Evolution of River Flows in the Sacramento and San Joaquin Valleys

Historical Level of Development Study

Technical Memorandum, Final

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Prepared by MWH
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Abbreviations and Acronyms

AFRP	Anadromous Fish Restoration Program
BO	biological opinion
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
CDEC	California Data Exchange Center
cfs	cubic feet per second
COA	Coordinated Operations Agreement
CU	consumptive use
CUAW	consumptive use of applied water
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
D-1485	State Water Board Water Rights Decision 1485
D-1641	State Water Board Water Rights Decision 1641
Delta	Sacramento-San Joaquin Delta
DWR	California Department of Water Resources
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ESA	Endangered Species Act
ET	evapotranspiration
EWA	Environmental Water Account
FCWCD	Flood Control and Water Conservation District
HEC-DSS	Hydrologic Engineering Center Data Storage System
ID	Irrigation District
IWFM	Integrated Water Flow Model
LOD	Level of Development
MAF	million acre-feet
M&I	municipal and industrial
MWD	Metropolitan Water District of Southern California
NMFS	National Marine Fisheries Service
PG&E	Pacific Gas and Electric
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RM	River Mile
ROD	Record of Decision
RPA	Reasonable and Prudent Alternative
SOD	South-of-Delta
SOW	Scope of Work
SWP	State Water Project
TAF	thousand acre-feet
TM	Technical Memorandum

USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VAMP	Vernalis Adaptive Management Plan
WD	Water District
WRESL	Water Resources Simulation Language
WRIMS	Water Resources Integrated Modeling System

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Executive Summary

Human activities during the 20th and early 21st centuries have dramatically affected inflows to the Sacramento-San Joaquin Delta (Delta) and freshwater outflow from the Delta to Suisun Bay. Upstream storage regulation has modified the seasonal pattern of river and channel flows. Diversions for irrigation and municipal and industrial (M&I) purposes have depleted surface waters. Changes in land use have altered the amount of surface runoff. Groundwater pumping has lowered groundwater elevations and reduced groundwater inflows to streams and rivers. Flood control measures and an extensive network of levees have ended the natural cycle of bank overflows and detention storage. This report describes the *Historical Level of Development Study* and associated analysis that was undertaken for the Metropolitan Water District of Southern California (MWD). The purpose of this study is to support ongoing investigations to explain how and why Delta outflows and salinity have changed over time. The point of departure for the study was the development of a model that simulates water conditions in the Central Valley at the 1900 'level of development.' This model serves as a baseline from which to measure the effects of development over 115 years, at approximately 20 year intervals. Human activities had already significantly modified the hydrology of the Central Valley by 1900. Therefore, this study does not measure effects of development relative to the "natural" or pristine baseline.

Study Approach

A set of 'fixed level of development' models were created to simulate the water resources of the Central Valley. Under a fixed level of development, water facilities, land-use, water supply contracts, and regulatory requirements are held constant over the period of simulation. The historical climate trace from October 1921 to September 2009 is used to represent the possible range of water supply conditions. A total of seven level of development (LOD) simulations were developed, as follows:

- 1900 LOD – characterized by early flood control measures, drainage of wetlands, and early irrigated agricultural development following the passage of the Wright Irrigation Act of 1887.
- 1920 LOD – characterized by growth of irrigated agriculture and industrial agriculture and construction of dams in upstream watersheds by water districts, water agencies, and power companies.
- 1940 LOD – characterized by significant expansion of cultivated lands and agribusiness, continued construction of dams in upstream watersheds.
- 1960 LOD – characterized by early operation of the Central Valley Project (CVP), completion of flood control measures, implementation of early Delta standards, and continued growth in irrigated agricultural development.
- 1980 LOD – characterized by completion of the CVP, early operation of the State Water Project (SWP) with low south-of-Delta contract demands, continued dam construction for local water supply projects, and implementation of State Water Board Water Rights Decision 1485 (D-1485) for Delta standards.
- 2000 LOD – characterized by the end of major water facility construction and the release of more stringent Delta standards through the State Water Board Water Rights Decision 1641 (D-1641).
- 2010 LOD – characterized by increasingly stringent Delta standards, including Reasonable and Prudent Alternatives contained in the U.S. Fish and Wildlife Service 2008 Biological Opinion

and National Marine Fisheries Service 2009 Biological Opinion for long-term operation of the CVP and SWP.

Over the last 115 years, the lands of the Central Valley have been radically transformed by the expansion of irrigated agriculture and the growth of major metropolitan areas. These changes have significantly affected both surface water and groundwater resources. Irrigated lands on the floor of the Central Valley, excluding the Tulare Lake region, now cover approximate 2.5 million acres. Dam construction has resulted in the ability to store up to 30 MAF of water; associated reservoir evaporative losses exceed 1 MAF per year. Stream diversions, including Delta diversions and exports have grown to 9 MAF. Groundwater inflows to the stream system have diminished. Water originating in the Sacramento and San Joaquin valleys is now exported to the San Francisco Bay Area, the Tulare Lake region, and the Central and South Coast.

Comparison of model results across these different levels of development provides insights in to how changes in land use, construction of water management facilities, and new regulatory requirements and operating policies have affected streamflows, and in particular inflows to the Delta, and net Delta outflows.

Modeling Tools

To represent historical water supplies and water use at different time horizons, a model must combine surface water and groundwater hydrology with water management, and be capable of simulating reservoir and water facility operations, agricultural, urban, and wetland water demands, stream diversions and return flows, rainfall-runoff processes, and groundwater flows in response to vertical stresses. No single simulation model was found that meets all the needs of the *Historical Level of Development Study*. Therefore, a suite of models was used for the analysis, as follows:

- **C2VSim**, an integrated numerical model that simulates water movement through the linked land surface, groundwater, and stream network of the Central Valley floor. The model was developed by the Bay-Delta Office of the California Department of Water Resources (DWR). The groundwater component of the model is built on a 3-dimensional finite element grid of 1,392 elements. The model is an application of the IWFM software, which is also developed and maintained by the Bay-Delta Office.
- **CalSim II**, jointly developed by DWR and the U.S. Department of Interior, Bureau of Reclamation (Reclamation) for performing planning studies related to CVP and SWP operations. The primary purpose of the model is to evaluate the water supply reliability of the CVP and SWP at current or future levels of development, with and without various assumed future facilities, and with different modes of facility operations. The model is an application of the WRIMS software, which is also developed and maintained by the Bay-Delta Office.
- **Spreadsheet-based models**, developed specifically for this study to simulate regulated streamflows for watersheds that contain water resources projects operated by local agencies (i.e., non-CVP, non-SWP).
- **Delta Consumptive Use (CU) models,** developed by DWR's Bay-Delta Office to calculate the net depletion of water from Delta channels from the combined effects of precipitation, open water evaporation, wetland evapotranspiration, and agricultural diversions and return flows.

All of the above models simulate monthly water conditions using the October 1921 through 2009 climate trace.[1] Spreadsheet-based models and C2VSim models were developed for each level of development. CalSim II models were developed for the 1980, 2000, and 2010 levels of development to define CVP and SWP operations.

The flow of data between the four models is shown in **Figure ES-1**. The spreadsheet-based models transform historical unimpaired flows at the boundary of the valley floor to impaired or regulated flows. The CalSim II models define storage and storage releases for CVP and SWP reservoirs, project contract allocations, and project exports from the Delta. The CV2Sim models simulate conditions on the valley floor including streamflows, stream diversions and return flows, and stream gains from rainfall-runoff and groundwater inflow.

Model Validation

Several shortcomings of the adopted modeling tools became apparent while conducting the analyses for this study. First, the hydrology of C2VSim and CalSim II are significantly different, and reservoir operations taken from CalSim II may not always be appropriate for the C2VSim hydrology. Second, C2VSim tends to over-estimate flows in some months and does not account for over-bank flooding that occurred in periods of high runoff before the construction of flood control dams as part of the CVP and a comprehensive levee and flood bypass system. Model modifications were introduced to reduce the effects of these model weaknesses when simulating each of the fixed level of developments. However, these modifications are imperfect, and while general trends may be ascertained from model results, inherent model weaknesses prevent detailed specific conclusions being made with a high degree of confidence.

