82-year simulation period in the hydrology development process and are forced as time series inputs in USRDOM. Table 5.8 shows the CALSIM II variables used and the translation method to obtain daily USRDOM inputs. Similarly, CAL2DOM converts monthly evaporation rates from CALSIM II for Trinity, Shasta, Whiskeytown, and Black Butte reservoirs to daily values.

TABLE 5.8
Reservoir Outflow in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
Black Butte Reservoir Outflow Release	QA1136	C42, D42	Converting monthly to daily, smoothed over 21 days while conserving monthly volume, and saved the result as average weekly values
Stony Creek Flow (above Black Butte)	IN1136	C41, I42	Converting monthly to daily, smoothed over 21 days while conserving monthly volume, and saved the result as average weekly values
Trinity Reservoir Evaporation	EV340	S1EVAP	Converts monthly evaporation rates to daily values
Whiskeytown Reservoir Evaporation	EV240	S3EVAP	
Shasta Reservoir Evaporation	EV220	S4EVAP	
Black Butte Reservoir Evaporation	EV1136	S42EVAP	

5.2.3.7 Minimum Reservoir Release Requirements

CAL2DOM estimates the minimum reservoir release requirements for Trinity, Shasta, and Whiskeytown reservoirs in USRDOM based on the identified CALSIM II operational controls. Table 5.9 shows the methodology and the variables used to compute the minimum release requirements for the three reservoirs under the final CAL2DOM approach.

As described earlier, the Shasta Reservoir minimum release requirement is set equal to the CALSIM II monthly release if the month is June through October, IBU conditions exist, and Sacramento/San Joaquin Delta controls are in effect. Additional release requirement is estimated by computing the maximum flow shortage at the Sacramento River control points (Keswick, Red Bluff Diversion Dam and Wilkins Slough). The assumed Clear Creek Tunnel flow is added to the flow shortage and the initial Shasta Reservoir outflow release is estimated (used to calculate shortages). Finally, the total flow is limited to 15,000 cfs, which is the capacity of the Keswick Powerplant, and the assumed Clear Creek Tunnel flow is removed.

The Trinity Reservoir minimum release is determined based on the minimum in-stream flow required in Trinity River below Lewiston and the required Clear Creek Tunnel flows. Clear Creek Tunnel flow (3,200 cfs, in general) is restricted based on whether Sacramento

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Clear Creek Tunnel Flow (Initial)	D100_INIT		D100, D100_IMPORT	Use CALSIM II D100 value if TRIN_TRUE = 1; smoothed to daily over 9 days, and saved the result as average weekly values
Trinity Reservoir Outflow Release	MR340	D100_INIT, IN330, QD244		IN330 subtracted from D100_INIT; the result is converted to daily, converted to average weekly value, and added the daily QD244 values
Whiskeytown Reservoir	QD214		C3_MIF	Converted to daily, ramped 2 days going up, and saved the result as average weekly values
Shasta Reservoir Outflow Release (Initial)	MR220_INIT		C4	Initial Shasta Reservoir outflow release was set to C4 value, if SHASTA_TRUE = 1; performed 21-day smoothing while conserving monthly volume, and saved the result as average weekly values
Keswick Reservoir Minimum Release	MR210		C5_MIF	Check to make sure at least the bypass flow is 3,250 cfs, then ramped 2 days going up and saved the result as average weekly values

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Estimated Flows at Keswick Reservoir Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT210_INIT	MR220_INIT, IN240, QD214	D100_INIT	Estimate of flow used to check compliance with Keswick Minimum Requirement (MR210) (QD214 is subtracted)
Estimated Additional Flow Needed to Satisfy Keswick Reservoir Compliance Point	MR210_SHORT	MR210, OUT210_INIT		Estimate of additional flow needed to comply with Keswick Minimum Requirement (MR210) (OUT210_INIT is subtracted; negatives are ignored)
Estimated Flows at Bend Bridge Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT182_INIT	OUT210_INIT, QD197, QD214, IN1901, IN1861, IN1851, IN182		Estimate of flow used to check potential flow needs at Bend Bridge (QD197 is subtracted)
Estimated Flows at Red Bluff Diversion Dam Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT175_INIT	OUT182_INIT, IN1801, IN1751, 0.1044 * IN142, QD175		Estimate of flow used to check compliance with Red Bluff Diversion Dam Bypass Flow (MR175) (includes 10.4% of IN142) (QD175 is subtracted)
Estimated Additional Flow Needed to Satisfy Red Bluff Diversion Dam Compliance Point	MR175_SHORT	MR175, OUT175_INIT,		Estimate of additional flow needed to comply with Red Bluff Diversion Dam Minimum Requirement (MR175) (OUT175_INIT is subtracted; negatives are ignored); 2-day FMA is used to mimic a 12-hour travel time
Estimated Flows at Hamilton City Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT150_INIT	OUT175_INIT, IN1652, IN1621, IN1701, IN1651, IN1601, QD155, 0.6419 * IN142, QD150		Estimate of flow used to check compliance with GCC Diversion Bypass Flow (MR150) (includes 64.2% of IN142) (QD155 and QD150 are subtracted)

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Estimated Additional Flow Needed to Satisfy Hamilton City Compliance Point	MR150_SHORT	MR150, OUT150_INIT		Estimate of additional flow needed to comply with Hamilton City Minimum Requirement (MR150) (OUT150_INIT is subtracted; negatives are ignored); 3-day FMA is used to mimic a 24-hour travel time
New Delevan Pipeline Release from NODOS (without Colusa Basin)	IN129		C17603	Converted to daily and smoothed over a 9-day period without conserving monthly volume and saved as average weekly values – ensured the release did not exist on the same day as a diversion from the River to the NODOS
Estimated Flows at Wilkins Slough Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT110_INIT	OUT150_INIT, IN1451, QA1136, QD1135, QD1134, 0.2537 * IN142, QD135, IN132, IN129, QD128, QD110		Estimate of flow used to check compliance with Wilkins Slough NCP Flow Objective (MR110) (includes 25.4% of IN142 and IN132 as well as NODOS New Delevan Pipeline IN129 and QD128) (includes Stony Creek components) (QD1135, QD1134, QD135, QD128 and QD110 are subtracted)
Estimated Additional Flow Needed to Satisfy Wilkins Slough Compliance Point	MR110_SHORT	MR110, OUT110_INIT		Estimate of additional flow needed to comply with Wilkins Slough Minimum Requirement (MR110) (OUT110_INIT is subtracted; negatives are ignored); 6-day FMA is used to mimic a 60-hour travel time
Colusa Basin Drain Flow and Colusa Basin Closure Adjustment	IN105		C184A, R134, demand_D134	Converted to daily and smoothed over a 21-day period conserving monthly volume and saved as average weekly values
Estimated Flows at Knights Landing Compliance Point (Only Considering Initial Release from Trinity or Shasta Reservoirs)	OUT105_INIT	OUT110_INIT, IN105		Estimate of flow used to set Knights Landing boundary condition flow

TABLE 5.9
Determination of Trinity, Whiskeytown, and Shasta Reservoirs Minimum Required Releases in CAL2DOM

Description	USRDOM (Result)	USRDOM (Input)	CALSIM II	Method used in computation
Estimated Additional Flow Needed to Satisfy Knights Landing Compliance Point	MR105_SHORT	MR105, OUT105_INIT		Estimate of additional flow needed to comply with Delta/IBU Requirements at Knights Landing (MR105) (OUT105_INIT is subtracted; negatives are ignored); 6-day FMA is used to mimic a 60-hour travel time
Shasta Reservoir Outflow Release (Option B Final)	MR220	MR210_SHORT, MR175_SHORT, MR150_SHORT, MR110_SHORT, D100_INIT, MR220_INIT		Final Shasta Reservoir outflow release determined by taking the maximum of each flow shortage to determine additional flow needed, added the assumed Clear Creek Tunnel flow and the initial Shasta Reservoir outflow release (used to calculate shortages), limited the total to 15,000 cfs (the capacity of the Keswick Powerplant), and removed the assumed Clear Creek Tunnel flow

River is in flood conditions (Tisdale weir spill greater than 500 cfs) and/or if high flow conditions exist in Whiskeytown Reservoir (inflow greater than 5,200 cfs).

The Whiskeytown Reservoir minimum release is determined based on the minimum in-stream flow required in Clear Creek below Whiskeytown. In the event of spilling at Whiskeytown Reservoir, any flows in excess of 4,200 cfs are routed into Clear Creek below Whiskeytown in addition to minimum in-stream flow requirement. Spring Creek Tunnel can divert up to 4,200 cfs.

5.2.4 Quality Assurance

A utility called 'OPCHK' (Operations Check) was developed as the quality assurance tool for USRDOM. OPCHK was configured using DZYMAN to generate data to perform quality assurance/quality control (QA/QC). It generates basic statistics for input, output, and model comparisons.

OPCHK checks for insufficient flows in diversions and at minimum requirement locations by comparing USRDOM outputs to the inputs. It checks for consistency between USRDOM outputs and CALSIM II outputs at key locations. OPCHK generates monthly equivalent flows of the USRDOM daily flows for post-analysis. Appendix B includes the list of variables that OPCHK computes and the DZYMAN instruction file for OPCHK.

5.3 Linkages with Other Models

Linkages between USRDOM and other habitat and water quality models have been identified and documented. Utilities were developed using DZYMAN to generate linkage datasets automatically for each implemented model linkage using the results from USRDOM. These models include USRWQM, Salmon Mortality Model (SALMOD), the Winter Run Chinook Life Cycle Model (WRCLCM), Sedimentation and River Hydraulics and Vegetation 1-Dimensional (SRH-1DV) model, Riparian Habitat Establishment Models (RHEM), Sacramento Ecological Flow Tool (Sac-EFT), and Colusa Basin Water Quality Model (CBWQM). Figure 5.2 shows the process diagram with the models involved in the simulating physical processes in Sacramento River. It shows the two different methods to determine daily operations, either by using CALSIM25Q and USRWQM or CAL2DOM and USRDOM. CALSIM25Q downscales monthly CALSIM II data and passes it to USRWQM. USRWQM in turn mimics CALSIM II operations on a daily scale and generates daily flows and temperatures for other models (red lines). CAL2DOM translates CALSIM II operations to guide USRDOM in simulating daily flows in the Sacramento River. These daily flows can be used by other models, including USRWQM, as shown in the figure by blue lines.

Figure 5.3 shows a detailed dataflow diagram with USRDOM being the central model, receiving information from various sources and providing daily flows to various models. CALSIM25Q is not shown in this figure because it is no longer needed. The flows for USRWQM are provided by USRDOM through a new utility called ‘USRWQMLink,’ which translates the USRDOM flow output to USRWQM. The items in green boxes are the utilities developed to enable the linkages between USRDOM and other models.

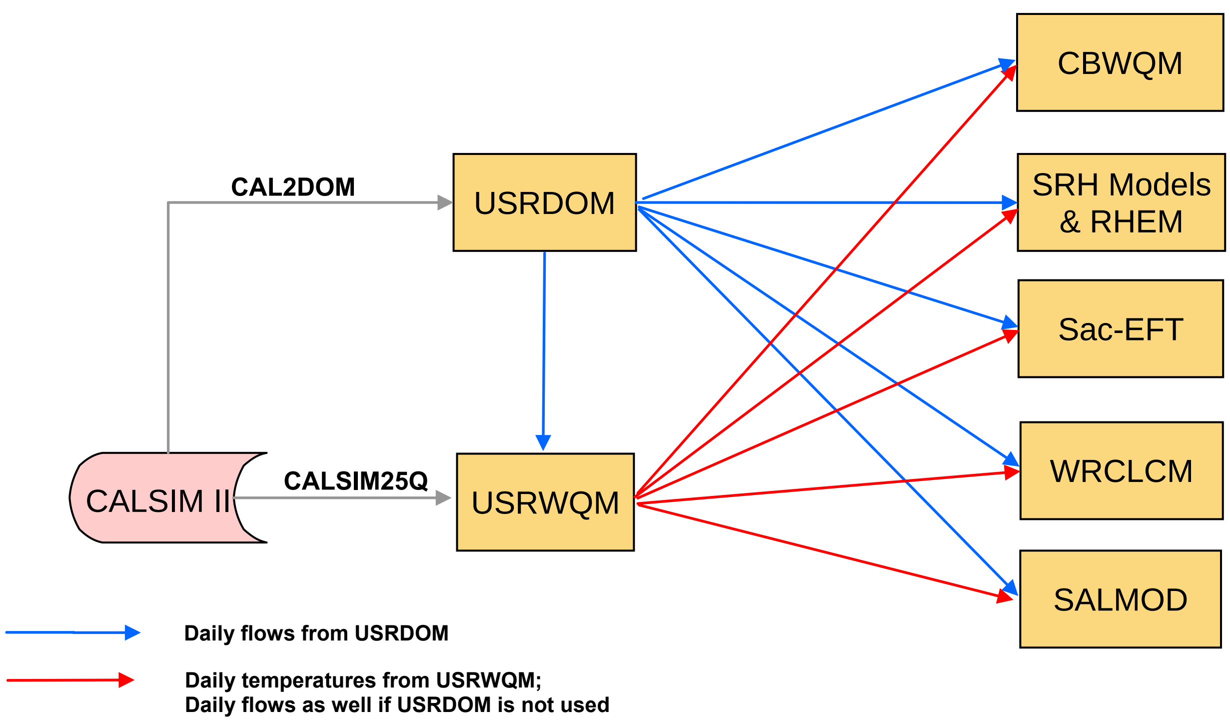


FIGURE 5.2

USRDOM Linkages with Other Models

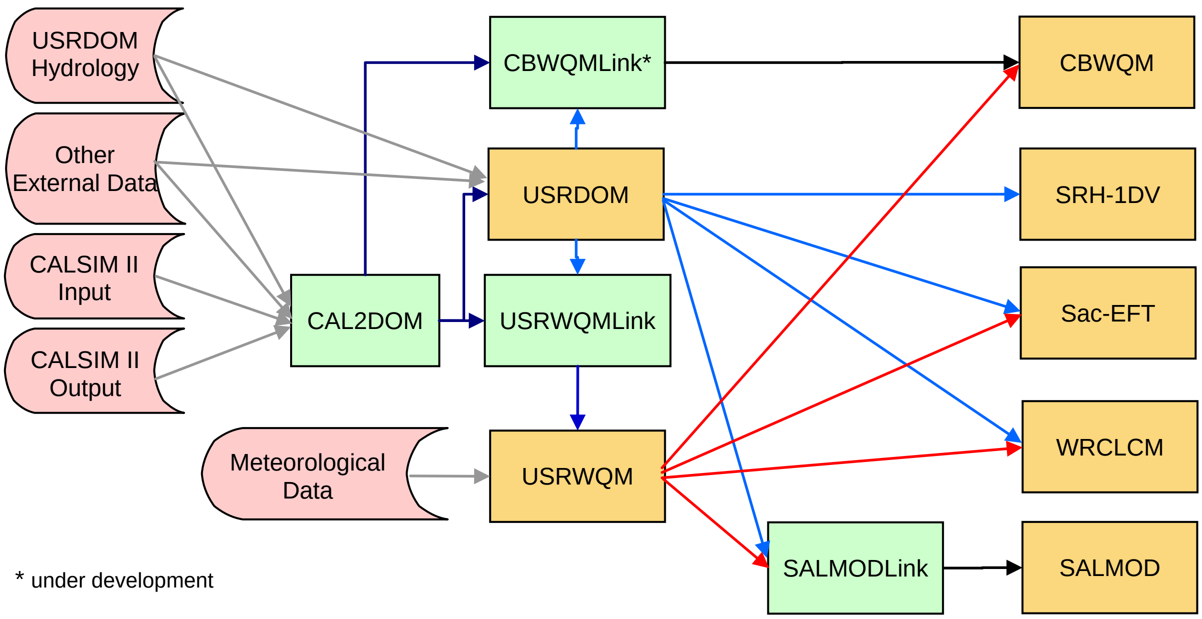


FIGURE 5.3
USRDOM Linkages and Utilities

5.3.1 USRWQM

USRWQM is Reclamation's temperature model for the Upper Sacramento River. A linkage has been developed between USRDOM and USRWQM so that the flow operations in USRWQM mimic USRDOM. A linkage document describing the translations between the two models has been developed. A new utility called 'USRWQMLink' has been developed using DZYMAN and incorporating the translations defined in the linkage document. Appendix C includes the linkage document and the DZYMAN instruction file for USRWQMLink.

5.3.2 SALMOD

SALMOD is a salmonid population model that simulates partial life cycle of four runs of Chinook salmon in the Upper Sacramento River. It depends on daily flow and temperature data. A linkage document was developed to identify the USRDOM flow outputs needed for SALMOD. The document also includes the temperature outputs from USRWQM needed for SALMOD. A new utility called 'SALMODLink' was developed to provide flow and temperature data needed for SALMOD. SALMODLink uses DZYMAN, which incorporates USRDOM and USRWQM translations identified in the linkage document. Appendix C contains the linkage document and the DZYMAN instructions file for SALMODLink.

