DWR-505

CalSim II Simulation of Historical SWP-CVP Operations

Technical Memorandum Report

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List of Abbreviations/Acronyms

ANN	Artificial Neural Network
BO	Biological Opinion
CALFED	State and federal agencies participating in the Bay-Delta Accord
CDFG	California Department of Fish and Game
COA	Coordinated Operations Agreement
CU	Consumptive Use
CUAW	Consumptive Use of Applied Water
CVGSM	Central Valley Groundwater Surface water Model
CVP	Central Valley Project
DSA	Depletion Study Area
DWR	Department of Water Resources
EBMUD	East Bay Municipal Utility District
FERC	Federal Energy Regulatory Commission
FRSA	Feather River Service Area
IEP	Interagency Ecological Program
LOD	Level of Development
NMFS	National Marine Fisheries Service
OCAP	Operating Criteria and Plan
SWP	State Water Project
SWRCB	State Water Resources Control Board
USFWS	United States Fish and Wildlife Service
WQCP	Water Quality Control Plan

CalSim II Historical Operations Study

EXECUTIVE SUMMARY

1 CALSIM II MODEL

CalSim is a generalized water resources planning tool developed jointly by the Department of Water Resources (DWR) and the US Bureau of Reclamation Mid-Pacific Region (Reclamation). CalSim II is the application of the CalSim software to model the State Water Project (SWP), the federal Central Valley Project (CVP) and areas tributary to the Sacramento-San Joaquin Delta (Delta). The primary purpose of the CalSim II model is to evaluate the water supply reliability of the CVP and SWP, 1) at current or future levels of development, 2) with and without various assumed future facilities and, 3) with different modes of facilities operations.

2 OBJECTIVE OF STUDY

The purpose of the *Historical Operations Study* is to evaluate the ability of CalSim II to represent CVP and SWP operations, in general, and the delivery capability of the projects, in particular, through the monthly simulation of recent historical conditions. The Historical Operations Study is part of a larger CalSim II evaluation process. Other components of the evaluation include a survey of the water community to gather their views and opinions of the model, a model peer review by leading academics and practitioners, and a sensitivity analysis on model inputs. It is hoped that this effort, to assess the quality and limitations of CalSim II, will lead to a wider debate about critical model issues, help direct model development in both the near and long term, and eventually lead to greater public confidence and acceptance of the model.

3 STUDY DESCRIPTION

The period of simulation for the Historical Operations Study is water years 1975 to 1998. This 24-year period includes the 1976-77 and 1987-92 droughts, as well as the driest (1977) and the wettest (1983) years on record. The version of CalSim II used for this study is the benchmark study dated 30 September 2002, but with some inputs changed to reflect the historically changing conditions rather than a fixed level of development. Model inflows correspond to the historical flow from gage records, or estimated from a hydrologic mass balance, or stream-flow correlation. Land use-based demands are calculated for annual varying land use, as determined from DWR’s land surveys and county commissioners’ reports. The operational logic has been revised to reflect the changing regulatory environment. The historical regulations have been simplified into three periods:

- October 1974 – September 1992: represented by State Water Resources Control Board (SWRCB) Water Right Decision 1485 (D-1485),

- October 1992 – September 1994: represented by D-1485 and the 1993 National Marine Fisheries Service (NMFS) winter-run chinook salmon biological opinion (minimum carryover storage in Lake Shasta, and temperature related minimum instream flows downstream of Keswick Reservoir),

- October 1994 – September 1998: represented by SWRCB Water Right Decision 1641 (D-1641) and the 1993 winter-run biological opinion.

The Historical Operations Study is limited in geographical scope to a dynamic operation of the Sacramento Valley, the Delta, and the CVP-SWP facilities south of the Delta. Delta inflows from the San Joaquin Valley and East Side streams are constrained to their historical values. Imports from the Trinity River system are similarly constrained.

4 RESULTS AND DISCUSSION

The key performance measures in evaluating CalSim II are considered to be SWP and CVP deliveries, project storage operations, and stream flows. During the study period of water years 1975-1998, SWP demands were historically much lower than current or projected level of demands. Simulation of historically wet years, when the system was not supply constrained, may therefore be a poor indicator of the model's ability to accurately simulate future levels of development. Particular attention is therefore placed on model results during the six-year drought of 1987-1992. Results for four key performance parameters are summarized in the table below. Table 7 in the main report presents results for a more complete list of performance parameters.

The table below shows that simulated SWP Table A and CVP south-of-Delta deliveries during the drought are *less* than historical values. Differences are, however, within 5 percent. Comparison of Sacramento Valley inflow to the Delta (flow at Freeport) is a good measure of how well the Sacramento Valley hydrology is simulated by Calsim II. Simulated Delta inflows are 0.3 percent greater than historical. Comparison of the Net Delta Outflow Index, a measure of how well the Sacramento-San Joaquin Delta is represented by Calsim II, appears favorable. Simulated values are 3.5 percent less than historical during the 1987-1992 period. The table also shows that simulated long-term (1975-1998) average deliveries compare quite well and are within 7 percent of historical values.

Performance Parameter	Dry-period average 1987-1992				Long-term average			
	Simulated	Historical	Difference		Simulated	Historical	Difference	
	taf/yr	taf/yr	taf/yr	%	taf/yr	taf/yr	taf/yr	%
SWP south-of-Delta Table A deliveries	1,930	2,030	-100	-4.9	1,810	1,790	20	1.1
CVP south-of-Delta deliveries	2,230	2,320	-90	-3.9	2,650	2,490	160	6.4
Sacramento Valley inflow to the Delta	9,700	9,670	30	0.3	19,830	19,920	-90	-0.5
Net Delta Outflow Index	5,270	5,090	180	3.5	19,070	19,690	-620	-3.1

The total volume of surface water to be held in storage or routed through the model network is the same as historical. Model inflows to the Delta can deviate from historical due to three reasons: storage regulation, groundwater pumping to supplement surface water diversions, and stream-aquifer interaction.

Differences in Delta inflows are primarily caused by differences in project storage regulation (i.e. Lake Shasta, Lake Oroville and Folsom Lake). Storage operations in CalSim II are driven by two sets of rule curves. The first set of rule curves determines how much of the available project water will be held as carryover storage and how much will be delivered to meet contractors' current-year demands. The second set of rule curves determines when and how-much water will be transferred from north of Delta storage to San Luis Reservoir. These two sets of rule curves are fixed throughout the period of simulation. The rule curves have been determined in prior simulations of CalSim II. They are subjective in nature, but balance the conflicting objectives to maximize long-term average annual deliveries, to maintain water deliveries during the critically dry period 1928-34, and to keep water levels in project reservoirs above minimum levels while meeting minimum flow requirements. Secondly, differences in Delta inflows are due to differences in upstream surface water diversions and return flows. The historical consumptive water demand must be met by the model. Differences in Delta inflow, after accounting for differences in upstream storage regulation, therefore reveal how well CalSim II matches the historical mix of surface water and groundwater to meet demands. Lastly inflows to the Delta are influenced by the stream-aquifer interaction.

For a given south-of-Delta demand and a given Delta inflow, differences in model and historical project exports are indicative of how well the model represents the regulatory operating constraints to which the projects must comply, and how the model simulates storage operations in the San Luis Reservoir.

Conclusions from the study can be framed in the form of answers to some frequently asked questions about CalSim II.

Does Calsim II overestimate the projects' ability to export water from the Delta?

For the supply constrained years 1987-1992 model exports from the Delta average 4,450 taf/yr compared to a historical six-year average of 4,460 taf/yr. This suggests that CalSim II's simulation of the Delta operations is representative of actual historical conditions.

Does CalSim II overestimate the availability of surface water in the Delta by meeting Sacramento Valley in-basin use through excessive groundwater pumping?

The mix of surface water and groundwater used by the model to meet Sacramento Valley consumptive demands depends primarily on project water allocation decisions and levels of minimum groundwater pumping that are specified in the model. Over the 24-year period average annual net groundwater extraction in CalSim II as compared to estimates based on the Central Valley Groundwater Surface water Model (CVGSM) is lower by 378 taf. The average annual net stream inflow from groundwater in CalSim II is 190 taf greater than estimated by the CVGSM for the same period. The combined effect of dynamically modeling groundwater operations in CalSim II (pumping, recharge and stream-aquifer interaction) leads to 188 taf/yr less water being available to the Delta. For the 1987-1992 period the combined effect results in 46 taf/yr additional water being available to the Delta.

How well does CalSim II represent stream flows?

Differences in long-term average annual flows at key stream locations are typically 1.2 percent or less. It is noted that differences are larger for the Sacramento River at the Ord

Ferry gage. At this location a proportion of the water diverted upstream returns downstream so that simulated river flows are sensitive to assumed model water use efficiencies.

How well does Calsim II simulate the Sacramento Valley system?

The net Sacramento Valley accretion is calculated as the Sacramento Valley Delta inflow less releases from Whiskeytown Reservoir, Keswick Reservoir, Lake Oroville and Folsom Lake. The historical 24-year average annual net accretion is 5,950 taf/yr compared with a model value of 5,920 taf/yr.

Do different reservoir operating rules in CalSim II translate into differences in project deliveries?

Simulated month-to-month and year-to-year model results can vary significantly from historical operations. This is primarily due to differences in storage operations. However when averaged over a longer period, model operations (stream flows and deliveries) are very close to historical.

CalSim II Historical Operations Study

1 INTRODUCTION

1.1 CalSim II Model

CalSim is a generalized water resource planning tool developed jointly by the Department of Water Resources (DWR) and the US Bureau of Reclamation Mid-Pacific Region (Reclamation). CalSim II is the application of the CalSim software to model the State Water Project (SWP), the federal Central Valley Project (CVP) and areas tributary to the Sacramento-San Joaquin Delta (Delta). The primary purpose of the CalSim II model is to evaluate the performance of the CVP and SWP systems at current or future levels of development. Comparative analysis of model results can be used to assess the water supply impacts of any proposed expansion of project facilities, changes in regulatory requirements, changes in operating criteria, or many other "what-if" scenarios.

All models have limitations. CalSim II is primarily a mass balance accounting model. Results are dependent upon the quality of the inflow hydrology and the estimated demands. Results also depend on the model operational logic and assigned priorities. Operational decisions must be formalized into mathematical algorithms even when they are in reality subjective in nature. Other limitations are imposed by the spatial and temporal resolution of the model. This report describes the Historical Operations Study undertaken by DWR's Bay-Delta Office as part of a comprehensive evaluation of CalSim II.

1.2 Objective of Study

CalSim II is central to CVP and SWP planning and management, and to many other federal, state, regional and local water related planning activities. The model is either currently being used or will be used to support analysis for the California Water Plan Update, CALFED's Integrated Storage Investigations and Conveyance Programs, South Delta Improvement Program (SDIP), development of the CVP Operating Criteria and Plan (OCAP) and the FERC relicensing of Oroville. Given the wide scope and important nature of these planning activities, accurate estimates of future water supply reliability are crucial. However model estimates of future project exports from the Delta have proved controversial. The purpose of the Historical Operations Study is to evaluate the ability of CalSim II to estimate the delivery capability of the CVP and SWP systems through the simulation of recent historical conditions. Model results should be consistent with past performance or reasons for differences clearly identified. The Historical Operations Study is part of a larger CalSim II evaluation process. Other components of the evaluation include a survey of the water community to gather their views and opinions on CalSim II, a model peer review by leading academics and practitioners, and a model sensitivity analysis. It is hoped that this effort, to assess the quality and limitations of CalSim II, will lead to a wider debate about critical model issues, help direct model development in both the near and long term, and eventually lead to greater public confidence and acceptance of the model.

1.3 Traditional Model Calibration and Verification

The traditional model calibration and verification process is difficult to apply to planning models, such as CalSim II, that predict operations and water supplies for a fixed current or future level of land use. Continuing development of new supplies, changes in demand and changes to regulatory requirements have resulted in considerable changes to the management of the CVP and SWP over the last 35 years. Projected operations to meet future demands are often predicated on future storage and conveyance facilities and are necessarily different from historical operations. Planning models cannot capture the details of historical operations that are influenced by many short-term events. Instead they aim to represent *long-term* system performance.

1.4 Previous Model Evaluation

DWR's previous planning model, DWRSIM was used by DWR for nearly 20 years. In 1992 as part of an evaluation of DWRSIM, historical Delta inflows were compared to those generated by the model. A specific operations study for normalized 1995 conditions was compared with historical flows for the period 1922-1991. Due to land use changes and the construction of storage and conveyance facilities for the CVP-SWP there were, as expected, substantial differences between model and historical Delta inflows. However, for the period 1982-1991 the average annual inflow differed by only 0.05 percent.

The first application of the CalSim software to the CVP-SWP system was named CalSim I. This model successfully mimicked DWRSIM and was regarded as 'proof of concept' of the new model engine (a mixed integer linear programming solver). CalSim II incorporates many improvements over CalSim I. These include revised hydrology, dynamic groundwater operation, revised project and non-project demands, dynamic allocation of deficiencies on project deliveries and improved modeling of flow-salinity relationships in the Delta.

2 OVERVIEW OF CALSIM II

2.1 Documentation

The following sections give an overview of the main components of the CalSim II model. These components include the inflow hydrology, agricultural and urban demands, contract entitlements, delivery allocation logic, and Delta operational constraints. For a more detailed description of modeling assumptions and procedures the reader is referred to the report prepared on the benchmark studies, dated September 30, 2002, and available from the DWR modeling home page (http://modeling.water.ca.gov). The September 30 version of the benchmark study is an update of the May 17, 2002, version that was used as a basis for the simulation runs in "The State Water Project Delivery Reliability Report," released in 2002.

2.2 Period of Simulation

Typically CalSim II simulates operation of the CVP-SWP system for a 73-year period using a monthly time-step. The model assumes that facilities, land use, water supply contracts and regulatory requirements are constant over this period, representing a fixed level of development (e.g. 2001, 2020 or 2030). The historical flow record October 1921 - September 1994, adjusted for the influence of land use change and upstream flow regulation, is used to represent the possible range of water supply conditions. Implicitly it is assumed that the past is a good indicator of future hydrologic conditions.

2.3 Representation of Surface Water System

CalSim II represents all areas that contribute flow to the Delta. The geographical coverage includes: the Sacramento River Valley, the San Joaquin River Valley, the Sacramento-San Joaquin Delta, the Upper Trinity River, the CVP and SWP deliveries to the Tulare Basin, and the SWP deliveries to the central and south coast regions. A network of nodes and arcs are used to represent this water resource system. Nodes, or control points, represent facilities or key points within the system being modeled. Storage nodes represent surface reservoirs or groundwater basins. Non-storage nodes represent flow junctions within the system such as a stream confluence or a diversion location. Arcs connect nodes and represent stream and canal reaches, pipelines, tunnels or other conveyance facilities. They also may represent an aggregation of flow components, e.g. total stream diversions within a region. As far as possible, the CalSim II network is physically based so that nodes and arcs have physical counterparts. Figure 1 shows the location of the principal CVP and SWP facilities. Figure 2 shows the geographical area represented by CalSim II. Figure 3 shows the system network used for the Historical Operations Study (this is a modified version of the standard CalSim II network ; some portions of the standard network schematic that represent river systems for which fixed historical input is used have been eliminated).

2.4 Representation of Groundwater System

The current representation of groundwater in CalSim II is only a first step towards developing a fully integrated groundwater surface water model. DWR is continuing development of the Central Valley Groundwater Surface water Model (CVGSM) with the long-term goal of dynamically linking this model to CalSim II. The current groundwater implementation in CalSim II is only used to calculate the stream-aquifer interaction.

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

2.5 Depletion Study Areas

In order to develop the input hydrology for CalSim II and its predecessor DWRSIM, DWR developed a set of depletion study areas (DSAs) that divide the Central Valley and the surrounding watersheds into 37 regions. The boundaries were chosen to facilitate the calculation of a water balance. Typically, their delineation follows drainage lines and watershed boundaries in the foothills and a combination of drainage and water service areas within the Central Valley floor. The lowest elevation of the principal stream in a DSA is called the “outflow point.” These points usually correspond to the location of stream gages where the historical flow is known. The DSAs are depicted in Figure 4. The DSA defines the spatial resolution of the CalSim II model in the Sacramento Valley. Water supplies and the majority of the demands are aggregated by DSA. Seven DSAs represent the Sacramento Valley floor; two additional DSAs represent the Delta.

2.6 Inflow Hydrology

2.6.1 General

All inflows to the model are preprocessed and are input as fixed monthly time series. Surface water inflows can be categorized as rim flows or as valley floor accretions. The rim flows represent streams that cross the boundary of the physical system being modeled and typically are inflows to the major foothill reservoirs or inflows from minor unregulated streams. Valley floor accretions represent surface water that originates within the boundary of the region being modeled from direct runoff. Preprocessed groundwater inflows include recharge from precipitation and subsurface groundwater inflow from the surrounding foothills.

2.6.2 Accretions

Accretions are calculated for each of the seven DSAs in the Sacramento Valley floor. They represent direct runoff from precipitation plus any inflow from rim basins or canal/stream imports that are not explicitly represented elsewhere in the model. The resulting accretions represent an aggregate flow and cannot be associated with any particular stream.

The historical accretions are calculated as the closure term of a hydrologic mass balance performed for each DSA. The historical depletion of surface water and groundwater supplies within the developed area is calculated using DWR's Consumptive Use (CU) model based on historical estimates of land use. Historical groundwater pumping, recharge and stream gains are taken from the historical run of CVGSM. Historical imports, exports, stream inflows and outflows are based on historical gage data.

2.6.3 Land Use Change Adjustment

To represent a fixed level of development, historical surface water inflows must be adjusted to account for the impact of land use change. Urbanization results in greater storm runoff. Clearing of native vegetation reduces the depletion of precipitation through evapotranspiration stored as soil moisture. The effects of land use change on direct runoff and groundwater recharge are calculated by simulating soil moisture conditions over the 73-year historical period. Changes in the consumptive use of precipitation are added (or subtracted) to the historical inflows/accretions.

2.7 Demands

2.7.1 General

Demands are preprocessed independent of CalSim II and may vary according to the specified level of development (e.g. 2001, 2020) and according to hydrologic conditions. They are typically input to the model as a monthly time series. Demands are classified as CVP project, SWP project, local project or non-project. CVP and SWP demands are separated into different classes based on contract type.

2.7.2 Agricultural Demands

Demands in the Sacramento River Basin (including the Feather and American River basins) and Delta are determined based on land use and vary by month and year according to hydrologic conditions. Land use-based demands are calculated using the CU model. The model simulates soil moisture conditions for 13 different crop types over the historical period. Irrigation demand is triggered when soil moisture falls below a specified minimum. The CU model calculates the crop consumptive use of applied water. The consumptive use is subsequently multiplied by water use efficiency factors to obtain a regional water requirement to be met from stream diversions or groundwater pumping. Agricultural demands in the Delta are represented more simply as an overall mass balance between precipitation and crop evapotranspiration.

CVP and SWP agricultural demands south of the Delta are based on contract amounts. CVP demands south of the Delta are assumed fixed at maximum contract amount and do not vary year to year. SWP agricultural demands in the San Joaquin Valley are capped to the full Table A amount, but are reduced in wetter years using an index developed from annual Kern River inflows to Lake Isabella. (Note: "Table A" refers to an exhibit to the water supply contracts between SWP contractors and DWR).

2.7.3 M&I Demands

Sacramento Valley M&I demands are not fully addressed in CalSim II. In general, indoor urban water use is considered non-consumptive and is ignored by the model. Outdoor urban water use is treated as an irrigation demand and is combined with the agricultural demands. M&I diversions, although not entirely consumptive, can have a large influence on reservoir operations. Both indoor and outdoor M&I surface water diversions have therefore been included in CalSim II for the American and Lower Sacramento River as they partially determine the operation of Folsom Lake. Outdoor urban demand is calculated by the CU model. The irrigated area is a fixed fraction of the total urban area as measured by DWR in land use surveys.

CVP and SWP south of Delta M&I demands are contract based. CVP demands are set to maximum contract amount and do not vary. SWP M&I demands south of the Delta are split into Metropolitan Water District of Southern California (MWDSC) and others. MWDSC demands are defined by the agency through a process of iteration between CalSim II and MWDSC's integrated resource planning simulation (IRPSIM) model, and vary from year to year. Other SWP M&I contractors' demands are fixed at their full Table A amount.

2.7.4 Water Use Efficiency in Sacramento Valley

Part of the water supply is consumed through crop evapotranspiration, part returns to the surface or groundwater system, and part is depleted or lost through canal evaporation and use by riparian vegetation. In CalSim II these non-recoverable losses are assumed to be 10 to15 percent of the crop consumptive use of applied water. Demands are input to CalSim II in the form of a regional diversion/pumping requirement to be met from either surface water or groundwater. Conveyance losses are not represented explicitly; efficiency and non-recoverable loss factors are used to determine the portion of the supply that will return to the system as surface return flow or as deep percolation to groundwater. Efficiency factors may vary by month and by year. Table 2 expresses the regional water use efficiency as the long-term average ratio between crop consumptive use of applied water and the diversion/pumping requirement. Where indoor urban water use is explicitly modeled, it is assumed that there is a 100 percent return flow to the surface water system.

2.7.5 Project/Non-Project Split

The CU model is used to estimate the aggregate demands for each DSA. Demands are subsequently disaggregated in CalSim II into project demands and non-project demands. Project demands are subject to reduced water allocations based on CVP and SWP contract provisions, while non-project demands are satisfied from sources other than project storage and project conveyance facilities and are reduced as a function of water availability in the absence of project operations. For each DSA, project demands are calculated as a fixed percentage of the total land use-based demand. The percentages are given in Table 2. The split between project and non-project demands was determined by comparing project acreage within each DSA to the total crop acreage within the DSA. The split is based on cropped acreage weighted by unit crop-specific CUAW values.

2.8 Contract Entitlements

2.8.1 Representation

Arcs representing surface water diversions in the Sacramento Valley are composed of a set of sub-arcs, one for each contractor type within the DSA (south of the Delta arcs represent a single contractor type) and one representing non-project diversions. An upper bound is placed on the flow through the project contractor arcs, which is the minimum of the land use-based demand or the maximum contract amount less any imposed deficiencies. Demand for individual project contractor types is calculated assuming that the land use-based demand is in proportion to the contract entitlement.

2.8.2 CVP Contractors

CVP contracts in the Sacramento Valley, excluding the American River basin, consist of settlement contracts, agricultural water service contracts, urban water service contracts, and refuge requirements. CVP contracts south of the Delta consist of exchange contracts, agricultural service contracts, and M&I service contracts. Table 3 lists the maximum contract amounts for each contract category.

If the Shasta index is critical then deliveries to the settlement contractors, exchange contractors, and refuges are reduced to 75 percent of contract amount. Allocation to these contractors is not affected by water availability, and they receive full allocation in all non-Shasta critical years. Water allocation to agricultural service contractors and M&I service contractors are accomplished using a tiered allocation. In the first tier, agricultural service contractors are reduced to 75 percent of contract amount while M&I allocations are not reduced. In the second tier, both M&I and agricultural service contractors are reduced by equal percent of allocation until M&I is reduced to 75 percent and agricultural service is reduced to 50 percent. In the third tier, M&I remains at 75 percent and agricultural service contractors are reduced to 25 percent of contract. In the fourth and final tier, M&I and agricultural service contractors are reduced on an equal percentage basis until M&I reaches 50 percent and agricultural service contractors are reduced to 0 percent.

2.8.3 SWP Contractors

Twenty-nine agencies have contracts for a long-term water supply from the SWP totaling about 4.2 million acre-feet annually, of which about 4.1 million acre-feet are for contracting agencies with service areas south of the Sacramento-San Joaquin Delta. About 70 percent of this amount is the contract entitlement for urban users and the remaining 30 percent for agricultural users. CalSim II allocations are set per the Monterey Agreement criteria, which imposes any deficiencies equally between agricultural and M&I requests as a percentage of the Table A amounts.

SWP demands north of the Delta are located entirely on the Feather River. Of the three Feather River area contractors, only County of Butte and City of Yuba City are represented in CalSim II; Plumas County FCWCD is located upstream and outside of the modeled area. The SWP has additional obligations to meet water demands of Feather River senior water right holders. The Feather River settlement contractors are entitled to approximately 1.0 maf/yr diversion from the Feather River. Typically their contracts with DWR specify that deliveries may be reduced during low flow conditions to Lake Oroville by no more than 50 percent in any one year, no more than 100 percent in any seven consecutive years, and not more than the reduction imposed on SWP contractors. However certain amounts of entitlement are not subject to deficiencies.

2.8.4 American River

Urban demands on the lower American River are based on the Sacramento Water Forum Agreement. In order to achieve the correct operation of Folsom Lake and the American River, CalSim II represents the full urban demand, both indoor and outdoor (i.e. both non-consumptive and consumptive).

2.9 Operational Priorities

Simulation models have traditionally required the user to formulate detailed operating rules that guide system operation in all eventualities. The operation rules are gradually adjusted based on model results until the desired outcome is achieved. Defining the initial set of operating rules is problematic and their subsequent adjustment time consuming. CalSim's use of a mixed integer linear programming solver allows the separation of system objectives from the details of how to achieve them. Objectives are implemented using a mix of weights and constraints. User specified weights represent priorities for allocating flow and storage. The weights are relative and indicate the order in which goals are to be attained. The relative size of the assigned weights requires that high-order priorities must be optimized before lower-order goals can be considered. The trading of a small degradation of a high-order priority for a large improvement in a low-order priority is effectively prevented. The use of single-step optimization reduces, rather than obviates, the need for operating rules. Strategic rules are still required in CalSim II to guide decisions with long-term consequences, e.g. target carryover storage, and transfer of project storage from north to south of the Delta.

2.10 Project Allocation Logic

Allocation of CVP and SWP water for a given year is based primarily on four variables: forecasted inflows, the volume of water in storage, projected carryover storage requirements, and in-basin and Delta regulatory requirements. CalSim II determines deliveries to CVP and SWP contractors based on runoff forecast information and standardized rule curves. Updates of delivery levels occur monthly from January 1 through May 1 for the SWP and March 1 through May 1 for the CVP as water supply forecasts become more reliable. SWP deliveries are determined based upon spring storage conditions at Lake Oroville and the SWP portion of San Luis Reservoir, forecasted runoff available to the SWP, and carryover storage targets. The CVP deliveries are similarly determined using water supply parameters, but for south-of-Delta deliveries additional conveyance capacity constraints are considered.

2.11 Non-Project Allocation Logic

Non-project demands are associated with riparian water rights, ground water pumping, or private storage projects. Project demands may be met from storage releases from CVP and SWP reservoirs, but no additional releases are made to satisfy non-project demands. CalSim II keeps separate track of stream flows unimpaired by project storage operations and diversions. Available water for non-project demand includes return flows from non-project diversions.

2.12 Groundwater Pumping Logic

Within the Sacramento Valley demand is met from a mix of surface water and groundwater. Farmers and urban municipalities may have access to either one or both of these supplies. Minimum groundwater pumping is specified in CalSim II to represent those demands that only have access to groundwater. The CalSim II operation logic is written so that demands are first met by groundwater pumping, up to the minimum specified volume. It is subsequently met by surface water diversions up to the contract amount for project demands and up to its availability for non-project demands. Any unmet demand is met by additional groundwater pumping so no shortages occur. Minimum groundwater pumping volumes are based on the historical Central Valley Groundwater Surface water Model (CVGSM) run. The minimum groundwater pumping is split into project and non-project groundwater pumping using the project non-project split described earlier.

2.13 Flow-Salinity Relationships in the Delta

The State Water Resources Control Board (SWRCB) specifies water quality standards for the Delta. Currently the CVP and SWP share the obligation to meet these standards as defined by the Coordinated Operation Agreement. Salinity standards must be translated into flow equivalents to be modeled in CalSim II. However flow-salinity relationships in the Delta are non-linear. CalSim II uses an external module to estimate the salinity at four water quality stations within the Delta. The module consists of an artificial neural network (ANN), trained using a one-dimensional hydrodynamic finite difference model of the Delta's channel system. CalSim II passes antecedent (previous month) flow conditions and known (or estimated) current month flows to an ANN dynamic link library (DLL). The DLL returns coefficients for a linear constraint that binds Sacramento River Delta inflows to Delta exports based on a piecewise linear approximation of the flow-salinity relationship.