Model Results

Model results include monthly streamflows for a wide range of hydrologic conditions. The metric for assessing changes in Sacramento Valley streamflows over the last 115 years is the combined simulated flow of the Sacramento River below Freeport[2] and the Yolo Bypass at the Lisbon Weir, located approximately 2 miles downstream from the Putah Creek confluence. **Figure ES-2** presents the average monthly hydrograph of this combined flow for the seven level of development studies over the 88-year period of simulation. The metric for assessing changes in San Joaquin Valley streamflows over 115 years is the simulated flow of the San Joaquin River near Vernalis. **Figure ES-2** also presents the average monthly hydrograph of the San Joaquin River flow for the seven level of development studies over the 88-year period of simulation. The main report includes average monthly hydrographs for these two metrics by water year type using the State Water Board Sacramento Valley 40-30-30 index.

[1] The publically released version of CalSim II simulates conditions from October 1921 through September 2003. For this study, CalSim II model results were extended through comparison with unpublished CalSim model results from October 1921 through September 2009.

[2] The flow at USGS gage 11447650, Sacramento at Freeport, combined with the discharge from the Sacramento Regional wastewater treatment plant.

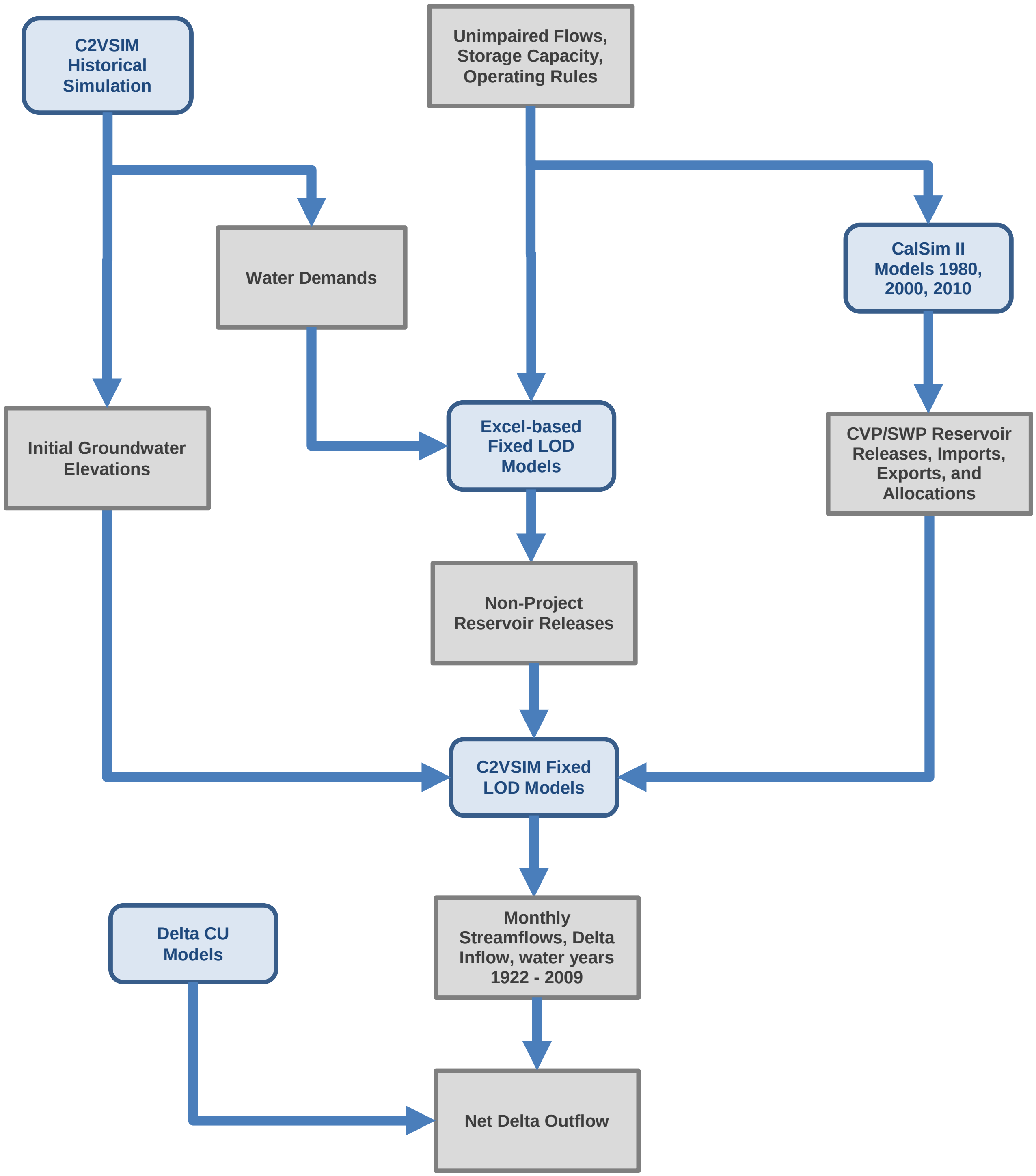


Figure ES-1. Flow of Information between Simulation Models

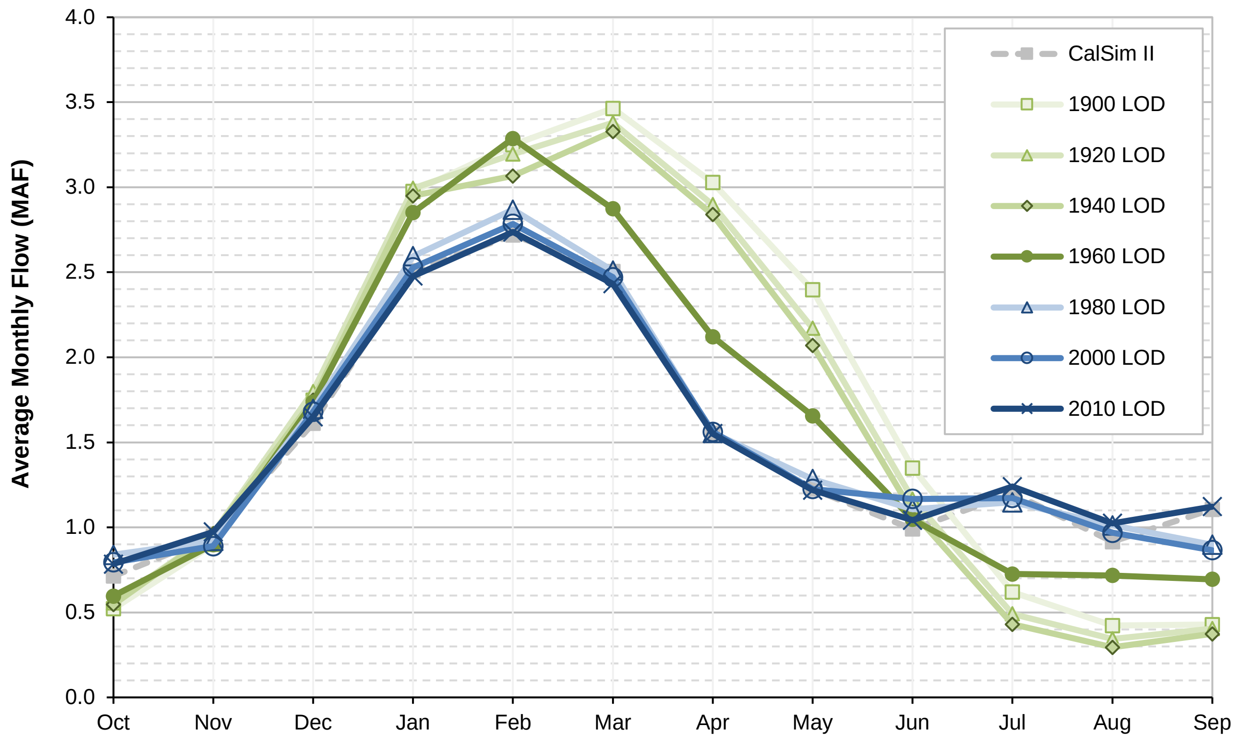
LOD = Fixed Level of Development

Major changes to the water resources of the Sacramento Valley occurred between 1940 and 1980. The two decades following 1940 were characterized by large increases in irrigated agricultural and the beginning of storage regulation by Shasta Lake and Dam. The growth in irrigated agriculture continued from 1960 through 1980; this period saw the introduction of the SWP and storage regulation by Lake Oroville and Oroville Dam. **Figure ES-2** clearly identifies the impacts of these developments to Sacramento Valley flows. At the 1900 LOD, the simulated winter pulse of water from the Sacramento Valley typically enters the Delta in February and March as a mix of snowmelt and rainfall-runoff. By 1980, simulated winter and spring flows are much diminished by diversions to storage in CVP and SWP reservoirs for later release. Sacramento River flows are depleted by direct diversions for irrigation from April through October. However, model results show that since the 1960s simulated Sacramento River flows in the summer and early fall increase with the level of development augmented by storage releases from project reservoirs to meet Delta outflow requirements and Delta export demands.