5.3.3 SRH Models and RHEM

SRH models include SRH-SIAM, SRH-Meander, SRH-2D, and SRH-1DV. RHEM provides inputs to the SRH-1DV model. A linkage document describing various flow outputs from USRDOM was developed for standardizing the data transfer from USRDOM to SRH models. The linkage document is included in Appendix C. Because no data manipulation was involved, no utility was created.

5.3.4 WRCLCM

WRCLCM is the Interactive Object-oriented Salmonid Simulation (IOS) winter-run Chinook life cycle model. It requires flow and temperature data. The daily flow outputs needed from USRDOM and the daily temperature outputs from USRWQM for the WRCLCM were identified and documented. The linkage document detailing the flow and temperature data used by WRCLCM is included in Appendix C. Because no data manipulation was involved, no utility was created.

5.3.5 CBWQM

CBWQM simulates daily flows and temperatures in the Colusa Basin region, including the proposed NODOS conveyance and storage features. It requires inputs from USRDOM and USRWQM for flows and temperatures, respectively. A document identifying the linkage between USRDOM and CBWQM is being developed.

5.3.6 Sac-EFT

Sac-EFT evaluates the ecological value of a proposed operations alternative from a multiple species point of view. It requires flow and temperature data from USRDOM and USRWQM. A linkage document detailing the dataflow between USRDOM and Sac-EFT is being developed.

5.4 Example Full-period Simulation

An example full-period USRDOM simulation was developed using the results from the CACMP V9B1 Future 1 CALSIM II simulation. The full functionality of the USRDOM toolset in the Common Assumptions framework was tested, including the OPCHK, USRWQMLink, and SALMODLink utilities. Figures 5.4 and 5.5 show the sample results from the simulation. Figure 5.4 compares the simulated end-of-the-day Shasta storage from USRDOM with the monthly CALSIM II end-of-month storage over a 10-year period. USRDOM result matches fairly closely to CALSIM II end-of-month storage. USRDOM shows encroachments into the flood space, which are absent in the monthly CALSIM II result. Figure 5.5 shows a comparison of Bend Bridge flow time series from daily USRDOM simulation and the monthly CALSIM II simulation. USRDOM matches the general trend observed in the monthly CALISM II flows, however exhibits daily variability. The daily variability in USRDOM result at times is more than double the monthly averages.

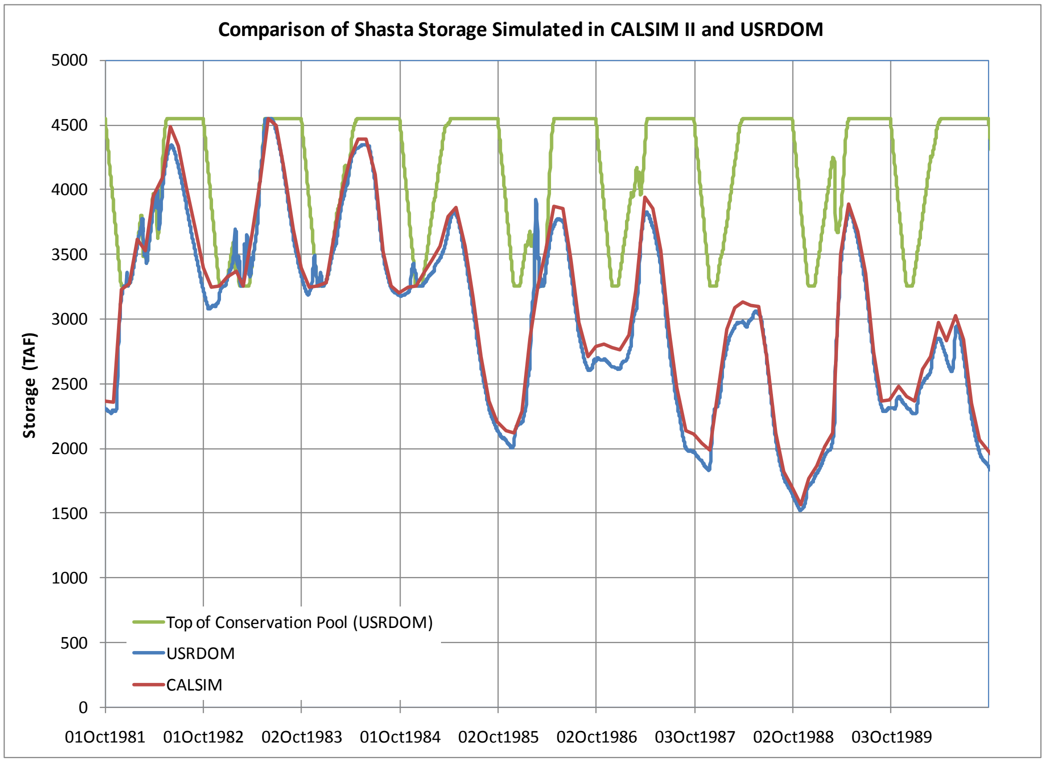


FIGURE 5.4
Comparison of Shasta Storage in CALSIM II and USRDOM Simulations

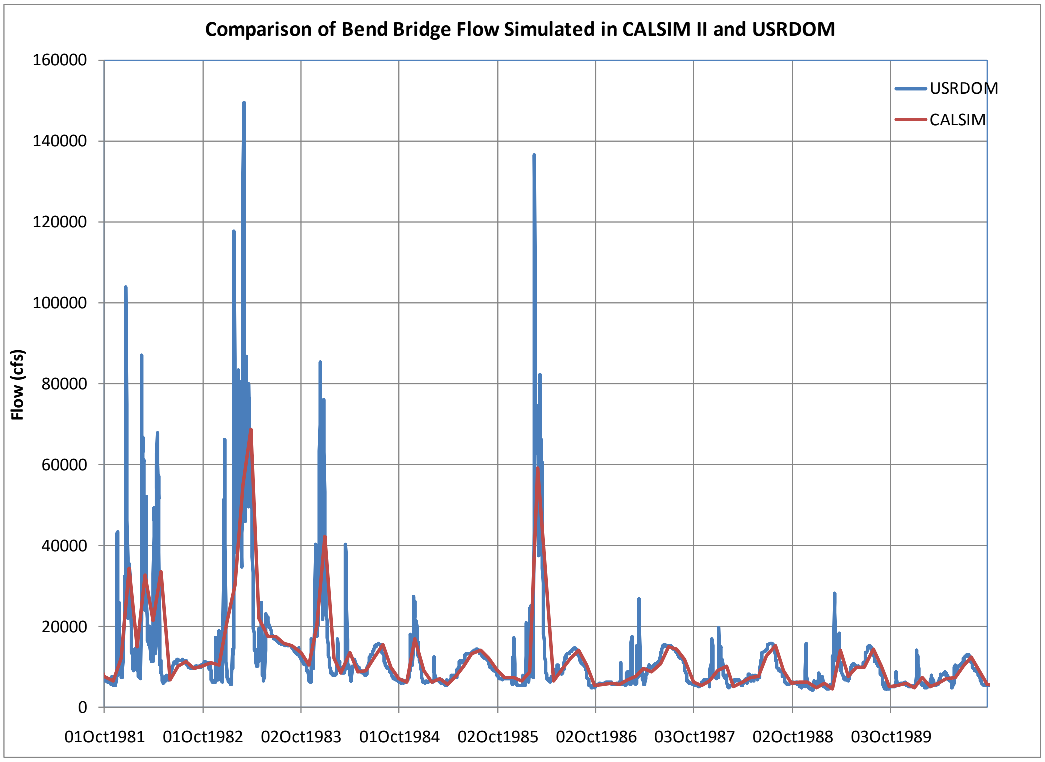


FIGURE 5.5
Comparison of Bend Bridge Flow in CALSIM II and USRDOM Simulations

5.5 Contrasting USRDOM and CALSIM25Q

USRDOM was developed to provide an alternative to the CALSIM25Q/USRWQM toolset (RMA, 2003) to simulate daily operations in the upper Sacramento River. Significant improvements have been achieved in the quality of the simulated daily flows using USRDOM. Table 5.10 provides a list of the key differences in the two approaches.

TABLE 5.10
Comparison of USRDOM and CALSIM25Q/USRWQM

USRDOM	CALSIM25Q/USRWQM (RMA, 2003)
Daily inflows based on historical flows	**Monthly inflows from CALSIM II patterned on daily historical flows**
Preserved the daily variability in the river flows because the ungaged flows from calibration/verification are used	Flows were smoothed; therefore, significant daily variability is lost in the river flows
Capable of simulating Shasta and Trinity reservoirs based on operating rules outside downstream control periods	Shasta and Trinity reservoir operations are fixed to match CALSIM II results smoothed to a daily timestep
Monthly CALSIM II diversions are smoothed to a weekly timestep	Monthly CALSIM II diversions are kept constant all month
Major CALSIM II diversion volumes within months are maintained	N/A
Option available to modify reservoir releases to ensure diversion volume available in the river; otherwise, diversion may be shorted on daily basis	Major CALSIM II diversion volumes are fixed and accounted for in the Shasta releases

5.6 Summary

USRDOM was developed to simulate daily reservoir operations and river flow conditions. It was successfully calibrated and verified for all ranges of flows in the Sacramento River. Trinity and Shasta reservoir operations in USRDOM have been adequately verified using the observed data.

USRDOM was modified to incorporate 82-year (full-period) simulation capabilities using CALSIM II data. Full-period hydrology was developed for projected level simulations. CAL2DOM, a CALSIM II to USRDOM translation utility, was developed and tested. An example full-period USRDOM simulation based on the CACMP v9B1 Future 1 scenario was developed, and extensive quality assurance and testing were performed.

USRDOM provides a good representation of daily operations on the Sacramento River that is an improvement over previously available models.

SECTION 6

USRDOM NODOS Sub-model

6.1 Overview

One of the key objectives of USRDOM is to support the feasibility study analyses for the proposed NODOS surface storage project. Therefore, USRDOM was enhanced to include the storage and conveyance features of NODOS in the Colusa Basin region. A sub-model specific to NODOS and Colusa Basin (USRDOM_CB) was created to simulate the projected diversions from the Sacramento River to NODOS and releases from NODOS back to the river on a daily timestep. A new pipeline connecting NODOS with the Sacramento River at river mile 159 (Delevan pipeline) provides an additional facility for this operation of NODOS. The existing TCC and GCC diversions would be re-operated to allow use of these facilities for operation of NODOS.

6.2 Model Schematic

The spatial domain of USRDOM was extended to include NODOS features such as TCC and GCC reaches; interconnections between Stony Creek and TCC; existing and proposed interconnections between the TCC and GCC, Sites Reservoir, and Funks Forebay; and new Delevan pipeline components. Figure 4.16 shows the extended USRDOM schematic with NODOS features. The channel reaches, connections, and capacity information were derived based on the NODOS implementation in the CALSIM II model used for the NODOS Administrative Draft Environmental Impact Report and Statement (ADEIRS)Analysis.

Implementing complex interconnections between Funks Forebay, TCC, and GCC was challenging because of the inherent limitations of HEC-5. Several NODOS conveyance features are proposed to be bi-directional, such as the proposed Delevan pipeline and the Funks Forebay-GCC intertie. Similarly, the exchange of flow between Funks Forebay and Sites Reservoir is bi-directional. Because, at any given node, HEC-5 allows only one channel connection with a downstream node and only one diversion, Funks Forebay was required to be simulated as seven control points to allow for all the interconnections. Several dummy reservoirs were needed to properly simulate the interconnections between Sacramento River, Funks Forebay, TCC, and GCC. Moreover, because HEC-5 does not allow the flow to be bi-directional in a channel and does not allow more than one channel between two nodes, Sites Reservoir was modeled as two reservoirs. The first reservoir receives water from the Funks Forebay and the second reservoir releases water to Funks Forebay. Table 6.1 shows the list of the new control points in the NODOS Sub-Model, along with the descriptions of the locations, HEC-5 IDs, and the assumed channel capacities. Channel routing was not implemented in USRDOM_CB.

TABLE 6.1
USRDOM NODOS Sub-model Schematic Information

Control Point #	Description of Control Point Location	Control Point ID in HEC-5	Channel Capacity (cfs)

1752	Dummy reservoir to route Tehama-Colusa Canal diversion from Sacramento River	1752-TCCDR	2,530
1750	Tehama-Colusa Canal downstream of Corning Canal	1750-TCC	2,400
1749	Tehama-Colusa Canal	1749-TCC	2,200
1748	Tehama-Colusa Canal	1748-TCC	2,100
1747	Tehama-Colusa Canal	1747-TCC	2,100
1746	Funks Forebay control points	1746-FUNKS	99,999
1745	Funks Forebay control points	1745-FUNKS	99,999
1744	Funks Forebay control points	1744-FUNKS	99,999
1743	Funks Forebay control points	1743-FUNKS	99,999
1742	Funks Forebay control points	1742-FUNKS	99,999
1741	Funks Forebay control points	1741-FUNKS	99,999
1740	Funks Forebay control points	1740-FUNKS	99,999
2740	Sites Reservoir	2740-SITES	999,999
2746	Dummy Sites Reservoir	2746-SITES	999,999
1501	Dummy reservoir to route Glenn-Colusa Canal diversion from Sacramento River	1501-GCCDR	3,000
1500	Glenn-Colusa Canal	1500-GCC	1,800
1499	Glenn-Colusa Canal	1499-GCC	1,200
1498	Glenn-Colusa Canal	1498-GCC	1,200
1497	Glenn-Colusa Canal	1497-GCC	1,200
1496	Glenn-Colusa Canal	1496-GCC	1,200
2498	Dummy reservoir to route diversion from Glenn-Colusa Canal to Funks Forebay	2498-GCCDR	999,999
1291	Dummy reservoir to route Delevan pipeline inflow from Sacramento River to Funks Forebay	1291-NODOSDR	99,999
1281	Dummy reservoir to route Delevan pipeline delivery from Funks Forebay to Sacramento River	1281-NODOSDR	99,999
1133	Dummy reservoir to route Stony Creek - TCC intertie flows	1133-STNYTC-INT	99,999

6.3 Model Input Dataset

All the model inputs related to USRDOM_CB are derived from the monthly CALSIM II operations, including inflows, evaporation, reservoir outflows, and diversions. The inflows coming into USRDOM_CB include the TCC, GCC, and Delevan pipeline diversions from the Sacramento River and Stony Creek–TCC intertie flows. Table 6.2 lists the inflows, including the control point where the flow comes in, the source of the flow, and the HEC-5 name for the inflow. Table 6.3 shows the diversions modeled in USRDOM_CB, including the corresponding CALSIM II variables, the control point where the flow is diverted, and the HEC-5 name for the diversion.

TABLE 6.2
Inflows in NODOS Sub-model

Inflow	Control Point Number at the Inflow Location	Source of Flow	HEC-5 Name for Inflow Time Series
TCC Diversion	1752	Sacramento River	QD175
GCC Diversion	1501	Sacramento River	QD150
Delevan Pipeline Diversion	1291	Sacramento River	QD128
Stony Creek–TCC Intertie	1133	Stony Creek	QD1134

TABLE 6.3
Diversions in NODOS Sub-model

Diversions	Corresponding Values in CALSIM II	Control Point Number at the Diversion Location	HEC-5 Name for Diversion Time Series
Corning Canal and WBA4 Diversions	D171	1752	QD1752
WBA4 Diversions	L172, D172	1750	QD1750
WBA7N Diversions	D174	1748	QD1748
Existing TCC-GCC Intertie Flow to GCC	C17502A	1746	QD1746
Delevan Pipeline Release to Sacramento River	C17603	1744	QD1744
Proposed Funks-GCC Intertie to GCC	C17502	1742	QD1742
Williams Outlet from Funks to GCC	C17502B	1741	QD1741
WBA7S Diversions	D178	1740	QD1740
EWA Release	D33	2746	QD2746
WBA8NN and Refuge Diversions	L143, D143A, D143A_WTS, D143A_EWA, D143B	1500	QD1500
Proposed Funks-GCC Intertie to Funks	D14401	1498	QD1498
WBA8NS Diversions	D145A, D145A_WTS, D145A_EWA, D145B	1496	QD1496
Sites Reservoir Evaporation Rate	S30EVAP	2740	EV2740

6.4 Modeling of Reservoir Operations

Sites Reservoir and Funks Forebay are two storage features proposed as part of NODOS. As explained earlier, because of limitations in HEC-5, Sites Reservoir is modeled as two reservoirs, one to receive water from Funks Forebay and the other to release water to Funks Forebay. Although Funks Forebay has some available storage, it is proposed as a regulating reservoir. Therefore, Funks Forebay was not modeled as a reservoir in HEC-5. Instead, it was modeled as an extension of TCC and represented by seven control points to allow for all the interactions that occur with Sites Reservoir, GCC, and the Sacramento River.