3 REVIEW OF HISTORICAL PROJECT OPERATIONS

In addition to changing facilities and the year-to-year hydrologic variation, management of the CVP-SWP has been affected by the release of SWRCB water quality control plans and water right decisions, state and federal biological opinions relating to Sacramento River and Delta native fish species, and discretionary agreements with other regulatory agencies. Summarized below are the major historical events that have affected the operation of the projects over the last four decades.

1960: SWP Water Supply Contracts
- MWDSC signs first of SWP water supply contracts.

1962: SWP South Bay Aqueduct
- First deliveries to Santa Clara County and Alameda County.

1963: CVP Trinity River Division
- First export of water from Trinity River to Whiskeytown Lake. Annual required minimum flow release from Lewiston Lake to Trinity River set at 120.5 taf.

1967: Water Right Decisions 1275 and 1291 (D-1275 and D-1291)
- D-1275, revised by D-1291, authorizes issuance of water right permits to DWR for the SWP. D-1275 includes agricultural salinity standards for the Delta.

1968: SWP Deliveries
- Lake Oroville fills for the first time. First water delivered to SWP San Joaquin Valley contractors.

1971: Water Right Decision 1379 (D-1379)
- D-1379 establishes new water quality standards for the Delta and Suisun Marsh to be met jointly by the CVP and SWP, rescinding previous requirements of D-1275 and D-1291. D-1379 later stayed by the courts as a result of litigation.

1972: SWP Deliveries
- First water delivered to SWP contractors in Southern California.

1976: Drought
- Start of two-year drought.

1977: Drought
- Water-year 1977 is driest year of record. SWRCB twice amends regulations for the Delta temporarily easing water quality standards.

1978: SWRCB Water Quality Control Plan (WQCP)
- 1978 WQCP establishes revised water quality objectives for flow and salinity in the Delta and Suisun Marsh.

1978: Water Right Decision 1485 (D-1485)

- D-1485 issued by SWRCB rescinds D-1275, D-1291 and D-1379.
- D-1485 introduces a four-river-index, water-year-type dependent standards for Delta water quality and outflow requirements and fishery protections. Export reductions imposed on projects; 3,000 cfs in May and June for both Tracy and Banks pumping plants, 4,600 cfs in July for Banks. Authorized SWP wheeling for CVP to redress impact of export restrictions in May and June.

1981: Trinity River Flow Evaluation

- USDI Secretarial Decision (January 16) directs minimum annual flow releases to the Trinity River of 340 taf in normal and wet years, 220 taf in dry years and 140 in critically dry years.

1986: Coordinated Operation Agreement (COA)

- Agreement between Reclamation and DWR defines sharing formula for meeting in-basin use and for partition of surplus flows. COA also provides for the CVP to wheel water through SWP facilities. COA replaces a system of year-to-year agreements that were in place since 1971.

1987: Suisun Marsh Preservation Agreement

- DWR, Reclamation and DFG sign Suisun Marsh Preservation Agreement, which provides water quality standards and provides details on implementing the plan.

1987: Drought

- Beginning of six-year drought begins, ends in 1992.

1988: SWP

- DWR completes North Bay Aqueduct pumping plant and the Suisun Marsh salinity control gates and establishes the Kern Water Bank for groundwater conjunctive use.

1989: Listing of Winter-run Salmon

- Sacramento River winter-run chinook salmon listed as threatened species by NMFS and endangered by CDFG, requiring operational changes in the CVP and SWP.

1991: Trinity River Flows

- USDI Secretarial Decision (May 8) specifies minimum annual flow releases to the Trinity River of 340 taf for water year 1992-1996.

1991: SWP Operations

- DWR expands capacity at Banks pumping plant to 10,300 cfs.
- Drought Water Bank Program created and activated to alleviate major cutbacks to contractors.

1992: Central Valley Project Improvement Act (CVPIA), Title XXXIV of PL 102-575

- CVPIA, passed by Congress, addresses several issues for improving water quality and ecosystem health, sets new guidelines for contracts and transfers, and dedicates 800 taf for fish and wildlife purposes in addition to Reclamation refuge water supplies.

1992: Drought Water Bank Program
- Drought water bank program activated to alleviate major cutbacks to contractors.

1992: Winter-run Chinook Salmon Biological Opinion (BO)
- A one-year BO issued by NMFS (February 14) on winter-run Chinook salmon specifies minimum flows below Keswick Dam to provide temperature control and requires the Red Bluff diversion dam gates to remain open for a longer period.

1992: Relaxation of Standards
- Salinity standards at Emmaton relaxed in June to maintain sufficient cool water supplies in north-of-Delta reservoirs for salmon spawning (in preference of not violating the Contra Costa Canal standard); Contra Costa Canal Intake standard of 155 days below 150mg/l relaxed in November-December (with restrictions on Banks/Tracy exports).

1993: Winter-run Chinook Salmon Biological Opinion (BO)
- Long-term BO released by NMFS (February 12) for the Sacramento River winter-run Chinook salmon. Requirements include 1.9 maf carryover storage in Lake Shasta, Sacramento River minimum flow requirement downstream of Keswick Dam, Qwest requirements to eliminate reverse flow, and constraints on the Delta cross-channel operations. BO limits incidental total take to less than 1 percent of the out-migration population.

1993: Delta Smelt Biological Opinion (BO)
- Delta smelt declared a federally threatened species. USFWS issues one-year BO (May 26). Incidental take requirements limit combined project exports to 4,000 cfs in May and 5,000 cfs in June. Additional Qwest standard specified.

1994: Drought Water Bank Program
- Drought water bank activated to alleviate major cutbacks to contractors.

1994: Delta Smelt Biological Opinion (BO)
- Second one-year BO released by USFWS (February 4). CVP-SWP operations found likely to jeopardize continued existence of Delta smelt. Reasonable and prudent alternative defines X2 estuarine habitat standard, adds additional net Delta outflow criteria and minimum flows for the San Joaquin at Vernalis.

1994: Monterey Agreement
- Monterey Agreement between DWR and SWP contractors (signed December 1) provides for greater flexibility in water operations. Provisions include permanent water transfers, creation of a turn-back pool, storage of water outside of SWP service area, and use of SWP facilities for transfer of non-SWP water. During shortages water to be allocated in proportion to contractors' Table A amounts.

1994: Bay-Delta Accord
- Bay-Delta Accord signed (December 15) by state and federal agencies.
- Agreement contains a set of standards that include export: inflow (E:I) restrictions on project pumping, X2, periods of closure for the Delta cross channel gate, minimum flows in the San Joaquin River at Vernalis and export limits during the April/May 30-day pulse-flow period.
- Compliance with take provisions of biological opinions under ESA to be achieved at no additional water cost to projects through adjustment of export pumping limits.

1994: SWRCB Draft Water Quality Control Plan (WQCP)
- Draft 1994 WQCP issued by SWRCB, developed concurrently with the Bay-Delta Accord.

1995: SWRCB Water Quality Control Plan (WQCP)
- WQCP defines new water quality objectives for the Delta. The WQCP contains revised EC and chloride standards and Delta outflow requirements. X2 standard specified. An export: inflow ratio limits total project pumping. Exports during the April 15 – May 15 San Joaquin pulse flow period limited to the greater of 1,500 cfs or the San Joaquin River flow at Vernalis.

1995: SWRCB Order WRO 95-6
- Temporary 3-year approval of CVP-SWP joint point of diversion.

1995: Delta Smelt Biological Opinion (BO)
- USFWS issues (March 6) long-term BO for Delta smelt, revising take limits at project export pumps.

1995: Winter-run Chinook Salmon Biological Opinion (BO)
- NMFS issues amendments (May 17) to 1993 BO to conform to Bay-Delta Accord, revising operation of the Delta cross channel, Qwest requirements and take limits at the project export pumps.

1998: SWRCB Order WRO 98-9
- Extends temporary conditional approval of CVP-SWP joint point of diversion.

1999: SWRCB Water Right Decision 1641 (D-1641)
- D-1641 implements objectives of the 1995 Water Quality Control Plan.
- Replaces D-1485 as modified by WRO 98-9.
- Amends CVP and SWP permits.

- Adopts the Vernalis Adaptive Management Program (VAMP).
- Conditional approval of joint point of diversion.

2000: SWRCB Order WR 2000-02

- Order denies petitions for reconsideration of D-1641. Amends several conditions of D-1641.

2000: Draft Trinity River EIS/EIR

- Preferred alternative specifies annual minimum flow releases of 369-815 taf/yr, depending on water year classification, and a minimum carryover of 600 taf.

2000: CALFED

- Framework for Action for proposed CALFED long-term plans signed.
- Release of final Programmatic EIS/EIR for the Bay-Delta Program.
- Record of Decision (ROD) signed implementing proposals listed in the Framework. ROD establishes the Environmental Water Account.

4 HISTORICAL OPERATIONS STUDY MODELING ASSUMPTIONS

4.1 Study Description

For the Historical Operations Study, the study period was selected to be water years 1975 to 1998. This 24-year period includes the 1976-77 and 1987-92 droughts, as well as the driest (1977) and the wettest (1983) years on record. Input to the current CalSim II model has been changed to reflect the historically changing rather than fixed conditions as is the case for studies at a specific level of development. Model inflows correspond to the historical flow from gage records, or estimated from a hydrologic mass balance, or stream-flow correlation. Land use-based demands are calculated for annual varying land use, as determined from DWR's land surveys and county commissioners' reports. Project contracts and entitlements have been changed to their historical level. The operational logic has been revised to reflect the changing regulatory environment, such as the release of the NMFS 1993 winter-run Chinook salmon biological opinion, and the release of the SWRCB 1995 Water Quality Control Plan.

The Historical Operations Study is limited in geographical scope to a dynamic operation of the Sacramento Valley, the Delta, and the CVP-SWP facilities south of the Delta. The study is derived from the Benchmark Study released on September 30, 2002, available at http://modeling.water.ca.gov. Changes to the Benchmark Study have been kept to a minimum so as to maintain the essence of the CalSim II model used for the estimate of projected water supply reliability at a specific level of development. The following sections describe the differences between the Historical Operations Study and the Benchmark Study.

4.2 Fixed Operations

Several decision variables that are dynamically determined in the CalSim II Benchmark Study are fixed at their historical level in the Historical Operations Study. These are described in the following sections.

4.2.1 Trinity River Exports to the Sacramento Valley

Minimum instream flows for the Trinity River are required to insure the preservation and propagation of fish and wildlife. Release requirements from Lewiston Lake have varied over the 24-year period of simulation as a result of USDI Secretarial Decisions and CDFG and CVPIA requests. To reduce the number of variables and focus on evaluating model's performance in simulating the Sacramento Valley's hydrology and the operation of the major upstream storage facilities, the Trinity system's imports to the Sacramento River Basin were constrained to their historical values based on the records provided to DWR by Reclamation. Figure 5 shows the historical flows for the 1975-1998 period.

4.2.2 San Joaquin River Flow at Vernalis

The CalSim II representation of the east side of the San Joaquin Valley is currently being substantially revised. This part of the system is operated independently of the SWP and other elements of the CVP. It was therefore decided to exclude the dynamic operation of the east San Joaquin Valley from the Historical Operations Study, and constrain San Joaquin River flows at Vernalis to their historical value. Figure 6 shows the historical flow at Vernalis, obtained from DAYFLOW (DAYFLOW is a historical database of daily average flows at various locations in the Sacramento San-Joaquin Delta maintained by DWR). The flow at Vernalis is relatively small, averaging about 3.7 maf/yr, as compared to the average annual flow of the Sacramento River at Freeport of approximately 16.8 maf/yr.

4.2.3 Mendota Pool Inflow

The Delta Mendota Canal deliveries to CVP exchange contractors in the San Joaquin Valley are made via the Mendota Pool. The Mendota Pool also serves water service contractors and the Mendota Wildlife Management Area. Flood control releases from Millerton Lake may be used to satisfy portions of the refuge and contractors' demands. Millerton Lake operations are coordinated with operations of the Delta Mendota Canal in the Delta Division so as to use all available Millerton Lake flood control releases before additional water is delivered to Mendota Pool. During wet hydrologic periods, overflow from the Kings River may enter the San Joaquin River Basin at the Mendota Pool through the Fresno Slough. This water is also used to meet demands at Mendota Pool. Flood control releases from Millerton Lake that exceed the requirements of the San Joaquin River Exchange contractors are diverted into the Chowchilla Bypass until flows in the Chowchilla Bypass reach its capacity of 6,500 cfs. This diversion of flow helps avoid flooding of agricultural lands located in the floodplain along the San Joaquin River below Gravelly Ford.

For the Historical Operations Study the inflow to the Mendota Pool is set equal to the combined flow of the San Joaquin River below the confluence of the Chowchilla Bypass and the inflow from the Fresno Slough. The average annual historical inflow to the Mendota Pool for the 24-year simulation period is 407 taf.

4.2.4 Delta Inflow from the East-Side Streams

The East-Side Streams is the collective name for a group of streams located between the American River and Stanislaus River that flow into the eastern Delta (Cosumnes, Mokelumne, Calaveras, and minor creeks). The watershed is represented by DSA 59. It includes New Hogan

Reservoir on the Calaveras River and Pardee and Camanche reservoirs on the Mokelumne River. No land use-based hydrology has been developed for DSA 59. For the 2001 and 2020 LOD model studies, demands are based on contract entitlement and recent historical deliveries. At a current or projected LOD, operation of the Mokelumne system is constrained to mimic output from EBMUD's simulation model EBMUDSIM. Rather than develop historical agricultural and urban demands for the area, and historical reservoir operation logic, it was decided to not model DSA 59 dynamically but constrain Delta inflow from DSA 59 to its historical level as estimated by DWR Hydrology and Operations Section. Figure 7 presents the historical data used in the simulation run for the inflow from the East-Side Streams.

4.2.5 American River M&I Deliveries

Various urban municipalities divert water from Folsom Lake. Rather than calculate a historical demand for the urban diversions from the American River, diversions have been constrained to the historical deliveries provided to DWR by Reclamation.

4.2.6 Wildlife Refuge Deliveries

Refuge demands in the Sacramento Valley comprise the National Wildlife Refuge complex (Sacramento NWR, Delevan NWR, Colusa NWR and Sutter NWR) and the Gray Lodge Wildlife Management Area. For the Benchmark Study, refuge demands are set at Level 2, as identified by Reclamation in their refuge water supply investigations. Level 2 corresponds to the recent historical average annual water delivery. For the Historical Operations Study refuge demands are set equal to Level 2.

4.2.7 Sacramento Valley Inflows

Sacramento Valley inflows and Valley floor accretions, including Sacramento River inflow to Lake Shasta, Feather River inflow to Lake Oroville, American River inflow to Lake Folsom, and local flows to Sacramento River from Cottonwood Creek, Paynes Creek, Thomes Creek, Stony Creek, Butte Creek, and inflow to Feather River from the Yuba-Bear river system, have been fixed at their historical level as estimated by DWR Hydrology and Operations Section. The total annual volume of these historical flows is shown in Figure 8. The Figure also shows the historical import from the Trinity River system, which averages about five percent of the total natural inflow to Sacramento River.

4.2.8 Delta Inflows

Inflows to the Delta other than from the Sacramento River and from the Yolo Bypass are fixed at their historical levels. Figure 9 shows the relative scale of the inflow to the Delta from the combined San Joaquin River and Eastside Streams as compared to the total inflow from the Sacramento River Basin.

4.3 Demands

4.3.1 Land-use Based Demands

As for the Benchmark Study, all agricultural and outdoor demands in the Sacramento Valley and Delta are land use based. Table 1 gives the estimated historical land use data in the

Sacramento Valley. Table 2 gives the corresponding consumptive use demand, the diversion/pumping requirement and, for comparison, the estimated maximum contract amount.

4.3.2 CVP Demands

As for the Benchmark Study, CVP annual contract entitlement serves as an upper bound on CVP deliveries both north and south of the Delta. It is assumed that the current contract amounts have been in place for the full 24-year period of simulation, with the exception of the San Felipe Unit that commenced deliveries in 1987. In the Historical Operations Study, like the Benchmark Study, CVP demands south of the Delta are set equal to the full contract amount (i.e. prior to any imposed deficiencies). Table 3 gives the assumed historical CVP demand and contract amounts provided to DWR by Reclamation.

4.3.3 SWP Demands

Table A

SWP long-term contractors submit their initial requests for Table A deliveries to DWR in December before the start of the contract year. These initial requests are made with no knowledge of the coming water year hydrologic conditions and therefore tend to be conservative. In wet years contractors typically revise requests downward depending on local wetness conditions and the availability of local supplies. The historical request data are available from SWPAO.

Table 4 lists the annual historical deliveries for the SWP, along with the contractors' requests and the approved allocations. Table A deliveries are subdivided into south-of-Delta (col. 2) and north-of-Delta (col. 3). The table also gives Article 12d, Article 14b, Article 21, and Turnback Pool Water. Column 12 of the table ('CalSim Format Table A Delivery') represents annual delivery adjusted to match the way that deliveries are represented in CalSim II. Deliveries made under Article 21 (interruptible deliveries) have been removed, and deliveries under Article 12d, Article 14B, and carryover are adjusted so that they are added to the previous year's delivery, the year that they were pumped from the Delta. Under historical conditions these deliveries were made in the following year.

In the Historical Operations Study the adjusted historical deliveries (Table 4, Col. 12) were used as SWP south-of-Delta contractors' demands in wet and above-normal years, when there was usually more than sufficient water available for making deliveries and the operation of the system was driven by contractors' demands. In the below-normal, dry and critical years, when the operation was supply driven, the annual demands were set at the initial contractors' requests. Table 5 lists the resulting demands for the south-of-Delta contractors used in each year of the study. North-of-Delta SWP contractors' demands are relatively small, and were held constant every year at the full Table A amount.

Water Rights

The Feather River Service Area is part of DSA 69. Demand for the FRSA is land use based and is calculated as 70 percent of the total DSA demand. Deliveries to water right holders within the FRSA are limited by the terms of their contracts with DWR. In the Historical Operations Study the contractual conditions are kept constant and are as provided by DWR's

State Water Project Analysis Office (SWPAO). In non-drought years the FRSA water rights holders are entitled to their full contract entitlement. In 'drought' years (1977, 1988 and 1991) part of their contract entitlement is subject to a reduction of up to 50 percent.

Article 21

Article 21 of the contracts permits delivery of surplus water in addition to Table A deliveries. Article 21 water is delivered directly from Banks Pumping Plant; it is not stored in San Luis Reservoir for later delivery to contractors. Article 21 deliveries do not impact Table A allocations. For the 2001 LOD Benchmark Study, Article 21 demand is set at 134 taf/month. Modeling of Article 21 water has little effect on the rest of the system, although changes in flows through the Delta may impact the flow-salinity relationship. For the Historical Operations Study it was decided not to model Article 21 water. Similarly, CalSim II does not model delivery of non-SWP water or deliveries made under the drought water bank program.

4.4 Monterey Agreement

The Monterey Agreement, signed by DWR and the State Water Contractors in December 1994, laid out principles for amending the water supply contracts. Prior to the agreement, shortage provisions in the contracts favored M&I contractors. Principle 2 of the Agreement states that each contractor will be allocated part of the total available project supply in proportion to the Table A amounts, irrespective of type of use. For the Historical Operations Study the SWP allocation procedure is based on the Monterey Agreement for the entire period of simulation. Given that San Luis Reservoir reregulates Delta exports, it is considered that total annual SWP model deliveries south of the Delta are not significantly affected by the allocation mechanism between agricultural and urban contractors.

4.5 Regulatory Baseline

Simulation of historical conditions rather than a fixed level of development requires accounting for the changing regulatory baseline to which project operations must adhere. For the Historical Operations Study the historical regulations have been simplified into three periods.

- October 1974 – September 1992: represented by State Water Resources Control Board (SWRCB) Water Right Decision 1485 (D-1485),
- October 1992 – September 1994: represented by D-1485 and the 1993 National Marine Fisheries Service (NMFS) winter-run chinook salmon biological opinion (minimum carryover storage in Lake Shasta, and temperature related minimum instream flows downstream of Keswick Rservoir),
- October 1994 – September 1998: represented by SWRCB Water Right Decision 1641 (D-1641) and the 1993 winter-run biological opinion

While this does not fully account for all the changes in project and system-wide operational criteria, especially export curtailments due to fish entrainment, it is considered a reasonable approximation for the current analysis. A more detailed description of the regulations modeled in each of these three periods is given in Table 6.

4.6 Initial Conditions
For the Historical Operations Study, initial reservoir storage conditions are set to historical September 1974 end-of-month storage.

4.7 Mass Balance Errors
The CalSim II accretions are closure terms in a hydrologic mass balance, and therefore include the sum of errors associated with the other terms. These include stream gage measurement errors, errors in estimating consumptive use of applied water (CUAW) and non-recoverable losses, as well as errors in estimating the historical net contribution of groundwater The advantage of using a hydrologic mass balance to estimate accretions is that many of these errors cancel out. For example, an over-estimation of historical CUAW will result in an over-estimate of the accretion. During model simulation the additional accretion is available to meet the over-estimated CUAW. Errors are introduced when the assumed model land use at a projected level of development varies from the historical land use. For this reason the CalSim II hydrology is less reliable for the earlier period of simulation. It can be shown that the additional model outflow to the Delta, Q_m, is:

$$\Delta Q_m = \left(\hat{Q}_h - \overline{Q}_h\right) + \left(GW_m - \hat{G}W_h\right)$$

where $\hat{Q}_h$ is the estimated historical outflow, $\overline{Q}_h$ is the actual historical outflow, GW_m is the net groundwater contribution (including the stream-aquifer interaction), and $\hat{G}W_h$ is the estimated groundwater contribution. Historical stream-aquifer interaction is estimated from CVGSM. Whether correct or not this estimate is built into the calculation of valley floor accretions, so that any departure from the *assumed* values will cause a difference in inflow to the Delta.

5 RESULTS

5.1 Historical Versus Simulated Operations
The performance of CalSim II in simulating historical conditions is presented in this section by focusing on how closely the model is able to reproduce project operations during the long-term (water years 1975-1998) and during the critically dry period (drought of 1987-1992). The results are summarized in Table 7. It is noted that the simulated month-to-month, and sometimes year-to-year, operation of the system may vary greatly from the actual historical operation, whilst long-term average flows and deliveries are typically close. Some of the factors that could contribute to these differences, subjectively listed in decreasing significance, are:

- Delivery versus carry-over storage rules
- Delta outflow requirements to comply with SWRCB standards
- South-of-Delta demand assumptions
- Level of north-of-Delta groundwater pumping
- Rule curves to transfer water from north of Delta reservoirs to San Luis Reservoir
- Crop consumptive use (of applied water) and agricultural water use efficiency

- Assumptions on historical land use, and project vs non-project demands
- Stream-aquifer interaction
- Historical operations based on daily decisions as opposed to simulated operation based on monthly decisions
- Implementation schedule of regulatory decisions
- Export curtailments due to fish take limits
- CVP reservoir balancing north-of-Delta (Shasta/Folsom)
- Compliance with the provisions of the Coordinated Operations Agreement (COA)
- Project export of surplus water and non-project water
- Flood control operations
- System scheduled and unscheduled outages
- Hydropower operations
- Drought water bank and water transfers

5.2 SWP Operations

5.2.1 South-of-Delta Deliveries

In order to simulate the historical conditions, SWP target deliveries were capped by the annual historical deliveries or contractors' requests, depending on the hydrologic conditions as described in section 4.3.3. Resulting annual deliveries for the period of 1975 through 1997 are shown in Figure 10. Simulated deliveries in 1981 and 1985 are lower than historical deliveries due to the lower initial contractors requests used as demands for those years according to the rules discussed in Section 4.4.3. The higher historical deliveries, however, indicate probable requests for higher deliveries subsequent to the submission of initial requests. Due to the particular interest in the delivery capability of the system in the 1987-1992 dry period, this period is highlighted in Figure 10, and presented separately in Figure 12.

Annual SWP deliveries are partly determined by reservoir carryover storage targets. Rules for establishing carryover storage have varied historically. In contrast to historical operations CalSim II uses a fixed procedure, that tends to be more conservative (i.e. assigns larger carryover storage targets) in dry years. To better compare year-by-year simulated and historical deliveries during the 1987-1992 dry period, the simulated values of deliveries shown in Figure 12 were adjusted to account for differences in storage utilization. This was done by adding to, or subtracting from the simulated annual deliveries, the difference between the simulated and the historical annual change in storage. If more storage was used in making the historical delivery, the additional storage was added to the simulated delivery, and if there were less storage utilization in the historical case, the simulated values were reduced by that storage difference (see the listing of the historical storage and drawdown, along with the corresponding values from the simulation run and the resulting adjustments to the simulated deliveries in Figure 13).

5.2.2 Surface Storage Operation

Lake Oroville on the Feather River is the only major SWP conservation facility in the Sacramento Valley. Storage withdrawals from Lake Oroville are made to meet the minimum flow requirements along the Feather River, the state share of obligations at the Delta, and project exports at Barker Slough for the North Bay Aqueduct as well as at the Banks Pumping Plant. Part of the water released by Lake Oroville and pumped at Banks Pumping Plant is transferred to San Luis Reservoir and stored in the SWP portion of that Reservoir when demands by the contractors along the California Aqueduct are lower than the allowable pumping. This stored water south of the Delta helps to meet a portion of the SWP deliveries during the periods when deliveries exceed the allowable pumping at Banks. Figure 11 compares the historical and simulated total storage in the SWP system reservoirs at the end of the water year. Figure 13 compares the total end-of-month storage in SWP system during the dry period of 1987-1992. The end-of-month storage for the same period in Lake Oroville and the SWP portion of San Luis Reservoir are compared in Figures 14 and 15.

5.2.3 North-of-Delta Deliveries

Figure 16 shows a comparison between the historical and simulated SWP deliveries to the FRSA for the period of 1975-1997. The deliveries include all of the senior water rights holders downstream of Lake Oroville (i.e. Joint Water District Board, Western Canal Water District, Garden Highway Mutual Water Company, Plumas Mutual Water Company, Thermalito Irrigation District, Tudor Mutual Water Company, and Oswald Water District). Diversions from Lake Oroville to the Oroville-Wyandotte Irrigation District via the Palermo Canal are not included. The historical 24-year average annual delivery to these water rights holders is 840 taf/yr compared to a simulated value of 880 taf/yr. However, the simulated values include a 43 taf/yr diversion to the Gray Lodge Wildlife Management Area. Historically up to 12 taf/yr of refuge water has been provided by the Biggs-West Gridley Water District which obtains water from the Feather River and Thermalito Afterbay. Additional refuge water may be provided by the CVP as part of an exchange agreement with the SWP. Any exchange water is not included in the historical SWP deliveries to the FRSA.

The contract entitlement in CalSim II for the FRSA water rights holders downstream of Lake Oroville is 948 taf/yr in non-drought years. This can drop to 630 taf/yr when deficiencies of up to 50 percent are imposed in “drought” years on some parts of the contract amount. CalSim II imposes 50 percent deficiencies in 1977, 1988 and 1991. In non-drought years the land use-based demand is usually significantly less than the contract entitlement (see Table 2).

5.3 CVP Operations

5.3.1 South-of-Delta Deliveries

Due to the limited availability of data, historical CVP annual south-of-Delta deliveries, shown in Figure 17, are limited to the 1982 -1997 period, with the 1987-1992 dry period highlighted. Figure 19 focuses on the dry period deliveries. Similar to the comparison bar chart for the SWP deliveries, the effect of storage utilization in the dry period was removed from the simulated values of delivery in Figure 19. This was done by adding to or subtracting from the simulated annual deliveries the annual change in storage used to make those deliveries in each year of the dry period. If more storage was used in making the historical delivery, the additional storage was added to the simulated delivery, and if there were less storage utilization in the historical case, the simulated values were reduced by that storage difference (see the listing of the historical storage and drawdown, along with the corresponding values from the simulation run and the resulting adjustments to the simulated deliveries in Figure 20).

5.3.2 Surface Storage Operation

The major CVP surface storage facilities in the Sacramento Valley are Shasta Reservoir, Keswick Reservoir, and Folsom Lake. Trinity Lake is not dynamically modeled in this study. Model imports to the Sacramento Basin made through the Andrew Carr's Tunnel are constrained to their historical value. Storage withdrawals from the Sacramento Valley reservoirs are made to meet the CVP in-basin demands, CVP requirements at the Delta, including the demands at the Tracy Pumping Plant, and minimum flow requirements along the way on the Sacramento River and the American River. Part of the water released by the CVP's upstream reservoirs and pumped at Tracy Pumping Plant is transferred to San Luis Reservoir and stored in the CVP portion of that reservoir when demands by the contractors along the Delta Mendota Canal and the joint use portion of the California Aqueduct are lower than the allowable pumping. Banks Pumping Plant also wheels a portion of the CVP's storage withdrawals to store in San Luis Reservoir when unused capacity is available at Banks Pumping Plant. Figure 18 compares storage in the CVP system reservoirs at the end of the water year. As mentioned above in the discussion of the CVP allocation logic (section 2.10), target carryover storage for the end of the water year is one of the factors that determine the allocation of water for making deliveries to the CVP contractors. Figures 20 through 23 compare the end-of-month storages at the CVP's surface storage facilities for the dry period of 1987-1992.