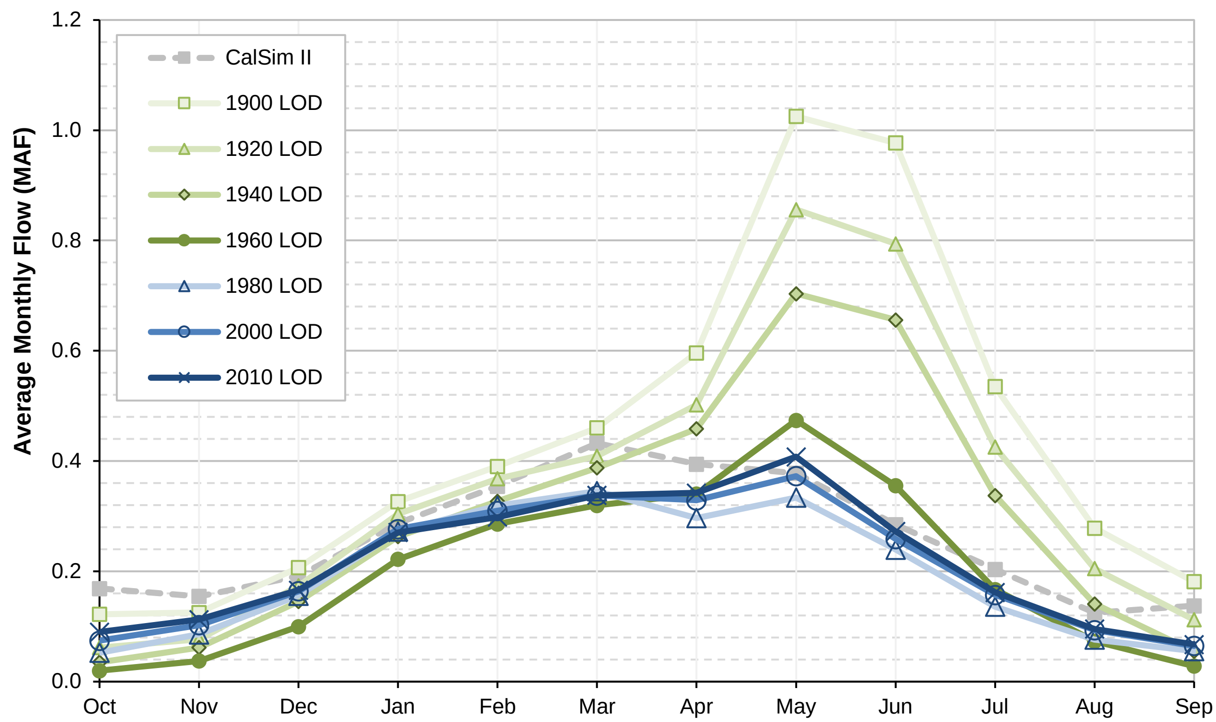
Simulated inflows to the Delta from the San Joaquin Valley at the 1900 LOD, typically arrive in the late spring and early summer during the months of May and June driven by snowmelt. Similar to the Sacramento Valley, development has significantly attenuated these peak monthly flows. This attenuation was mostly complete by the 1980s as the result of export of CVP water from Millerton Lake to the Tulare Lake region, and storage regulation and diversions from the Merced, Tuolumne, and Stanislaus rivers for local irrigated agriculture. Regulatory requirements put in place over the last 20 years have partly restored flows in the San Joaquin River in April and May.

Figure ES-3 presents seasonal and annual total Delta inflow for each level of development. Simulated annual Delta inflows decrease steadily from the 1900 to 1980 LOD; thereafter, Delta inflows stay relatively constant. For the months of January through June, simulated flows decrease with increasing level of development. From July through October, Delta inflows increase with the level of development.

Tidally-averaged Delta outflow, or net Delta outflow, is typically computed from a water balance considering Delta inflows, in-Delta water use, and Delta diversions and exports. **Figure ES-4** presents the average monthly hydrograph of net Delta outflow for the seven level of development studies over the 88-year period of simulation. The major changes in simulated net Delta outflow occur between the 1940 and 1980 LOD. Moving from the 1940 to 1960 LOD, net Delta outflow decreases by 2.1 MAF, primarily because of upstream agricultural development. At the 1960 LOD, in-Delta diversions and exports account for approximately 23 percent of the decrease in net Delta outflow compared to the 1940 LOD. By 1980, the growth in in-Delta diversions and exports account for approximately 83 percent of the decrease in net Delta outflow compared to the 1960 LOD.