To represent flow availability in Funks Forebay for diversions to GCC and Sacramento River, inflows into Funks Forebay are accounted for at the three upstream control points representing Funks Forebay. Diversions are taken from the five downstream control points. Inflow from Sites Reservoir to Funks Forebay is located at the most upstream control point 1746. The existing TCC-GCC intertie is represented as a diversion from control point 1746 to control point 1500. The Delevan pipeline diversion from the Sacramento River comes into control point 1745 just downstream of the Sites inflow. The flow from GCC to Funks Forebay through the proposed intertie comes in next at control point 1744. The diversion from Funks Forebay to GCC through the proposed intertie occurs at control point 1742. The diversion from Funks Forebay to GCC through the Williams Outlet occurs at control point 1741. Finally, the flow pumped into Sites Reservoir is diverted from the most downstream control point, 1740, from which the WBA7 diversions are also taken.

Storage changes because of evaporation and outflow from the Sites Reservoir are simulated at the first reservoir (control point 2740), where the inflow from Funks Forebay (control point 1740) enters. Information related to reservoir levels, storage, outlet capacities, area, and elevation relationships for the Sites Reservoir were obtained from CALSIM II model for each NODOS Alternative. The outflow for the Sites Reservoir is fixed, (HEC-5 is forced to release a specified outflow from the reservoir at each timestep). Based on the operations assumed in CALSIM II, a constant outflow of 6,800 cfs was assumed for the entire simulation time period. This outflow is routed to the second Sites Reservoir represented by a dummy reservoir in HEC-5 without any associated storage. After water for the Environmental Water Account is diverted from this dummy reservoir, the remaining flow is routed back to the most upstream Funks Forebay control point (1746).

6.5 USRDOM and NODOS Sub-model (USRDOM_CB)

Because USRDOM with the NODOS Sub-model exceeded the maximum number of control points allowed by HEC-5 (80), it was not possible to simulate the NODOS Sub-model in the standard two steps process used in the USRDOM Full Verification Simulation and the Projected Condition Simulation. Therefore, a three-step process was used to simulate the NODOS Sub-model (Figure 6.1). The first two steps simulate the standard USRDOM schematic without the Colusa Basin region. However, all diversions and inflows common to both models (TCC, GCC, Delevan diversions, Delevan inflow, and Stony-TCC intertie flow) are accounted for in the standard USRDOM simulation. The simulated Sacramento River flow downstream of the Paynes Creek confluence from the second step is assumed as the upstream boundary for USRDOM_CB. Therefore, the domain of the USRDOM_CB includes the Sacramento River downstream of the Paynes Creek confluence and the Colusa Basin region with the NODOS features. This approach is reliable as long as the inflows and diversions common to USRDOM and USRDOM_CB are simulated in both models.

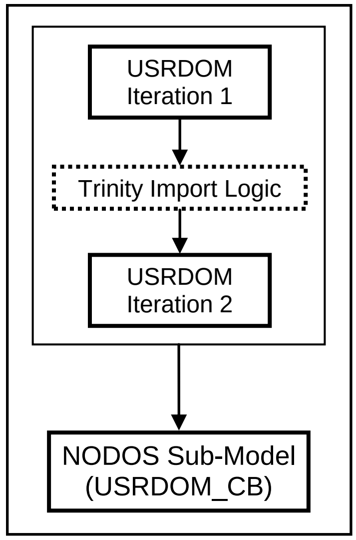


FIGURE 6.1
Strategy for Simulating USRDOM_CB

6.6 Modifications to CAL2DOM

The operations in USRDOM_CB depend on monthly CALSIM II operations. Therefore, the monthly CALSIM II operations are translated to a daily timestep for use in USRDOM_CB. CAL2DOM was modified to include translation of Colusa Basin and NODOS-related operations from CALSIM II to a daily timestep. Because the operations are fixed in the NODOS Sub-model, the translation of the monthly CALSIM II data is straightforward. The most common approach involved converting the monthly data to daily, smoothing over a 21-day period while conserving monthly volume, and saving the daily time series using average weekly values. For four diversions (the existing TCC-GCC intertie flow, the releases to the Sacramento River through the new Delevan pipeline, and the release and filling of NODOS through the proposed Funks-GCC intertie), 9-day smoothing is performed without conserving the monthly volume because of issues with channel capacity constraints.
Table 6.4 lists the NODOS-related operations that are translated by CAL2DOM, along with the CALSIM II variables used and the methodology used for the translation. The GCC diversion from the Sacramento River is estimated on a daily basis to get an accurate estimate instead of simply translating the monthly GCC diversion from CALSIM II. This estimate is required because of the frequency of channel capacity constraints occurring in the GCC. The DZYMAN configuration and instruction files for the Colusa Basin version of CAL2DOM are included in Appendix B. In addition to the above changes some other changes have been made to CAL2DOM to ascertain consistency between the CALSIM II and USRDOM results. Specifically, the CAL2DOM shortage computations used in determining the Shasta release requirement in the USRDOM_CB model are modified. CAL2DOM computations to estimate minimum reservoir release requirements are described in section 5.2.3.7 and Table 5.9. Estimates of the additional flow needed to satisfy the flow required at Red Bluff Diver Dam, Hamilton City and Wilkins Slough compliance points (MR175_SHORT, MR150_SHORT and MR110_SHORT) are limited to the corresponding minimum instream flows specified in CALSIM II to address the daily variability due to the unregulated flows (C112_MIFADJ, C114_MIFADJ and C129_MIFADJ).

TABLE 6.4
Computation of USRDOM_CB Specific Operations in CAL2DOM

Description	USRDOM (Result)	CALSIM II	Comment
Corning Canal and WBA4 Diversions	QD1752	D171	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA4 Diversions	QD1750	L172, D172	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA7N Diversions	QD1748	D174	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Existing TCC-GCC Intertie Flow	QD1747	C17502A	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
New Delevan Pipeline Release from NODOS	QD1744	C17603	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
Proposed TCC-GCC Intertie Flow - Release from NODOS	QD1742	C17502	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
Williams Outlet Flow	QD1741	C17502B	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA7S Diversions	QD1740	D178	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
WBA8NN and Refuge Diversions	QD1500	L143, D143A, D143A_WTS, D143A_EWA, D143B	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Proposed TCC-GCC Intertie Flow - For Filling NODOS	QD1498	D14401	Converted to daily and smoothed over a 9-day period, without conserving monthly volume, and saved as average weekly values
WBA8NS and Refuge Diversions	QD1496	D145A, D145A_WTS, D145A_EWA, D145B	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Sites Reservoir Evaporation	EV2740	S30EVAP	Converted monthly evaporation rates to daily values
Sites Reservoir EWA Outflow Release	QD2746	D33	Converted to daily and smoothed over a 21-day period, conserving monthly volume, and saved as average weekly values
Hamilton City Diversion (Glenn-Colusa Canal)	QD150	QD1500, QD1747, QD1498, QD1742, QD1496, QD1741	Flow needed from Sacramento River for the GCC (QD1747, QD1742 and QD1741 are subtracted)

6.7 Quality Assurance and Linkages with Other Models

The utilities developed to perform QA/QC and create linkage datasets for other models using the output from USRDOM were modified to retrieve the necessary data directly from USRDOM_CB. Specifically, alternate versions of OPCHK and USRWQMLink were created to use USRDOM_CB results directly. This allows scenario testing with NODOS while maintaining linkages with other models. New instructions were added to OPCHK to create a Colusa Basin version for checking USRDOM outputs against inputs and for checking USRDOM/USRDOM_CB outputs at key locations against CALSIM II outputs. The DZYMAN configuration and instruction files for the Colusa Basin version of OPCHK and USRWQMLink are included in Appendix B.

6.8 Example Full-period Simulation

An example full-period USRDOM_CB simulation was developed using the results from the CACMP V9B1 NODOS 1 CALSIM II simulation. The full functionality of the USRDOM toolset including USRDOM_CB was tested within the Common Assumptions framework, including the OPCHK, USRWQMLink, and SALMODLink utilities.

Figures 6.2 and 6.3 show the sample results from the example full-period simulation. Figure 6.2 compares the simulated Knights Landing flow from USRDOM and USRDOM_CB models to show that there is no difference in the Sacramento River operations from the inclusion of the Colusa Basin region in the USRDOM_CB model. In other words, the three-step model does not result in any differences in the Sacramento River operations from the two-step model. This is expected since the Delevan Pipeline diversion and inflow values are simulated in the two-step model as well. Figure 6.3 compares the simulated CALSIM II end-of-month storage in Sites Reservoir with end-of-the-day storage from USRDOM_CB over a 10-year period. Figure 6.3 indicates that Sites Reservoir storage is nearly identical in both the models. The slight differences in Sites Reservoir storage between the two models result from channel capacity constraints in USRDOM_CB.

6.9 NODOS Sub-model Implementation Summary

The spatial domain of USRDOM was extended to include NODOS and Colusa Basin storage and conveyance features. The operations of NODOS in USRDOM_CB are fixed to CALSIM II and the CAL2DOM utility was modified to translate CALSIM II NODOS operations to provide inputs to the USRDOM_CB model. A three-step approach was developed to run a full-period daily USRDOM and USRDOM_CB simulations using inputs from NODOS CALSIM II scenarios. The utilities to generate QA/QC metrics (OPCHK) and USRWQM linkage dataset (USRWQMLink) were updated to incorporate Colusa Basin results. An example full-period USRDOM_CB simulation based on CACMP v9B1 NODOS1 scenario was developed and extensive quality assurance and testing was performed. Using the results from USRDOM_CB, example model linkage datasets were also developed. Finally, USRDOM has been developed so that the model can be modified to analyze diversion conditions for NODOS dynamically or through iteration with an external processor (DZYMAN based). The tool is ready to be used to study potential benefits and impacts of the proposed NODOS alternatives.

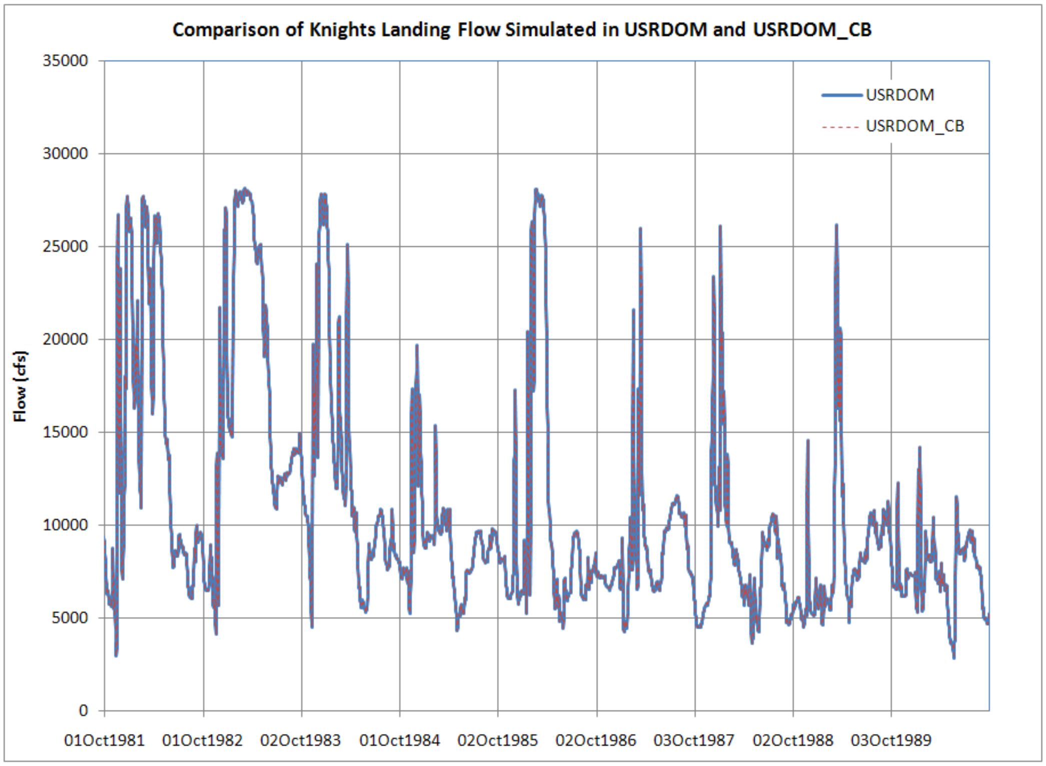


FIGURE 6.2
USRDOM and USRDOM_CB Simulated Knights Landing Flow

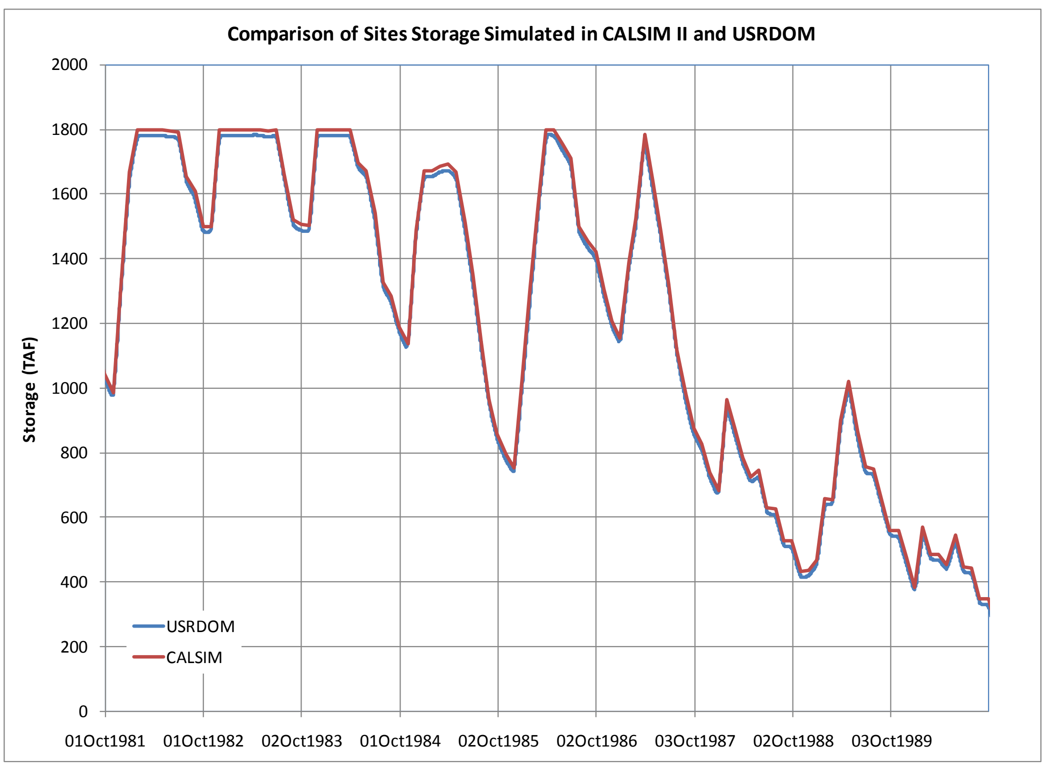


FIGURE 6.3
USRDOM_CB and CALSIM II Simulated Sites Reservoir Storage

6.10 Application of USRDOM to NODOS ADEIRS Alternatives

USRDOM is used in several ways as part of modeling of the operations of NODOS ADEIRS Alternatives. First,it was used to test and finalize the CALSIM II operations for the NODOS Alternatives. Then the daily storage and flow results from USRDOM were used for various temperature, biological and flow regime models used in the evaluation of NODOS Alternatives. This section describes how USRDOM has been applied in the evaluation of the NODOS Alternatives.

6.10.1 Description of the Alternatives

The assumptions for the Existing Conditions and No Action Alternative are summarized in an October 1, 2010 memorandum, "Assumptions for Existing and Future No Action Alternative Conditions CALSIM II and DSM2 Models" (see file: *Confirmation_of_Baselines_Assumptions_070510_compiled_100110.pdf*). The assumptions for the NODOS Alternatives are summarized in a January 5, 2011 document, "Definition of Proposed Alternatives for Evaluation in the North-of-the-Delta Offstream Storage Administrative Draft Environmental Impact Report and Statement" (see file: *Definition of Proposed Alternatives for Evaluation in NODOS ADEIR 2011-01-05 SS_JW.pdf*).

Three Alternatives have been identified by the lead agencies for the NODOS ADEIRS. Alternatives A, B, and C differ in the storage or conveyance capacities. The three proposed alternatives are as follows:

- Alternative A (ALT A) has a 1.2 MAF storage capacity with existing Tehama-Colusa Canal (2,100 cfs) and Glenn-Colusa Irrigation District Canal (1,800 cfs) and a new Delevan pipeline with a diversion capacity of 2,000 cfs and release capacity of 1,500 cfs.
- Alternative B (ALT B) has a 1.8 MAF storage capacity with existing Tehama-Colusa Canal (2,100 cfs) and Glenn-Colusa Irrigation District Canal (1,800 cfs) and a new release only Delevan pipeline (release capacity of 1,500 cfs). There are no fish screen intake and pumping plant associated with the new Delevan pipeline.
- Alternative C (ALT C) is similar to Alternative B, except the new Delevan pipeline has a fish screen intake and pumping plant with a diversion capacity of 2,000 cfs and a release capacity of 1,500 cfs..