5.3.3 North-of-Delta Deliveries

Figure 24 shows the CVP contract-year (March-February) total deliveries north of the Delta in the Sacramento Valley for the period of 1982-1997.

5.4 Delta Exports

Figures 25 through 30 present comparisons between the simulated and historical CVP and SWP exports from the south Delta facilities. Historical values for exports by the CVP and SWP were obtained from DAYFLOW average daily data, and as such included all types of diversions, project and non-project, made at the Banks and Tracy pumping plants. Since the simulated values of the Delta exports by Banks Pumping Plant do not include any Article 21 water, or any non-project water transfers, the values obtained from DAYFLOW for the historical exports were adjusted to be more comparable to the simulated values. The adjustments included the subtraction of the Article 21 water, and exports that were made to transfer drought water bank supplies. Due to lack of data availability no other adjustments for non-project pumping were made.

5.5 Sacramento and Feather River Flows at Key Locations

Figures 31 through 34 provide a comparison of the historical and simulated flows at the four major gaging stations along the Sacramento River and at the mouth of the Feather River. The historical flow in the Feather River is estimated from a hydrologic mass balance.

5.6 Sacramento Valley Delta Inflow

The combined Sacramento River and Yolo Bypass flows represent the integration of the inflow hydrology, upstream reservoir operations in the Sacramento Valley, stream diversions and returns, and the net effect of the groundwater operations. The differences in simulated and historical flows are due to differences in the surface storage operations, net groundwater extraction, and stream-groundwater interaction. Figure 35 shows the comparison between the simulated and historical outflow from the Sacramento Valley to the Delta for the period of 1975-1998.

5.7 Sacramento Valley Net Depletion

For operational studies the Sacramento Valley can be regarded as a 'black box'. The input is the combined releases and diversions (if any) from Whiskeytown Reservoir, Keswick Reservoir, Lake Oroville and Lake Natomas plus diversions from Folsom Lake. The output is the flow into the Delta via the Sacramento River and Yolo Bypass. The difference between the input and output represents the net depletion by the system. The net accretion is the combined effect of inflows, diversions, return flows, evaporation, seepage and groundwater inflow. The historical and model net accretion are compared in Figure 36.

5.8 Net Delta Outflow Index

Direct measurement of net Delta outflow is impractical because of huge tidal effects. However, since net outflow is one of the primary factors in controlling Delta water quality, a calculated value known as the Net Delta Outflow Index was developed. It is an approximation of freshwater flowing seaward past Chipps Island. Historical values of the net Delta outflow were obtained from DAYFLOW, which estimates this variable by performing a water balance at the boundary of the Sacramento-San Joaquin Delta, taking Chipps Island as the western limit.

$$Q_{OUT} = Q_{TOT} + Q_{PREC} - Q_{GCD} - Q_{EXPORTS} - Q_{MISDV}$$

Where:

- Q_{OUT} is the net Delta outflow at Chipps Island.
- Q_{TOT} is the total Delta inflow, consisting of inflows from the Sacramento River at Freeport, the Yolo Bypass, and the Eastside Streams, including San Joaquin River.
- Q_{PREC} is the Delta precipitation runoff.
- Q_{GCD} is the Delta gross channel depletion.
- $Q_{EXPORTS}$ is the total Delta exports and diversions, consisting of the diversions by the CVP at Tracy Pumping Plant, Contra Costa Water District diversions at Rock Slough, State Water Project diversions at Banks Pumping Plant, and the diversions at Barker Slough for the North Bay Aqueduct.
- Q_{MISDV} is the flooded island and island storage diversions, if any.

Figure 37 presents a comparison between the historical and simulated values of NDOI.

5.9 Groundwater Operations

5.9.1 Groundwater Pumping

Net groundwater pumping is the sum of groundwater pumping less deep percolation from irrigation. Table 8 compares CalSim II and CVGSM historical values for the seven DSAs of the Sacramento Valley. Over the 24-year period of simulation CalSim II extracts 378 taf/yr less groundwater than historical (as estimated by CVGSM). This difference is relatively small compared to the total Sacramento Valley demand of approximately 6.0 maf. During the 1987-1992 period CalSim II extracts 62 taf/yr less than historical. The lower groundwater pumping in CalSim II translates into greater use of surface water to meet demand, with resulting less inflow to the Delta.

5.9.2 Stream-Aquifer Interaction

CVGSM and CalSim II estimates of the stream-aquifer interaction are compared in Table 9. The results show that the multi-cell groundwater model implemented in CalSim II is unable to mimic the stream-aquifer interaction as simulated by CVGSM. This is probably due to the coarse nature of the multi-cell model. Poor representation of groundwater in CalSim II results in an over-estimate of stream gains from groundwater of 190 taf/yr. During the 1987-1992 dry-period the model over-estimate of stream gains falls to 108 taf/yr. Although the multi-cell model in CalSim II is currently undergoing some refinement, it is unlikely that modeling of the stream-aquifer interaction can be significantly improved without replacement of the multi-cell model with a dynamically linked CalSim-CVGSM and the recalibration of CVGSM based on the new IGSM 2 code developed by DWR.

5.9.3 Implications

The net effect of the dynamic groundwater operations in CalSim II (pumping, recharge from deep percolation, and the stream-aquifer interaction) is to reduce the available surface water flow to the Delta by 188 taf/yr over the 24-year period. However during the 1987-1992 dry-period, groundwater operations result in a slightly greater flow to the Delta of 46 taf/yr.

6 OTHER CALSIM II EVALUATION STUDIES

6.1 Overview

The following sections describe additional modeling activities that are part of the overall CalSim II evaluation. They consist of two additional supporting studies and a model sensitivity analysis. The two supporting studies isolate a component of the CalSim II model for further analysis. Boundary flows between the isolated component and the rest of the system are fixed at the historical level.

6.2 Delta Flow-Salinity Relationship

Separate historical evaluations of the ANN model are being conducted by DWR and Reclamation as part of a review of the flow-salinity modeling in CalSim II. A “stripped-down” version of CalSim II will be developed containing only the necessary input files and code logic to simulate Delta flow conditions and salinity calculations. Initial conditions and input flow data for the sub-model will be fixed at the historical level. Historical flow data will be taken from

DAYFLOW. Historical electrical conductivity data will be taken from the Inter-Agency Ecological Program website. The CalSim II sub-model will simulate Delta flow and salinity conditions for the period 1965-2000. A technical report of the ANN evaluation will be published.

6.3 Daily vs. Monthly Time-step

CalSim II simulates the CVP-SWP system using a monthly operational time-step during which time flows are assumed to be constant. This study will evaluate the errors introduced by using a monthly time-step. The study will compare project exports from CalSim II to the daily Delta model developed by DWR. In the first part of the study the daily model will be run with the daily Delta inflow set equal to the average monthly inflow as determined by the CalSim II historical run, i.e. with no day-to-day flow variation. In the second part of the study the daily model will be re-run, but imposing a daily fluctuating flow pattern on the Delta inflow. This two-stage approach will distinguish between the impacts of modeling Delta regulations at a daily time scale to the impacts due to the varying daily flow pattern. A technical report of this evaluation will be published.

6.4 Sensitivity Analysis

Sensitivity analysis is the process of changing the value of model inputs, one at a time, over a range of values, to determine the marginal change in output. The analysis is used to identify the parameters that most influence model results. Sensitivity analysis can also be used to check the model response is appropriate for the input being varied.

Sensitivity analysis for CalSim II requires identifying what output should be used as performance measures. This may depend on the parameter being varied, but would typically be north of Delta deliveries, project exports from the Delta and flows in environmentally sensitive parts of the system, both long-term and for the drought periods. The purpose of the sensitivity analysis is two-fold: to provide confidence limits on model results; and to direct future work on refining values of the key parameters. Sensitivity analysis will be conducted on hydrologic inputs related to supply and demand, and required flows to meet water quality standards in the Delta. The sensitivity analysis will be performed using the latest benchmark study for a 2001 level of development. A technical report of this evaluation will be published.

Tables

Table 1. Sacramento Valley Estimated Historical Land Use 1975-1998 (acres)

Year	Pasture	Alfalfa	Sugar Beets	Field Crops	Rice	Truck Crops	Orchard	Grain	Tomatoes	Vineyard	Citrus/ Olives	Cotton	Total Ag	Urban
1975	216,600	118,100	101,500	387,800	435,700	66,600	283,400	326,600	145,200	5,500	14,100	0	2,101,100	226,200
1976	215,200	109,000	109,400	429,700	407,900	58,200	284,100	381,700	146,900	5,900	14,000	0	2,162,000	237,500
1977	201,700	116,100	91,300	436,400	335,700	53,800	286,600	391,900	168,800	6,000	14,300	0	2,102,600	244,500
1978	206,900	107,300	88,300	401,700	400,200	59,500	284,600	386,400	163,100	6,300	14,400	0	2,118,700	253,800
1979	206,800	105,300	85,500	381,600	442,500	59,800	287,900	384,300	146,100	7,000	14,500	0	2,121,300	261,700
1980	209,400	107,900	94,300	350,800	488,100	65,400	293,700	343,700	134,000	6,600	15,300	0	2,109,200	269,210
1981	204,100	104,400	97,400	346,500	475,900	66,500	289,900	391,000	133,000	7,200	15,100	0	2,131,000	283,994
1982	201,700	99,300	66,500	391,400	508,400	68,500	296,000	262,600	131,500	7,300	15,600	0	2,048,800	299,600
1983	199,700	100,700	71,100	258,400	421,900	49,400	286,500	195,500	125,700	7,600	15,900	0	1,732,400	314,442
1984	197,700	110,000	96,500	330,600	446,500	72,200	279,800	249,800	129,500	7,800	16,300	0	1,936,700	329,269
1985	196,400	115,300	100,100	297,400	402,900	72,600	290,100	316,000	122,300	8,300	16,500	0	1,937,900	337,258
1986	195,500	119,100	82,000	229,200	382,600	75,900	297,500	305,900	117,400	8,500	16,600	0	1,830,200	344,887
1987	194,700	129,900	98,400	202,400	389,600	75,600	305,600	289,900	115,000	8,700	16,800	0	1,826,600	352,597
1988	194,400	137,200	100,800	200,500	451,900	77,100	307,500	304,600	123,800	9,000	17,000	0	1,923,800	360,056
1989	187,400	138,300	86,500	227,200	446,200	81,800	313,200	409,100	142,100	9,900	17,400	0	2,059,100	368,401
1990	177,200	140,400	75,200	253,600	413,300	86,000	312,300	409,300	148,700	11,000	17,000	0	2,044,000	376,300
1991	177,100	140,400	75,200	253,700	413,400	86,100	313,000	407,800	148,700	11,000	16,400	0	2,042,800	386,800
1992	177,100	140,400	75,200	253,700	413,400	86,100	313,000	407,800	148,700	11,000	16,400	0	2,042,800	399,659
1993	190,658	140,328	95,910	275,629	504,679	82,629	319,126	349,779	149,420	11,290	16,079	8,900	2,144,427	412,635
1994	177,338	140,620	75,536	253,700	413,400	88,290	314,680	410,905	153,296	11,000	16,400	8,900	2,064,065	425,265
1995	177,741	136,900	35,900	389,700	499,300	76,800	328,900	160,043	198,200	13,100	28,400	4,200	2,049,184	420,046
1996	171,784	138,800	18,600	392,800	490,940	79,710	347,550	246,262	199,100	18,700	29,100	4,400	2,137,746	425,219
1997	168,345	139,400	22,300	415,270	522,680	74,970	336,620	195,289	154,300	24,100	28,900	8,500	2,090,674	430,397
1998	168,505	156,100	16,400	368,460	492,700	75,450	364,300	142,244	160,000	27,500	29,000	8,700	2,009,359	435,566

Note: Table includes Delta land use

Table 2. CalSim II Historical North of Delta Demands and Contract Entitlements

DSA	Total Land Area (000 ac)	Crop Consumptive Use of Applied Water varies (taf/yr)	Regional Water Use Efficiency varies	Total Diversion/Pumping Requirement varies (taf/yr)	Minimum Groundwater Pumping (taf/yr)	Project Fraction of Demand	Project Diversion/Pumping Requirement varies (taf/yr)	Project Minimum Groundwater Pumping (taf/yr)	Net Project Diversion Requirement varies (taf/yr)	Maximum Contract Amount: Shasta Critical Year (taf/yr)	Maximum Contract Amount: Shasta Non-Critical Year (taf/yr)
58	1,603	72 - 147	0.59	122 - 249	36	0.90	110 - 224	32	77 - 192	205	255
10	755	285 - 426	0.63	450 - 672	348	0.19	86 - 128	66	19 - 62	41	43
12	914	690 - 1,009	0.59 - 0.63	1,155 - 1,663	29	0.75	866 - 1,247	22	845 - 1,226	1,009	1,250
15	351	366 - 708	0.67 - 0.69	548 - 1,040	54	0.66	362 - 686	36	326 - 651	598	797
65	592	368 - 615	0.82 - 0.84	440 - 749	130	0.12	53 - 90	16	37 - 74	68	90
69	910	844 - 1,195	0.57 - 0.71	1,406 - 2,023	302	0.70	984 - 1,416	211	773 - 1,205	630[10]	1,020
70	492	332 - 540	0.60	551 - 896	120	0.38	209 - 340	46	164 - 295	119[11]	158[11]

Notes:

1. The crop consumptive use of applied water is the portion of applied water that is used to meet crop evapotranspiration or is stored as soil moisture in the root zone.
2. The regional water use efficiency is the ratio of the crop consumptive use of applied water to the combined volume of stream diversion and groundwater pumping.
3. The diversion/pumping requirement is the combined volume of stream diversion and groundwater pumping required to meet the irrigation demand.
4. The minimum groundwater pumping is the volume of pumping that must occur before surface water is used to meet demand.
5. The project fraction of demand is the fraction of the total demand that is attributable to CVP or SWP water service contractors and settlement contractors.
6. The project diversion/pumping requirement is the combined volume of stream diversion and groundwater pumping required to meet the irrigation demand of CVP/SWP contractors.
7. The project minimum groundwater pumping is the volume of pumping by CVP/SWP contractors that must occur before surface water is used to meet CVP/SWP demands.
8. The net project diversion requirement is the required stream diversions to meet the CVP/SWP demands, i.e. after accounting for the project minimum groundwater pumping.
9. The maximum contract amount is the sum of CVP and SWP contractors’ entitlement. In Shasta critical years, settlement contractors are subject to a 25% cut.
10. Assuming “drought” conditions for the Feather River Service Area and a 50% imposed reduction.
11. Does not include CVP contracts on the American River.

Table 3. CalSim II Historical CVP Annual Contract Entitlement

Type	Maximum Contract Entitlement (taf/yr)
North-of-Delta[1]	
Settlement contractors	2,219
Urban water service contractors	19
Agricultural water service contractors	361
Wildlife Refuge Areas[2]	177
Total North-of-Delta	2,716
South-of-Delta	
Urban water service contractors	144
Agricultural water service contractors	1,841
Exchange contractors	875
Wildlife refuge areas	288
Losses[3]	184
Total South-of-Delta	3,332
Grand Total	6,048

Notes:

1. CVP contracts on the American River are not included.
2. Corresponds to the level 2 refuge demands for the Sacramento, Delevan, Colusa and Sutter National Wildlife Refuges and the Gray Lodge Wildlife Management Area. Includes 15% conveyance losses for the west-side wildlife refuges, 10% for Sutter NWR and 17% for Gray Lodge WMA.
3. Associated with the Delta Mendota Canal.

Table 4. Historical SWP Deliveries, Contractors Requests, Approved Allocations 1962 – 2003 (af)

Year	Table A South of Delta	Table A North of Delta	Art. 12D	Art. 14B	Art. 21 or Surplus	Turnback	Carryover	Total	Total Table A	Total* Table A South of Delta	CALSIM ** Format Table A Delivery	Contractor's Request	Approved Allocation
1962	-	-	-	-	-	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-	-	-	-	-	-
1964	-	-	-	-	-	-	-	-	-	-	-	-	-
1965	-	-	-	-	-	-	-	-	-	-	-	-	-
1966	-	-	-	-	-	-	-	-	-	-	-	-	-
1967	36,171	-	-	-	-	-	-	36,171	36,171	36,171	36,171	83,634	83,634
1968	182,389	-	-	-	110,854	-	-	293,243	182,389	182,389	182,389	191,500	191,500
1969	193,020	-	-	-	72,397	-	-	265,417	193,020	193,020	193,020	267,395	267,395
1970	233,923	70	-	-	131,848	-	-	365,841	233,993	233,923	233,923	252,787	252,787
1971	357,084	256	-	-	294,581	-	-	651,921	357,340	357,084	357,084	375,590	375,590
1972	611,110	691	-	-	422,322	-	-	1,034,123	611,801	611,110	611,110	594,054	594,054
1973	692,156	732	-	-	294,916	-	-	987,804	692,888	692,156	692,156	929,445	929,445
1974	873,300	775	-	-	412,453	-	-	1,286,528	874,075	873,300	873,300	959,335	959,335
1975	1,223,332	658	-	-	620,685	-	-	1,844,675	1,223,990	1,223,332	1,223,332	1,287,960	1,287,960
1976	1,372,093	909	-	-	531,685	-	-	1,904,687	1,373,002	1,372,093	1,377,958	1,368,462	1,368,462
1977	594,536	1,009	-	-	323,415	-	5,865	924,825	601,410	600,401	789,556	1,157,424	1,157,424
1978	1,289,752	857	139,034	-	16,215	-	55,986	1,501,844	1,485,629	1,484,772	1,497,356	1,828,624	1,828,624
1979	1,451,661	631	200,604	7,000	644,830	-	-	2,304,726	1,659,896	1,659,265	1,451,839	1,833,508	1,833,508
1980	1,535,716	562	-	-	405,417	-	178	1,941,873	1,536,456	1,535,894	1,536,775	1,569,964	1,569,964
1981	1,928,928	576	-	-	921,028	-	1,059	2,851,591	1,930,563	1,929,987	1,928,928	1,579,520	1,579,520
1982	1,752,809	639	-	-	239,734	-	-	1,993,182	1,753,448	1,752,809	1,752,809	2,064,110	2,064,110
1983	1,186,569	587	-	-	13,624	-	-	1,200,780	1,187,156	1,186,569	1,186,610	2,021,652	2,021,652
1984	1,590,944	557	-	-	271,017	-	41	1,862,559	1,591,542	1,590,985	1,593,941	1,567,520	1,567,520
1985	1,995,871	624	-	-	312,977	-	2,997	2,312,469	1,999,492	1,998,868	2,039,015	1,891,849	1,891,849
1986	1,961,027	958	-	-	36,863	-	43,144	2,041,992	2,005,129	2,004,171	1,961,027	2,364,193	2,364,193
1987	2,136,780	999	-	-	114,907	-	-	2,252,686	2,137,779	2,136,780	2,204,361	2,717,215	2,717,215
1988	2,317,976	1,211	-	-	-	-	67,581	2,386,768	2,386,768	2,385,557	2,467,131	2,595,120	2,595,120
1989	2,709,178	1,189	-	-	-	-	149,155	2,859,522	2,859,522	2,858,333	2,808,024	2,999,451	2,999,451
1990	2,452,178	1,422	-	-	90	-	98,846	2,552,536	2,552,446	2,551,024	2,479,213	3,116,623	2,648,993
1991	521,025	1,013	-	-	3,521	-	27,035	552,594	549,073	548,060	616,791	3,484,687	672,417
1992	1,374,444	1,244	3,484	-	1,156	-	92,282	1,472,610	1,471,454	1,470,210	1,596,028	3,630,618	1,634,685
1993	2,092,205	1,446	1,999	-	-	-	219,585	2,315,235	2,315,235	2,313,789	2,092,205	2,750,395	2,750,395
1994	1,747,495	1,856	-	-	112,625	-	-	1,861,976	1,749,351	1,747,495	1,825,496	2,691,379	1,911,027
1995	1,869,671	1,421	-	25,000	64,330	-	53,001	2,013,423	1,949,093	1,947,672	2,003,085	3,159,450	2,344,076
1996	2,205,065	1,437	-	-	28,647	174,909	133,414	2,543,472	2,514,825	2,513,388	2,379,974	2,701,707	2,701,707
1997	2,289,565	1,421	-	-	21,432	62,544	-	2,374,962	2,353,530	2,352,109	2,408,225	2,977,246	2,977,246
1998	1,616,922	1,581	-	17,180	20,288	75,000	38,936	1,769,907	1,749,619	1,748,038	1,691,922	3,191,045	3,191,045
1999	2,520,084	1,382	-	-	158,070	217,437	-	2,896,973	2,738,903	2,737,521	2,955,913	3,214,259	3,214,259
2000	2,711,984	1,487	-	-	308,257	282,305	218,392	3,522,425	3,214,168	3,212,681	3,328,414	3,617,267	3,406,083
2001	1,387,828	1,578	-	-	40,779	18,140	334,125	1,782,450	1,741,671	1,740,093	1,566,567	4,124,136	1,607,570
2002	2,521,654	1,589	-	-	43,116	45,252	160,599	2,772,210	2,729,094	2,727,505	***	3,913,698	2,887,014
2003												4,126,926	3,714,233
Total	53,536,445	33,367	345,121	49,180	6,994,079	875,587	1,702,221	63,536,000	56,541,921	56,508,554	53,941,648	79,199,748	68,161,062

* Total Table A South of Delta Delivery = Table A South of Delta + Art. 12D + Art. 14B + Turnback + Carryover

** CALSIM Format Table A Delivery = Table A South of Delta + Next year's Art. 12D + Next year's Art. 14B + Turnback + Next year's Carryover

*** Year 2003 Art. 12D, Art. 14B and carryover are needed to calculate 2002 delivery in CALSIM format

Table 5. SWP Table A Model Demands

Calendar Year	Sacramento River Index Classification	Model Demand Assumptions	Contractors' Total Request (taf)	CalSim Format Table A Delivery (taf)	Model Demand (taf)
1975	W	Historical Delivery	1,288	1,223	1,223
1976	C	Historical Delivery	1,368	1,378	1,378
1977	C	Contractors Request	1,157	790	1,157
1978	AN	Historical Delivery	1,829	1,497	1,497
1979	BN	Contractors Request	1,834	1,452	1,834
1980	AN	Historical Delivery	1,570	1,537	1,537
1981	D	Contractors Request	1,580	1,929	1,580
1982	W	Historical Delivery	2,064	1,753	1,753
1983	W	Historical Delivery	2,022	1,187	1,187
1984	W	Historical Delivery	1,568	1,594	1,594
1985	D	Contractors Request	1,892	2,039	1,892
1986	W	Historical Delivery	2,364	1,961	1,961
1987	D	Contractors Request	2,717	2,204	2,717
1988	C	Contractors Request	2,595	2,467	2,595
1989	D	Contractors Request	2,999	2,808	2,999
1990	C	Contractors Request	3,117	2,479	3,117
1991	C	Contractors Request	3,485	617	3,485
1992	C	Contractors Request	3,631	1,596	3,631
1993	AN	Historical Delivery	2,750	2,092	2,092
1994	C	Contractors Request	2,691	1,825	2,691
1995	W	Historical Delivery	3,159	2,003	2,003
1996	W	Historical Delivery	2,702	2,380	2,380
1997	W	Historical Delivery	2,977	2,408	2,408
1998	W	Historical Delivery	3,191	1,692	1,692

Table 6. CalSim II Historical Regulatory Standards and Operating Criteria Assumptions

Period of Simulation	WY: 1974-1992	WY: 1993-1994	WY: 1995-1998
Regulatory Standards			
Trinity River			
Minimum Flow below Lewiston Dam	Not modeled	Same	Same
Trinity Reservoir End-of-September Minimum Storage	Not modeled	Same	Same
Clear Creek			
Minimum Flow below Whiskeytown Dam	Downstream water rights, 1963 Reclamation Proposal to USFWS and NPS	Same	Same
Upper Sacramento River			
Shasta Lake End-of-September Minimum Storage	None	SWRCB WR 1993 Winter-run Biological Opinion (1900 taf)	Same
Minimum Flow below Keswick Dam	Flows for SWRCB WR 90-5	Flows for SWRCB WR 90-5 and 1993 Winter-run Biological Opinion temperature control	Same
Feather River			
Minimum Flow below Thermalito Diversion Dam	1983 DWR, DFG Agreement (600 cfs)	Same	Same
Minimum Flow below Thermalito Afterbay outlet	1983 DWR, DFG Agreement (1000 – 1700 cfs)	Same	Same
American River			
Minimum Flow below Nimbus Dam	SWRCB D-893 (see accompanying Operations Criteria)	Same	Same
Minimum Flow at H Street Bridge	SWRCB D-893	Same	Same
Lower Sacramento River			
Minimum Flow near Rio Vista	SWRCB D-1485	Same	SWRCB D-1641
Sacramento-San Joaquin Delta	SWRCB D-1485	Same	SWRCB D-1641

Period of Simulation	WY: 1974-1992	WY: 1993-1994	WY: 1995-1998
Operations Criteria			
Upper Sacramento River			
Flow Objective for Navigation (Wilkins Slough)	Discretionary 3,500 – 5,000 CFS based on Lake Shasta storage condition	Same	Same
American River			
Folsom Dam Flood Control	SAFCA, Interim-Reoperation of Folsom Dam, Variable 400/670 (without outlet modifications)	Same	Same
Flow below Nimbus Dam	Discretionary operations criteria corresponding to SWRCB D-893 required minimum flow	Same	Same
CVP Water Allocation			
CVP Settlement and Exchange	100% (75% in Shasta Critical years)	Same	Same
CVP Refuges	100% (75% in Shasta Critical years)	Same	Same
CVP Agriculture	100% - 0% based on supply	Same	Same
CVP Municipal & Industrial	100% - 50% based on supply	Same	Same
SWP Water Allocation			
North of Delta (FRSA)	Contract specific	Same	Same
South of Delta	Based on supply; Monterey Agreement	Same	Same
CVP/SWP Coordinated Operations			
Sharing of Responsibility for In-Basin-Use	1986 Coordinated Operations Agreement	Same	Same
Sharing of Surplus Flows	1986 Coordinated Operations Agreement	Same	Same
Sharing of Restricted Export Capacity	Not Applicable	Same	Equal sharing of export capacity under SWRCB D-1641

Table 7. Summary of Key Results

Figure/ Table	Performance Parameter	Dry-period average 1987-1992 Simulated (taf/yr)	Historical (taf/yr)	Difference (taf/yr)	(%)	Long-term average Simulated (taf/yr)	Historical (taf/yr)	Difference (taf/yr)	(%)
F.10, F.12	SWP south-of-Delta Table A deliveries	1,930	2,030	-100	-4.9	1,810	1,790	20	1.1
F.11	Total carryover storage in SWP reservoirs	2,020	1,910	110	5.8	3,190	2,810	380	13.5
F.16	SWP north-of-Delta deliveries	810	770	40	5.2	880	840	40	4.8
F.17, F.19	CVP south-of-Delta deliveries	2,230	2,320	-90	-3.9	2,650	2,490	160	6.4
F.18	Total carryover storage in CVP reservoirs	2,880	2,290	590	25.8	3,560	3,380	180	5.3
F.24	CVP north-of-Delta deliveries	1,960	1,810	150	8.3	1,960	1,750	210	12
F.25, F.26	Delta exports by Banks and Tracy pumping plants	4,450	4,460	-10	-0.2	4,670	4,320	350	8.1
F.27, F.28	Delta exports by Banks Pumping Plant	2,010	2,220	-210	-9.5	2,090	1,980	110	5.6
F.29, F.30	Delta exports by Tracy Pumping Plant	2,440	2,240	200	8.9	2,580	2,340	240	10.3
F.31	Sacramento River flow below Red Bluff diversion dam	5,830	5,860	-30	-0.5	9,020	9,100	-80	-0.9
F.32	Sacramento River flow at Ord Ferry	6,510	6,620	-110	-1.7	10,960	11,090	-130	-1.2
F.33	Sacramento River flow at Knights Landing	5,080	5,290	-210	-4.0	9,400	9,840	-440	-4.5
F.34	Feather River flow at mouth	3,000	2,800	200	7.1	6,740	6,820	-80	-1.2
F.35	Sacramento Valley inflow to the Delta	9,700	9,670	30	0.3	19,830	19,920	-90	-0.5
F.36	Sacramento Valley net accretion	1,103	1,155	-52	-4.5	5,920	5,950	-30	-0.5
F.37	Net Delta Outflow Index	5,270	5,090	180	3.5	19,070	19,690	-620	-3.1

Notes:
1. SWP long-term average deliveries are for the period 1975-1997.
2. CVP long-term average deliveries are for the period 1982-1997.
3. Historical exports for Banks do not include Article 21 and Drought Water Bank water.
4. Figures rounded to nearest 10 taf.