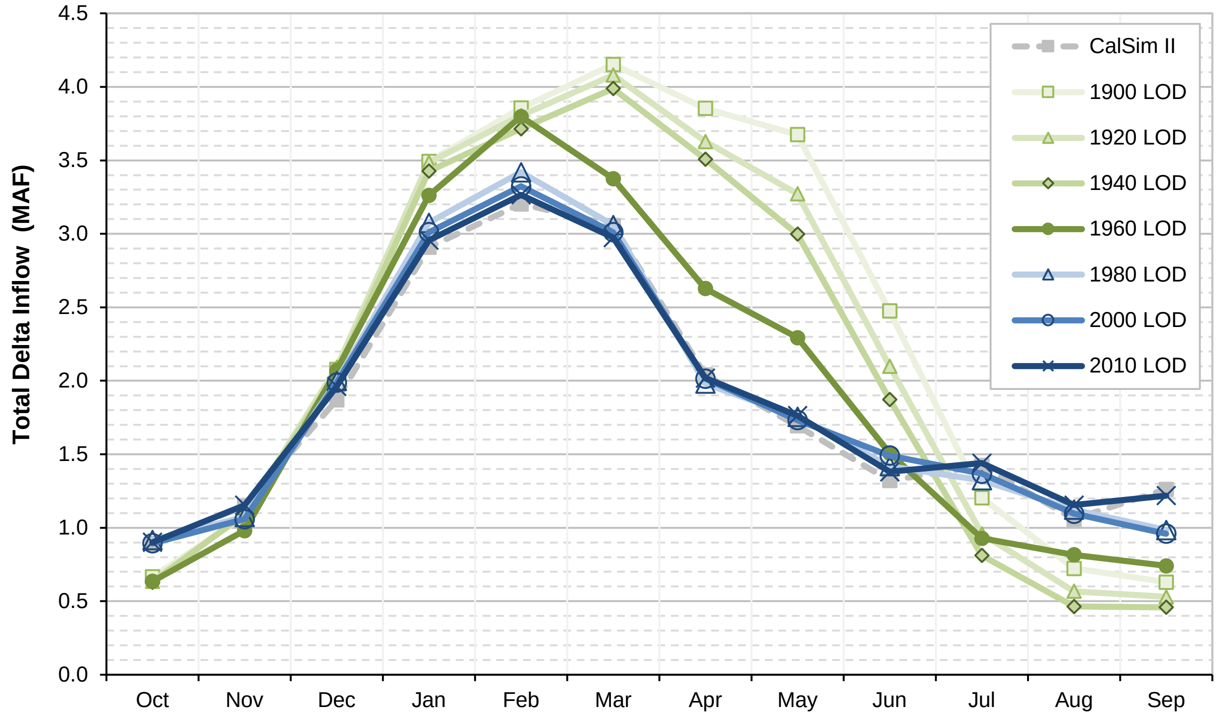


(a) Sacramento Valley Inflow to Delta - Average Monthly Flows

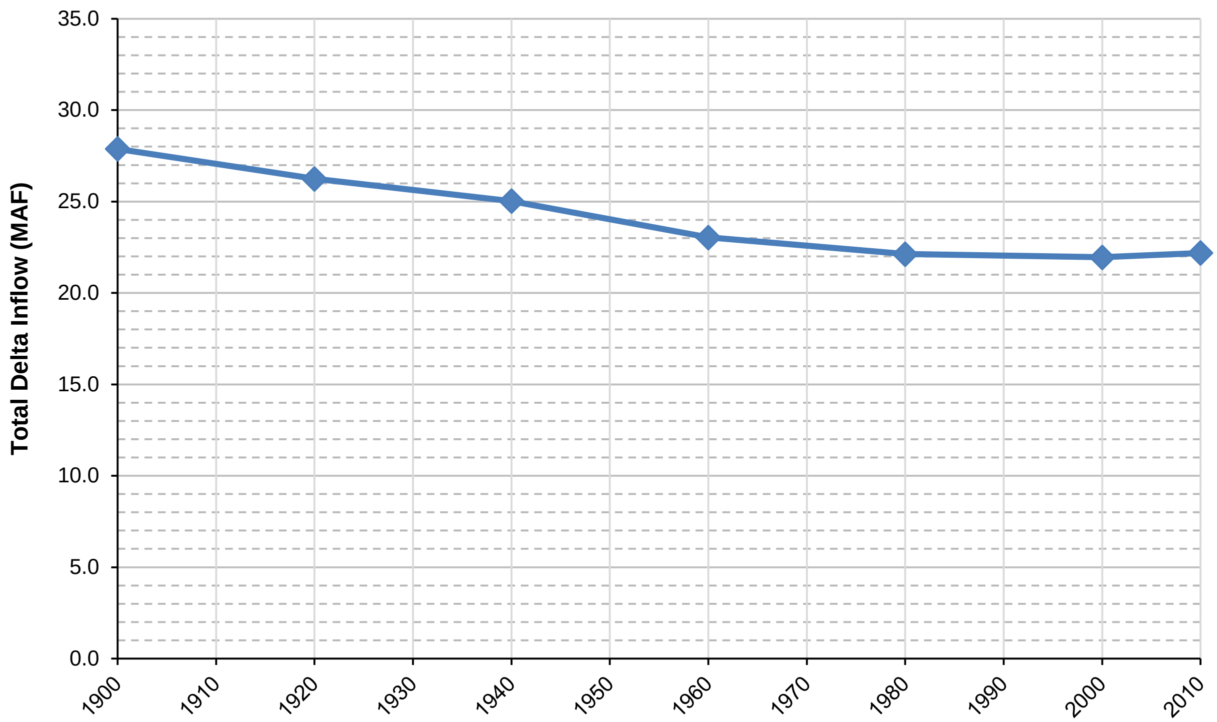


(b) San Joaquin Valley Inflow to Delta Average Annual Flows

Figure ES-2. Simulated Sacramento and San Joaquin Valley Inflow to Delta, All Levels of Development: Water Years 1922-2009

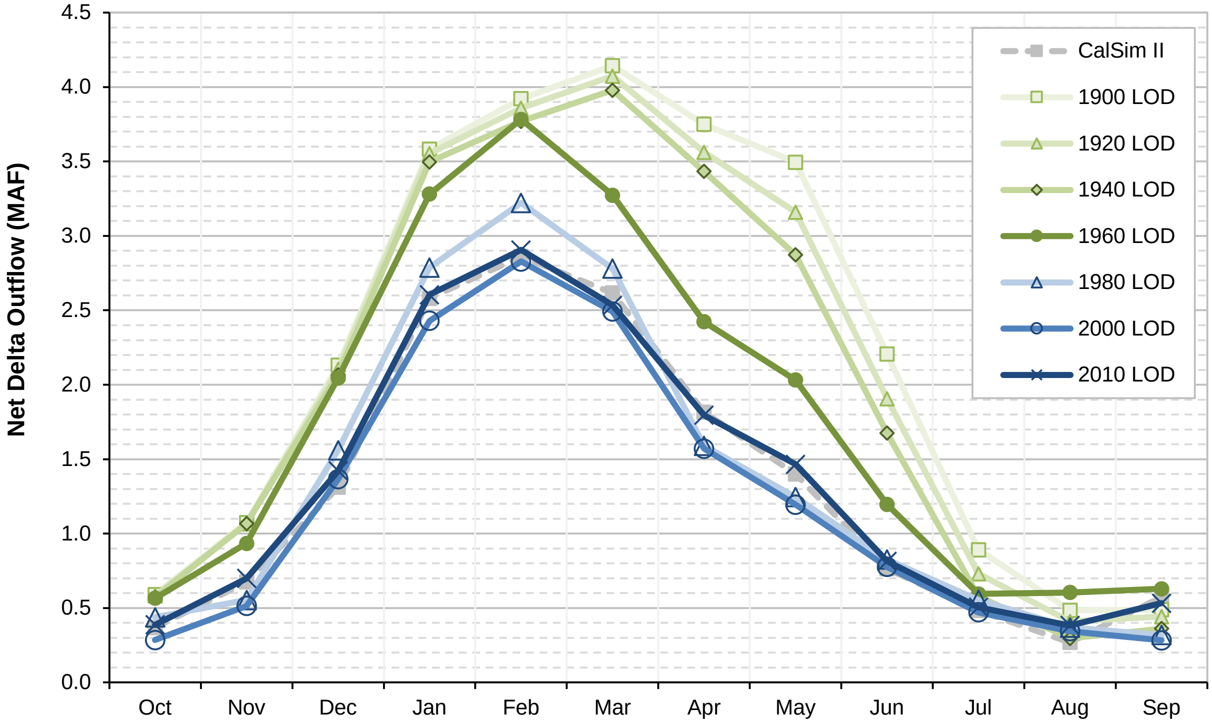


(a) Average Monthly Flows

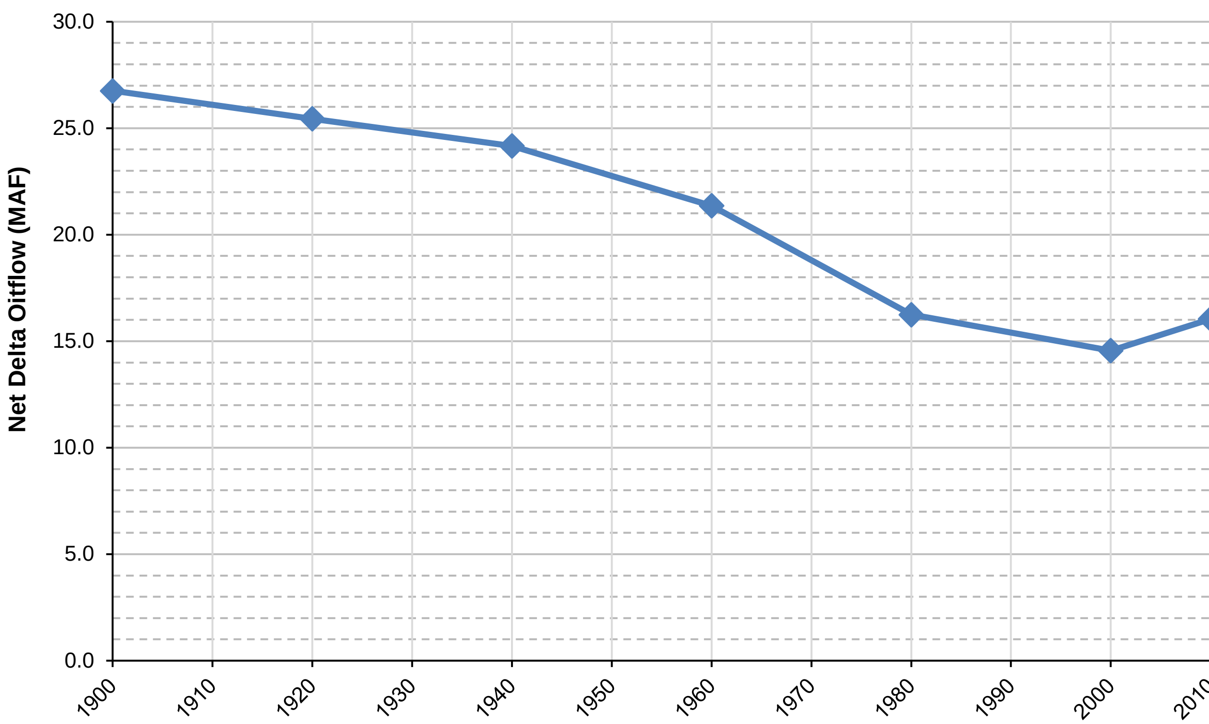


(b) Average Annual Flows

Figure ES-3. Simulated Total Delta Inflow, All Levels of Development: Water Years 1922-2009



(a) Average Monthly Flows



(b) Average Annual Flows

Figure ES-4. Simulated Net Delta Outflows, All Levels of Development: Water Years 1922-2009

Climate Change

Since the beginning of the 20th century, average daily surface temperatures for California have risen approximately 1.5 °F, changing the snow accumulation and snow melt regime in the Sierra Nevada, Trinity, and Cascade mountains, and the rainfall-runoff pattern of watersheds at lower elevations. A supplemental analysis was undertaken to investigate the impacts of these historical temperature changes on river flows, Delta inflows, and net Delta outflows. For each level of development, perturbation factors were used to transform model flow data at the locations where rivers and streams exit the foothills to enter the valley floor. The purpose of this transformation was twofold: first to remove the effects of a rising temperature trend over the period of simulation; and second to incorporate the temperature effects of climate change into the simulated flows associated with a given level of development. For example, unimpaired streamflows at the 1980 LOD include the effects of climate change that existed in 1980 (compared to a 1900 baseline).