Several ecosystem enhancement actions (EEA) are proposed to show the ability of NODOS Alternatives to support the ecological goals of the system. Some of the key EEA actions identified include improving coldwater pool storage in Shasta Lake and increasing the availability of coldwater to provide suitable habitat conditions for different life stages of Chinook Salmon, stabilize flows in the Sacramento River during fall months to minimize dewatering of fall-run Chinook salmon redds and reduce diversions at RBDD and Hamilton City by meeting local demands with water from the Sites Reservoir.

6.10.2 NODOS Intake Operations Assumptions

The operational assumptions for the three NODOS intakes, namely existing TCC Intake, GCC Intake and the proposed Delevan Pipeline Intake are described in this section. In general, Red Bluff, Hamilton City and the proposed Delevan Pipeline diversions to Sites Reservoir storage are permitted in any month of the year. However, each intake has specific conveyance and maintenance restrictions, bypass flow restrictions and diversion restrictions associated with pulse flow protection that were assumed in the modeling.

6.10.2.1 Conveyance Capacities and Maintenance Periods

The lead agencies in coordination with the TCCA and GCID authorities laid out the following assumptions for the three NODOS intakes. This section summarizes the key assumptions used in the model for the conveyance capacities and the maintenance periods for the each intake, except where noted.

- Red Bluff Diversions (for filling of NODOS)
  - Tehama Colusa Canal Capacity:
    - At Red Bluff: 2,250 cfs minus diversions for non-Sites Reservoir operations
    - At Funks Forebay: 2,100 cfs minus flows for non-Sites Reservoir operations
    - Approximately 50 to 60 cfs of capacity is assumed to be used for other winter time operations of the canal. (This capacity is reserved for winter time operations in CALSIM II, however this water is not routed.)
  - No dedicated period for maintenance assuming:
    - Every other year one month is available between December 1st to February 15th, and
    - Every fifth year two or more months are available between December 1st to February 15th
    - These outages are not modeled as dedicated outages in CALSIM II, instead these are the outcomes of the winter operations in the Colusa Basin conveyance system
- Hamilton City Diversions (for filling of NODOS)
  - Glenn Colusa Canal Capacity:
    - At Hamilton City: 3,000 cfs minus diversions for non-Sites Reservoir operations
    - At Terminal Regulating Reservoir (TRR) intertie to Funks Fore-bay: 1,800 cfs minus flows for non-Sites Reservoir operations
    - The capacities listed in Table 6.5 are assumed to be used for other winter time operations of the canal

TABLE 6.5
Assumed Glenn Colusa Canal Conveyance Capacities for other Winter Time Operations of the Canal

Oct	Nov	Dec	Jan	Feb	Mar
513 cfs	534 cfs	389 cfs	235 cfs	56 cfs	48 cfs

  - Dedicated maintenance period is required from January 7th through February 21st every year
- New Delevan Pipeline Diversions/Releases

- Dedicated maintenance period is required from April 1st to May 31st under Alternatives A and C (intake, screen and sediment related maintenance)
- No diversions or releases allowed during maintenance period

6.10.2.2 Bypass Flow Requirements

Diversions to storage are restricted until the specified bypass flow requirements achieved at each of the three intakes. These requirements must be met for the diversions to storage to occur.

- Downstream of Red Bluff Diversion Dam, a bypass flow requirement was assumed based on the existing State Water Resources Control Board minimum flow requirement. A 3-day moving average flow was used for assessing this bypass flow requirement. Following flow was used as the required bypass flow downstream of Hamilton City:
  - 3,250 cfs (3 day average)
- Downstream of Hamilton City, a bypass flow requirement was assumed based on the existing operational requirement for the GCC intake. A 3-day moving average flow was used for assessing this bypass flow requirement. Following flow was used as the required bypass flow downstream of Hamilton City:
  - 4,000 cfs (3 day average)
- At Wilkins Slough location, a bypass flow requirement was assumed for the protection of the navigational control point requirement. This is mainly to protect the water levels for the long-time water users diverting along the Sacramento River in this reach. A 3-day moving average flow was used for assessing this bypass flow requirement. Following flow was used as the required bypass flow at Wilkin Slough:
  - 5,000 cfs (3 day average)
- At Freeport/Hood location, bypass flow requirement was assumed for the protection of the Delta from water quality impact. Approximate flows needed to maintain the X2 at or west of Chipps Island were assumed for the bypass flows. It was assumed that a moving average criterion of 15 day or greater would be sufficient since water quality depends on the antecedent conditions and is insensitive to instantaneous flow variations. Monthly average was assumed as approximate to the 15 day or greater moving average. Following flows were used as the required bypass flows at Freeport:
  - 15,000 cfs in January
  - 13,000 cfs in December or February through June
  - Otherwise 11,000 cfs

6.10.2.3 Pulse Flow Protection

NODOS winter diversion operating criteria was identified considering the importance of limiting the potential impact of winter diversions on fisheries resources. This sub-section summarizes the diversion restriction criteria used in the modeling of NODOS Alternatives to protect pulse flow conditions associated with outmigration of juvenile winter-, spring-, fall- and late fall-run Chinook salmon.

Pulse flows are defined by peaks in the impaired hydrograph, rather than scheduled operational events. The peak flows originate primarily from tributaries that come into the river downstream of Keswick Dam. Pulse flows provide key biological cues for the fish species and enhance the turbidity effects. The period for pulse protection was assumed to extend from October through May to address outmigration of juvenile winter-, spring-, fall- and late fall-run Chinook salmon, as well as a portion of the steelhead juvenile outmigration period. Diversions were restricted for up to one qualified pulse event recognized in each month of the October through May period, and is recognized for the month in which it ends.

Bend Bridge flow was used to identify pulse signals as part of the modeling. If the 3-day trailing average of Bend Bridge flows exceeds 15,000 cfs, a pulse event is assumed to be initiated if the previous day was not already in a pulse event. A pulse event is terminated seven days after initiation, constituting a qualified pulse event, or if the three-day trailing average drops below 15,000 cfs during the seven days following initiation, without constituting a qualified pulse event.

Diversions to NODOS storage are restricted if pulse conditions exist at Bend Bridge, if a qualified pulse event has not already occurred within the given month, and if Bend Bridge daily flows are less than 25,000 cfs. Diversions are otherwise unrestricted and are therefore limited only by the available capacity. Figure 6.4 provides an example where the pulse protection periods were identified based on the assumptions described above.

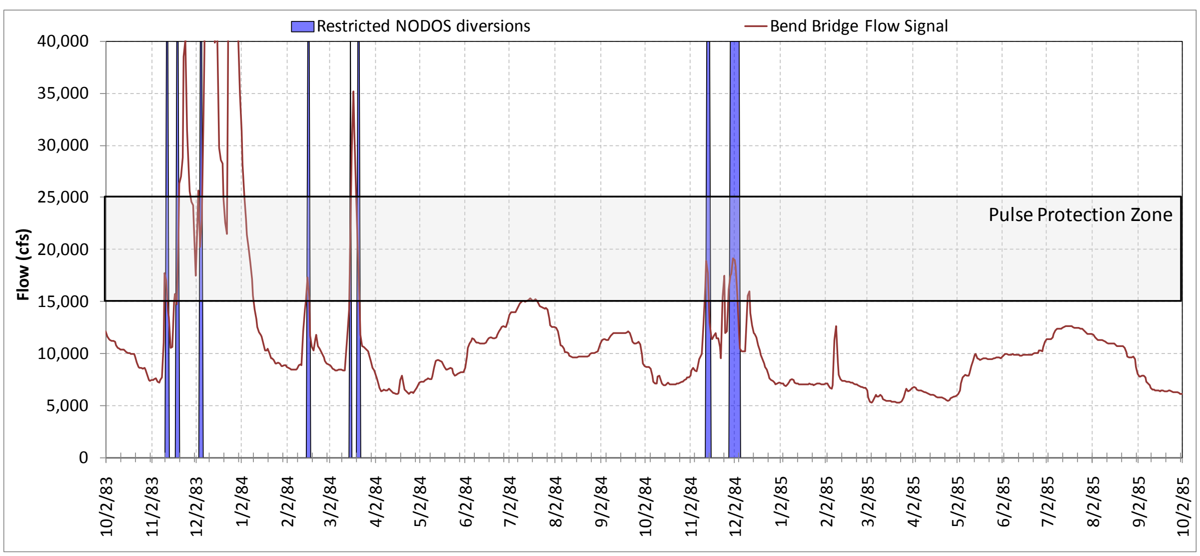


FIGURE 6.4
Example of Pulse Protection Assumed in the NODOS Alternatives Modeling

6.10.3 NODOS Operations Modeling Process

CALSIM II was the core model used to simulate the NODOS operations. However, the assumptions related to the intake operations as described above require daily flow data in determining the diversions allowed at the intakes, in turn affecting the system-wide operations. Since CALSIM II is a monthly timestep model, USRDOM results were used to enforce the intake operations on a sub-monthly scale. Due to the complexity in the intake operational rules, a spreadsheet tool was developed to implement the operational constraints using the daily results from the USRDOM. Further, the models were iterated to ensure all the intake operations assumptions were simulated accurately. Figure 6.5 shows the schematic of the modeling process used to simulate NODOS operations.

In the first iteration, CALSIM II and USRDOM models are simulated for a NODOS Alternative to determine the days requiring the pulse protection. A draft CALSIM II simulation was run with all the physical, regulatory and operational assumptions for the NODOS Alternative. The results from this “draft” CALSIM II simulation were used to run the USRDOM model. The USRDOM setup included NODOS assumptions consistent with the draft CALSIM II. Since this USRDOM run is used to estimate daily flows in the river to determine the days requiring pulse protection, the diversions at the TCC, GCC and proposed Delevan intakes are restricted to meet the agricultural demands and other local uses in Colusa Basin region. The CAL2DOM logic was altered to estimate the diversions at the three intake locations without including the diversions for filling Sites Reservoir in this USRDOM run (called as, draft USRDOM No Fills Run). The results from the draft USRDOM No Fills run are used in a spreadsheet tool to determine the number of days under pulse protection in each month, over the 82-year period.

In the second iteration, the draft CALSIM II from the first iteration is re-run with the pulse protection data, to simulate the final monthly operations for the NODOS Alternative. The goal of this iteration is to determine the daily diversion amounts at the TCC, GCC and proposed Delevan pipeline intakes. Since the complexity involved in simulating capacity and maintenance constraints, bypass flow requirements and pulse protection restrictions simultaneously, the existing CAL2DOM logic to determine the daily diversions at the three intakes is insufficient. Therefore, the results from the final CALSIM II simulation are used to run another USRDOM simulation without including the diversions needed to fill the Sites Reservoir at the three intake locations (called as, final USRDOM No Fills Run). The purpose of this final USRDOM No Fills run is to determine the daily flows in the Sacramento River at key control points. This data is used in a spreadsheet tool to determine the daily diversions required to fill Sites Reservoir at the three intakes while complying with all the operational rules.

The daily diversions for the Sites fills at the three intakes are determined in three steps in the spreadsheet tool. In the first step the available diversion capacity is determined based on the capacity and maintenance constraints described above. In addition, based on the daily USRDOM flow the available flow to meet the monthly average diversion for fill (from CALSIM II) is determined at each intake, while meeting the bypass flow requirements. If there are no pulse flow restrictions for a given day, then the diversion at each intake is estimated as the minimum of available capacity and the available flow for diversion.

If the total diversion volumes at each intake from the first step for each month are less than the amount determined in CALSIM II, additional diversions needed to make up the difference are estimated in the second step. In this step, the additional diversions are made up at any of the three intakes depending on the available diversion capacity and the available flow for the diversion. First TCC intake is checked, then the GCC intake and finally the proposed Delevan pipeline intake for any available diversion capacity for each month.

Based on the diversions from the second step, the months with volumes continue to be short of the CALSIM II values are flagged in the third and final step. These shortages are carried forward to the next months in which the diversion capacity and the flow for the diversion are available. This carrying forward of the shortages is only allowed in November though May months, which generally is the Sites Reservoir filling period. The availability of the flow for the diversion is estimated as the Wilkins Slough flow in excess of the minimum flow requirement at Knights Landing (estimated in CAL2DOM).

In this process, a few reasonable simplifying assumptions were made for modeling purposes, mainly because CALSIM II determines the diversions at the three intakes on a monthly timestep without knowing the daily constraints due to the intake operations assumptions and the daily variability in the unregulated flows. It is assumed that in reality based on the available real-time monitoring, there is enough flexibility in TCC, GCC and proposed Delevan pipeline operations and in the interoperability among the three conveyance systems such that the diversions to fill Sites Reservoir can be made up –

1. through diversions at any of the three intake locations while meeting all the intake operations assumptions at each intake, and
2. through diversions in any of the months during the fill season of November through May if usable diversion capacity and divertible flow is available.

In the third iteration final USRDOM run is simulated using the final CALSIM II results and the daily diversions for fills from the final step of the spreadsheet tool. CAL2DOM is modified to combine the diversions for the fills and the diversions for meeting local Colusa Basin demands to determine the total daily diversions at each of the three intakes. The flow and storage results from the final USRDOM simulation are used to run the USRWQM for Sacramento River temperatures and other models to study the biological and flow regime effects of the NODOS Alternatives.

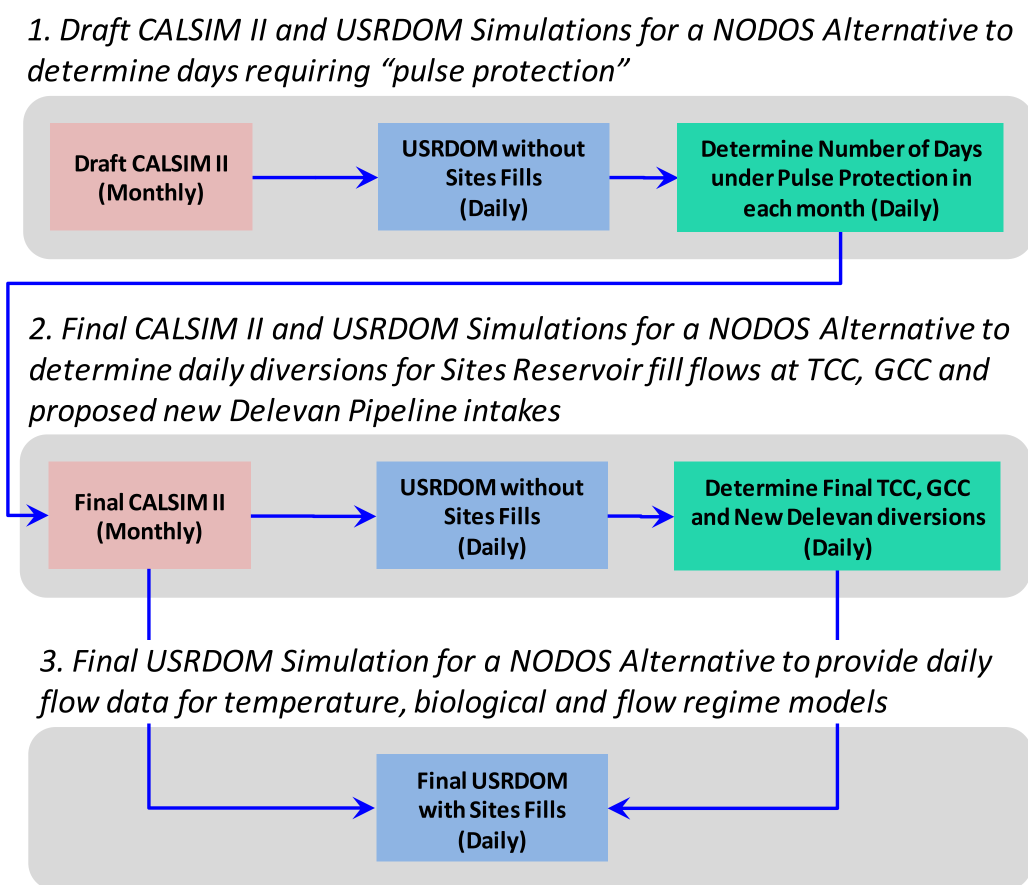


FIGURE 6.5
Operations Modeling Process used for the NODOS Alternatives Evaluation

6.10.4 Results and Discussion

This section presents a few key results from the USRDOM simulations for NODOS Alternatives A, B, and C, No Action Alternative and Existing Condition. The results presented in here are based on the daily results from the USRDOM simulations. Plots showing probability of exceedance of the 82 year daily results are presented for several flow and storage results.

Figure 6.6 shows a time series comparison of the Sites Reservoir storage for NODOS Alternatives A, B and C. Additional conveyance to fill the Sites Reservoir in the form of the proposed Delevan pipeline causes higher storage in ALT C than ALT B even though both simulations initialized from same storage. ALT A follows similar pattern as the other ALTs B and C, it is limited by storage capacity of about 1.2 MAF. Interestingly, in a critically dry year such as 1926, both ALT A and C resulted in similar storage conditions, even though ALT C includes additional storage capacity. Another interesting observation is that all the Alternatives show rapid decline in storage (almost 1 MAF drop in less than a year) going in to a dry year. Further, ALT C by the virtue of starting at a higher storage condition, last longer in to a dry period. Figure 6.7 shows the probability of exceedance of the daily Sites

Reservoir storage for NODOS Alternatives A, B and C. In the driest 20% of the years ALT B shows the lowest storage levels of all the three Alternatives.