Table 8. Average Annual Net Groundwater Pumping

	DSA 58 (taf/yr)	DSA 10 (taf/yr)	DSA 12 (taf/yr)	DSA 15 (taf/yr)	DSA 65 (taf/yr)	DSA 69 (taf/yr)	DSA 70 (taf/yr)	Total (taf/yr)
1975-1998 long-term average								
CalSim II	18	305	68	28	349	145	144	1,058
CVGSM	56	368	72	255	262	222	201	1,436
Difference	-38	-63	-4	-227	87	-77	-57	-378
1987-1992 dry-period average								
CalSim II	16	313	33	28	342	215	127	1074
CVGSM	58	391	2	163	247	104	171	1136
Difference	-42	-78	31	-135	95	111	-44	-62

Table 9. Average Annual Stream Gain from Groundwater

	DSA 58 (taf/yr)	DSA 10 (taf/yr)	DSA 12 (taf/yr)	DSA 15 (taf/yr)	DSA 65 (taf/yr)	DSA 69 (taf/yr)	DSA 70 (taf/yr)	Total (taf/yr)
1975-1998 long-term average								
CalSim II	91	53	N/A	65	N/A	57	-23	243
CVGSM	77	44	N/A	-70	N/A	69	-67	53
Difference	14	9	N/A	135	N/A	-12	44	190
1987-1992 dry-period average								
CalSim II	92	54	N/A	99	N/A	52	-11	286
CVGSM	71	59	N/A	-4	N/A	112	-61	178
Difference	21	-5	N/A	103	N/A	-60	50	108

Figures

Figure 1. Major Features of California's Water System

Figure 2. Geographical Coverage of CalSim II

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Figure 3a. CalSim II Schematic for Historical Operations Study, Sheet 1 of 2

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Figure 3b. CalSim II Schematic for Historical Operations Study, Sheet 2 of 2

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Figure 4. Depletion Study Areas

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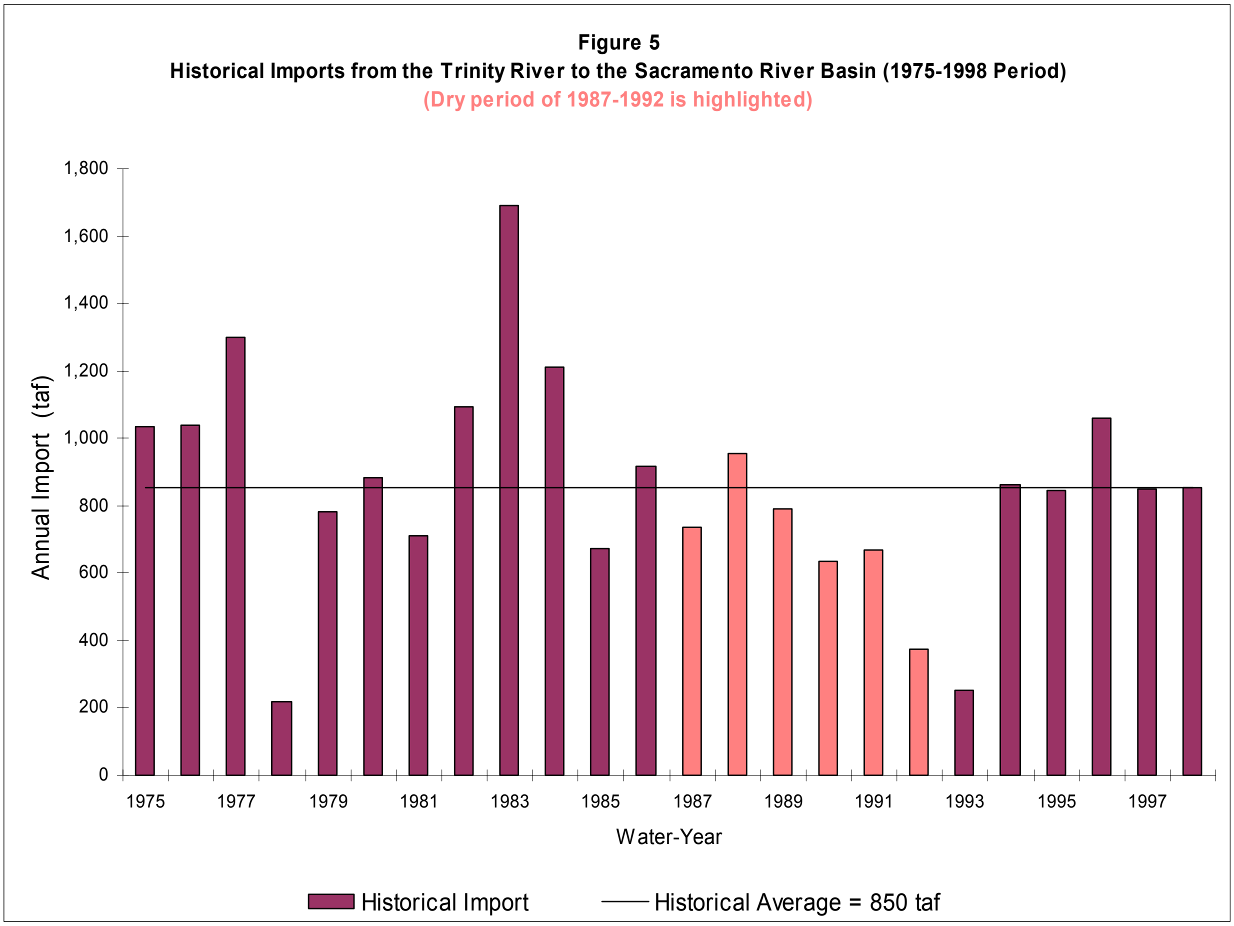

Figure 5 shows the historical imports through the Clear Creek Tunnel for the 1975-1998 period used in the Historical Operations Study for the CalSim II evaluation. The average annual import during the 6-year drought of 1987-1992 is about 670 taf per year.

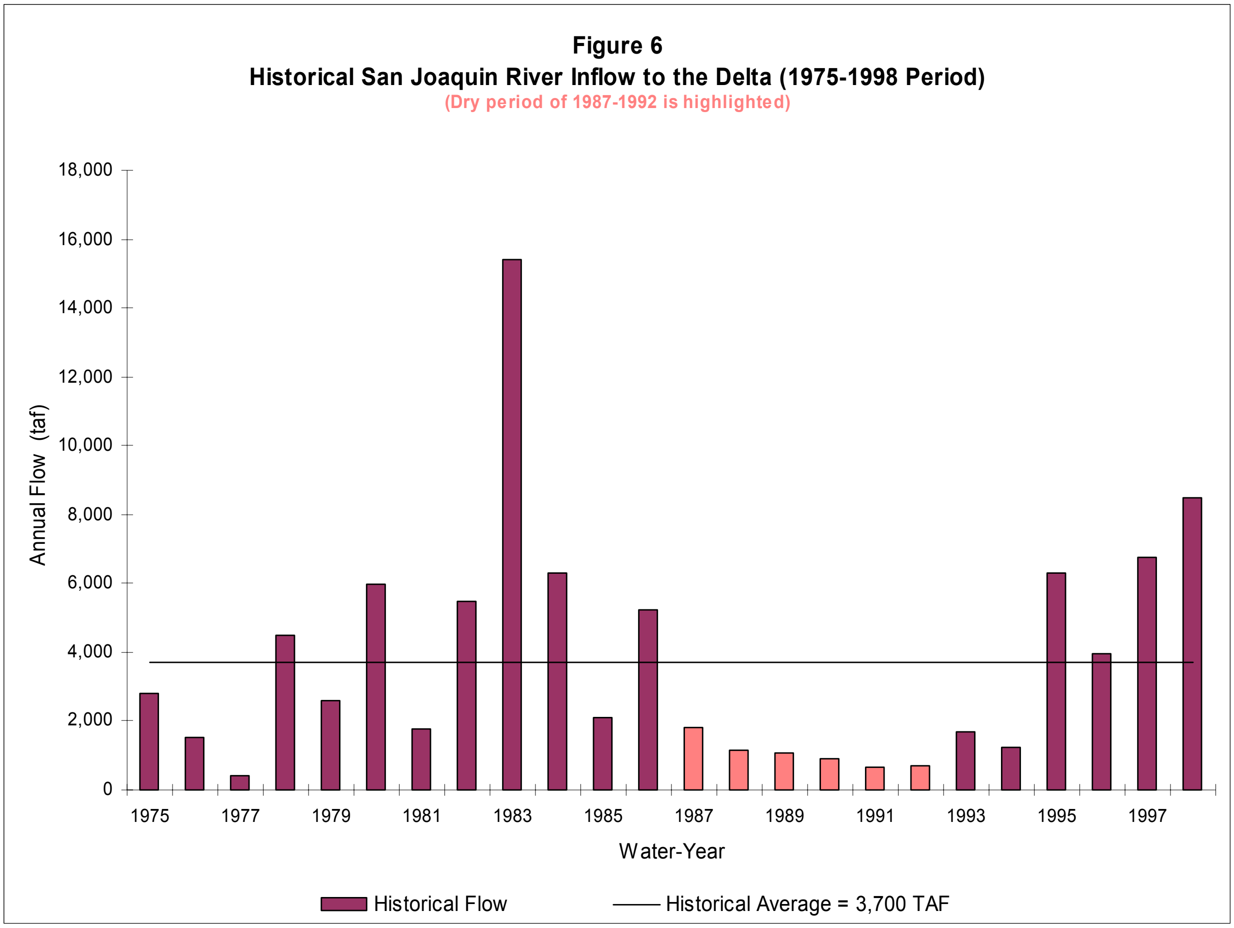

Figure 6 shows the historical inflow to the Delta from the San Joaquin River for the 1975-1998 period. These historical values were used in the Historical Operations Study for the CalSim II evaluation. The average annual inflow during the 6-year drought of 1987-1992 is about 1,050 taf per year.

Figure 7
Historical Eastside Streams Inflow to the Delta (1975-1998 Period)
(Dry period of 1987-1992 is highlighted)

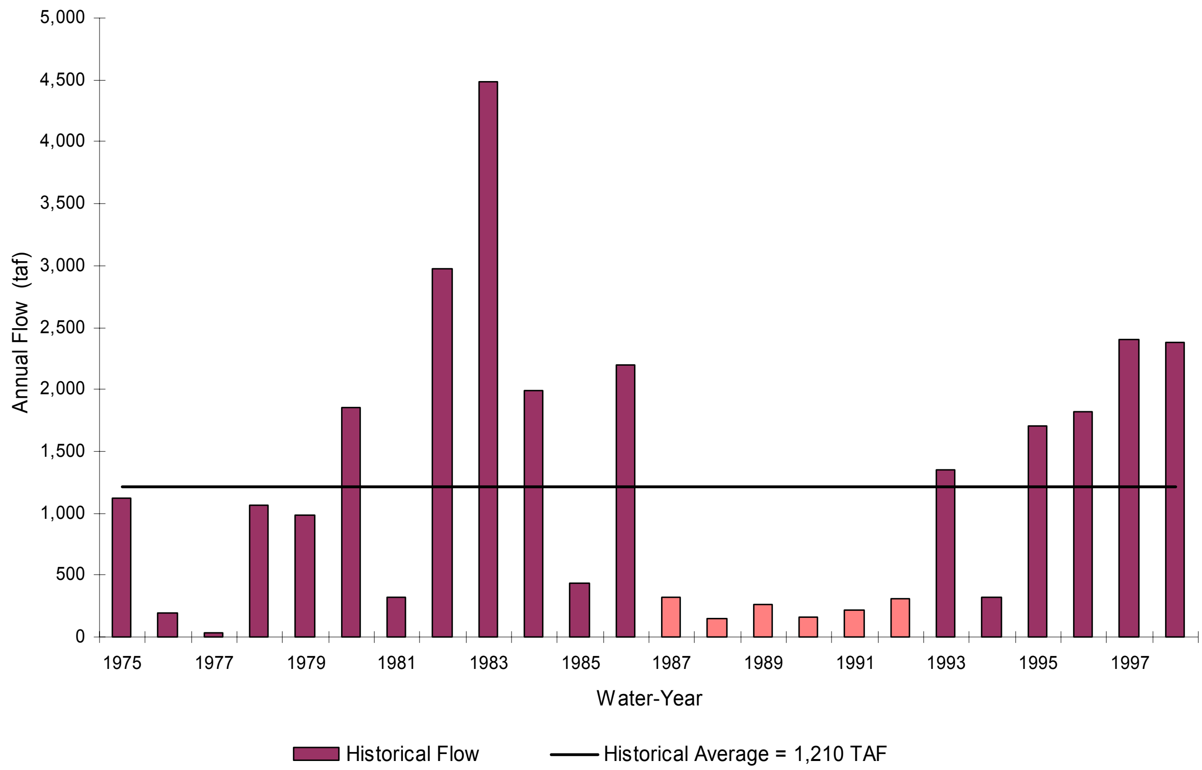

Figure 7 shows the historical inflow to the Delta from the Eastside Streams, including the Cosumnes, Mokelumne, and the Calaveras rivers for the 1975-1998 period. These historical values were used in the Historical Operations Study for the CalSim II evaluation. The average annual inflow during the 6-year drought of 1987-1992 is about 240 taf per year.

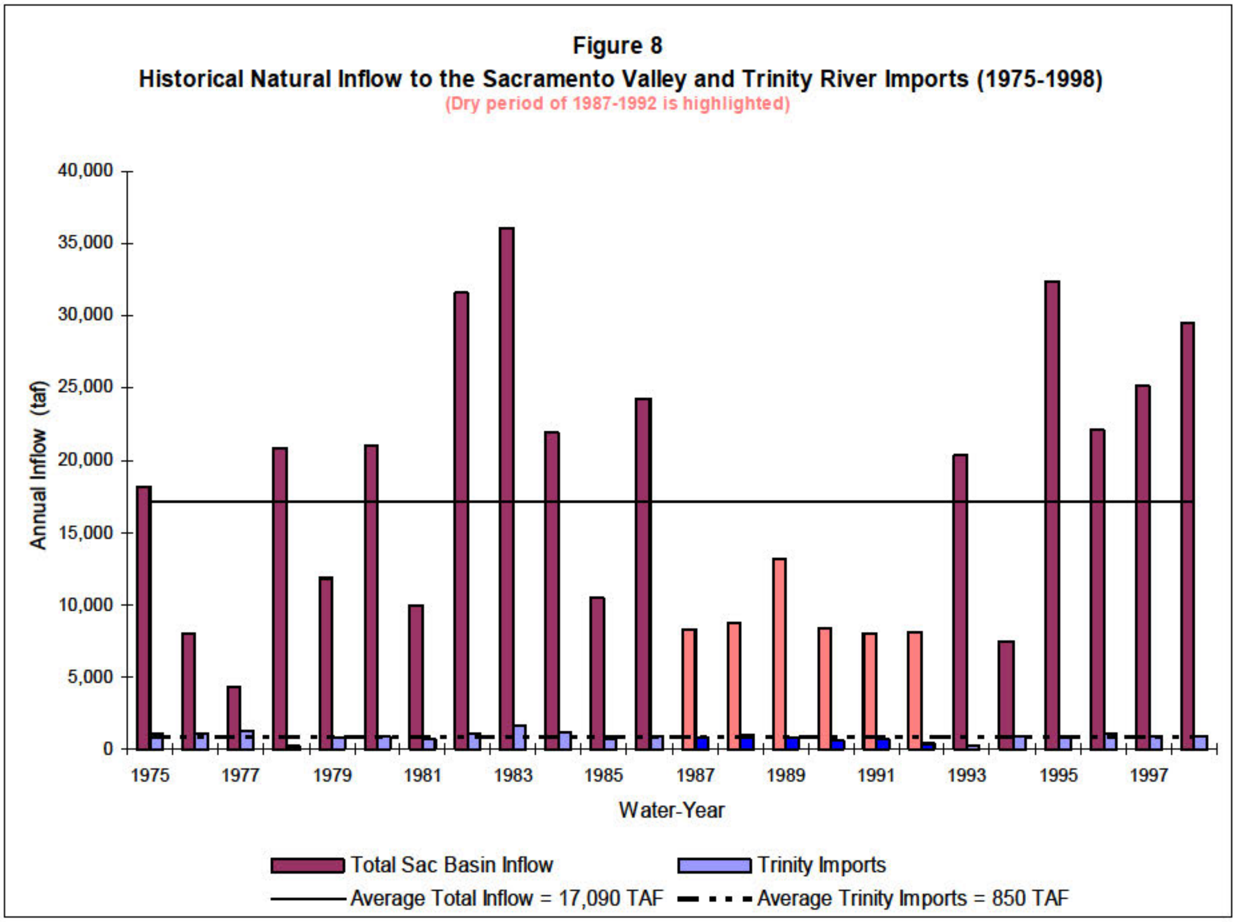

Figure 8 shows a comparison between the historical Trinity imports and the total historical natural inflow to the Sacramento Valley. Natural inflow consists of the inflow to major reservoirs and basin accretions. The long-term average import from the Trinity River is only about 5.0 percent of the total natural inflow to the Sacramento Valley. The historical average annual natural inflow to the Sacramento Valley during the 6-year drought of 1987-1992 is about 9,130 taf per year. The average for the historical imports from the Trinity River during the drought is 670 taf per year, about 7.3 percent, as compared to the natural inflow.

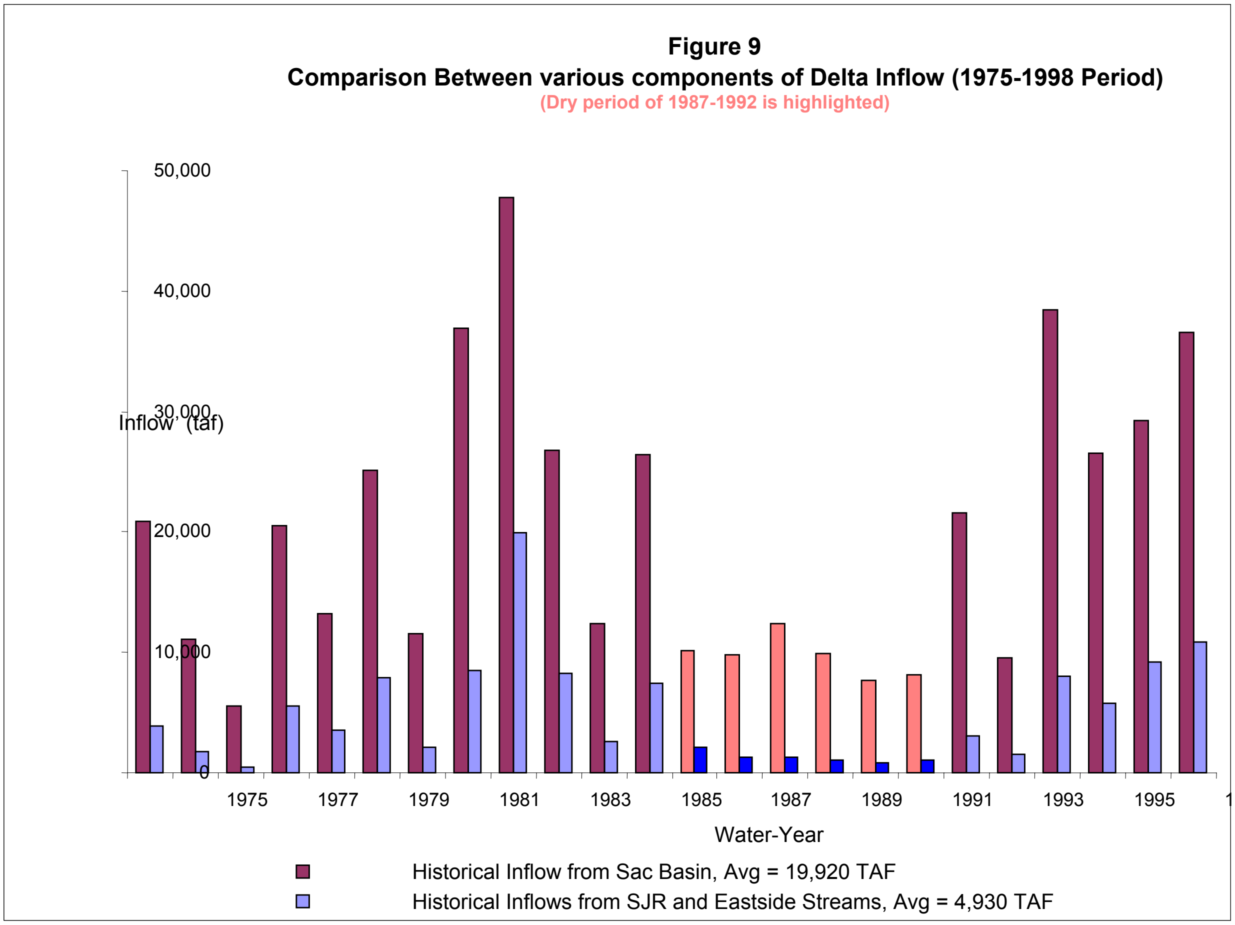

Figure 9 shows a comparison between the historical inflow to the Delta from the combined San Joaquin River and the Eastside Streams and the historical Delta inflow from the Sacramento Basin. The long-term average of the inflows from the San Joaquin River and the Eastside Streams are about 24.8 percent of the historical Delta inflow from the Sacramento Basin. The historical average annual inflow from the Sacramento Valley during the 6-year drought of 1987-1992 is about 9,670 taf per year. The average for the historical inflow from the San Joaquin Basin and the Eastside Streams during the drought is 1,340 taf per year, about 13.9 percent of the inflow from the Sacramento Basin.

Figure 10
SWP South-of-DeltaTable A Deliveries (1975-1997 Period)
(Dry period of 1987-1992 is highlighted)

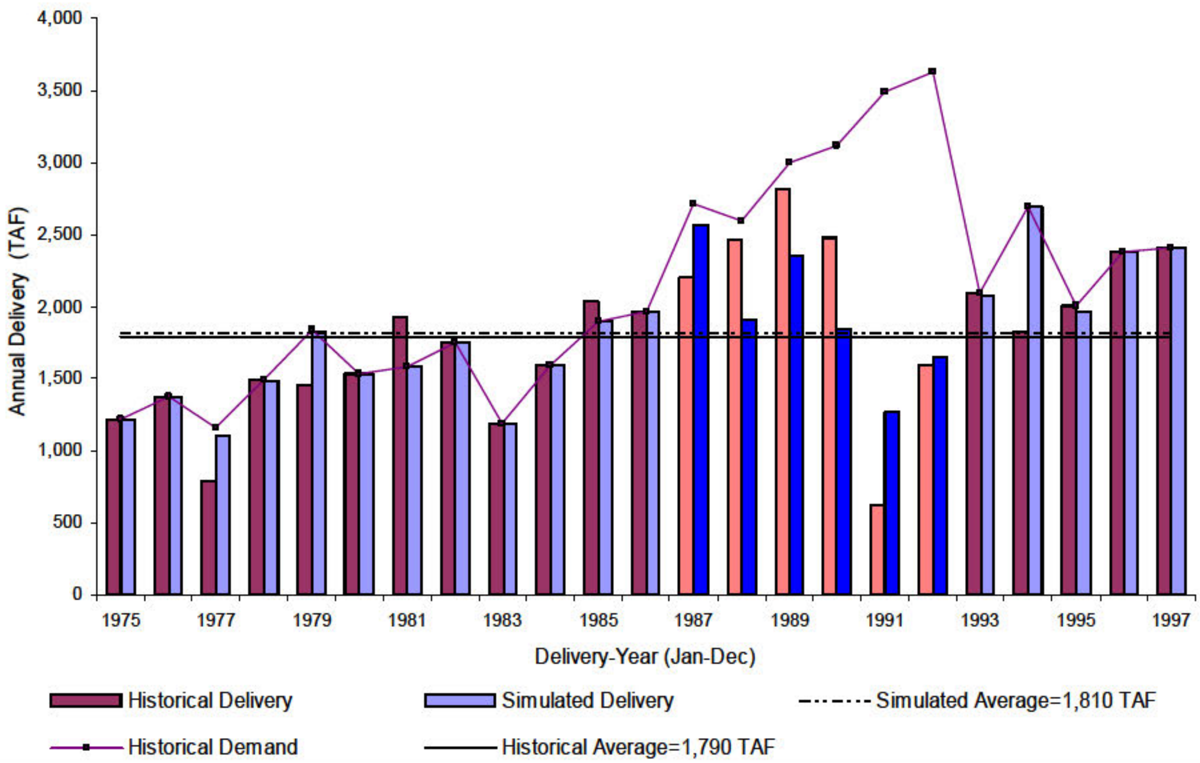

Figure 10 shows a comparison of historical and simulated SWP deliveries to south-of-Delta contractors for calendar years 1975 to 1997. Simulated deliveries in 1981 and 1985 are lower than historical deliveries due to the lower initial contractors requests used as demands for those years according to the rules discussed in Section 4.4.3. The higher historical deliveries, however, indicate that there might have been a revision in contractors' requests for higher deliveries subsequent to their submission of initial requests. Long-term average of the simulated deliveries exceeds that of the historical deliveries by approximately 1.1 percent. Both historical and simulated deliveries include only Table A deliveries without any Article 21 or non-project deliveries.

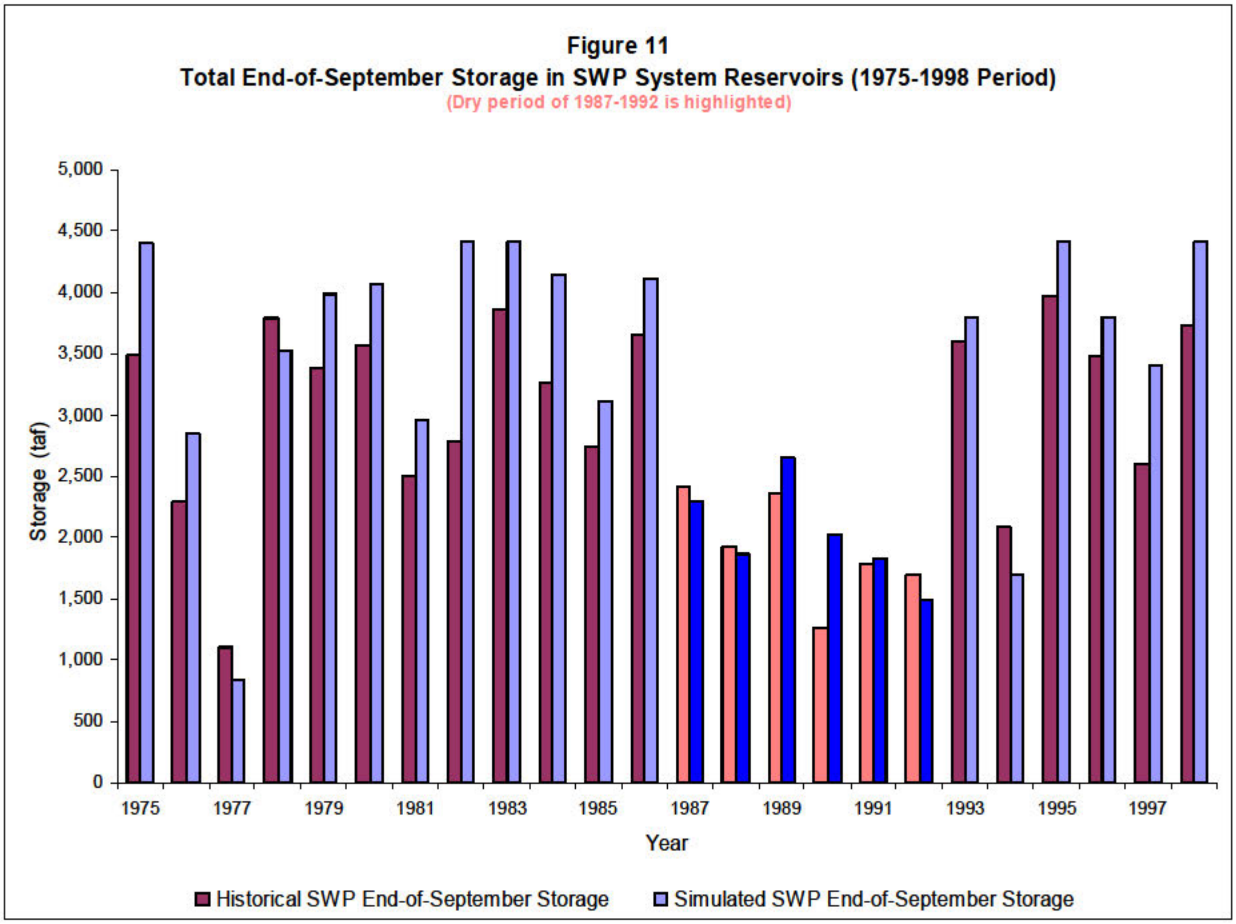

Figure 11 shows the total storage in the SWP system reservoirs at the end of each water year. The carryover storage in the system (Lake Oroville + SWP San Luis Reservoir) is one of the factors that determine the SWP allocations.