The analysis presented in this report suggests that temperature-driven, climate change effects on Delta flows are not significant compared to the effects of human actions in the upstream watersheds. Possible reasons for the lack of a clear climate signal are as follows:

- Climate change modeling did not address changing patterns of precipitation.
- Climate change modeling did not address changes to evaporative demand on the valley floor.
- Rising temperature trends before 1970 are muted.
- Low elevation watersheds are relatively unaffected by rising temperatures.
- The timing of the climate-change signal from high elevation watersheds varies with elevation; e.g., the seasonal shift in flows from the Lake Shasta watershed is different from that for the Lake Oroville watershed.
- Storage regulation dampens the climate change signal.

The analysis considers the climate change effects of the 20th century and first decade of the 21st century. Conclusions from this analysis should not detract from the very serious impacts of climate change that are expected to occur during the middle and late parts of the 21st century,

Conclusions

The *Historical Level of Development Study* provides a set of model results to assist in understanding both how and why streamflows in the Sacramento and San Joaquin valleys have changed over a 115-year span, beginning in 1900. By using a fixed level of development approach, the influence of hydrology is separated from human actions.

The major conclusions of the study are as follows:

- Long-term average annual Delta inflows decline steadily from the 1900 LOD to 1980 LOD, and thereafter stay relatively constant. The decline in flows before 1980 are observed across both the Sacramento and San Joaquin valleys and are primarily caused by agricultural development.

- For the Sacramento Valley, the largest declines in Delta inflows occur from February through May. These declines are partially offset by increased Delta inflows from July through September after the construction of the CVP and SWP, as simulated in the later levels of development.

- For the San Joaquin River, the decline in Delta inflows is most marked for May and June, and to a lesser degree, the adjacent months of April and July.

- The shift in timing of Delta inflows is most noticeable in critical years during which July to September Delta inflows are considerably greater for the later levels of development.

- Long-term average annual net Delta outflow declines at an accelerating rate from 1900 LOD to 1980 LOD because of the demands of irrigated agriculture in the upstream watersheds. The steepest decline in outflow between 1960 and 1980 also is associated with CVP and SWP export pumping in the south Delta. There is a modest recovery in net Delta outflow for the 2010 LOD.

- Groundwater inflows that sustained streamflows in the summer and fall have diminished and in some instances become negative as groundwater levels have fallen over the 20th century. Additionally, stream seepage losses in the winter months have increased. Falling groundwater levels are largely attributed to increased pumping for agricultural and municipal purposes.

Chapter 1
Purpose and Scope of Work

The San Francisco Estuary, composed of the San Francisco Bay and the Sacramento-San Joaquin River Delta (Delta), is the largest estuary along the Pacific coast of the United States. This estuary is a vast and vitally important ecosystem. It also serves as the hub of California's water system, which delivers drinking water to 25 million residents and irrigation water to 4 million acres of farmland from the Delta's tributary watersheds in the Central Valley (Fox et al., 2015).

Human activities have dramatically affected inflows to the Delta relative to those that existed early in the 20th century. Upstream storage regulation has changed the seasonal pattern of river and channel flows. Diversions for irrigation and municipal and industrial (M&I) purposes have depleted surface waters. Changes in land use have affected the amount and timing of surface runoff. Groundwater pumping has impacted groundwater elevations and groundwater inflows to streams and rivers. Additionally, flood control measures and an extensive network of levees have ended the natural cycle of bank overflows and detention storage.

This Technical Memorandum (TM) describes the *Historical Level of Development Study* and associated analysis that was undertaken for the Metropolitan Water District of Southern California (MWD). This TM was prepared as part of Task 11 (Technical Memorandum) of the Scope of Work (SOW), dated August 4, 2014.[3] The purpose of this work is to support ongoing studies to explain how and why Delta outflows and salinity have changed over time. Work undertaken includes the creation of a model that simulates water conditions in the Central Valley at the 1900 'level of development.' This model serves as a baseline from which to measure the effects of development over the last 115 years, at approximately 20 year intervals. Given that human activities had already modified the hydrology of the Central Valley to a large degree by 1900, this study does not measure effects of development relative to a "natural" or pre-development baseline.

Study Approach

A set of 'fixed level of development' model studies were created to simulate the water resources of the Central Valley. Under a fixed level of development, water facilities, land-use, water supply contracts, and regulatory requirements are held constant over the period of simulation. The historical climate trace from October 1921 to September 2009 is used to represent the possible range of water supply conditions. A total of seven level of development (LOD) simulations were developed, as follows:

- 1900 LOD – characterized by early flood control measures, drainage of wetlands, and early irrigated agricultural development following the passage of the Wright Irrigation Act of 1887.
- 1920 LOD – characterized by growth of irrigated agriculture and industrial agriculture and construction of dams in upstream watersheds by water districts, water agencies, and power companies.

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[3] *Hydrology Development (Delta Flow and Salinity Trends Support)*. Metropolitan Water District of Southern California, Task Order 01, Master Contract #143875.

- 1940 LOD – characterized by significant expansion in agricultural development and agribusiness and continued construction of dams in upstream watersheds.
- 1960 LOD – characterized by early operation of the Central Valley Project (CVP), completion of flood control measures, implementation of early Delta standards, and continued growth in irrigated agricultural development.
- 1980 LOD – characterized by completion of the CVP, early operation of the State Water Project (SWP) with low south-of-Delta contract demands, continued dam construction for local water supply projects, and implementation of State Water Board Water Rights Decision 1485 (D-1485) for Delta standards.
- 2000 LOD – characterized by the end of major water facility construction and the release of more stringent Delta standards through the State Water Board Water Rights Decision 1641 (D-1641).
- 2010 LOD – characterized by increasingly stringent Delta standards, including Reasonable and Prudent Alternatives contained in the U.S. Fish and Wildlife Service 2008 Biological Opinion and National Marine Fisheries Service 2009 Biological Opinion for long-term operation of the CVP and SWP.

Comparison of model results across different levels of development provides insights in to how land use change, water management facilities, regulatory requirements, and operating policies have affected flows over much of the 20th century and the beginning of the 21st century. For example, comparison of 1960 LOD and 1980 LOD Stanislaus River flows illustrates how construction and operation of New Melones Dam has changed the flow regime of that river. At the 1960 LOD, river flows are regulated by Old Melones Dam based on the 1922–2009 historical hydrology. In contrast, the 1980 LOD simulates operation of New Melones Dam for approximately the same hydrologic trace.[4]

Organization of Technical Memorandum

This TM is organized into ten chapters and two appendices, as follows:

- **Chapter 1, Purpose and Scope of Work**, describes the *Historical Level of Development Study*.
- **Chapter 2, Historical Timeline**, discusses the influences on the water landscape and how these have changed streamflows over the 20th century.
- **Chapter 3, Modeling Tools and Data,** describes the simulation tools used for this study and the major data sources.
- **Chapter 4, C2VSim Model,** describes the integrated surface water groundwater model used to simulate streamflows for each of the fixed level of development studies.
- **Chapter 5, CalSim II Models,** describes the CalSim II models that were created for the 1980, 2000, and 2010 levels of development to define CVP and SWP operations.

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[4] Inflows to New Melones Dam also are affected by upstream storage regulation. Beardsley and Donnell dams were completed in 1957. New Spicer Dam was completed in 1990. No new dams were completed between 1960 and 1980.

- **Chapter 6, Spreadsheet Models**, describes the spreadsheet models that were developed for Central Valley rivers and streams having significant storage regulation.

- **Chapter 7, Model Results,** summarizes C2VSim model results for seven fixed levels of development studies.

- **Chapter 8, Climate Change,** summarizes C2VSim model results for six fixed levels of development studies that were modified for climate change, and compares the results to those obtained under corresponding conditions without climate change.

- **Chapter 9, Conclusions,** presents the major findings of the study.

- **Chapter 10, References**, presents sources cited in this report.

- **Appendix A, Electronic Files,** describes the electronic files delivered to MWD as part of this study.