Probability of exceedance of daily diversions at the Tehama Colusa Canal Intake near Red Bluff is shown for the NODOS Alternatives A, B and C, No Action Alternative and Existing Condition simulations in Figures 6.8 and 6.9. Three NODOS Alternatives show higher diversions at the Tehama Colusa Canal Intake. The flows in excess of the diversions shown for No Action Alternative and Existing Condition are for filling the Sites Reservoir. This occurs mainly in November through May months as shown in Figure 6.9. Note that all the NODOS Alternatives include an additional 250 cfs pump at Tehama Colusa Canal Intake near Red Bluff. In May through September months, the TCC diversions are less than the No Action Alternative as Sites Reservoir releases for the local demands in the Colusa Basin during this period reducing the diversions at the Sacramento River. The winter diversions at TCC intake are higher in ALT B compared to ALT C as in ALT B diversions for filling Sites Reservoir can only occur at TCC and GCC intakes. Diversions can occur at the proposed Delevan Pipeline intake in ALT C and ALT A. Since the Sites Reservoir storage is lower in ALT A, it has the lowest winter diversions at TCC intake. ALT B summer diversions at TCC intake are closer to the No Action Alternative unlike the diversions in ALT A and ALT C as some of the summer diversions are shifted to Delevan intake in the latter cases. Therefore, ALT B does not show similar levels of reduction in the diversions at the Sacramento River as ALT A and ALT C.

Probability of exceedance of daily diversions at the Glenn Colusa Canal Intake near Hamilton City is shown for the NODOS Alternatives A, B and C, No Action Alternative and Existing Condition simulations in Figures 6.10 and 6.11. The GCC intake diversions in the NODOS Alternatives exhibit similar patterns as the TCC diversions. During the winter months, the diversions at GCC intake are higher in the NODOS Alternative compared to the No Action Alternative and the Existing Condition run, so as to fill the Sites Reservoir. Again, Alt B has the highest diversions of the three alternatives due to the reduced diversion capacity. Because of the scheduled maintenance in January and February (3 weeks in each month), the diversions for fill remain lower at GCC intake in all the alternatives. During June and July, the diversions at Hamilton City are reduced in the NODOS Alternatives for two reasons. First, Sites Reservoir releases for meeting the local demands in the summer months and second, the diversions at Hamilton City are shifted to proposed Delevan pipeline intake during June and July to reduce impacts to the Green Sturgeon habitat in the vicinity of Hamilton City. The second reason does not apply to ALT B and therefore, does not show same level of reduction in diversions at Sacramento River as ALT A and C in the summer months. Note that all the alternatives assumed 3000 cfs capacity for the Hamilton City Intake. Flows exceeding 3000 cfs are caused by the smoothing function used by the USRDOM and are an artifact of the modeling process.

Figure 6.12 shows the probability of exceedance of daily diversion at proposed Delevan Pipeline Intake for NODOS Alternatives A and C. The intake does not exist in the ALT B. ALT C shows slightly higher diversions compared to ALT A. The diversions at the Delevan intake mainly occur in November through March months for filling the Sites Reservoir in all years and also in April and May only during Dry and Critical years. Except for Dry and Critical years, the Delevan Intake and Pipeline is shut down for maintenance. For Alternative A and C this means the Pipeline is also shut down for releases to the river in these months. In June and July the diversions continue to occur at the Delevan Pipeline to deliver water to meet the Colusa Basin demands as the diversions at TCC and GCC are reduced and shifted to Delevan to protect the habitat for Green Sturgeon. These diversions are delivered directly to the local needs and do not contribute to the Sites storage. Note that NODOS Alternatives A and C include the Delevan Intake with a capacity to divert up to 2000 cfs Flows exceeding 2000 cfs are caused by the smoothing function used by USRDOM and are an artifact of the modeling process.

Figure 6.13 shows the probability of exceedance of daily flow from Funks Reservoir to Sacramento River through the proposed Delevan Pipeline for NODOS Alternatives A, B and C. The three Alternatives include 1500 cfs release capacity through the Delevan Pipeline. Majority of releases occur during the summer and fall months when the downstream demands on the Sacramento River are higher. In April and May months, ALT A and ALT C show releases only during Dry and Critical years. ALT B, however, continue to make releases during April and May as the pipeline is not shut down for the maintenance. ALT B also shows higher releases in June and July, as in ALT A and ALT C, the Pipeline is used to divert water shifted from TCC and GCC to meet the Colusa Basin demands. In a few winter months (February and March), releases are made through Delevan Pipeline to enhance the occurrence of X2 at or west of Chipps Island.

Figure 6.14 shows the probability of exceedance of daily flow (fills) from Funks Reservoir to Sites Reservoir for NODOS Alternatives A, B and C. ALT B shows lower fill flows into Sites Reservoir compared to ALT A and C, however, occur for more days. This is due to the reduce diversion capacity in ALT B. ALT A and C, on the other hand, can divert more flows and for shorter periods to fill the Sites Reservoir. Figure 6.15 shows the probability of exceedance of daily flow (releases) from Sites Reservoir to Funks Reservoir for NODOS Alternatives A, B and C. Releases from Sites Reservoir are used for meeting local demands in the Colusa Basin and for the downstream needs along the Sacramento River. The patterns are similar to the Delevan Pipeline releases described above. ALT C can sustain the releases for longer periods because of the higher carry over storage.

Figure 6.16 shows the probability of exceedance of daily fill flows from Tehama Colusa Canal to Sites Reservoir through Funks Reservoir for NODOS Alternatives A, B and C. Figure 6.17 shows the probability of exceedance of daily fill flows from Glenn Colusa Canal to Sites Reservoir through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C. As described above, the diversions for filling Sites Reservoir are higher in ALT B compared to ALT A and ALT C. The diversions for fills generally occur during November through May months in all alternatives. All scenarios assume 2100 cfs for the TC Canal capacity constraint just upstream of Funks Reservoir. Flows exceeding 2100 cfs in TCC are generally caused by the smoothing function used by USRDOM and are an artifact of the modeling process. For GCC, all scenarios assume 1800 cfs as the Canal capacity constraint just upstream of the TRR. However, this is at times reduced in consideration of ongoing GCC winter operations that are not explicitly included in the CALSIM II or USRDOM models. Also, as noted earlier the GCC is shut down for maintenance for three weeks each in January and February months, thus reducing the fill flows.

Figure 6.18shows the probability of exceedance of daily flow (release) from Funks Reservoir to Glenn Colusa Canal through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C. This release occurs to supply irrigation flows in the lower Colusa

Basin by doing so, the GCC diversion from the Sacramento River is reduced. ALT B shows the lowest releases to meet the local demands in the Colusa Basin of the three alternatives. These releases mainly occur during April through November months.

Figure 6.19 shows the probability of exceedance of daily flow from Tehama Colusa Canal to Glenn Colusa Canal through the existing intertie for NODOS Alternatives A, B and C. Figure 6.20 shows the probability of exceedance of combined daily flow in TCC downstream of Funks Reservoir and flow through Williams Outlet for NODOS Alternatives A, B and C. Both the plots show that all the alternatives have similar flows at these three locations. Again, these flows serve the local demands in the Colusa Basin region and mainly exist during April through November months. These flows can be releases from Sites Reservoir as well as diversions at the Sacramento River.

Figure 6.21and 6.22 show the daily Shasta Reservoir storage for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition simulations. All the NODOS Alternatives show higher storage conditions than the No Action Alternative and Existing Condition run as Sites Reservoir is able to meet some of the downstream demands in the former cases that were solely served by Shasta Reservoir in the latter. Also, Shasta storage drawdown is proportional to the Sites storage drawdown in the NODOS Alternatives, during the drier years. The higher storage conditions in Shasta Reservoir under the NODOS Alternatives enable increased coldwater pool volumes and increased flexibility to use the additional storage for improved temperature control and other habitat improvement needs on the Sacramento River.

Figures 6.23 to 6.26 show the daily spills into the Sutter Bypass for NODOS Alternative A, B and C, No Action Alternative and Existing Condition simulations at Ord Ferry, Moulton Weir, Colusa Weir and Tisdale Weirs along the Sacramento River. Spills at Ord Ferry and Moulton Weir under the NODOS Alternatives are similar to the No Action Alternative and Existing Condition run, however, slightly lower at Colusa and Tisdale weirs, due to the increased diversions along the Sacramento River.

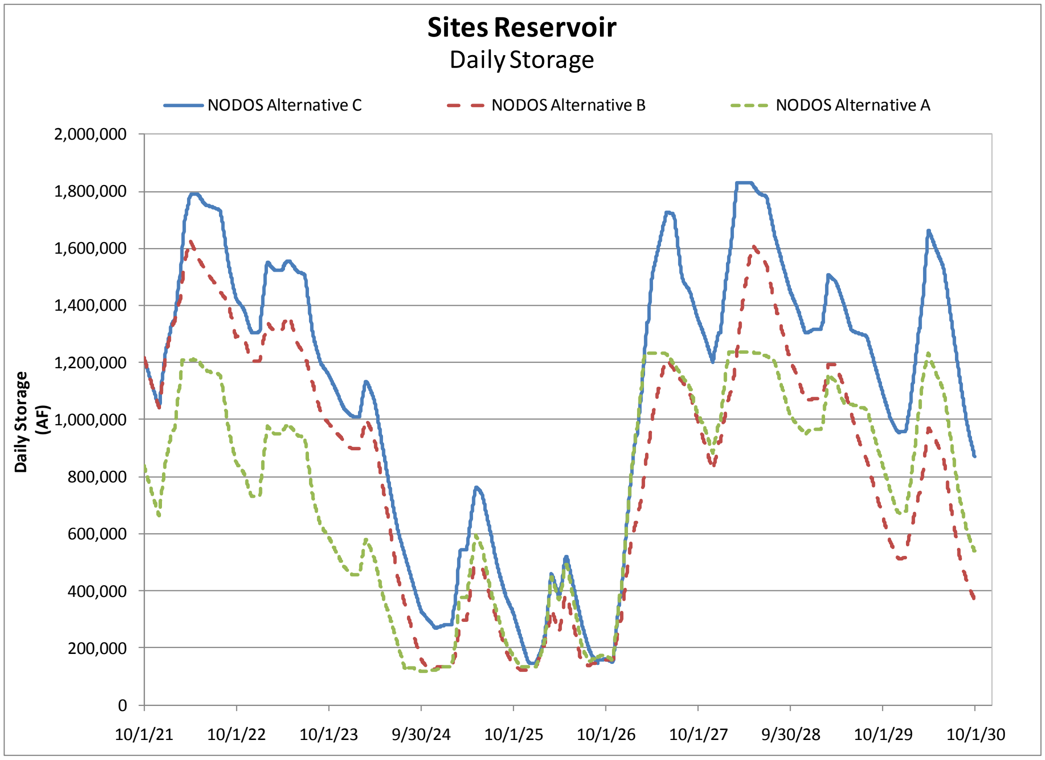


FIGURE 6.6
Daily Sites Reservoir Storage for NODOS Alternatives A, B and C

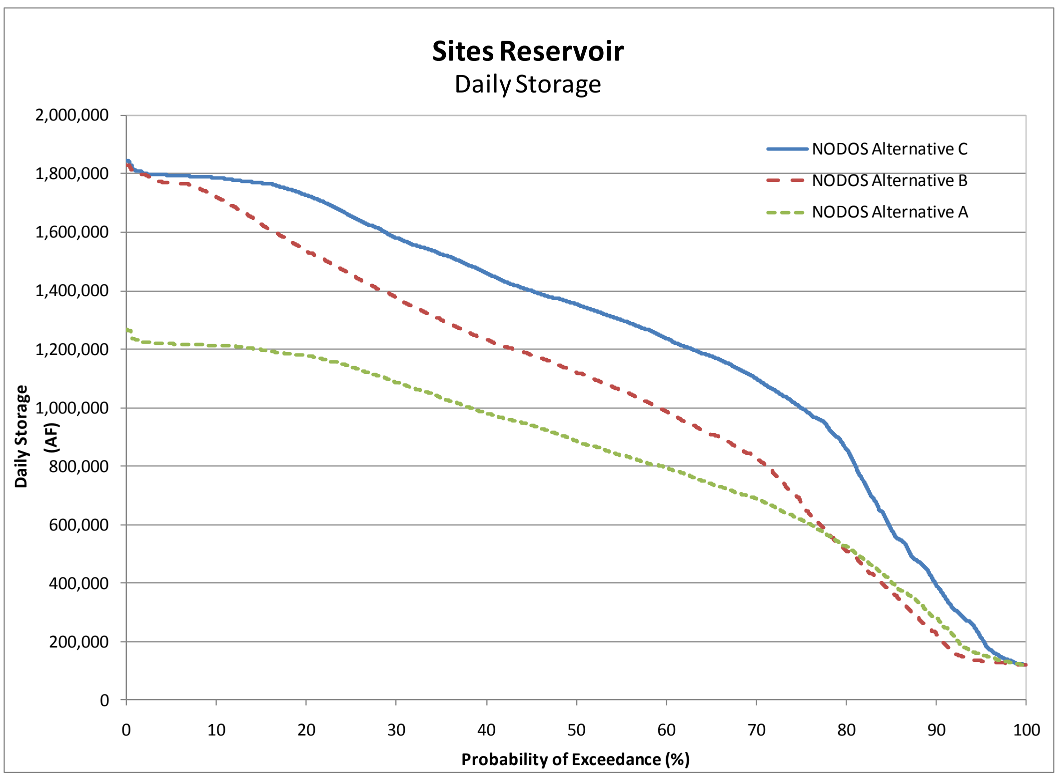


FIGURE 6.7
Probability of Exceedance of Daily Sites Reservoir Storage for NODOS Alternatives A, B and C

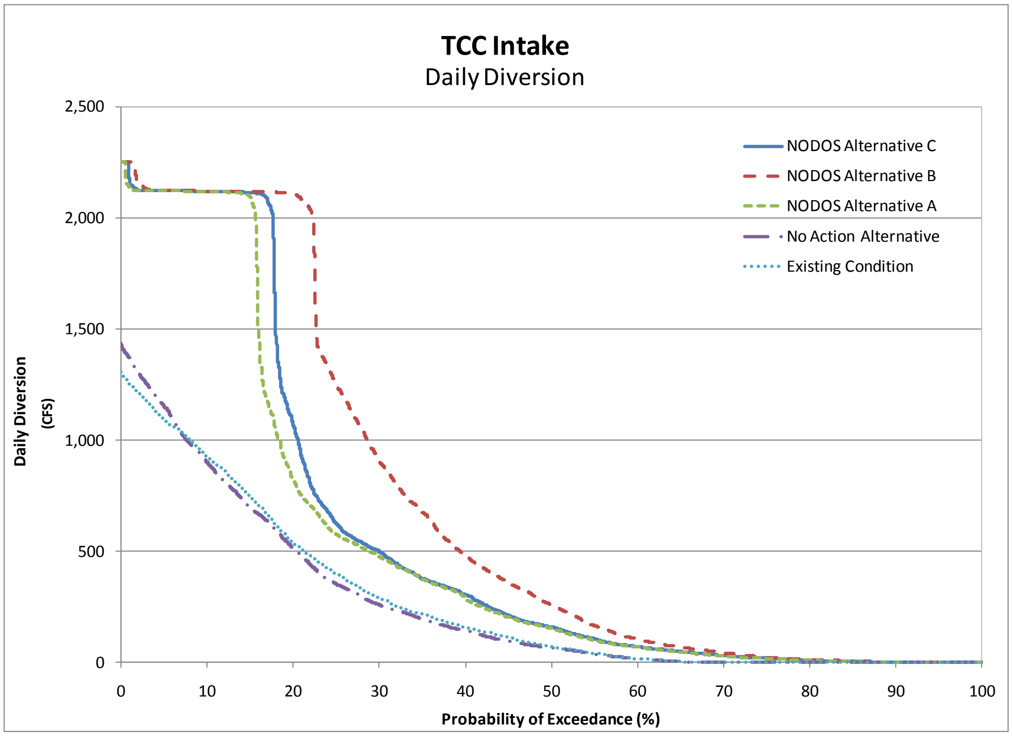


FIGURE 6.8
Probability of Exceedance of Daily Diversion at Tehama Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