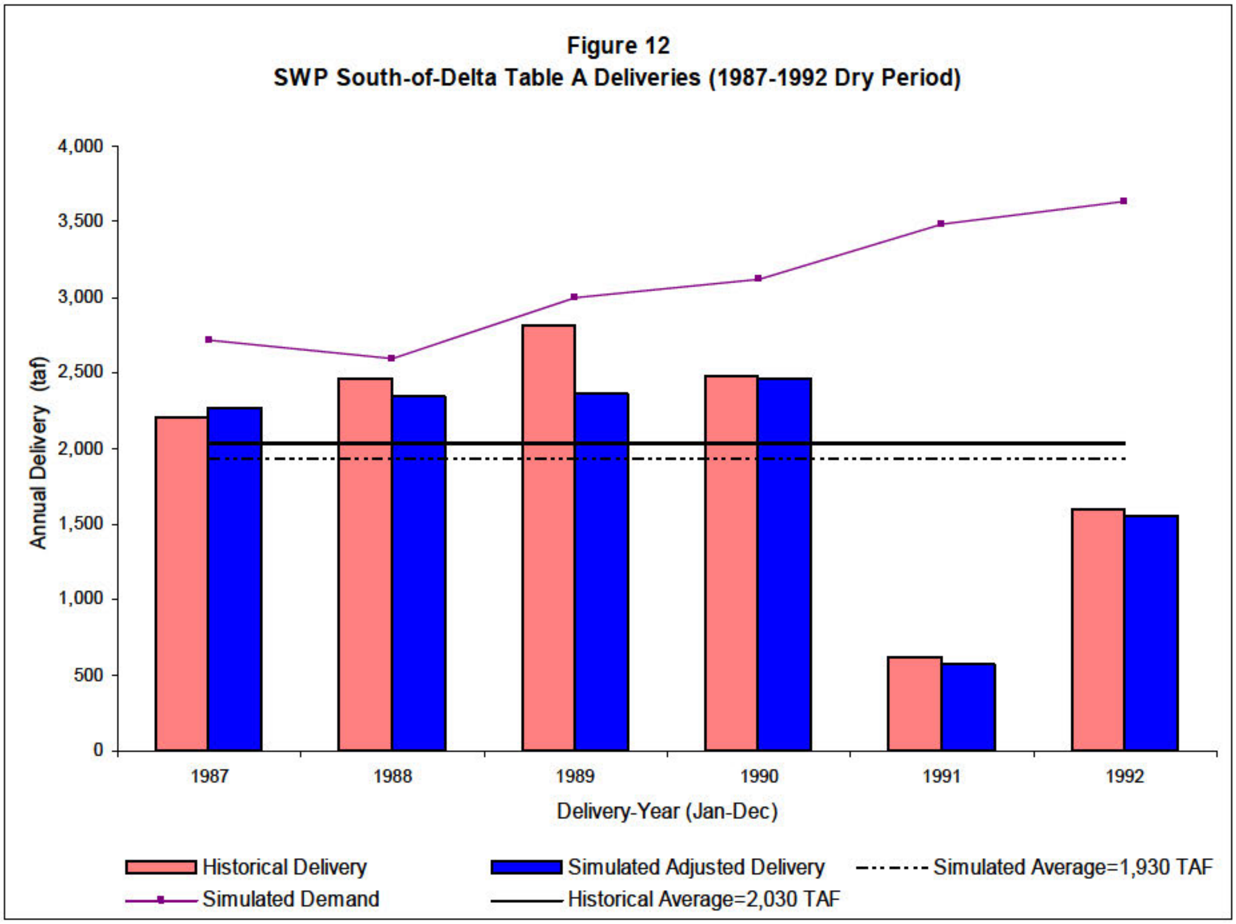

Figure 12 shows a comparison of historical and simulated SWP deliveries to south-of-Delta contractors during the drought of 1987-1992. Simulated annual deliveries during the drought have been adjusted to account for the difference in storage utilization in any given year. After the corrections for storage utilization, the 6-year critical period average of the simulated deliveries is lower than that of the historical deliveries by approximately 4.9 percent. The adjusted simulated deliveries shown in the bar chart are computed as the gross delivery for each calendar year of simulation minus the difference between the historical and simulated values of storage used from January 1 to December 31 of that year. For the first year of the drought, 1987, the storage difference between March 31 (the highest system storage just before the onset of the drought) and December 31 was used. Storage differences are based on the total SWP system storage (Oroville and SWP San Luis). Both, historical and simulated deliveries include only Table A deliveries to the south-of-Delta contractors, without any Article 21 or any non-project deliveries.

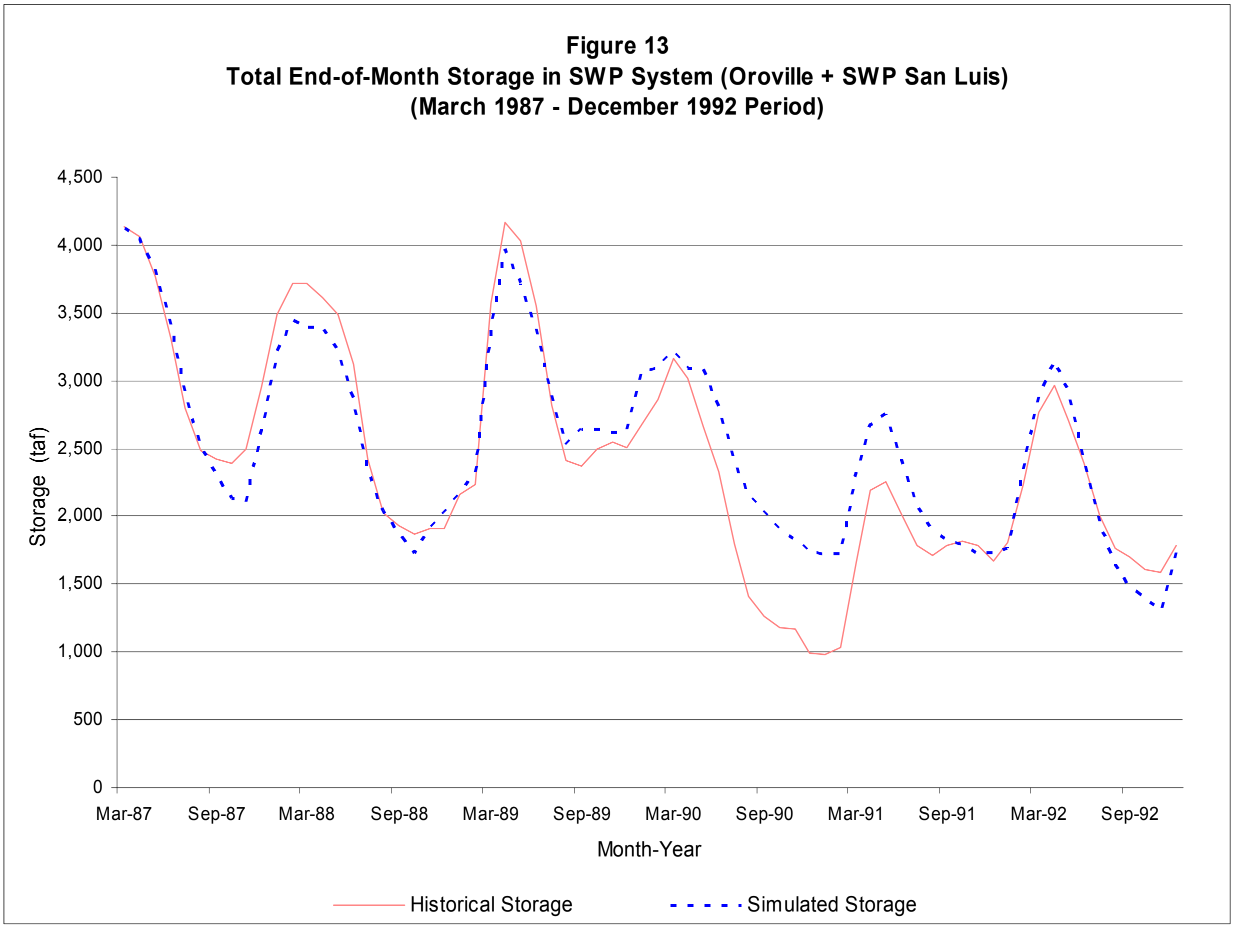

Figure 13 shows a line plot of the end-of-month SWP storage (Oroville plus SWP San Luis) for the 1987-1992 drought. The historical storage at the outset of the drought on March 31, 1987 was 4,139 taf. The corresponding storage marking the end of the drought on November 30, 1992 was 1,591 taf. The table below lists the storage values and the corresponding annual changes in storage for the beginning of each calendar year. The storage change for the first year of the drought was based on the end of March 1987 when the system storage was at its highest level before the drought began. Differences in the historical operation criteria and those used in the simulation study may result in different ending storages in SWP system. These storage differences were used to compute the adjustments for delivery bar charts presented in Figure 12.

	Historical		Simulated		Difference
	Storage	Storage Change	Storage	Storage Change	
March 31 1987	4,139	NA	4,120	NA	NA
January 1 1988	2,958	1,181	2,634	1,486	305
January 1 1989	1,908	1,050	2,026	608	-442
January 1 1990	2,505	-597	2,635	-609	-12
January 1 1991	993	1,512	1,738	897	-615
January 1 1992	1,675	-682	1,730	8	690
January 1 1993	1,785	-110	1,748	-18	92

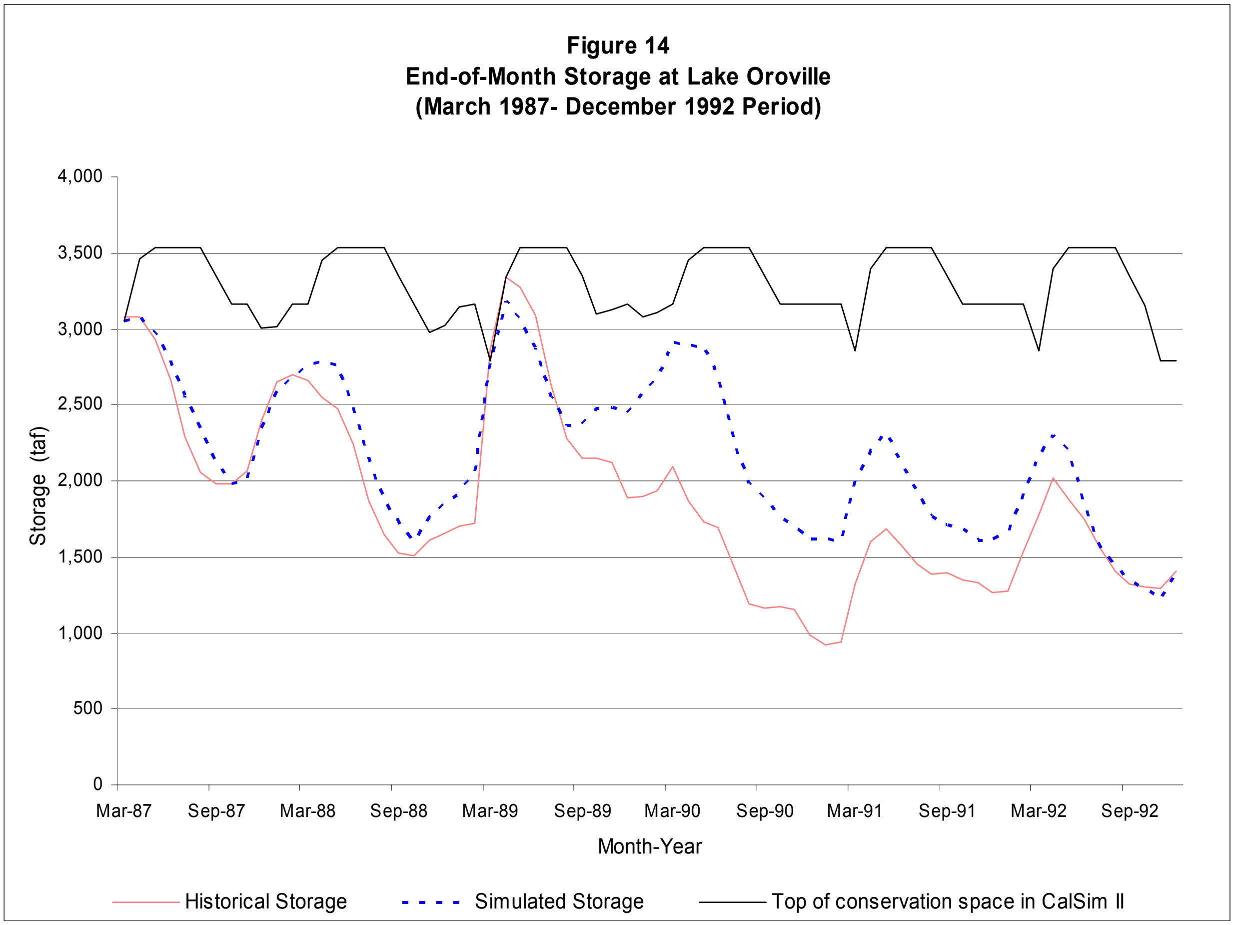

Figure 14 shows a line plot of end-of-month storage in Lake Oroville for the 1987-1992 drought. The historical storage at the outset of the drought on March 31, 1987, was 3,087 taf. The corresponding storage marking the end of the drought on November 30, 1992, was 1,294 taf. The table below lists the storage values and the corresponding annual changes in storage for the beginning of each calendar year. The storage change for the first year of the drought was based on the end-of-March 1987 quantities when the system storage was at its highest level, just before the drought began. Differences in the historical operation criteria and those used in the simulation study may result in different ending storages in Lake Oroville.

	Historical		Simulated		Difference
	Storage	Storage Change	Storage	Storage Change	
March 31 1987	3,078	NA	3,053	NA	NA
January 1 1988	2,388	690	2,344	709	19
January 1 1989	1,660	728	1,849	495	-233
January 1 1990	1,889	-229	2,445	-596	-367
January 1 1991	987	902	1,618	827	-75
January 1 1992	1,266	-279	1,620	- 2	277
January 1 1993	1,402	-136	1,382	238	374

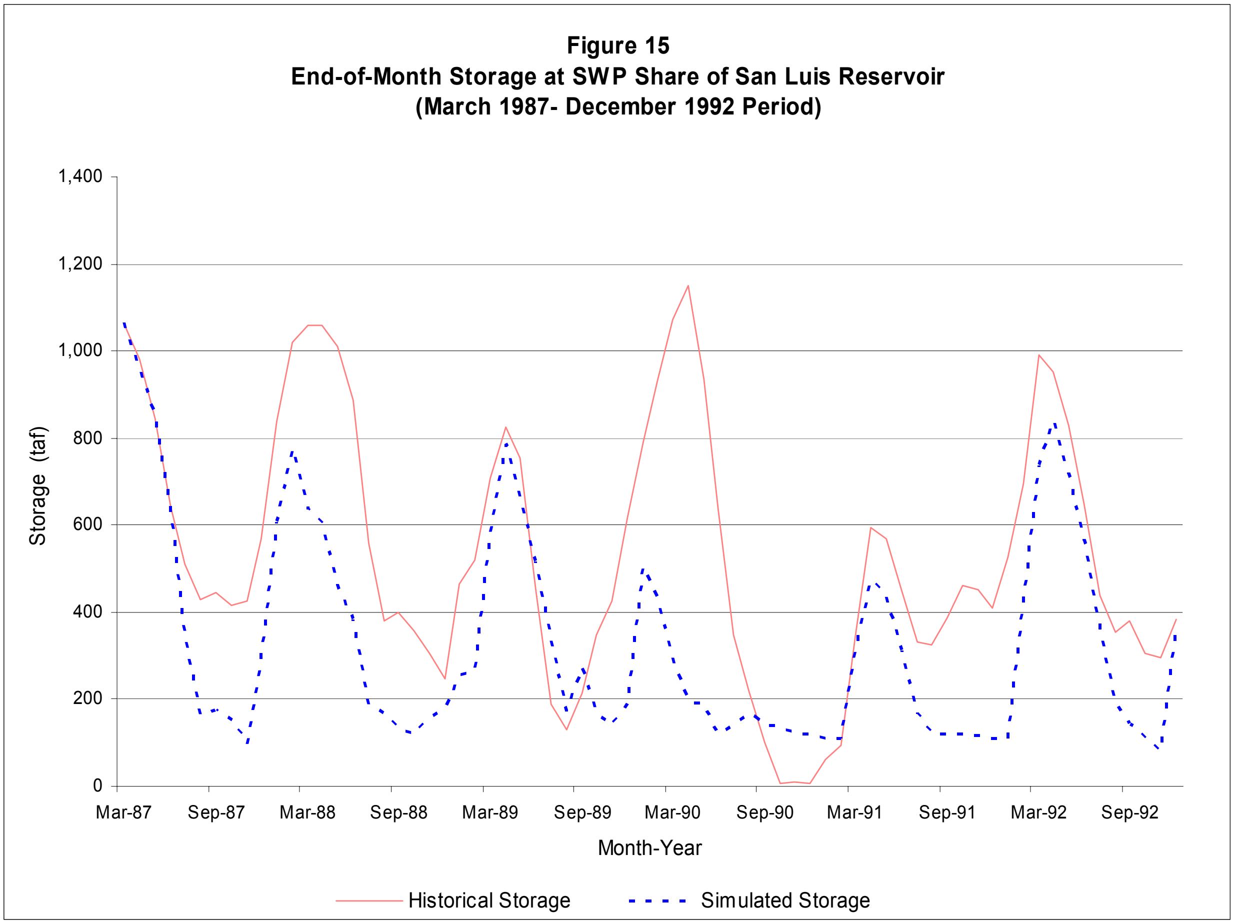

Figure 15
End-of-Month Storage at SWP Share of San Luis Reservoir
(March 1987- December 1992 Period)

Figure 15 shows a line plot of end-of-month storage in SWP portion of San Luis Reservoir for the 1987-1992 drought. The historical storage at the outset of the drought on March 31, 1987, was 1,061. The corresponding storage marking the end of the drought on November 30, 1992, was 297. The table below lists the storage values and the corresponding annual changes in storage for the beginning of each calendar year. The storage change for the first year of the drought was based on the end-of-March 1987 quantities when the system storage was at its highest level, just before the drought began. Differences in the operation criteria and SWP San Luis rule curve between the historical operation and those used in the simulation study may result in different ending storages in San Luis Reservoir.

	Historical		Simulated		Difference
	Storage	Storage Change	Storage	Storage Change	
March 31 1987	1,061	NA	1,067	NA	NA
January 1 1988	570	491	291	776	285
January 1 1989	248	322	176	115	-207
January 1 1990	616	-368	190	-14	354
January 1 1991	6	610	119	71	-539
January 1 1992	410	-404	110	9	413
January 1 1993	383	27	366	-256	-283

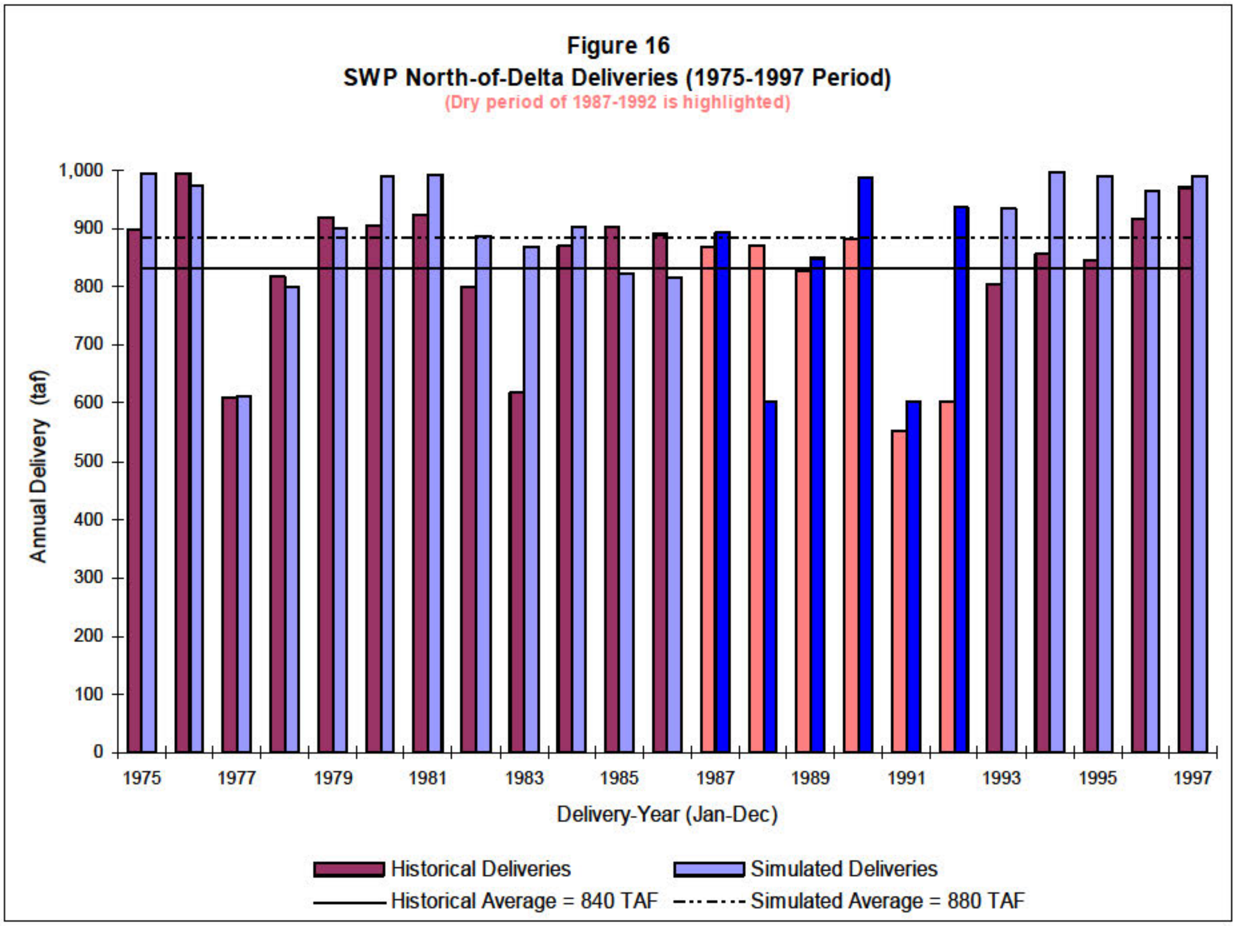

Figure 16 shows the bar chart of comparison between the historical and simulated deliveries made to SWP north-of-Delta contractors and senior water right holders in FRSA for the period of 1975-1997. The total includes deliveries made to all of the senior water rights holders downstream of Lake Oroville (i.e. Joint Water District Board, Western Canal Water District, Garden Highway Mutual Water Company, Plumas Mutual Water Company, Thermalito Irrigation District, Tudor Mutual Water Company, and Oswald Water District). The long-term average of the simulated deliveries exceeds that of the historical deliveries by approximately 4.8 percent. The historical average annual delivery during the 6-year drought of 1987-1992 is about 770 taf per year. The average for the simulated values during the drought is 810 taf per year, a difference of about 5.2 percent.

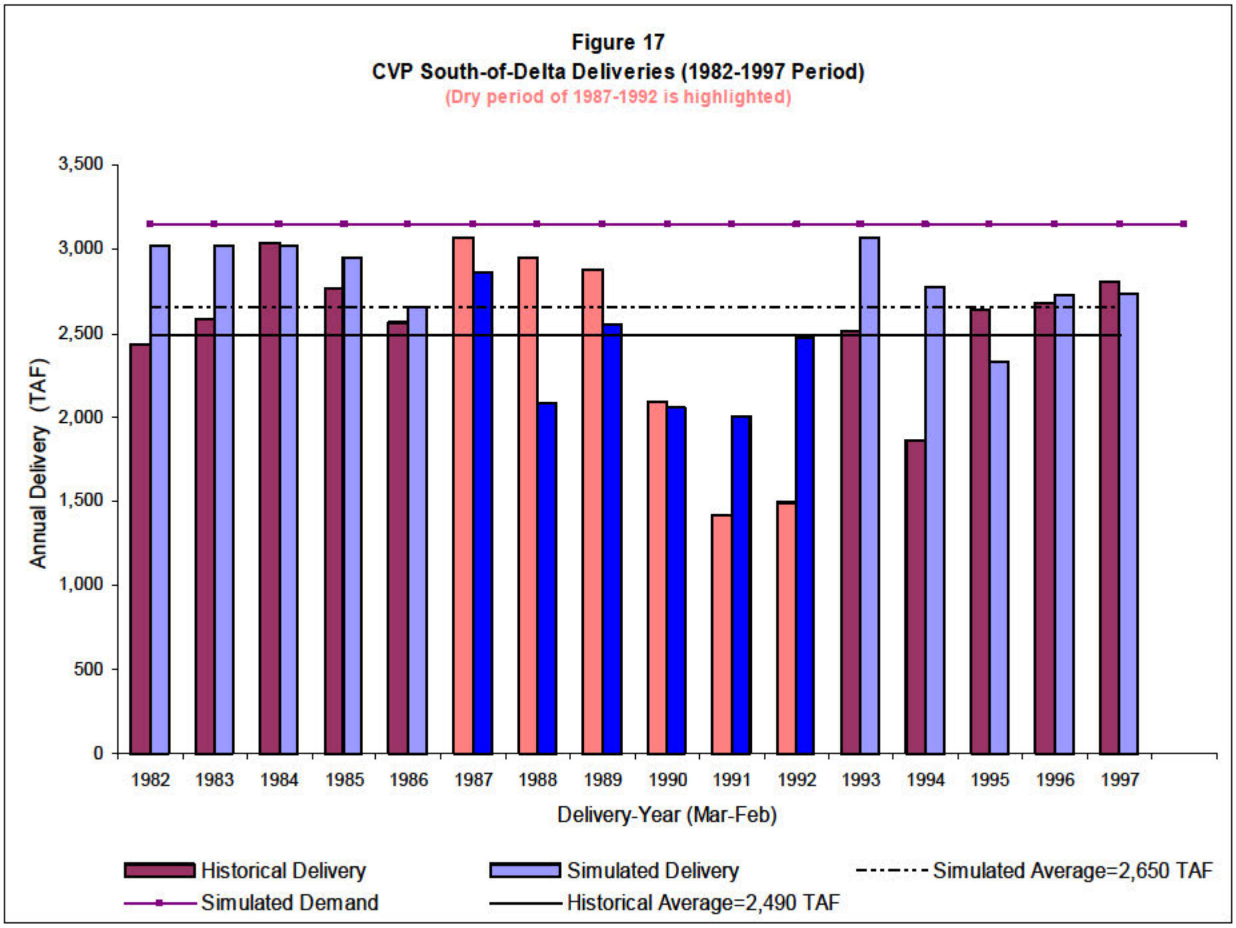

Figure 17 shows a comparison of historical and simulated CVP deliveries to south-of-Delta contractors for calendar years 1982 to 1997. The long-term average of the simulated deliveries exceeds that of the historical deliveries by approximately 6.4 percent. Differences between demand and other operation between historical and simulation criteria may result in different deliveries.