- **Appendix B, CalSim II,** briefly describes additional CalSim II simulations that were conducted at the request of MWD to support the Delta Flow and Salinity Trends analysis being conducted by the agency.

- **Appendix C, State Water Project Demands,** describes the development of SWP water demands for the 1980 level of development.

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Chapter 2
Historical Timeline

The lands of the Central Valley have been radically modified since the mid-18th century when the first European settlers arrived. The geomorphology of the Sacramento and San Joaquin valleys were largely formed and defined by regular seasonal flooding. The major rivers did not have adequate capacity to carry normal winter rainfall-runoff and spring snowmelt (Grunsky 1929), so overflowed their banks into vast natural flood basins flanking both sides of the Sacramento and San Joaquin Rivers (Hall 1880; Grunsky 1929). Sediment deposited as the rivers spread out over the floodplain build-up natural levees. Flood water flowed through a series of sloughs that ran parallel to the major channels. Pre-development, the river banks were lined with lush riparian forest. The floodplains contained large expanses of tule marsh, seasonal wetlands, vernal pools, grasslands, lakes, sloughs and other landforms that slowed the passage of flood waters (Whipple et al. 2012; Holmes and Eckmann 1912). High groundwater levels sustained marsh and riparian forest evapotranspiration (ET) through the summer and fall (TBI 1998; Bertoldi et al. 1991; Williamson et al. 1989; Davis et al. 1959).

The discovery of gold along the American River in 1848 spurred agricultural and urban development in the Central Valley. Thousands of new settlers arrived. Cities sprang up along major waterways used to transport miners, their supplies, and gold. Riparian forests along the major rivers were harvested for wood to fuel the steamboats plying the rivers, to build infrastructure, and for farms on the natural levies flanking the major rivers (Katibah 1984). In that same year, the federal government transferred ownership of "swamp and overflowed lands" to California on the condition that they be drained and reclaimed. As lands were cleared, cattle grazing was replaced by wheat production, and by the mid-1850s, the state's wheat output exceeded local consumption, making California a major exporter of grain.

This chapter briefly describes how development of the Sacramento and northern San Joaquin valleys[5] has affected streamflows, Delta inflows, and tidally-averaged Delta outflows. Surface water diversions to support irrigated agriculture have depleted streamflows. Groundwater pumping for agricultural and M&I purposes has lowered water tables and reduced groundwater inflows to streams and rivers. Reservoirs have altered the seasonal pattern of flow and attenuated flood flows. Flood control works have accelerated conveyance of high flows towards the Delta, blocking their natural retention in the floodplains. For the purposes of this chapter, 1900 serves as a baseline to which the evolving landscape of the 20th and early 21st century are compared.

Land Use

In the early days of European development, farming in the Sacramento Valley was largely dedicated to raising cattle and dryland farming for grain production. One of the first areas developed for irrigated agriculture was Yolo County; diversions from Cache Creek for irrigation purposes began in 1856. In 1865, water for irrigation was also diverted from Stony Creek. In the following decades, many of the canals and flumes built to support hydraulic mining were rededicated for irrigation of orchards and vineyards in the foothills. Bulletin 26 (DPW, 1931a) estimates that the area of irrigation in the

[5] The Tulare Lake region of the San Joaquin Valley is not considered, as apart from flood flows from the Kings River that spill northwards to the Mendota Pool on the San Joaquin River, the Tulare Lake Region is an internally draining basin.

'Sacramento River Basin' in 1880 was considerably less than 100,000 acres. A census taken by the federal government in 1902 reports that the irrigated area in the Sacramento River Basin covered 206,300 acres. In 1913, the Conservation Commission of California reported an irrigated area of 312,000 acres based on data collected in 1911. A second federal census in 1919 reported an irrigated area of 641,000 acres for the Sacramento River Basin. By 1929, this area had increased to approximately 860,000 acres (DPW, 1931a) and was distributed as follows: 550,000 acres on the valley floor, 103,000 acres within the 'Sacramento' Delta, 66,000 acres in the Sierra Nevada foothills and adjacent valleys, and 138,000 acres in the mountain valleys. Approximately, 134,000 acres of irrigated land were located in 29 irrigation districts formed under the California Irrigation District Act. Most of the expansion in irrigated lands was dedicated to orchards and rice production. The first irrigation development in the San Joaquin Valley was on the Merced River with the construction of a canal system in 1852. By 1890, major irrigation systems has been constructed in the Mokelumne, Stanislaus, Tuolumne, Merced, and Fresno watersheds. Development on the main stem of the San Joaquin River began in the early 20th century.

DWR's Bay-Delta Office has constructed estimates of historical land use in the Sacramento Valley and northern San Joaquin Valley as part of its Consumptive Use (CU) model (DWR, 1979; WRMI, 1991) and as part of the C2VSim model (Brush and Dogrul, 2013). Land-use data are available for water year 1922 through 2009. Land use data for the 1900s and 1910s are reported by the Department of Public Works in Bulletin 26 (DPW, 1931a), Bulletin 27 (DPW, 1931b), and Bulletin 29 (DPW, 1931c).

Figure 2-1 presents the growth of irrigated agriculture on the floor of the Sacramento and north San Joaquin valleys from 1900 through 2009 based on data contained in DWR's C2VSim model, which is discussed in **Chapter 3**. Land use for 1900 is based on data published in Table 12 of Bulletin 27 (DPW, 1931b). C2VSim data shows a plateau in irrigation development in the 1920s and 1930s. However, this is not consistent with Bulletin 27, which reports a steady increase in irrigated lands between 1923 and 1929. In general, with the exception of the Delta, irrigated acreage in the Central Valley increased steadily from 1900, until reaching a plateau in the mid-1970s. Much of the variation in irrigated land area since 1980 has been caused by changes in rice production.

Figure 2-2 presents the growth in urban area from 1900 through 2009 on the floor of the Sacramento and north San Joaquin valleys based on data contained in DWR's C2VSim model. The growth of urban lands accelerated in the 1950s and 1960s. The apparent drop in urban area on the Sacramento Valley floor in 2003 is associated with a model data extension (the original model simulated historical conditions from 1922 through 2003). It suggests that the extent of urban lands before that date may have been over-estimated.