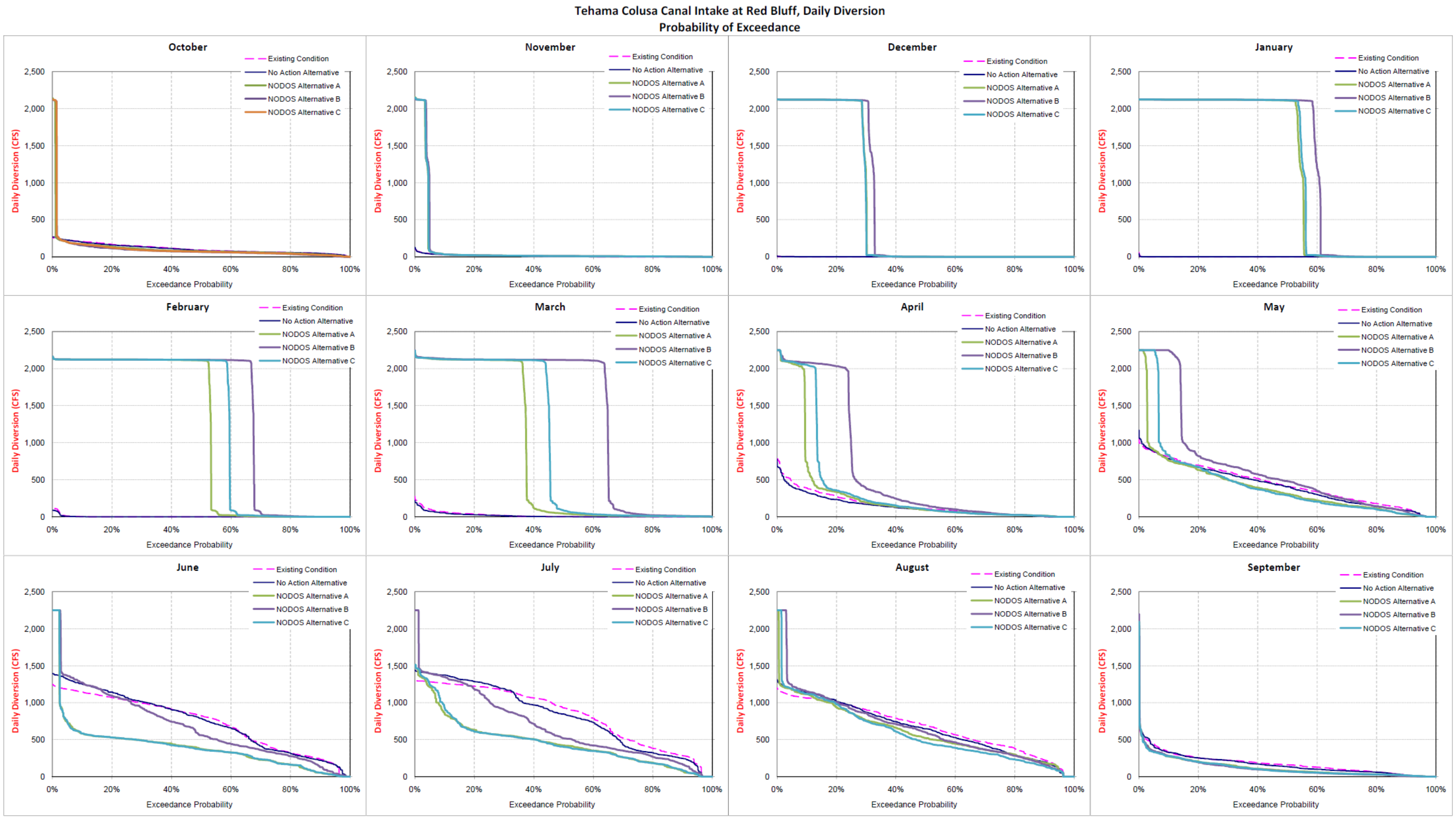


FIGURE 6.9
Probability of Exceedance of Daily Diversion at Tehama Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations by Month

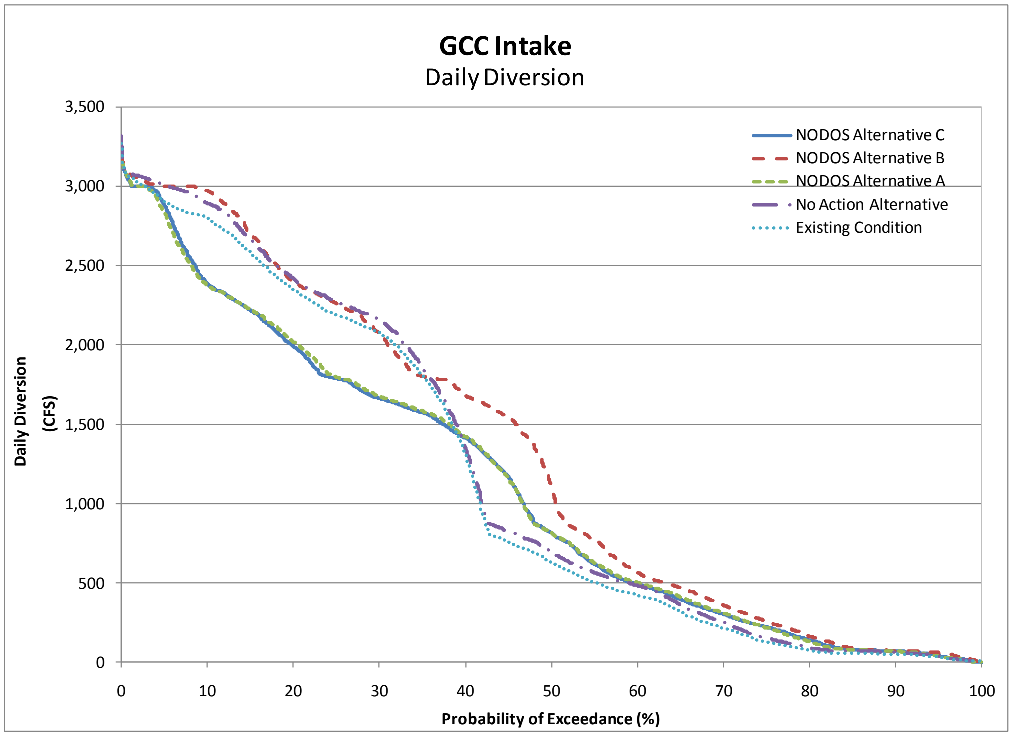


FIGURE 6.10
Probability of Exceedance of Daily Diversion at Glenn Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

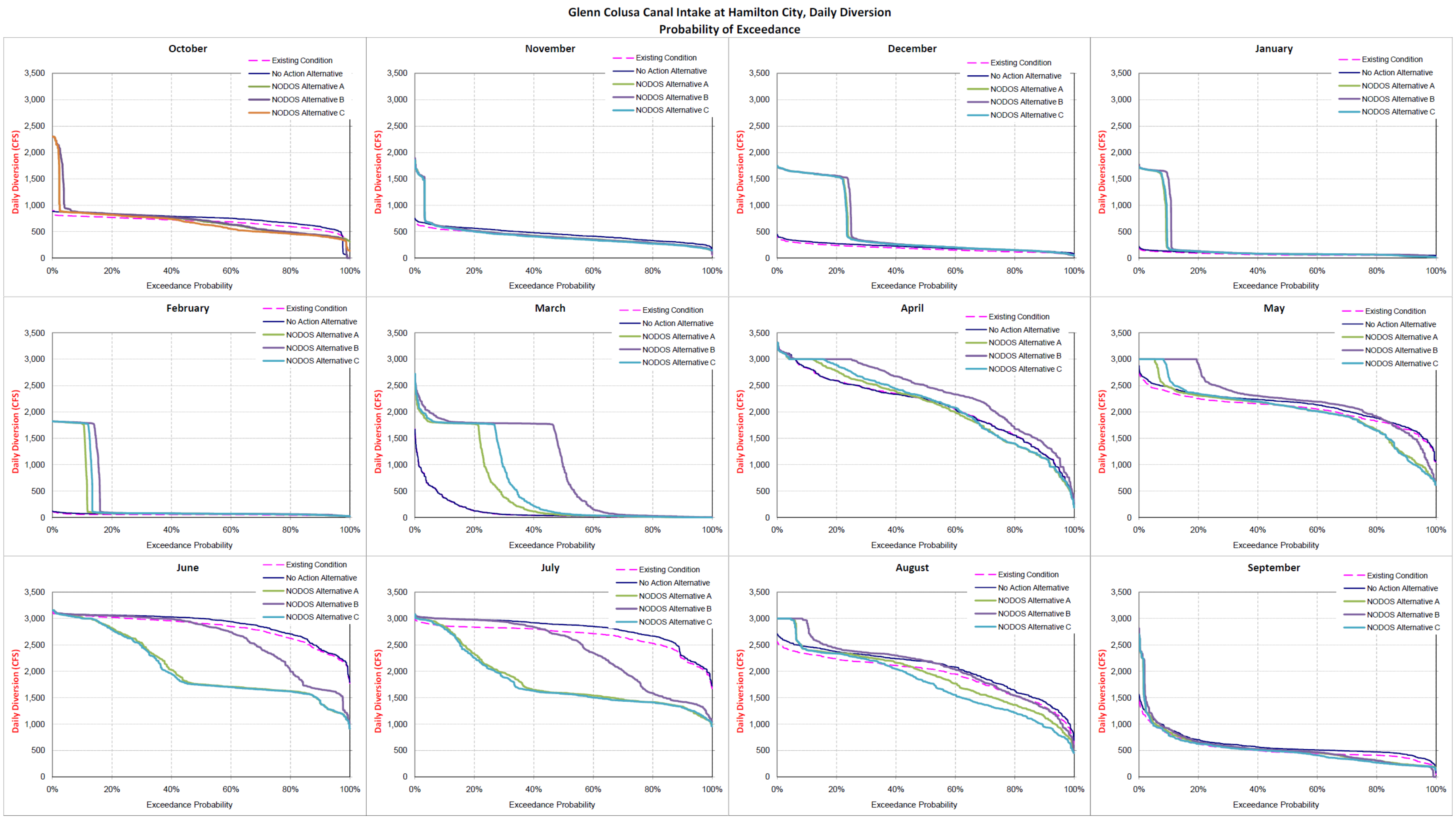


FIGURE 6.11
Probability of Exceedance of Daily Diversion at Glenn Colusa Canal Intake for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations by Month

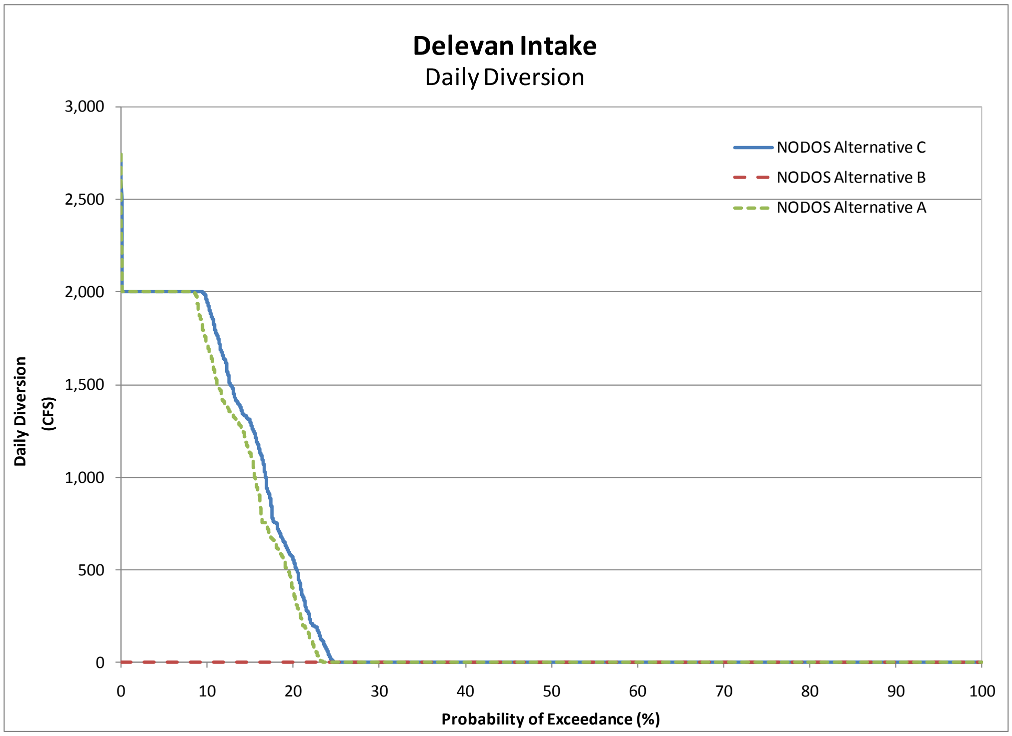


FIGURE 6.12
Probability of Exceedance of Daily Diversion at Proposed Delevan Pipeline Intake for NODOS Alternatives A and C

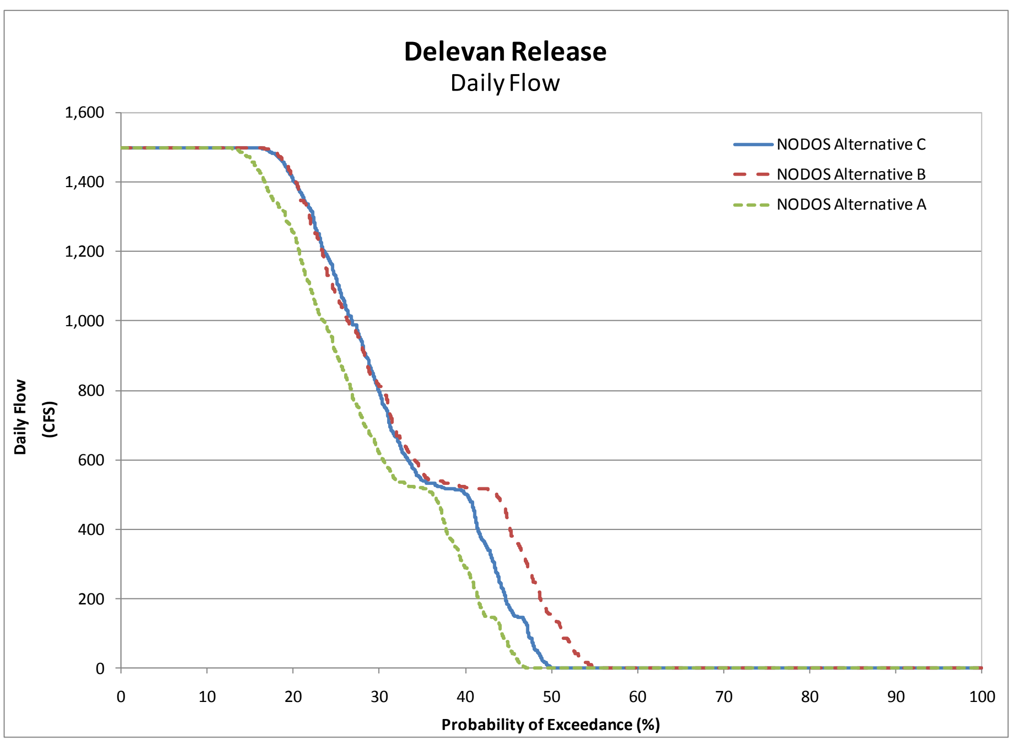


FIGURE 6.13
Probability of Exceedance of Daily Flow from Funks Reservoir to Sacramento River through Proposed Delevan Pipeline for NODOS Alternatives A, B and C

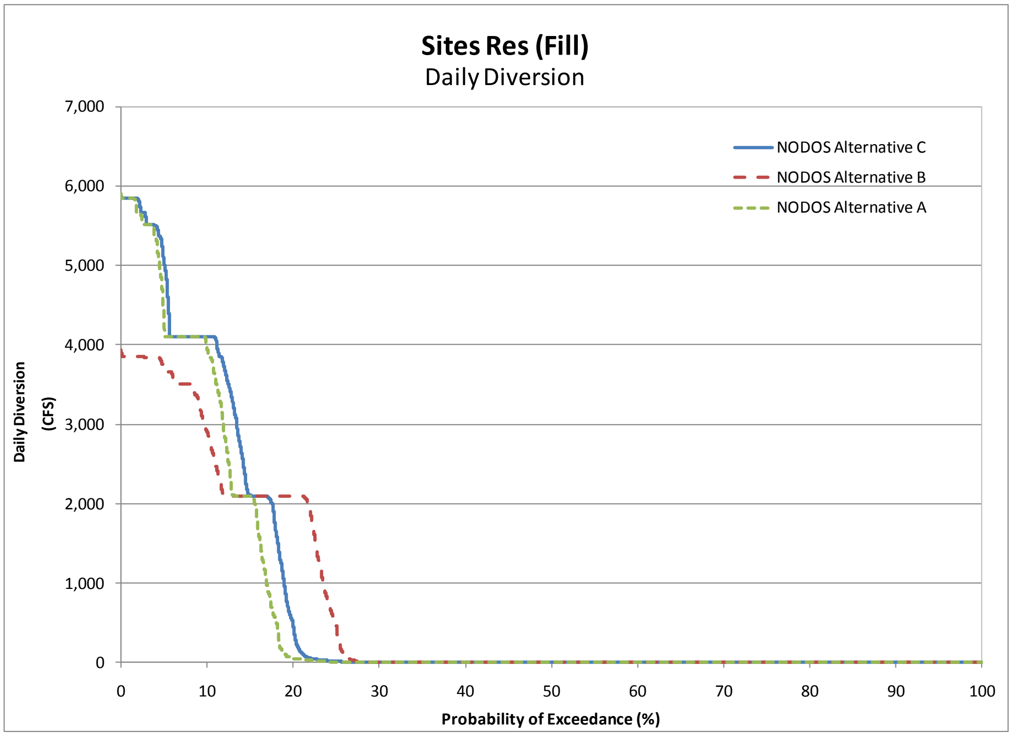


FIGURE 6.14
Probability of Exceedance of Daily Flow from Funks Reservoir to Sites Reservoir for NODOS Alternatives A, B and C