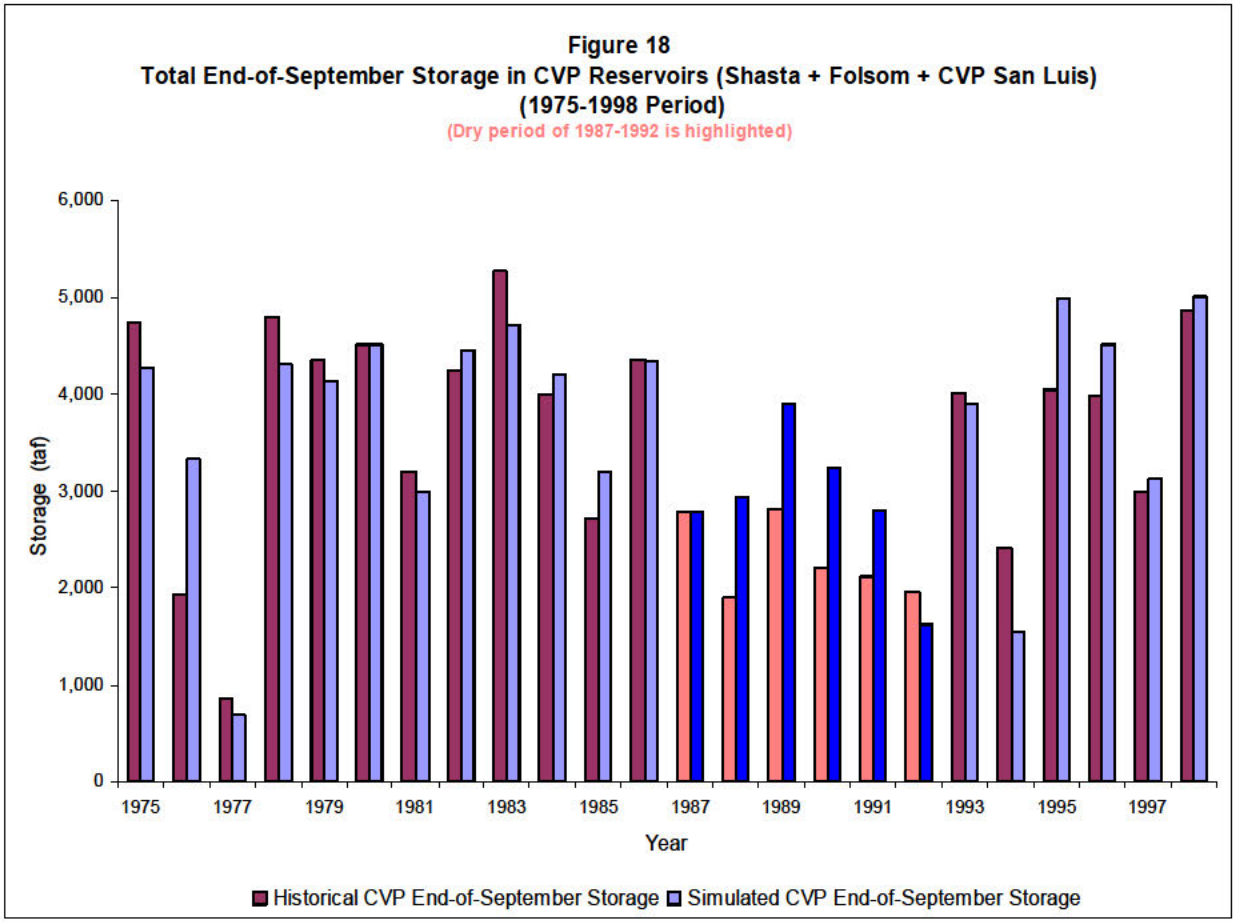

Figure 18 shows the total storage in the CVP system (Shasta, Folsom, CVP San Luis) reservoirs at the end of each water year. System carryover storage at the end of the water year is one of the factors that determine the allocation of water for making deliveries to CVP contractors.

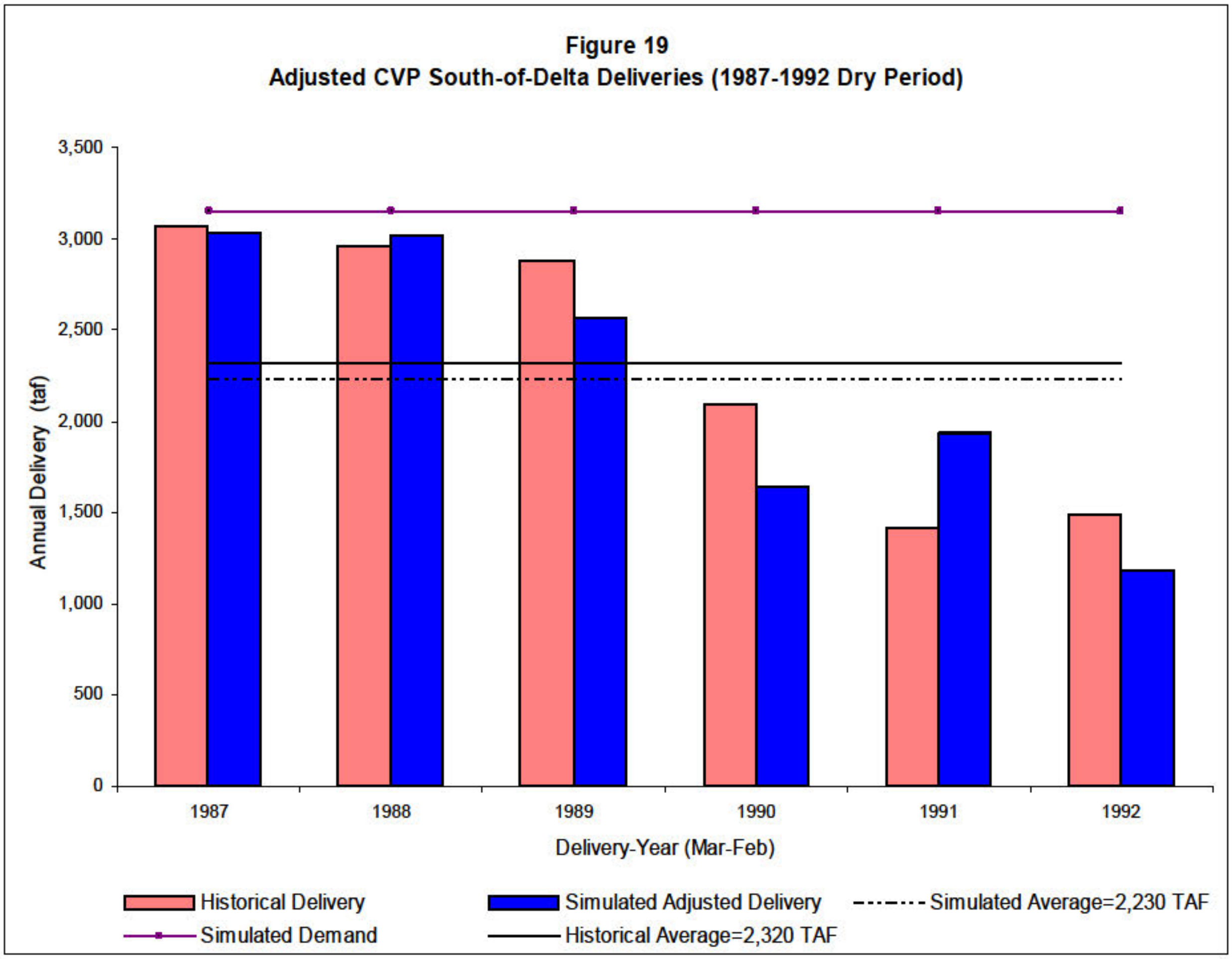

Figure 19 shows a comparison of historical and simulated CVP deliveries to south-of-Delta contractors during the 1987-1992 drought. Simulated annual deliveries during the drought have been adjusted to account for the difference in storage utilization in any given year. After the corrections for storage utilization during the critical period the 6-year average of the simulated deliveries is lower than that of the historical deliveries by approximately 3.9 percent. The adjusted simulated deliveries shown in this bar chart are computed as the gross delivery for each delivery year of simulation minus the difference between the historical and simulated values of storage used from March 1 to February 28(29) of the following year. For the first year of the drought, 1987, the storage difference between March 31 (the highest system storage just before the onset of the drought) and February 29, 1988, was used. Storage differences are based on the total CVP system storage (Shasta, Folsom, and CVP San Luis).

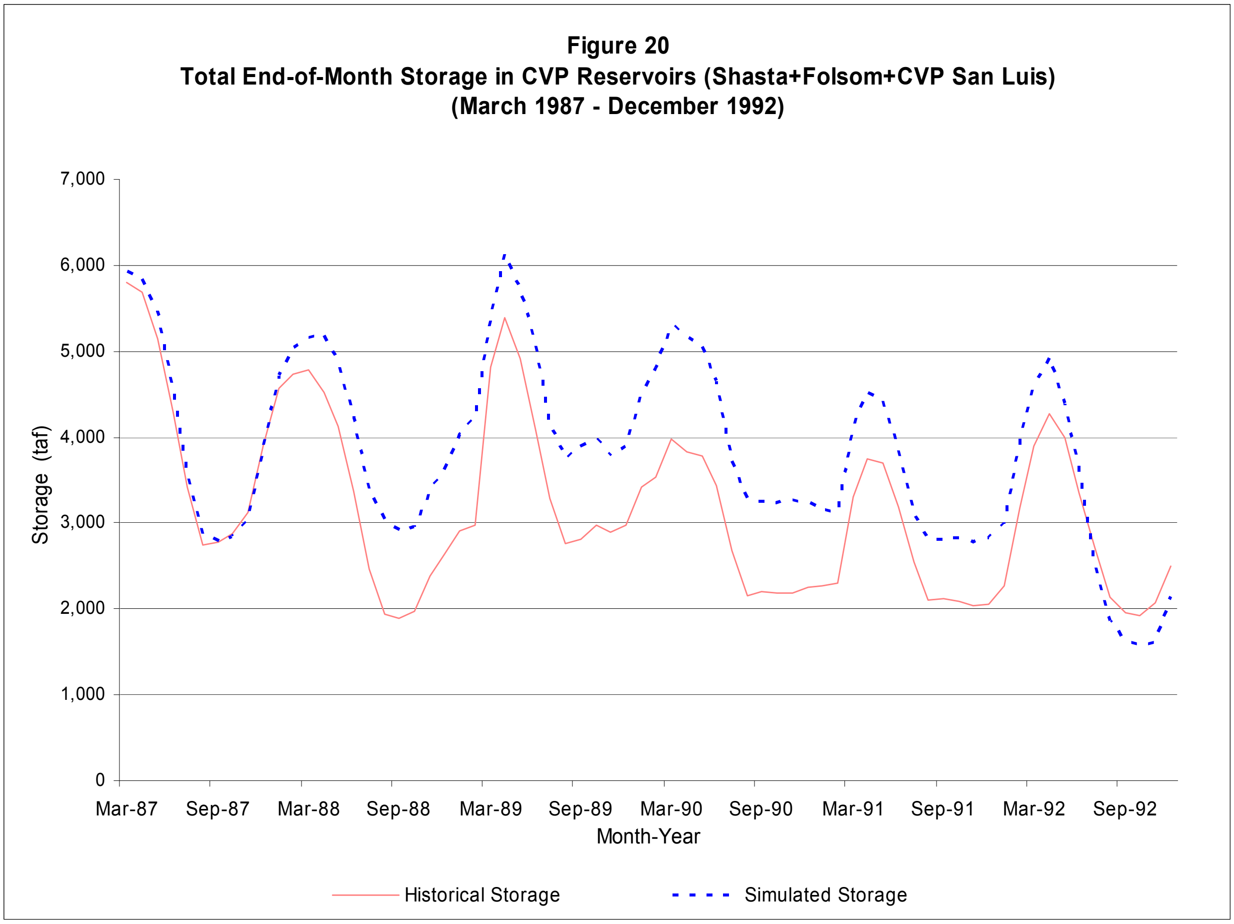

Figure 20 shows a line plot of end-of-month CVP storage (Shasta, Folsom, and CVP San Luis) for the 1987-1992 drought. The historical storage at the outset of the drought on March 31, 1987, was 5,807 taf. The corresponding storage marking the end of the drought on October 31, 1992, was 1,914. The table below lists the storage values and the corresponding annual change in storage for the beginning of each delivery year. The storage change for the first year of the drought was based on the end-of-March 1987 when the system storage was at its highest level, just before the drought began. Differences in the historical operation criteria and those used in the simulation study results in different ending storages in the CVP system. These storage differences were used to compute the adjustments for delivery bar charts presented in Figure 19.

	Historical		Simulated		Difference
	Storage	Storage Change	Storage	Storage Change	
March 31 1987	5,807	NA	5,938	NA	NA
January 1 1988	4,728	1,079	5,032	906	-173
January 1 1989	2,982	1,746	4,231	801	-945
January 1 1990	3,538	-556	4,794	-563	-7
January 1 1991	2,298	1,240	3,135	1,659	419
January 1 1992	3,165	-867	3,935	-800	67
January 1 1993	4,608	-1,443	4,092	-157	1,286

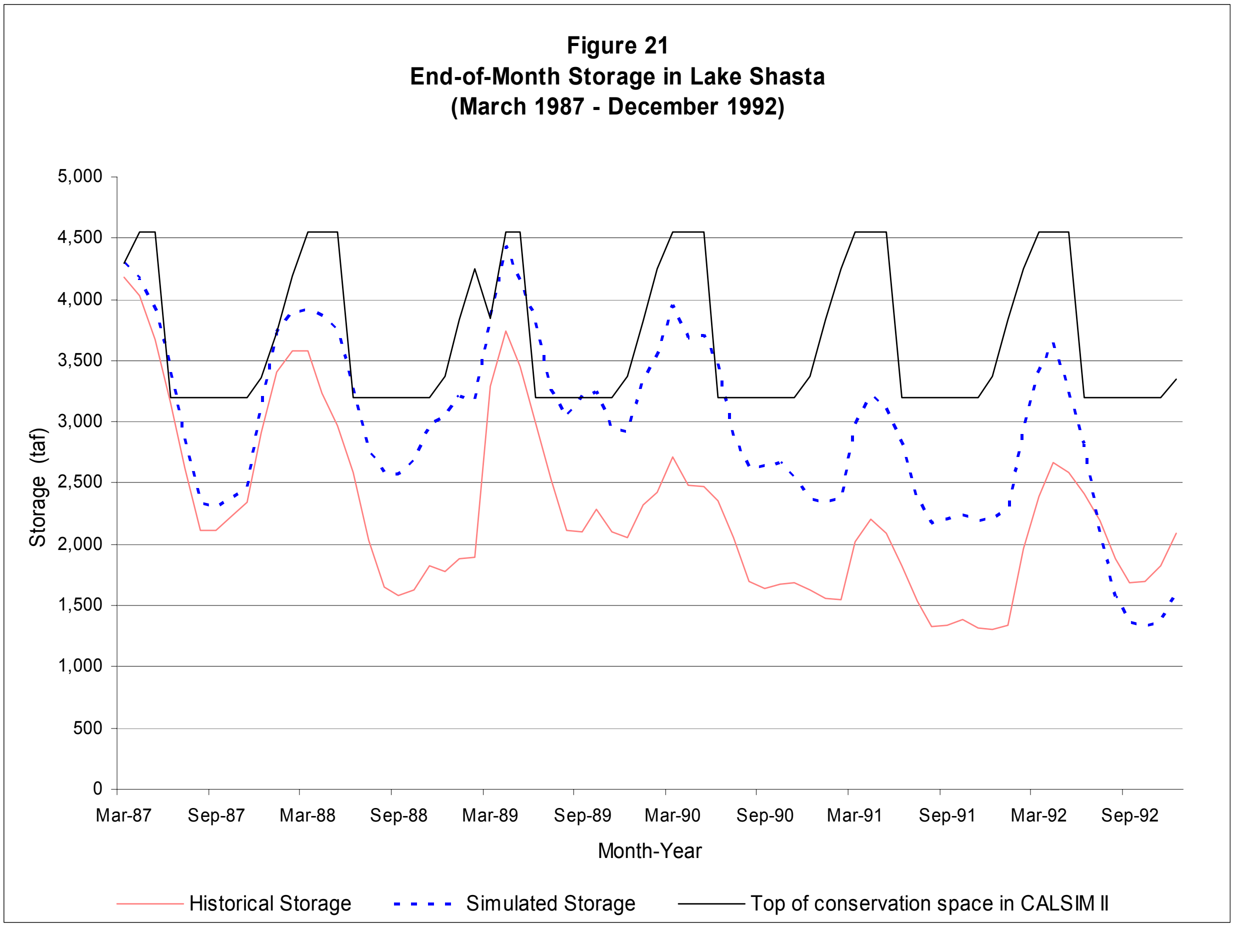

Figure 21 shows a plot of end-of-month storage in Lake Shasta for the 1987-1992 drought. The historical storage at the outset of the drought on March 31, 1987, was 4,182 taf. The corresponding storage marking the end of the drought on September 30, 1992, was 1,683 taf. The table below lists the storage values and the corresponding changes in storage for the beginning of each delivery year. The storage change for the first year of the drought was based on the end-of-March 1987 when the system storage was at its highest level, just before the drought began.

	Historical		Simulated		Difference
	Storage	Storage Change	Storage	Storage Change	
March 31 1987	4,182	NA	4,298	NA	NA
January 1 1988	3,583	599	3,896	402	- 197
January 1 1989	1,896	1,687	3,186	710	- 977
January 1 1990	2,429	- 533	3,542	- 356	177
January 1 1991	1,543	886	2,376	1,166	280
January 1 1992	1,966	- 423	2,940	- 564	- 141
January 1 1993	3,459	-1,493	3,022	- 82	1,411

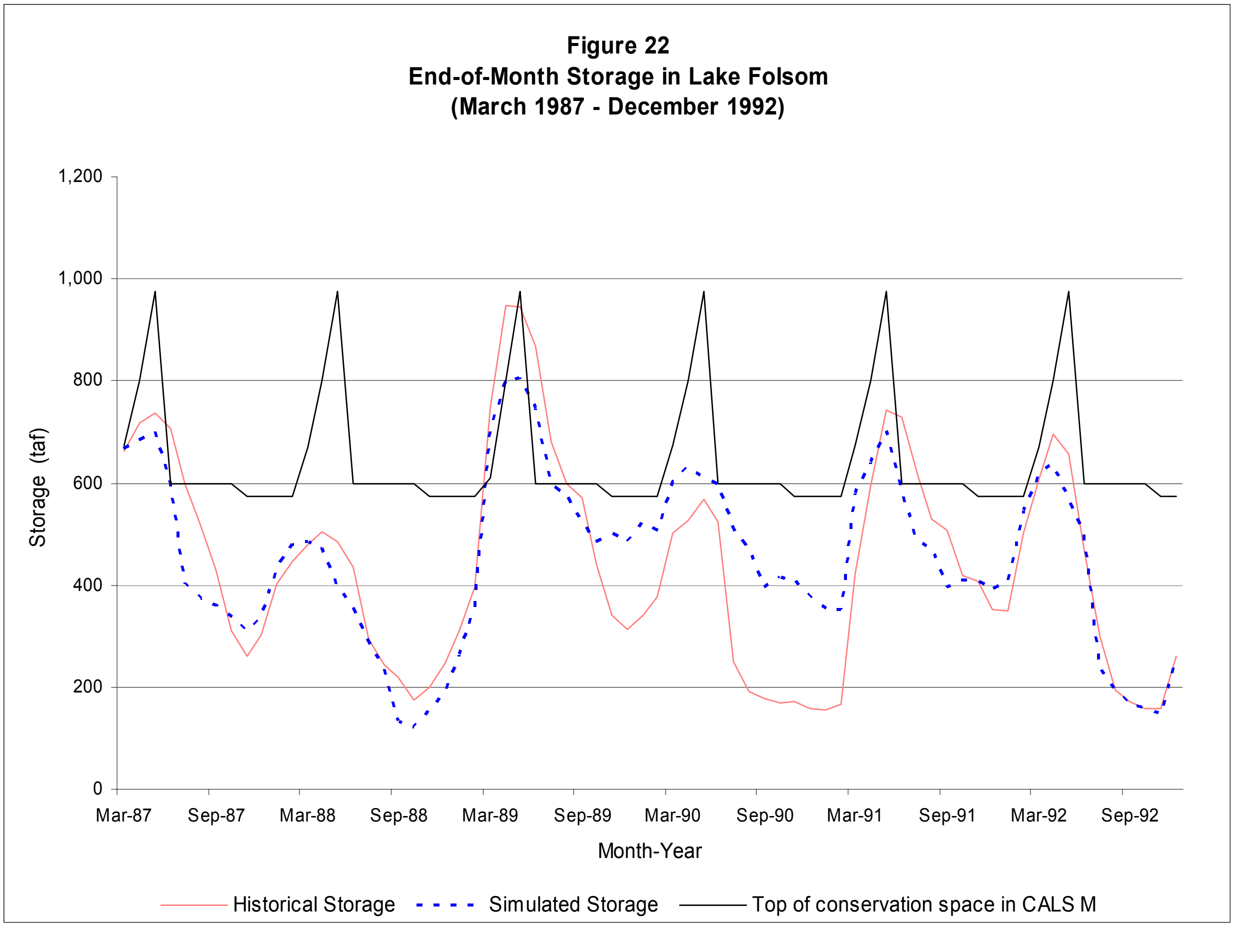

Figure 22 shows a plot of end-of-month storage in Lake Folsom for the 1987-1992 drought. The historical storage at the outset of the drought on March 31, 1987, was 662 taf. The corresponding marking the end of the drought on November 30, 1992, was 157 taf. The table below lists the storage values and the corresponding changes in storage for the beginning of each delivery year. The storage change for the first year of the drought was based on the end-of-March 1987 when the system storage was at its highest level, just before the drought began.

	Historical		Simulated		Difference
	Storage	Storage Change	Storage	Storage Change	
March 31 1987	662	NA	668	NA	NA
January 1 1988	447	215	480	188	-27
January 1 1989	398	49	356	124	75
January 1 1990	378	20	506	-150	-170
January 1 1991	167	211	351	155	-56
January 1 1992	502	-335	546	-195	140
January 1 1993	505	-3	555	-9	-6

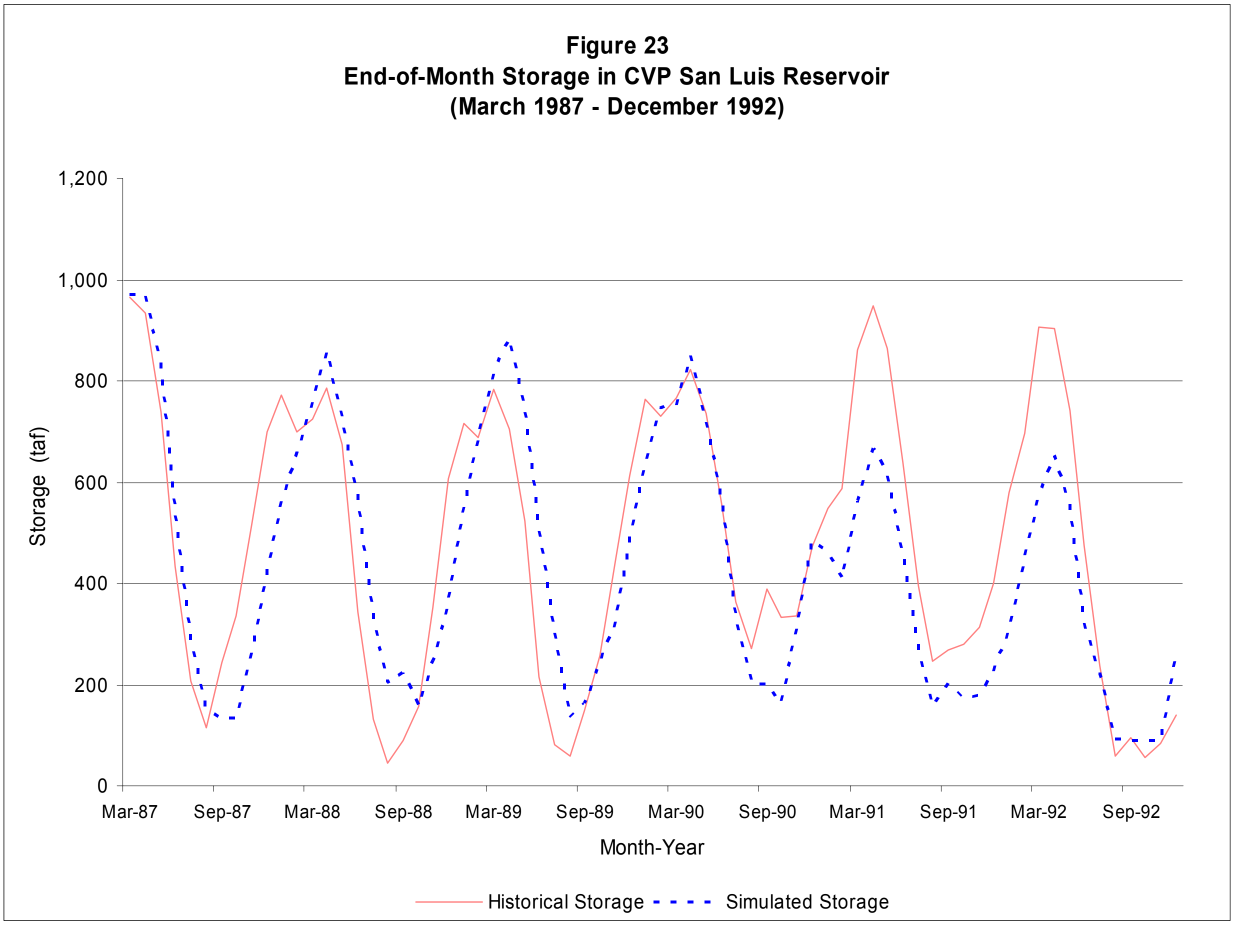

Figure 23 shows a plot of end-of-month storage in CVP San Luis Reservoir for the 1987-1992 drought. The historical storage at the outset of the drought on March 31, 1987, was 964 taf. The corresponding storage marking the end of the drought on October 31, 1992, was 57 taf. The table below lists the storage values and the corresponding changes in storage for the beginning of each delivery year. The storage change for the first year of the drought was based on the end-of-March 1987 when the system storage was at its highest level, just before the drought began.