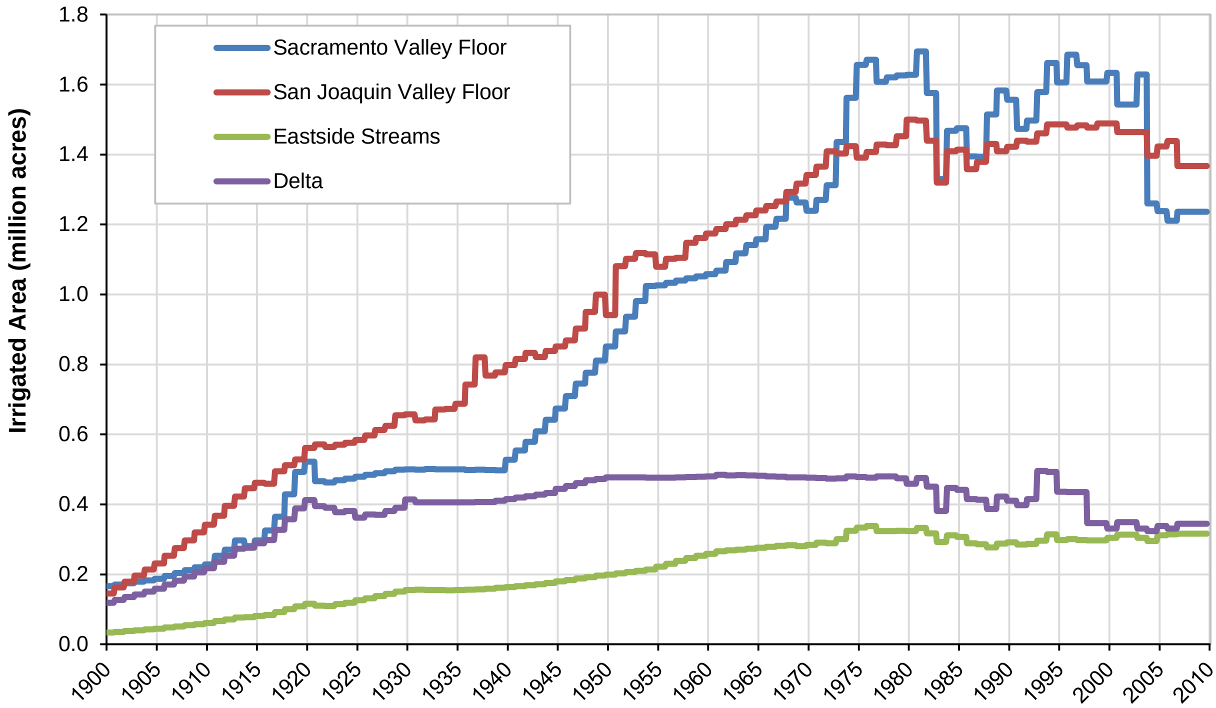


Figure 2-1. Growth of Irrigated Agricultural Area

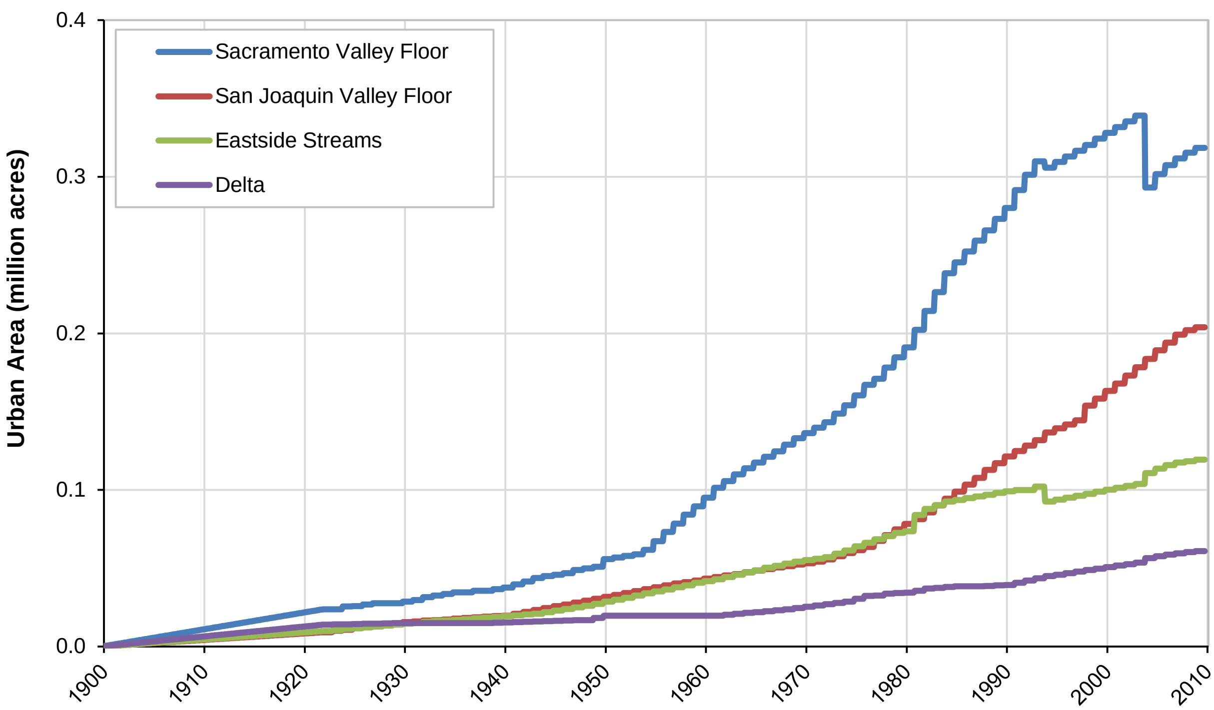


Figure 2-2. Growth of Urban Area

Reservoir Storage
Dam construction for hydropower, irrigation, and M&I water supply has affected the seasonality of streamflows and depleted these flows through evaporative losses. The earliest dams in California, built in the late 1800s and very early 1900s, diverted water for hydropower and local irrigation and usually had little storage capacity. Bulletin 27 (DPW, 1931b) estimates the total storage capacity in the Central Valley to be just 2 TAF in 1850, increasing to 200 TAF in 1907, a hundred fold increase. The first dams for water supply were built in the Hetch Hetchy Valley of the Tuolumne River in 1923 by the City and County of San Francisco and on the Mokelumne River in 1929 by East Bay Municipal Utility District (EBMUD).

Figure 2-3 shows the growth in total storage capacity on the Sacramento and San Joaquin rivers and their tributaries from 1900 through 2010. Many of the largest dams, in terms of storage capacity, are associated with the CVP and SWP.

DWR has estimated reservoir evaporation losses statewide based on daily data for 60 reservoirs collected for water year 2000 and data collected for 250 reservoirs statewide for water year 1998. In 2000, evaporation losses from man-made lakes and reservoirs in the Sacramento River Hydrologic Region totaled 800 TAF per year, and a further 480 TAF per year in the San Joaquin River Hydrologic Region.

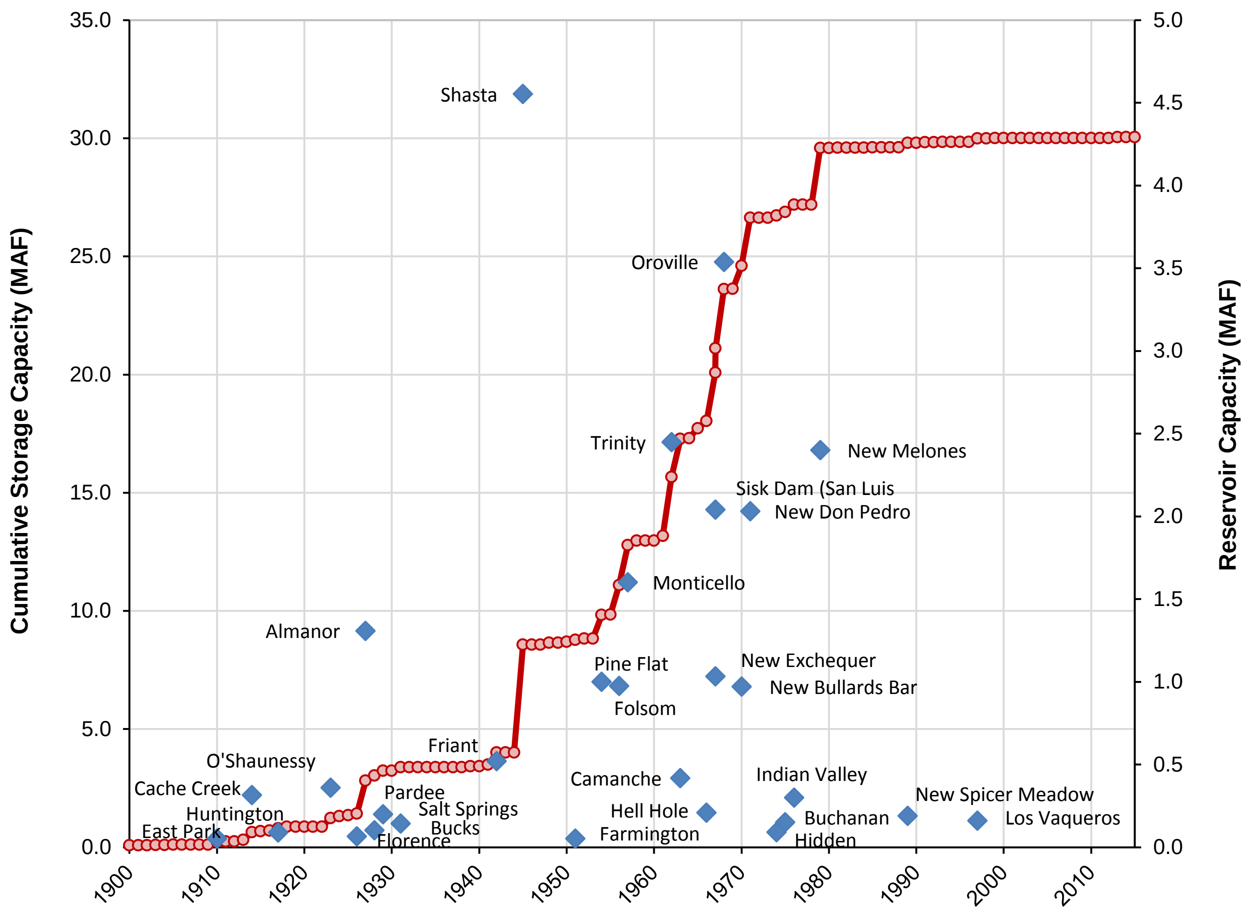


Figure 2-3. Development of Surface Water Storage

Evapotranspiration

Land development associated with irrigated agriculture has changed the amount and seasonal pattern of ET from the land surface. In the absence of a high groundwater table or overbank flooding, natural vegetation depends on rainfall for its source of soil moisture. Therefore, ET from non-irrigated lands rapidly declines in April and May after the end of the winter rains. In contrast, irrigated lands results in high ET rates throughout the summer and early fall, sustained by irrigation. Irrigated lands dedicated to annual crops with a summer growing season are typically bare in winter. Bare soil evaporation is usually limited to the top 4 to 6 inches of the soil profile, so in dry years actual ET is often low from these lands.