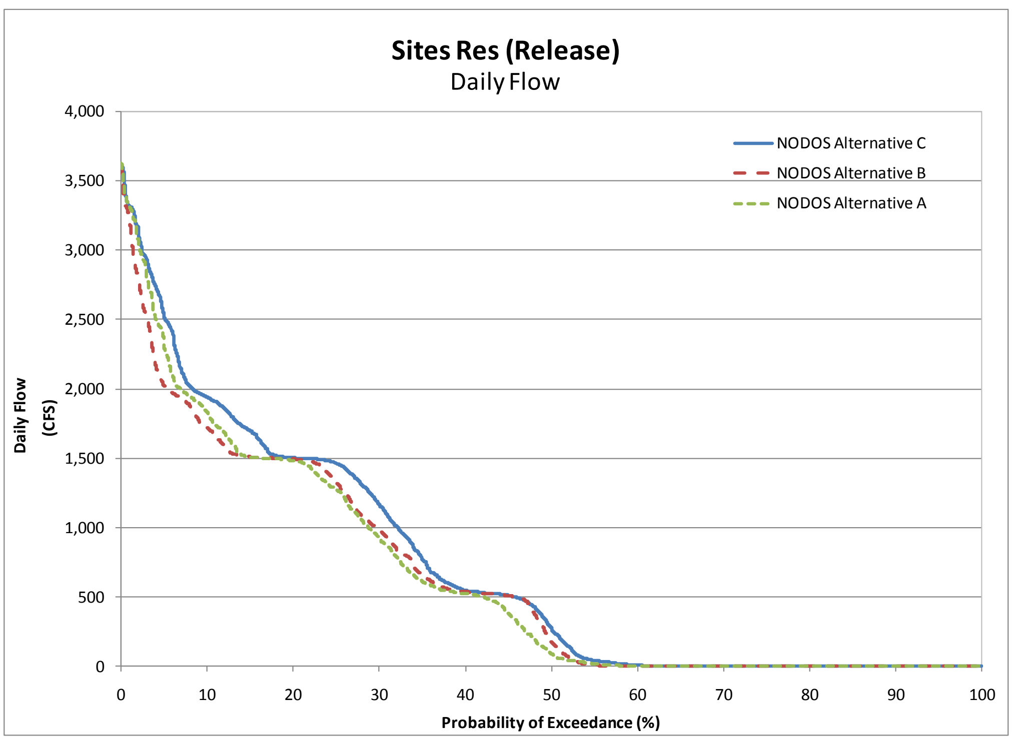


FIGURE 6.15
Probability of Exceedance of Daily Flow from Sites Reservoir to Funks Reservoir for NODOS Alternatives A, B and C

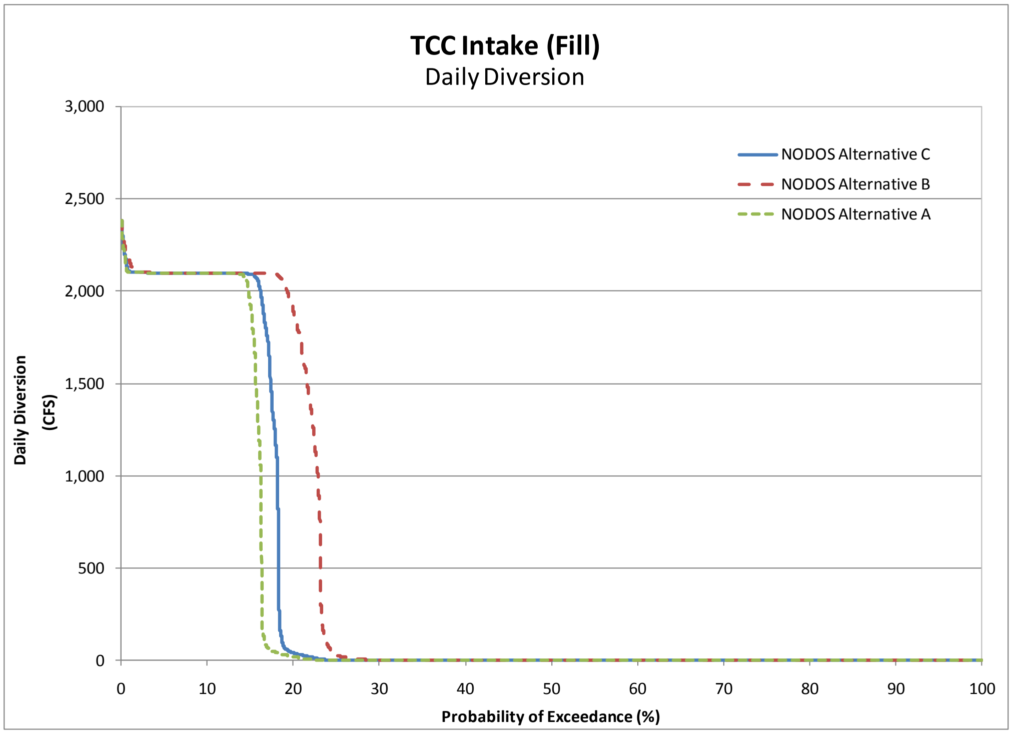


FIGURE 6.16
Probability of Exceedance of Daily Flow from Tehama Colusa Canal to Sites Reservoir through Funks Reservoir for NODOS Alternatives A, B and C

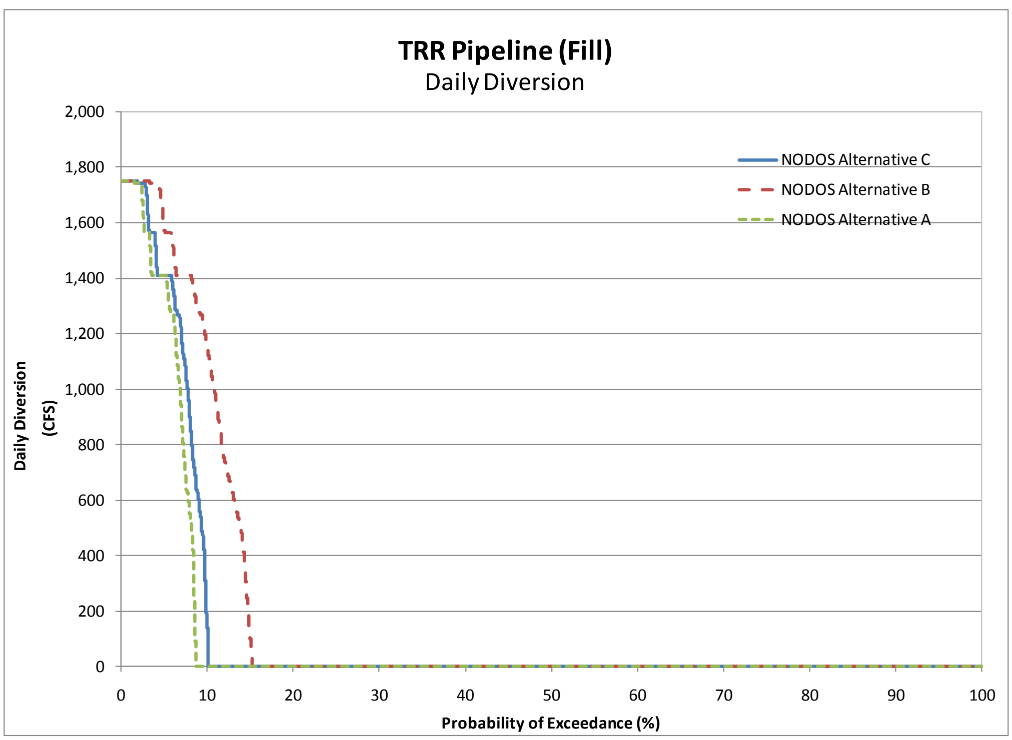


FIGURE 6.17
Probability of Exceedance of Daily Flow from Glenn Colusa Canal to Sites Reservoir through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C

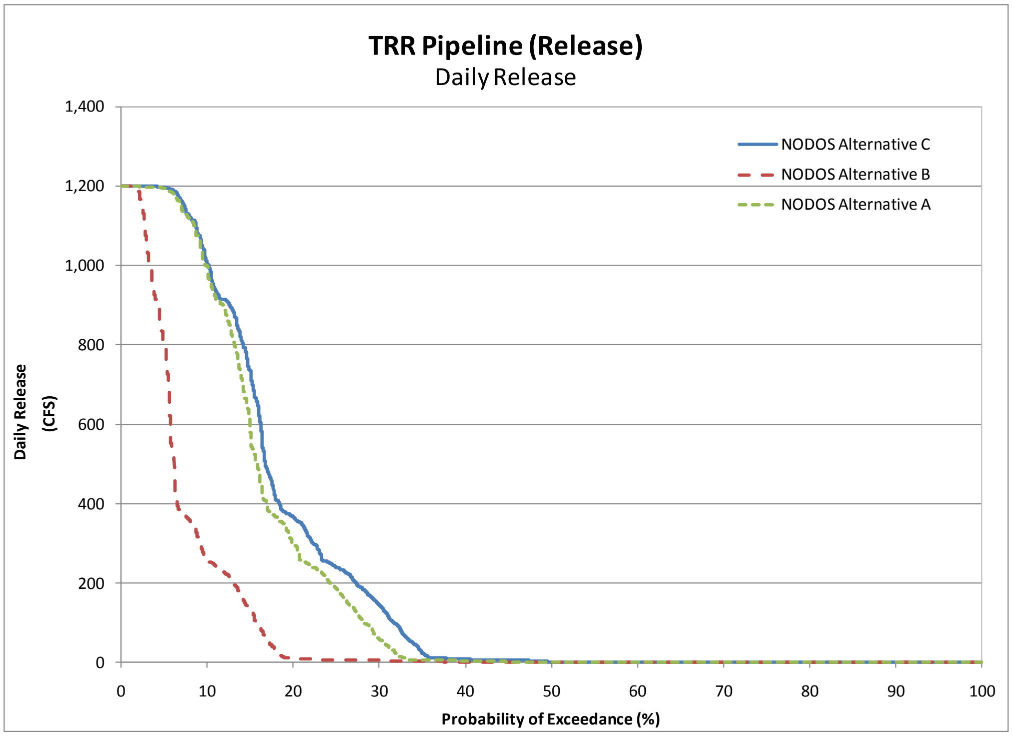


FIGURE 6.18
Probability of Exceedance of Daily Flow from Funks Reservoir to Glenn Colusa Canal through Terminal Regulating Reservoir Pipeline for NODOS Alternatives A, B and C

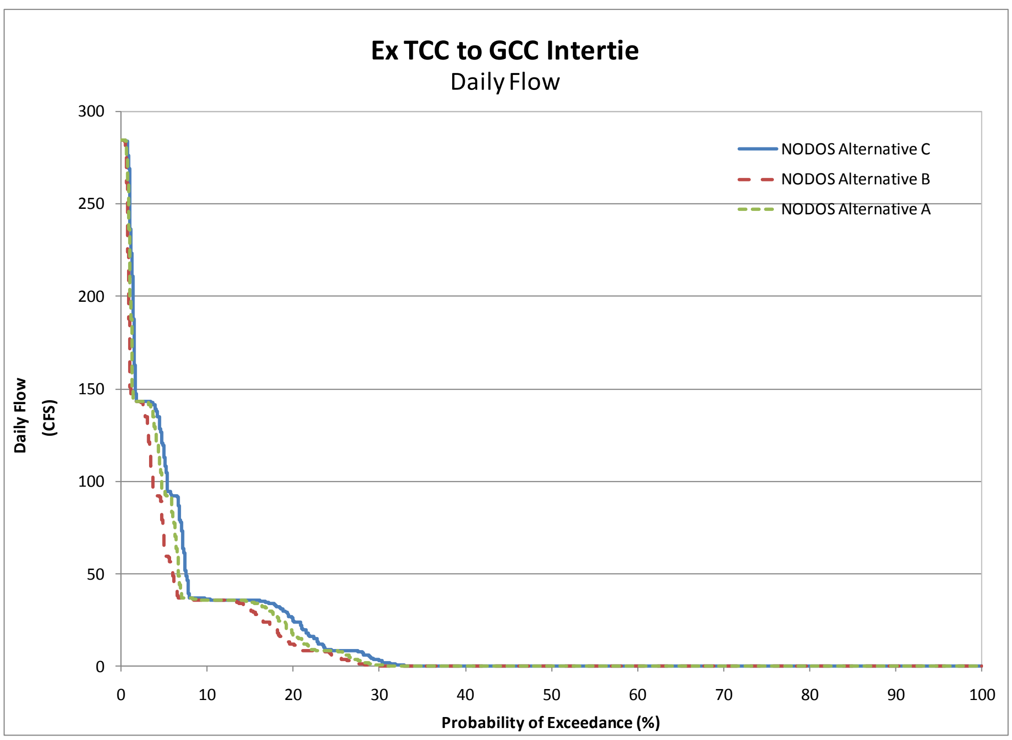


FIGURE 6.19
Probability of Exceedance of Daily Flow from Tehama Colusa Canal to Glenn Colusa Canal through Existing Intertie for NODOS Alternatives A, B and C

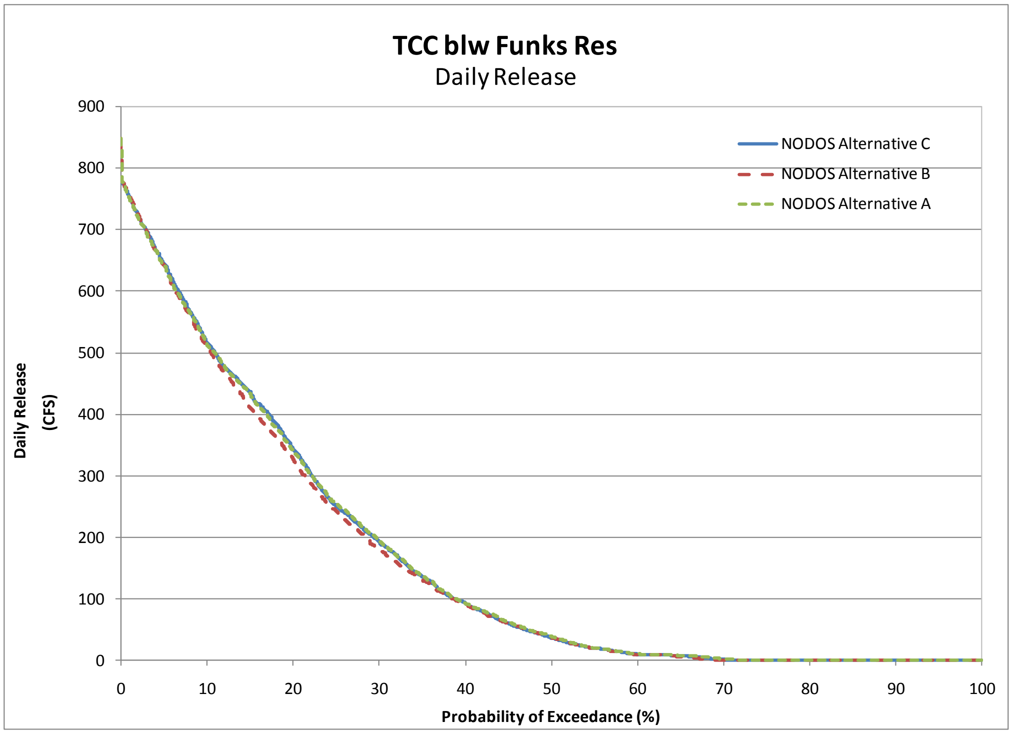


FIGURE 6.20
Probability of Exceedance of Daily Flow in TCC below Funks Reservoir and flow through Williams Outlet for NODOS Alternatives A, B and C