	Historical		Simulated		Difference
	Storage	Storage Change	Storage	Storage Change	
March 31 1987	964	NA	972	NA	NA
January 1 1988	698	266	656	316	50
January 1 1989	689	9	688	-32	-41
January 1 1990	731	-42	746	-58	-16
January 1 1991	588	143	408	338	195
January 1 1992	698	-110	449	-41	69
January 1 1993	645	53	515	-66	-119

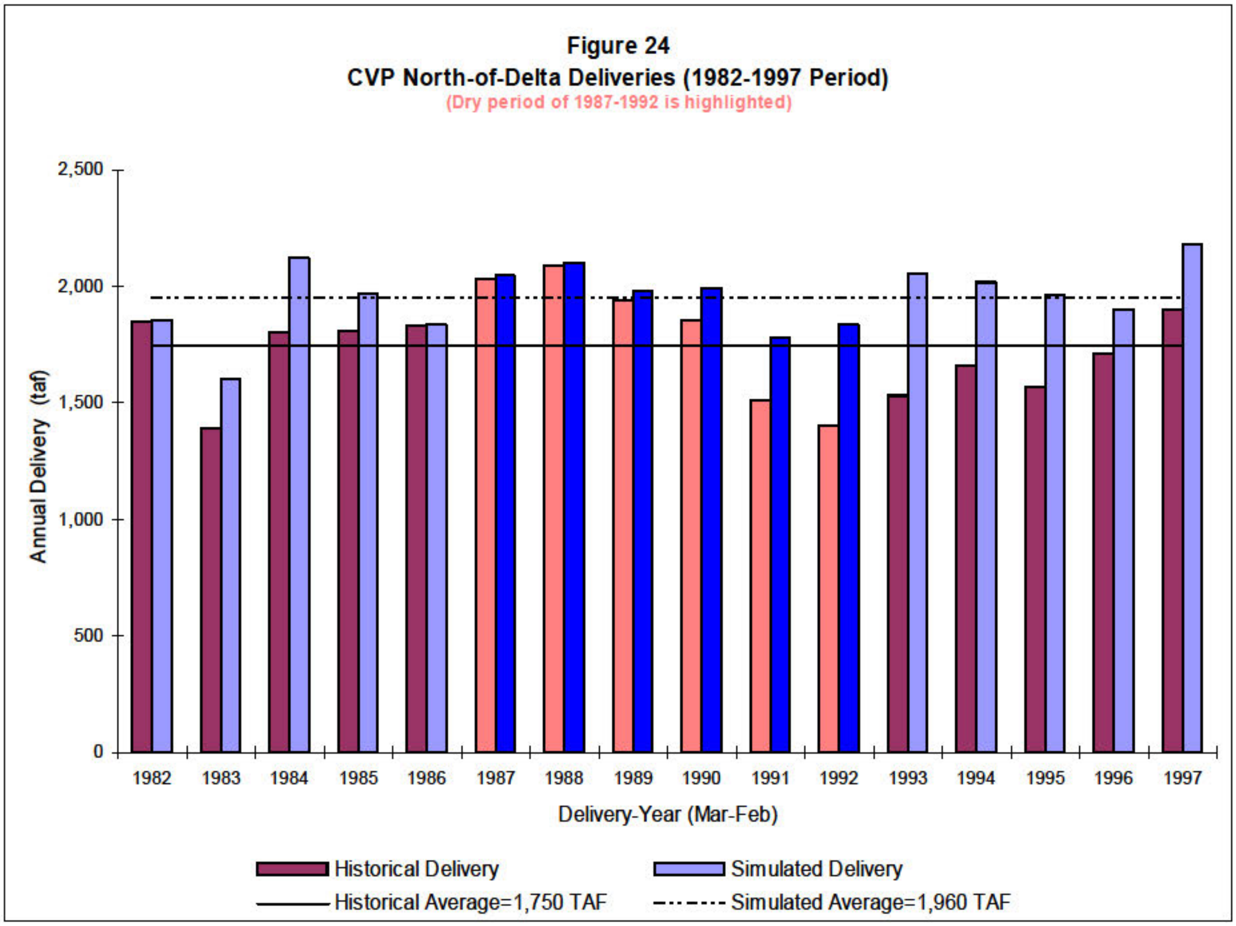

Figure 24 shows the bar chart of comparison between the historical and simulated deliveries made to the CVP north-of-Delta contractors in the Sacramento Valley for the period of 1982-1997. They include the Tehema-Colusa Canal service area, Corning Canal service area, Glenn-Colusa ID, Anderson-Cottonwood ID, City of Redding, Maxwell ID, Provident ID, Princeton-Codora-Glenn ID, Colusa IC, Meridian Farms WC, Pelger Mutual WC, RD 1004, RD 108, Roberts Ditch IC, Sartain MWD, Sutter MWC, Swinford Traft IC, Tisdale Irrigation and Drainage Company, and Sacramento, Delevan, and Colusa Refuge Areas. The long-term average of the simulated deliveries exceeds that of the historical deliveries by 12.0 percent. The historical average annual delivery during the 6-year drought of 1987-1992 is about 1,810 taf per year. The average for the simulated values during the drought is 1,960 taf per year, a difference of about 8.3 percent.

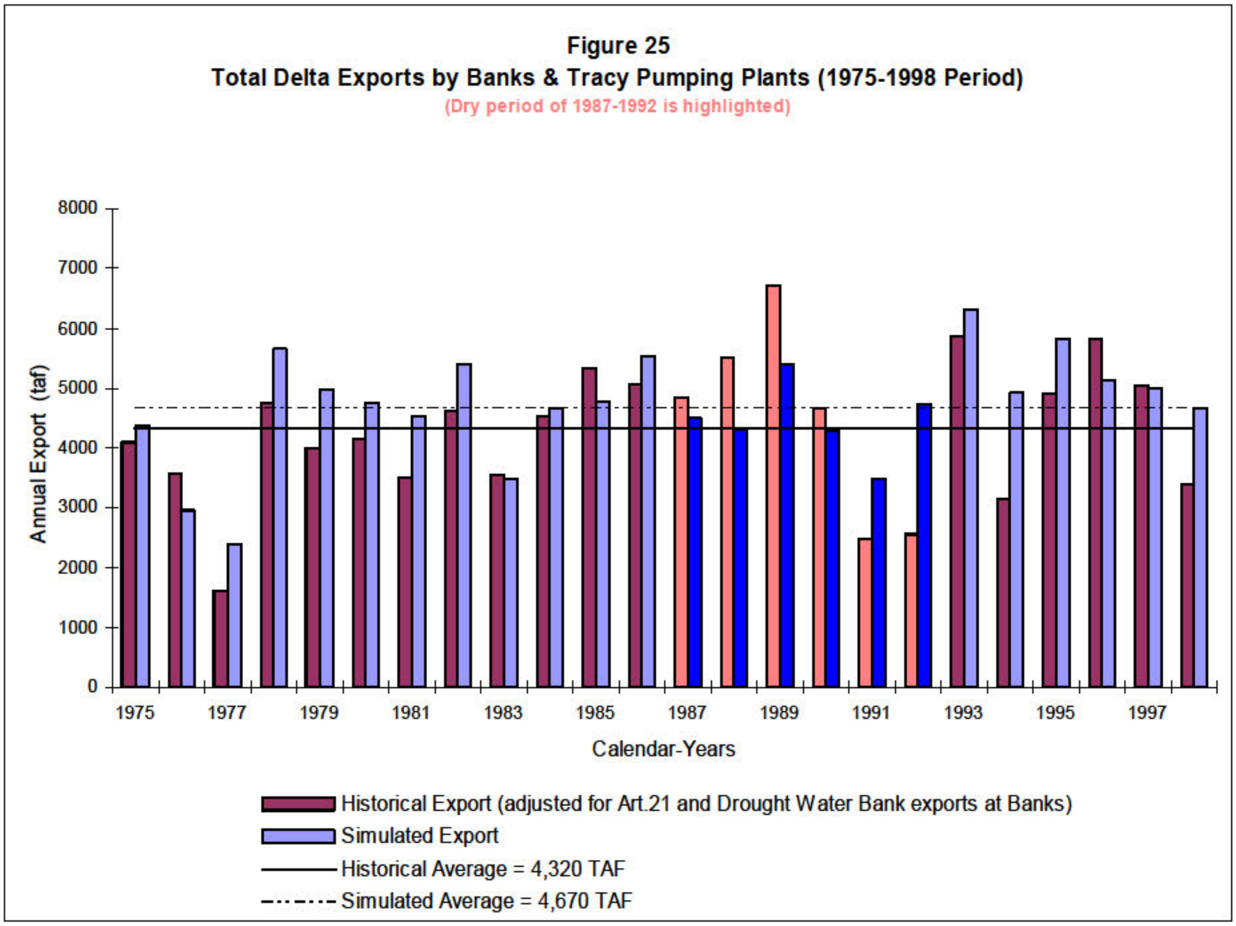

Figure 25 shows the total project exports made from the Delta by the CVP and SWP pumping facilities. Historical values for total exports were obtained from DAYFLOW average daily data, and as such included all types of diversions, project and non-project, made at the Clifton Court Forebay by the Banks Pumping Plant. Since the simulated values of the Delta exports by Banks Pumping Plant did not include any Article 21 water or any non-project water transfers, the values obtained from DAYFLOW for the historical exports were adjusted to be more comparable to the simulated values. The adjustments were made for Article 21 water and exports that were made to transfer Drought Water Bank supplies, only. No other non-project exports were included in the adjustments. After these adjustments, the simulated long-term average annual exports exceeded the historical average by approximately 8.1 percent.

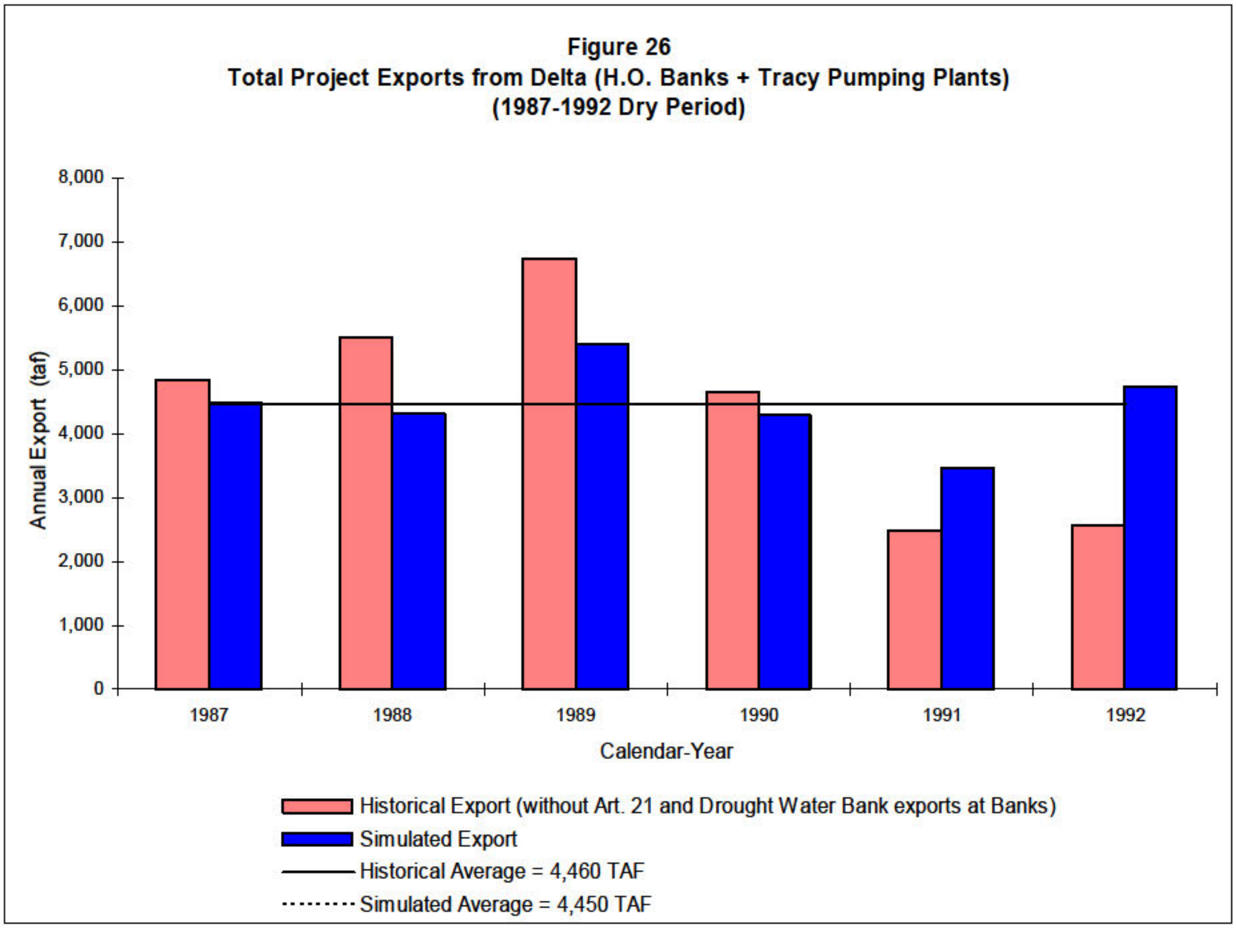

Figure 26 shows the total project exports made from the Delta by the CVP and SWP pumping facilities during the 1987-1992 dry period. Historical values for total exports were obtained from DAYFLOW average daily data, and as such included all types of diversions, project and non-project, made at the Clifton Court Forebay by the Banks Pumping Plant. Since the simulated values of the Delta exports by Banks Pumping Plant did not include any Article 21 water or any non-project water transfers, the values obtained from DAYFLOW for the historical exports were adjusted to be more comparable to the simulated values. The adjustments were made for Article 21 water and exports that were made to transfer Drought Water Bank supplies, only. No other non-project exports were included in the adjustments. After these adjustments, the historical average annual export during the 6-year drought of 1987-1992 is about 4,460 taf per year. The average for the simulated values during the drought is 4,450 taf per year, a difference of about 0.2 percent.

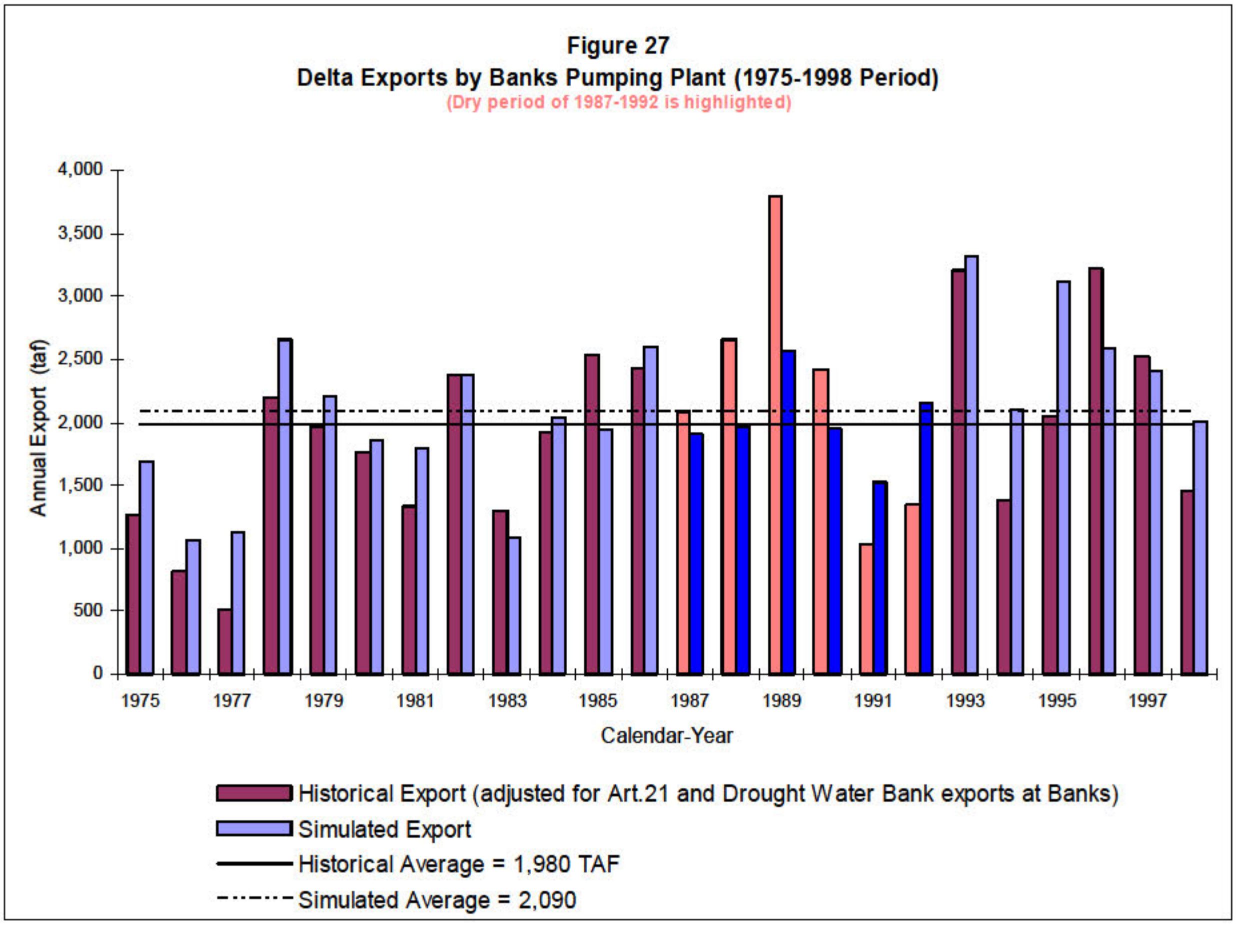

Figure 27 shows the total exports made from the Delta by the Banks Pumping Plant. Historical values for exports at Banks Pumping Plant were obtained from DAYFLOW average daily data, and as such included all types of diversions, project and non-project, made at the Clifton Court Forebay. Since the simulated values of the Delta exports by Banks Pumping Plant did not include any Article 21 water, or any non-project water transfers the values obtained from DAYFLOW for the historical exports were adjusted to be more comparable to the simulated values. The adjustments were made for Article 21 water and exports that were made to transfer Drought Water Bank supplies, only. No other non-project exports were included in the adjustments. After these adjustments the simulated long-term average annual exports exceeded the historical average by approximately 5.6 percent.

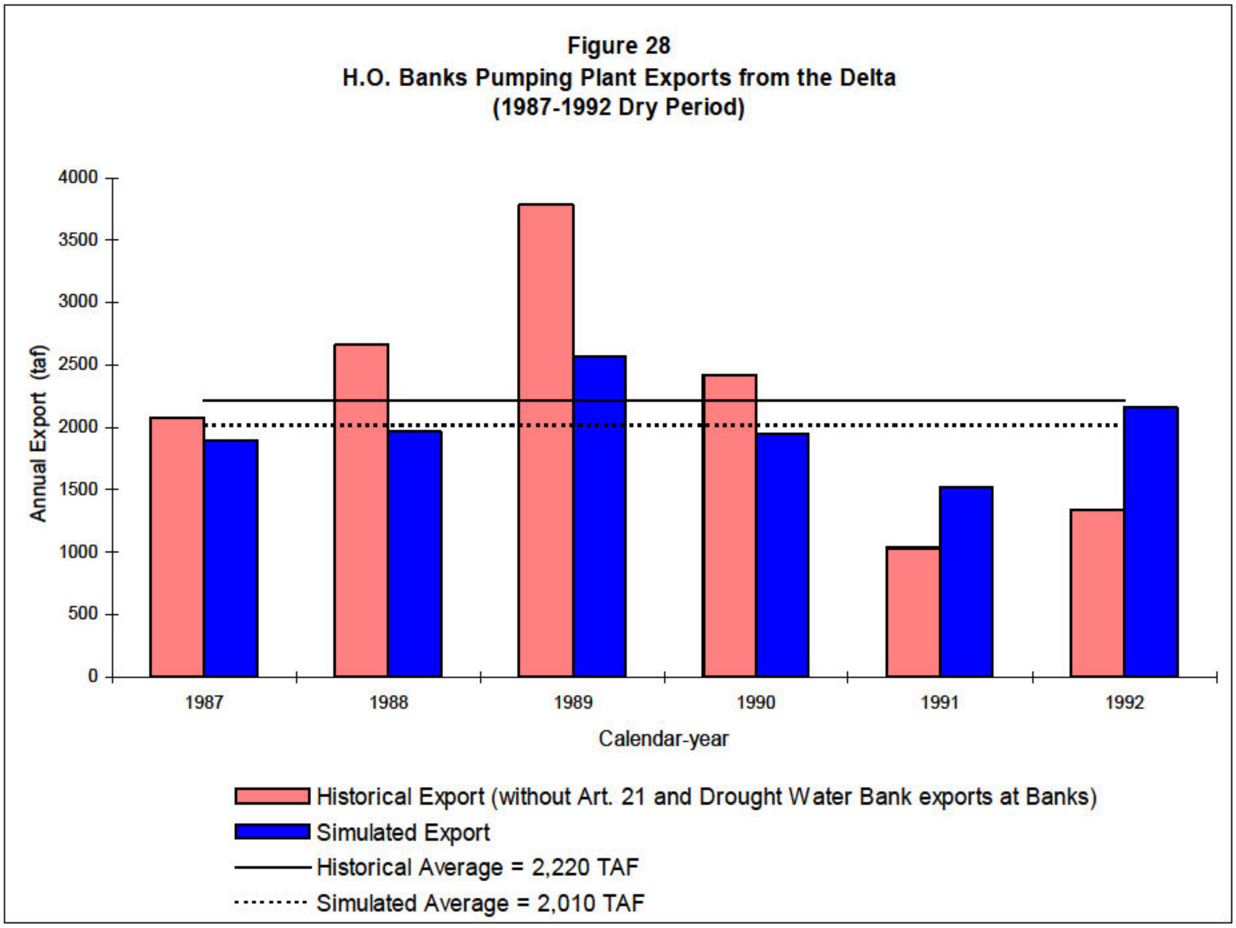

Figure 28 shows the total exports made from the Delta by the Banks Pumping Plant. Historical values for exports at Banks Pumping Plant were obtained from DAYFLOW average daily data, and as such included all types of diversions, project and non-project, made at the Clifton Court Forebay. Since the simulated values of the Delta exports by Banks Pumping Plant did not include any Article 21 water, or any non-project water transfers the values obtained from DAYFLOW for the historical exports were adjusted to be more comparable to the simulated values. The adjustments were made for Article 21 water and exports that were made to transfer Drought Water Bank supplies, only. No other non-project exports were included in the adjustments. After these adjustments, the historical average annual adjusted export during the 6-year drought of 1987-1992 is about 2,220 taf per year. The average for the simulated values during the drought is 2,010 taf per year, a difference of about 9.5 percent.

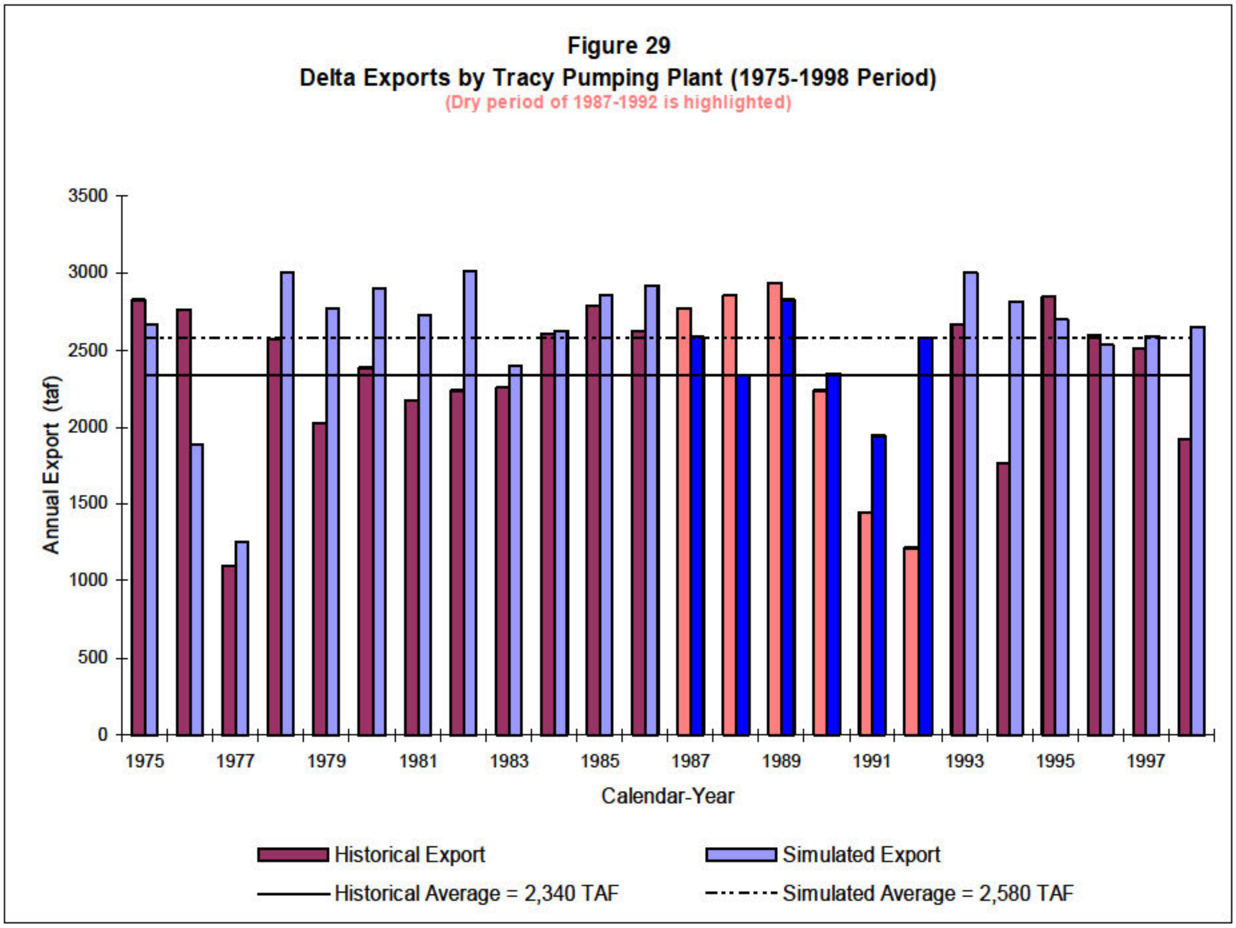

Figure 29 shows the total exports made from the Delta by the Tracy Pumping Plant. Historical values were obtained from DAYFLOW. The simulated long-term average annual exports exceeded the historical average by approximately 10.3 percent.

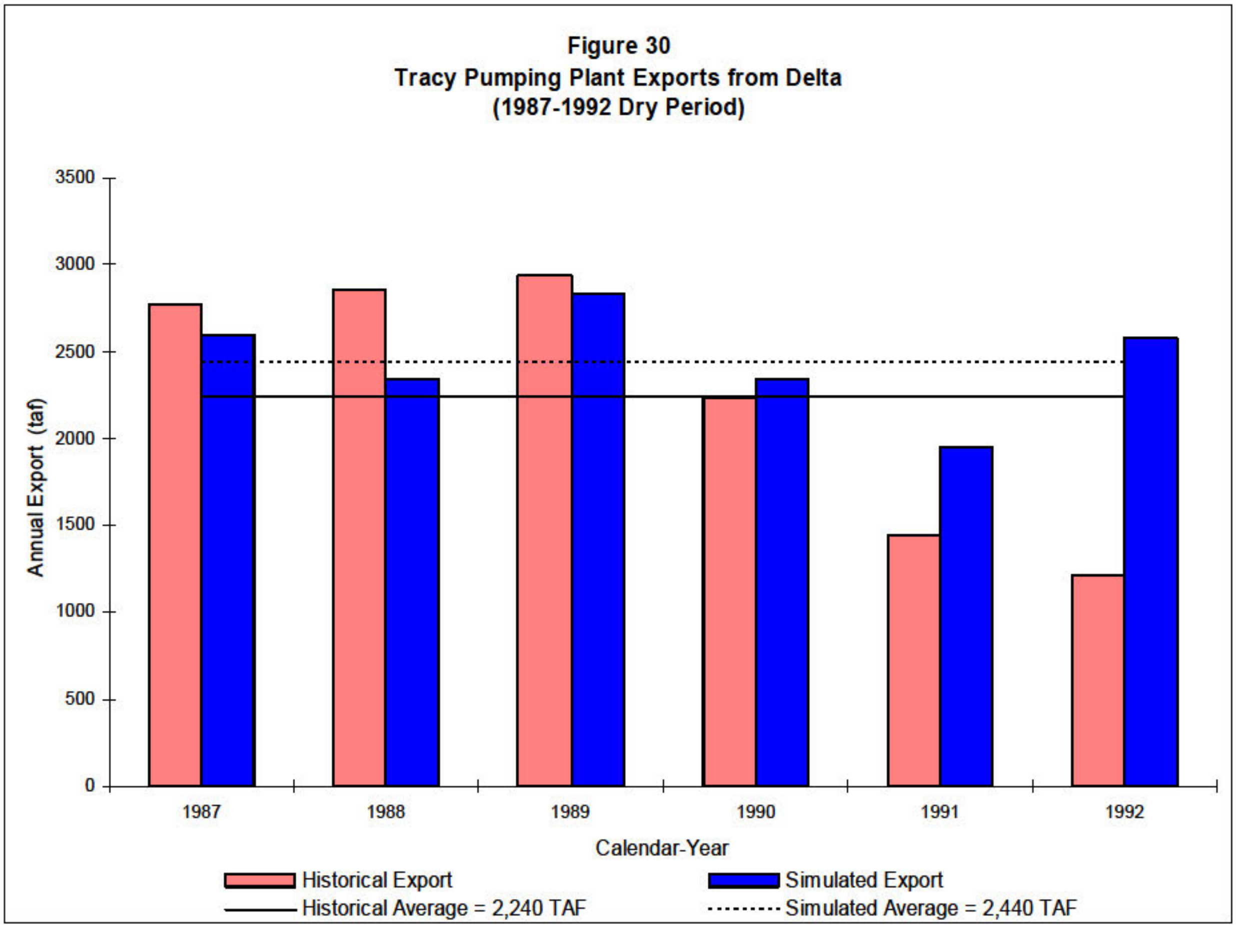

Figure 30 shows the total exports made from the Delta by the Tracy Pumping Plant during the dry period of 1987-1992. Historical values were obtained from DAYFLOW. The historical average annual export during the 6-year drought is about 2,240 taf per year. The average for the simulated values during the same period is 2,440 taf per year, a difference of about 8.9 percent.