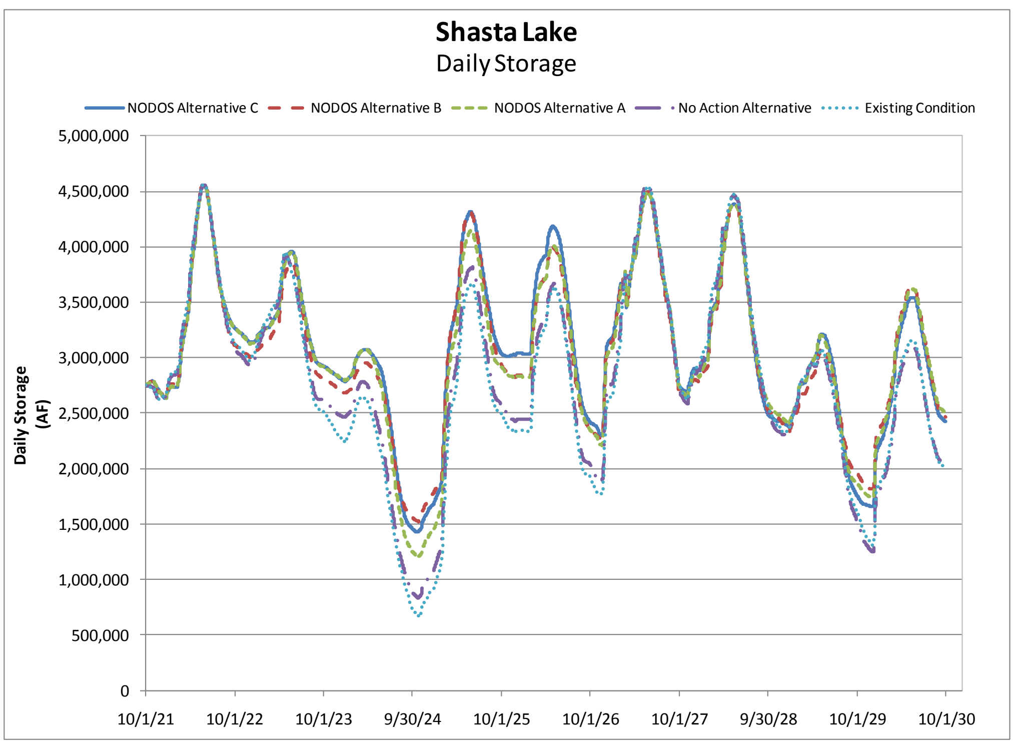


FIGURE 6.21
Daily Shasta Reservoir Storage for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

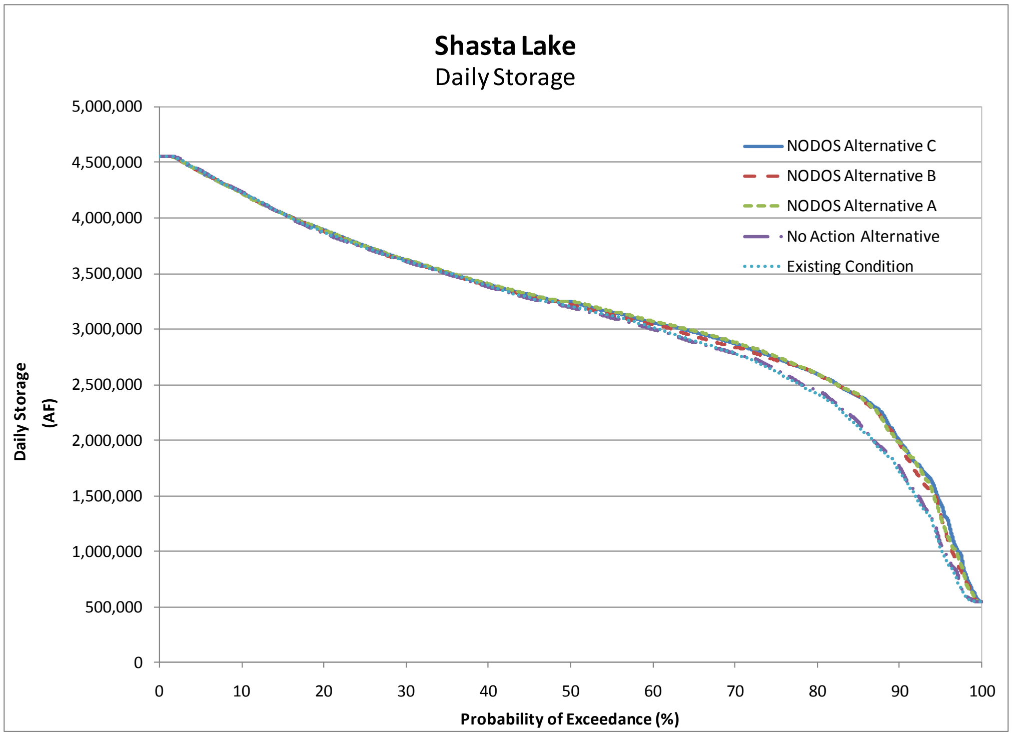


FIGURE 6.22
Probability of Exceedance of Daily Shasta Reservoir Storage for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

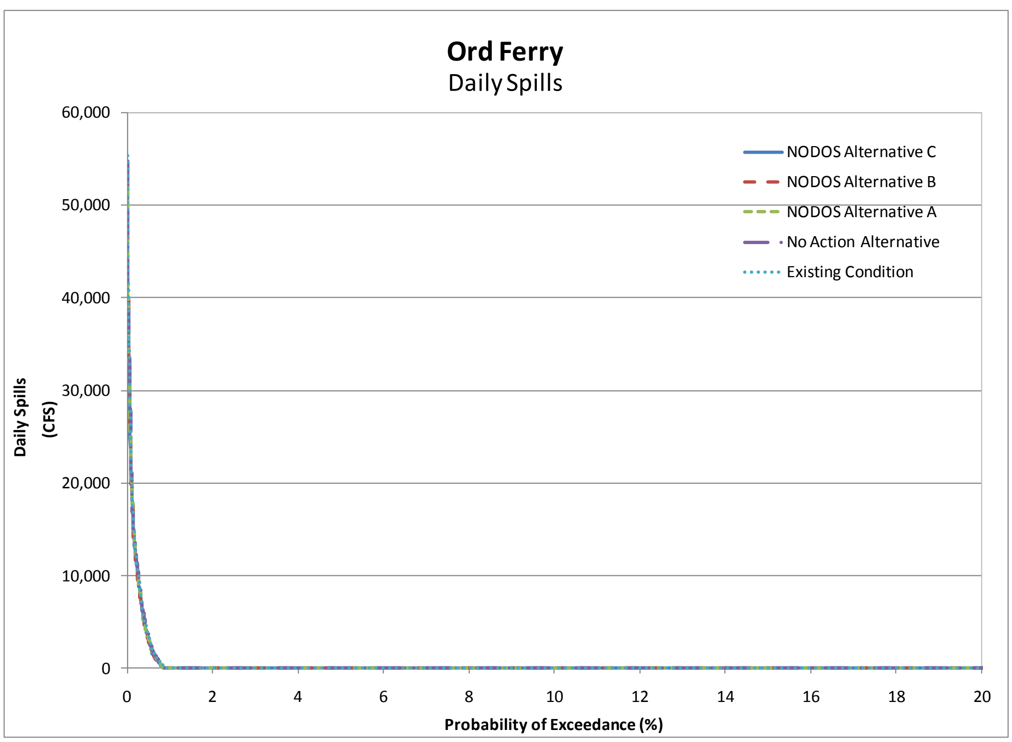


FIGURE 6.23
Probability of Exceedance of Daily Ord Ferry Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

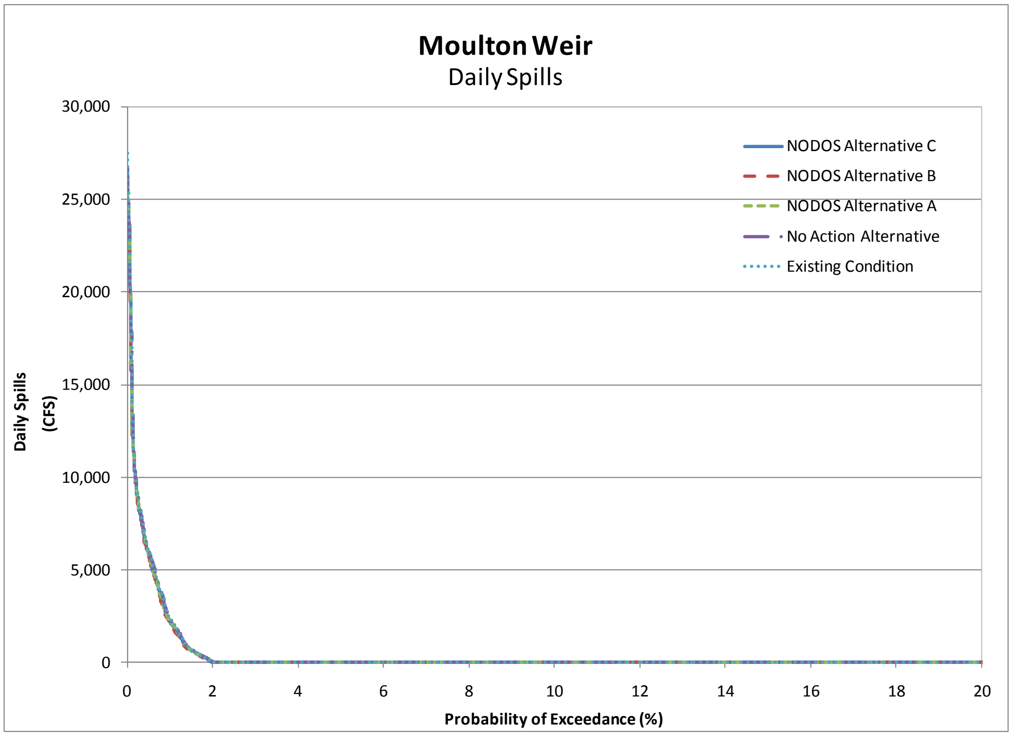


FIGURE 6.24
Probability of Exceedance of Daily Moulton Weir Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

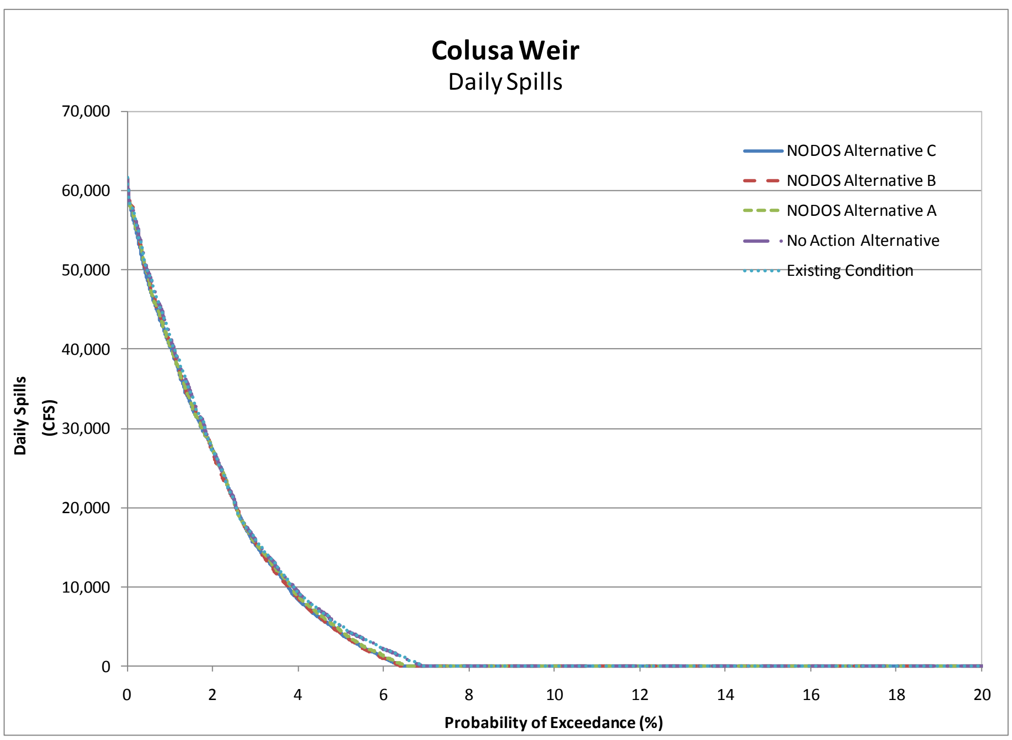


FIGURE 6.25
Probability of Exceedance of Daily Colusa Weir Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

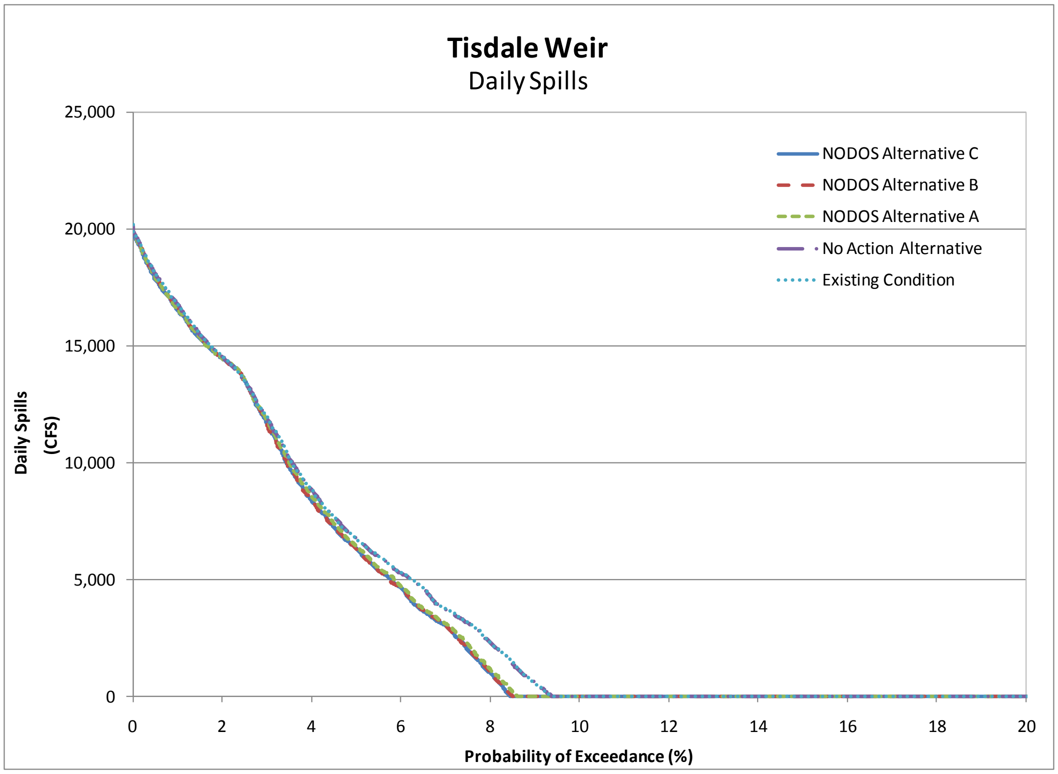


FIGURE 6.26
Probability of Exceedance of Daily Tisdale Weir Spills for NODOS Alternatives A, B and C, No Action Alternative and Existing Condition Simulations

6.10.5 Summary

USRDOM simulates daily flow and storage conditions. It utilizes results from CALSIM II to evaluate the impacts of changing diversion, in-basin use and Delta operations under projected conditions within current or future regulatory and operational regimes. It couples the downstream monthly operational decisions in CALSIM II to a simulation of the associated sub-monthly operational response at Lake Shasta depending on the inflows. It is particularly useful in verifying the CALSIM II simulated river conditions and the availability of excess flows to fill the proposed Sites Reservoir under the capacity and operational constraints of the three intakes at Red Bluff, Hamilton City and Delevan locations. Therefore, USRDOM was successfully used to evaluate the NODOS ADEIRS Alternatives. USRDOM was used to simulate daily flows to inform CALSIM II (monthly) about the potential restrictions on the diversions due to pulse flow conditions. It was also used to evaluate storage conditions in Lake Shasta and Sites Reservoir, flow conditions on a daily-weekly time scale along the Sacramento River from Keswick Dam to Knights Landing and in the Colusa Basin conveyance. The results from USRDOM are used in temperature, biological and flow regime models to evaluate NODOS Alternatives. It was also used to identify sources of flows on a sub-monthly time-step to study likely water quality impacts.

6.10.6 Limitations

In using the USRDOM results for the Alternatives evaluation following limitations should be noted:

The USRDOM calibration for Clear Creek flows below Whiskeytown Dam is significantly weaker than for other flows in the Trinity and Sacramento River systems. It is recommended that the CALSIM II model alone be used as the basis for impact assessment on Clear Creek flows.

In the downscaling of CALSIM II boundary condition flows for use in the USRDOM model simulations, diversions at Red Bluff, Hamilton City and the New Delevan Pipeline (proposed NODOS alternatives) are smoothed from monthly to daily timestep. In this smoothing operation, in order to conserve volume and have a gradual change in diversion flows (as opposed to sharp changes at monthly or other time scale boundaries), there are some days in which diversions are represented in the model at flow rates that exceed the sustainable rate of the physical capacity of these facilities. It is recommended that any assessment of flows or other parameters linked to the peak flow rate of these diversions use monthly average values rather than daily or other sub-monthly average values.

The CALSIM II model is used to establish system operational conditions and the USRDOM model is used to interpret these on a daily time-step; all residuals and inconsistencies between the CALSIM II and USRDOM models accumulate in storage facilities modeled, including Sites Reservoir; the Sites Reservoir storage in the USRDOM model sometimes exceeds physical capacity slightly due to this inconsistency between the models.

SECTION 7

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