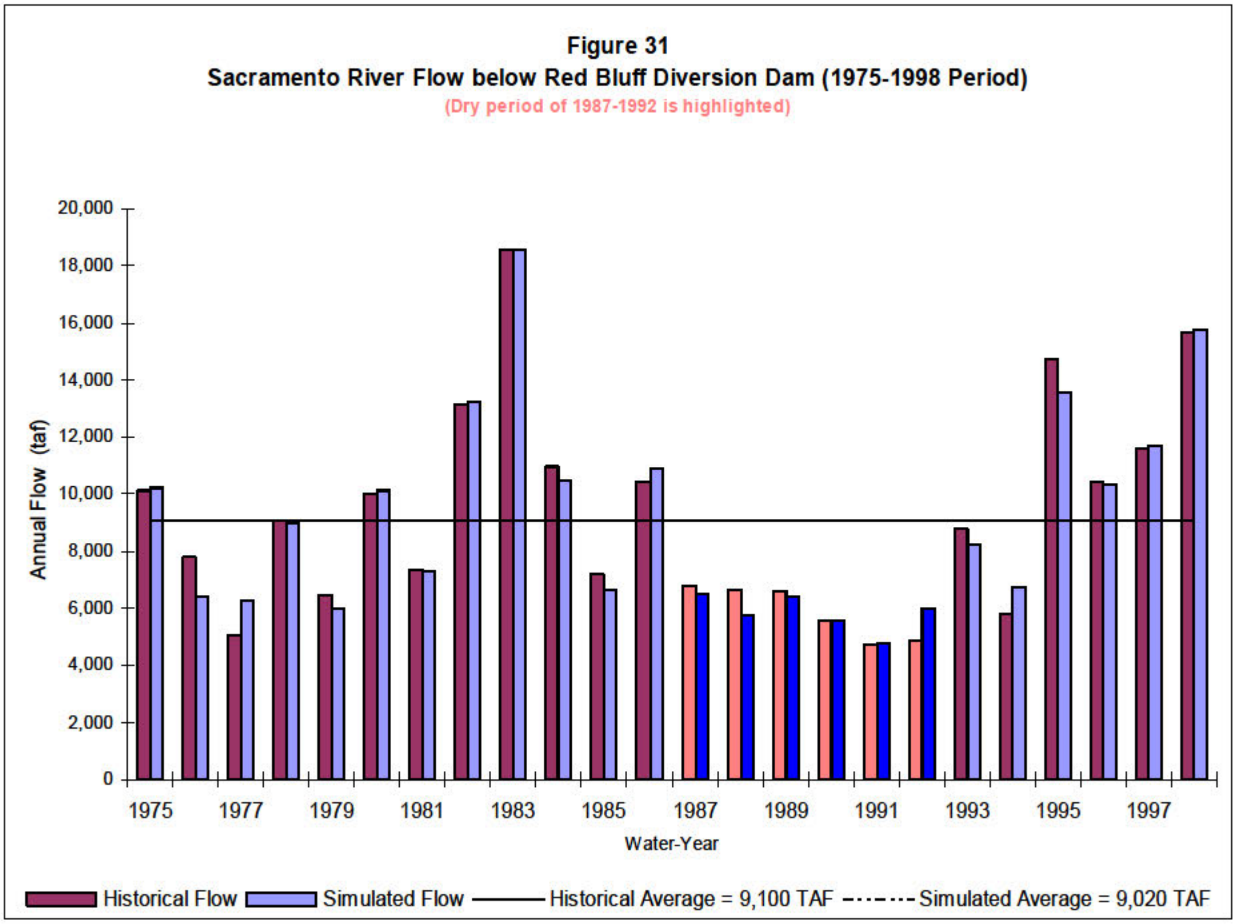

Figure 31 provides a comparison of the historical and simulated flows at the gaging station below the Red Bluff Diversion Dam on the Sacramento River. The long-term average of the simulated values is lower than that of the historical values by less than 1.0 percent. The historical average annual flow during the 6-year drought of 1987-1992 is about 5,860 taf per year. The average for the simulated values during the drought is 5,830 taf per year, a difference of about 0.5 percent.

Figure 32
Sacramento River Flow at Ord Ferry (1975-1998 Period)
(Dry period of 1987-1992 is highlighted)

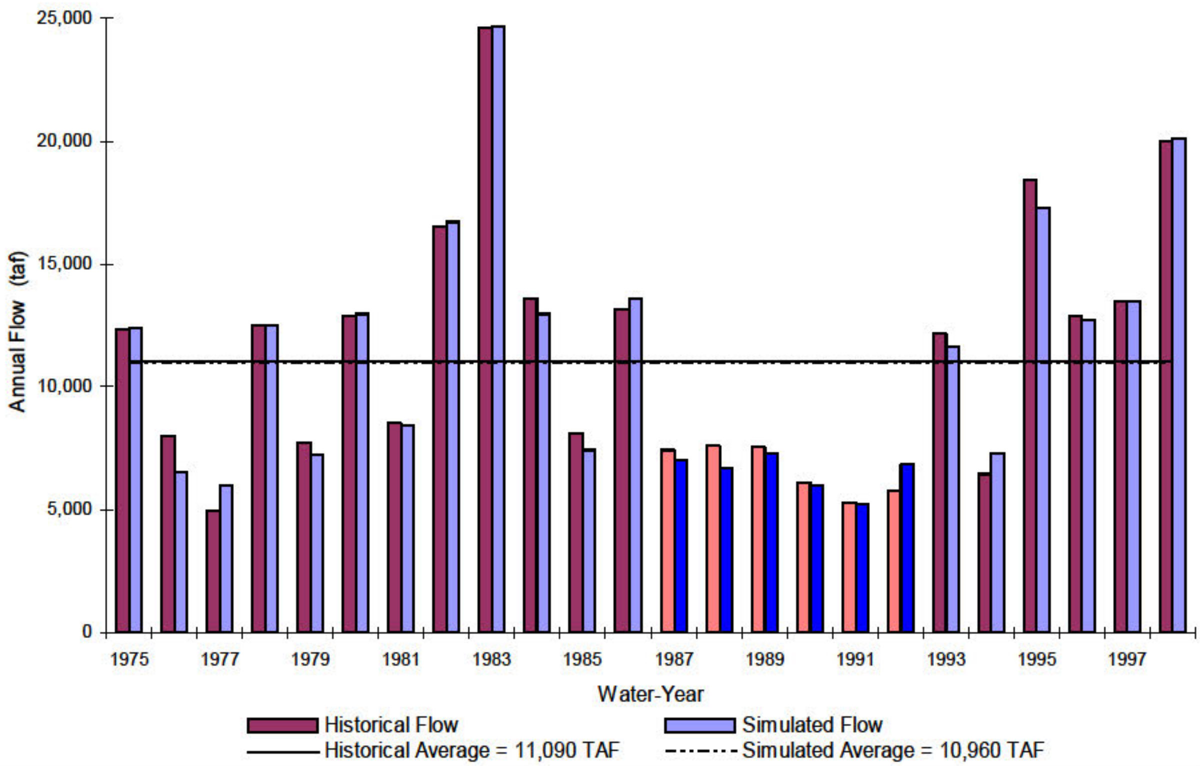

Figure 32 provides a comparison of the historical and simulated flows at the gaging station near Ord Ferry on the Sacramento River. The long-term average of the simulated values is lower than that of the historical values by about 1.2 percent. The historical average annual flow during the 6-year drought of 1987-1992 is about 6,620 taf per year. The average for the simulated values during the drought is 6,510 taf per year, a difference of about 1.7 percent.

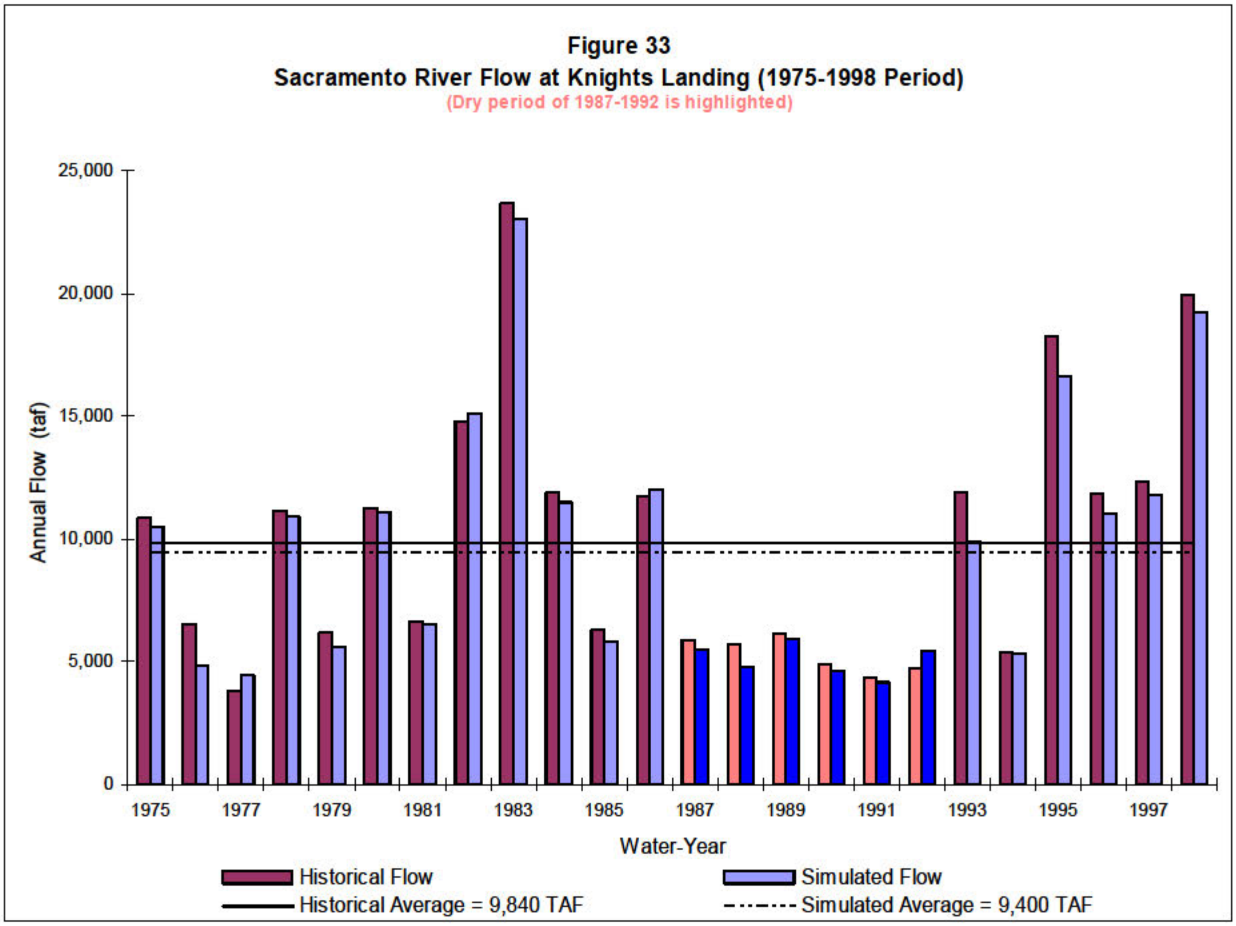

Figure 33 provides a comparison of the historical and simulated flows at the Knights Landing gaging station on the Sacramento River. The long-term average of the simulated values is lower than that of the historical values by about 4.5 percent. The historical average annual flow during the 6-year drought of 1987-1992 is about 5,290 taf per year. The average for the simulated values during the drought is 5,080 taf per year, a difference of about 4.0 percent.

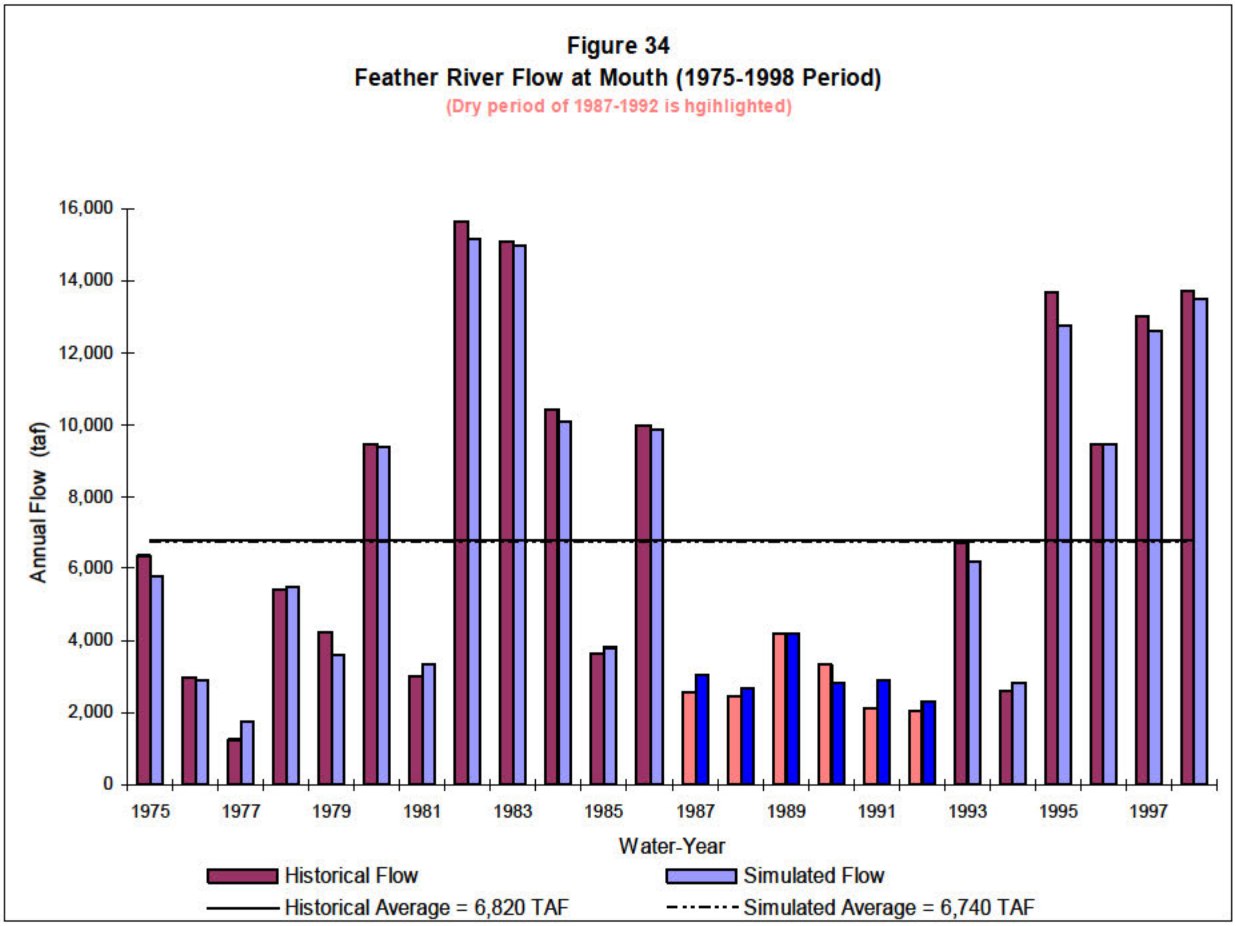

Figure 34 provides a comparison of the historical and simulated flows in the Feather River at confluence with the Sacramento River. The long-term average of the simulated values is lower than that of the historical values by about 1.2 percent. The historical average annual flow during the 6-year drought of 1987-1992 is about 2,800 taf per year. The average for the simulated values during the drought is 3,000 taf per year, a difference of about 7.1 percent.

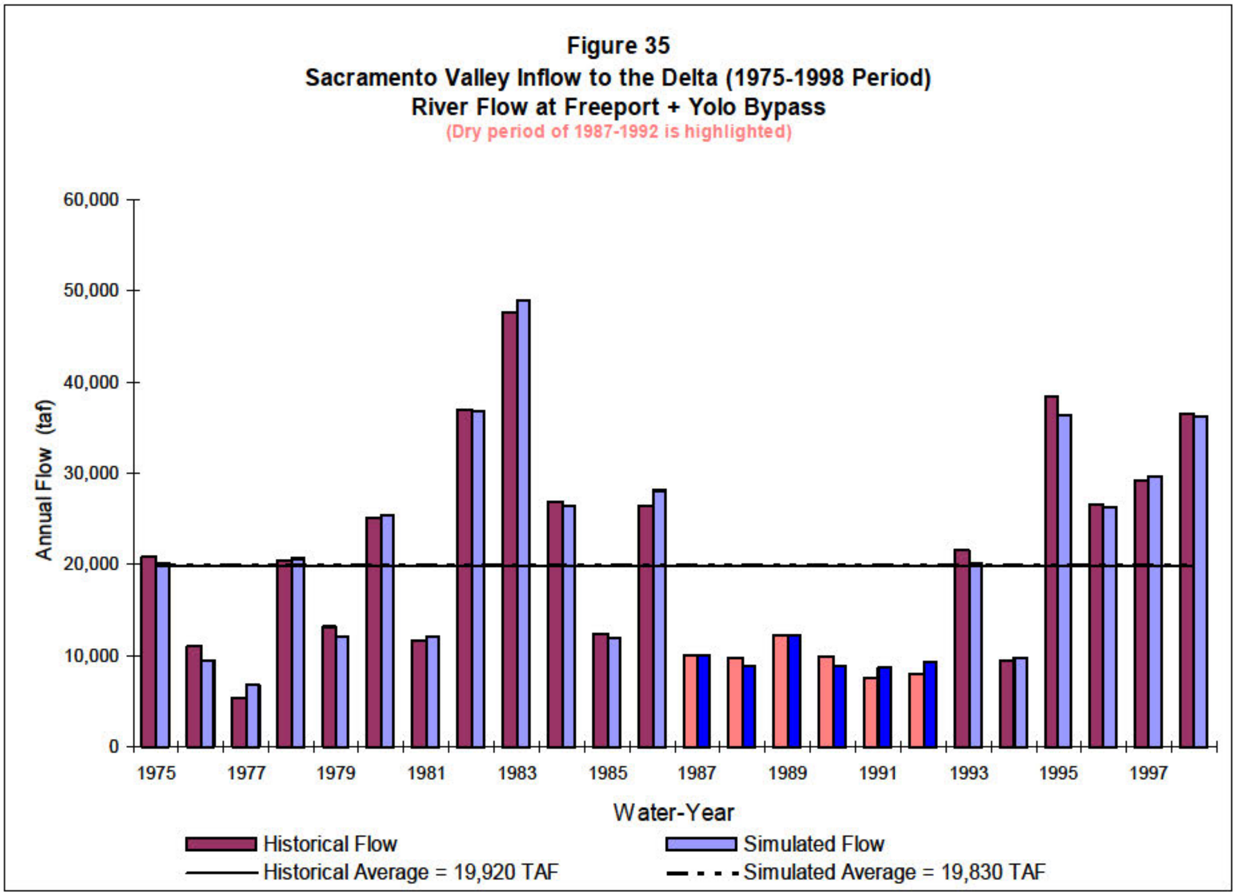

Figure 35 shows the comparison between the simulated and historical outflow from the Sacramento Valley to the Delta for the period of 1975-1998. This outflow includes the flow on the Sacramento River at Freeport plus the outflow from the Yolo Bypass. The long-term average of the simulated values is lower than that of the historical values by 0.5 percent. The historical average annual inflow during the 6-year drought of 1987-1992 is about 9,670 taf per year. The average for the simulated values during the drought is 9,700 taf per year, a difference of about 0.3 percent.

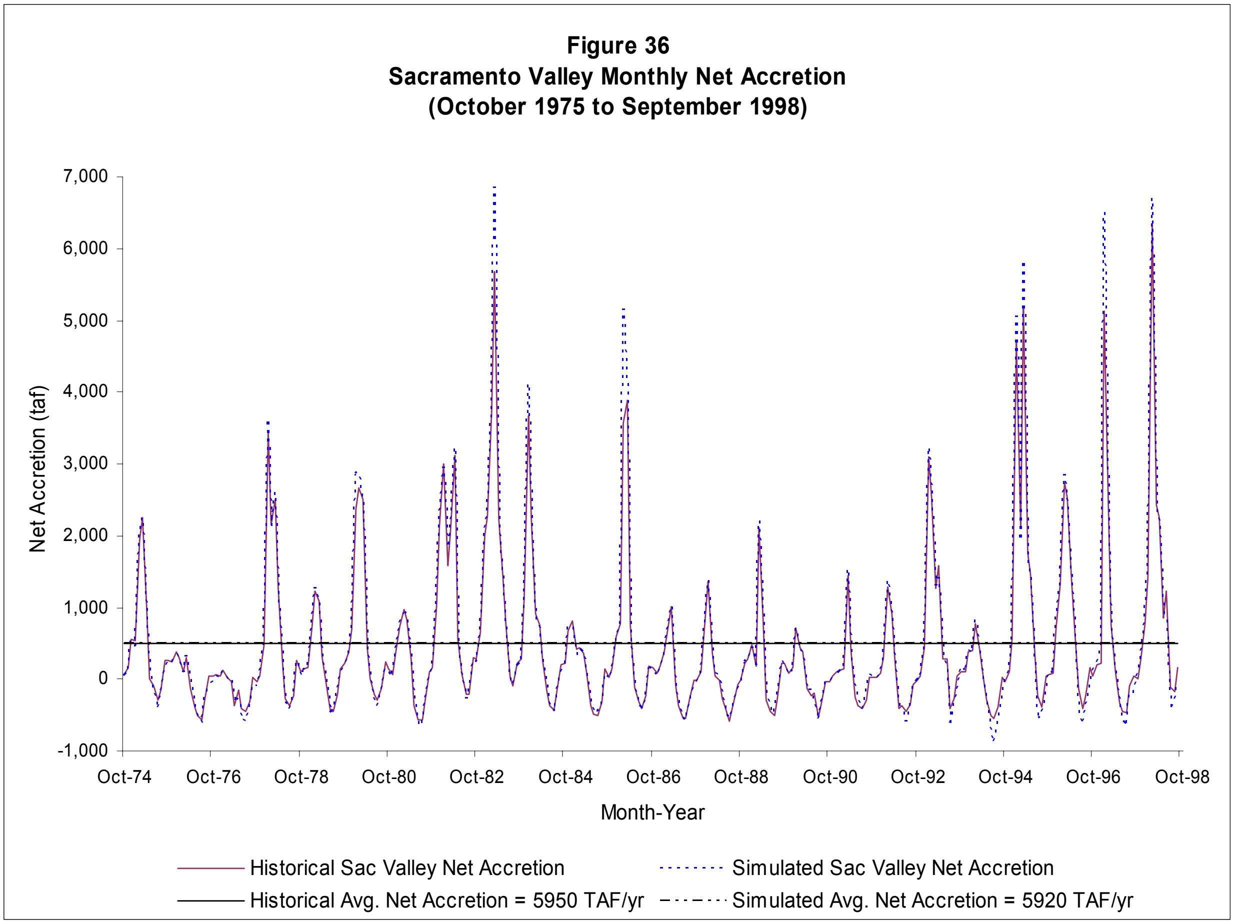

Figure 36 shows the net monthly Sacramento Valley accretion. This is calculated as the Delta inflow less the major reservoir releases. Inflow to the Delta is the sum of the Sacramento River flow at Freeport and the flow in the Yolo Bypass. The reservoir releases are calculated as the sum of releases from Whiskeytown Lake (including lake diversions), Keswick Reservoir, Lake Orville (including lake diversions to the Palermo Canal) and Lake Natomas (including lake pumped diversions for both Natomas and Folsom). The long-term average of the simulated values is approximately 0.5 percent lower than historical. The historical average annual net accretion during the 6-year drought of 1987-1992 is 1,155 taf/yr, compared to a simulated value of 1,103 taf/yr.

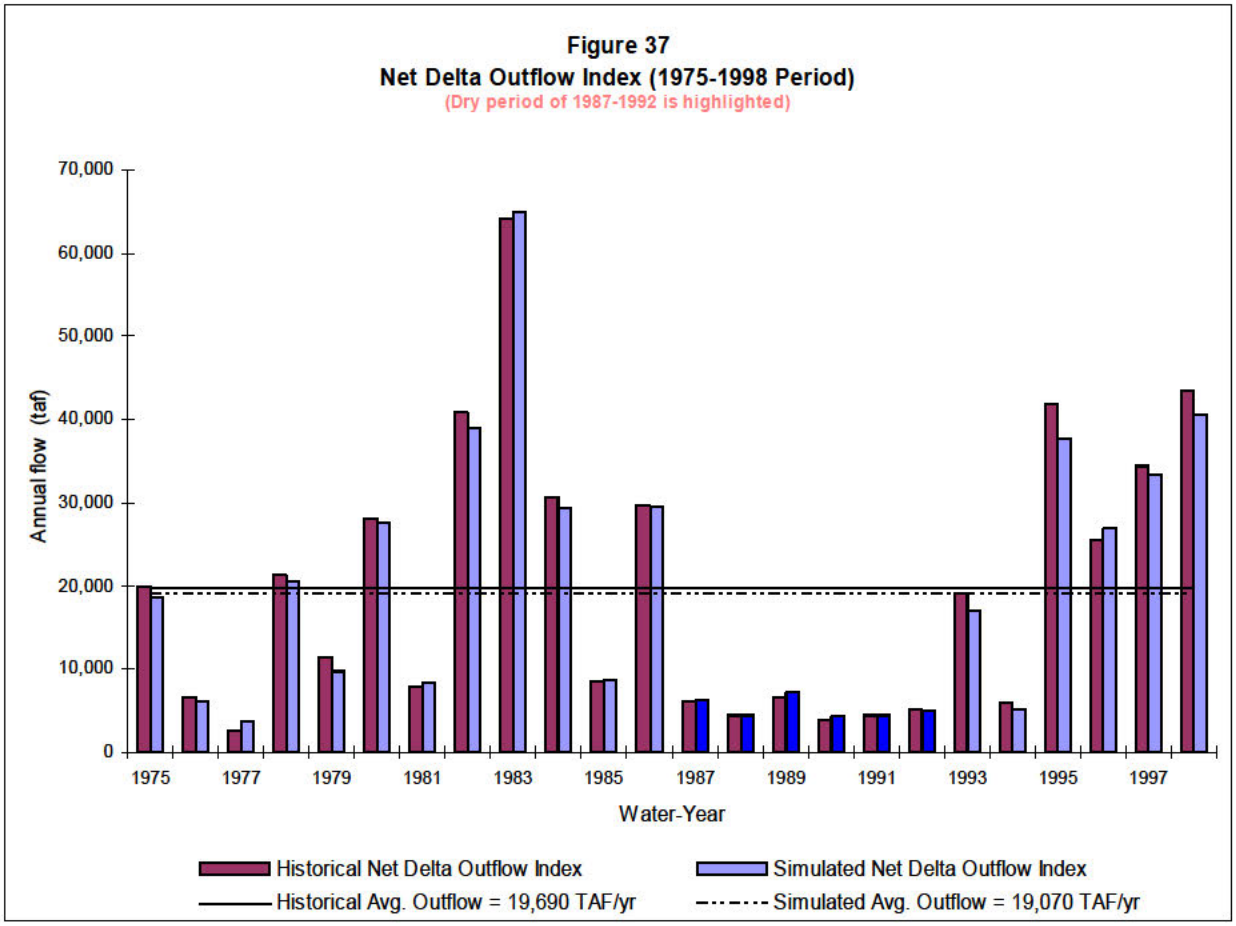

Figure 37 presents a comparison between the historical and simulated values of the Net Delta Outflow Index. Historical values of the NDOI were obtained from DAYFLOW, which estimates this variable by performing a water balance at the boundary of the Sacramento-San Joaquin Delta, taking Chipps Island as the western limit. The long-term average of the simulated values is lower than that of the historical values by about 3.1 percent. The historical average annual outflow during the 6-year drought of 1987-1992 is about 5,090 taf per year. The average for the simulated values during the drought is 5,270 taf per year, a difference of about 3.5 percent.