Estimates of historical ET are available from the C2VSim model output. **Figure 2-4** presents simulated annual ET under historical land use conditions from 1922 through 2009. For the Central Valley, excluding the Tulare Lake region, ET rates increase by approximately 40 percent over the 88 years of simulation, equivalent to approximately 5 million acre-feet (MAF). **Figure 2-5** illustrates how the seasonality of ET has changed by comparing average monthly simulated ET over two 10-year periods: 1922-1931 and 2000-2009. May through October ET is significant higher for the latter period.

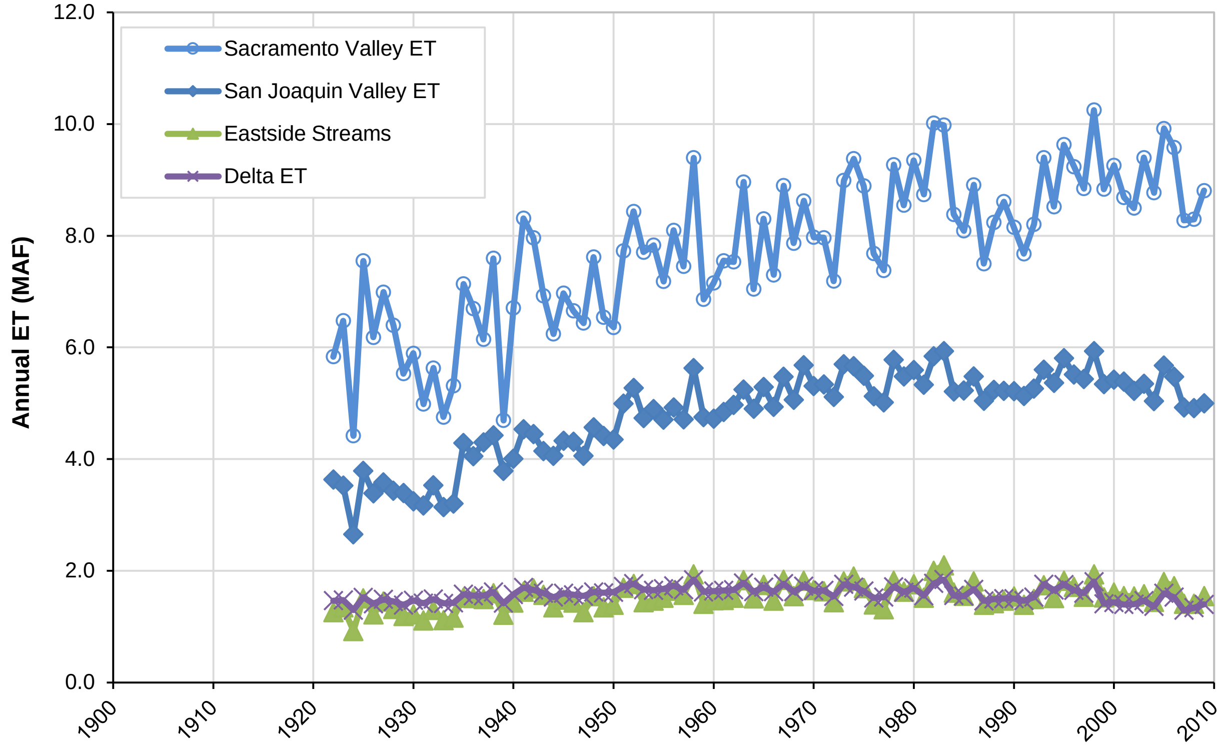


Figure 2-4. Simulated Annual Evapotranspiration under Historical Conditions

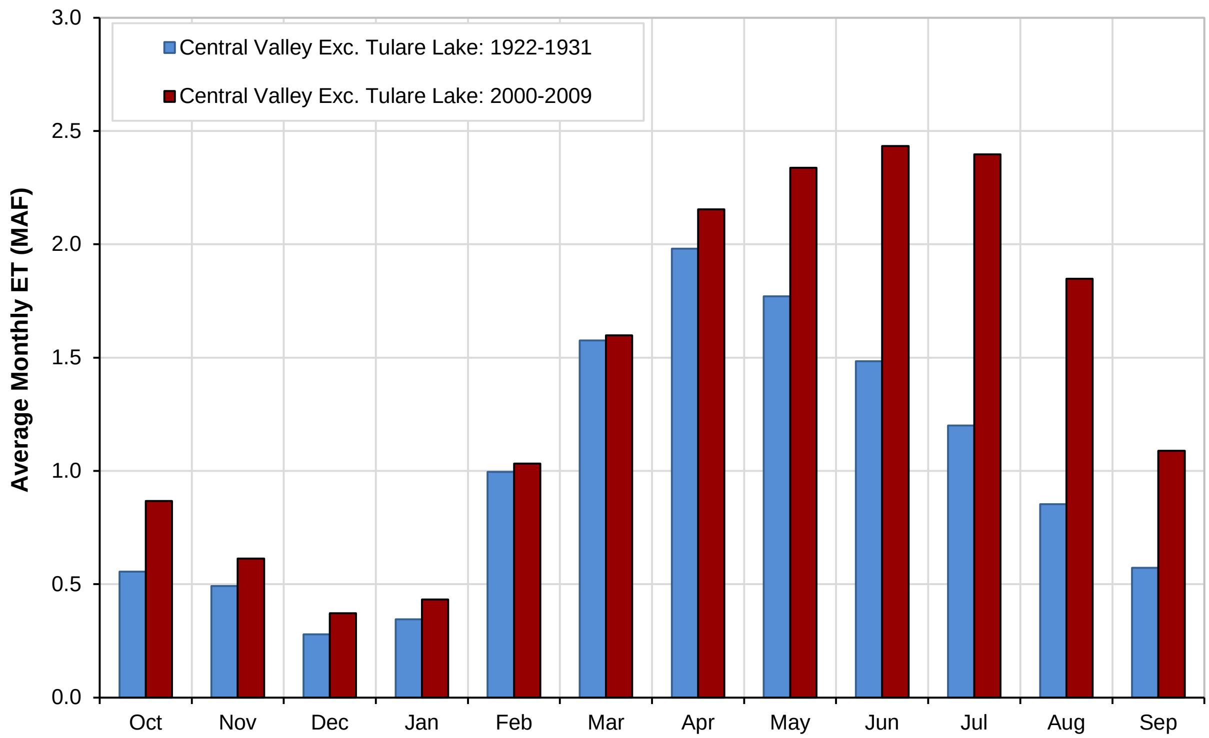


Figure 2-5. Simulated Average Monthly Evapotranspiration under Historical Conditions

Stream Diversions

Water for irrigation derives from stream diversions and groundwater pumping. Historical diversion data are available from many different sources, including DPW and DWR bulletins, Reclamation reports and records, and local water agencies and districts. Bulletin 23, published continuously between 1930 and 1965, presents data on diversions, streamflow, return flow, water use and salinity in the Sacramento and San Joaquin River system.[6] The first bulletin published in 1930 covers water years 1924 through 1928. The scope of the series was broadened in Bulletin 23-56 to include additional data for stream and river systems. The series was discontinued in 1965, following the publication of Bulletin 23-62. The bulletin was published annually from 1963 through 1975 and was last published in 1988.

Figure 2-6 presents the annual historical diversions from Sacramento Valley streams, as compiled from the above sources and contained in the C2VSim model input files. Stream diversions increase by approximately 260 percent over the 88 years of simulation, equivalent to 3.1 MAF. **Figure 2-7** presents the annual historical diversions from San Joaquin Valley streams (excluding the Tulare Lake region), as contained in the C2VSim model input files. Stream diversions increase by approximately 70 percent over the 88 years of simulation, equivalent to 2.0 MAF.[7]

[6] Between 1930 and 1935 the Bulletin was titled *Report of the Sacramento-San Joaquin Water Supervisor.* In 1936, the title was changed to *Sacramento-San Joaquin Water Supervision,* and in 1959 the title became *Surface Water Flow*.

[7] Including water delivered from the Delta-Mendota Canal and California Aqueduct.

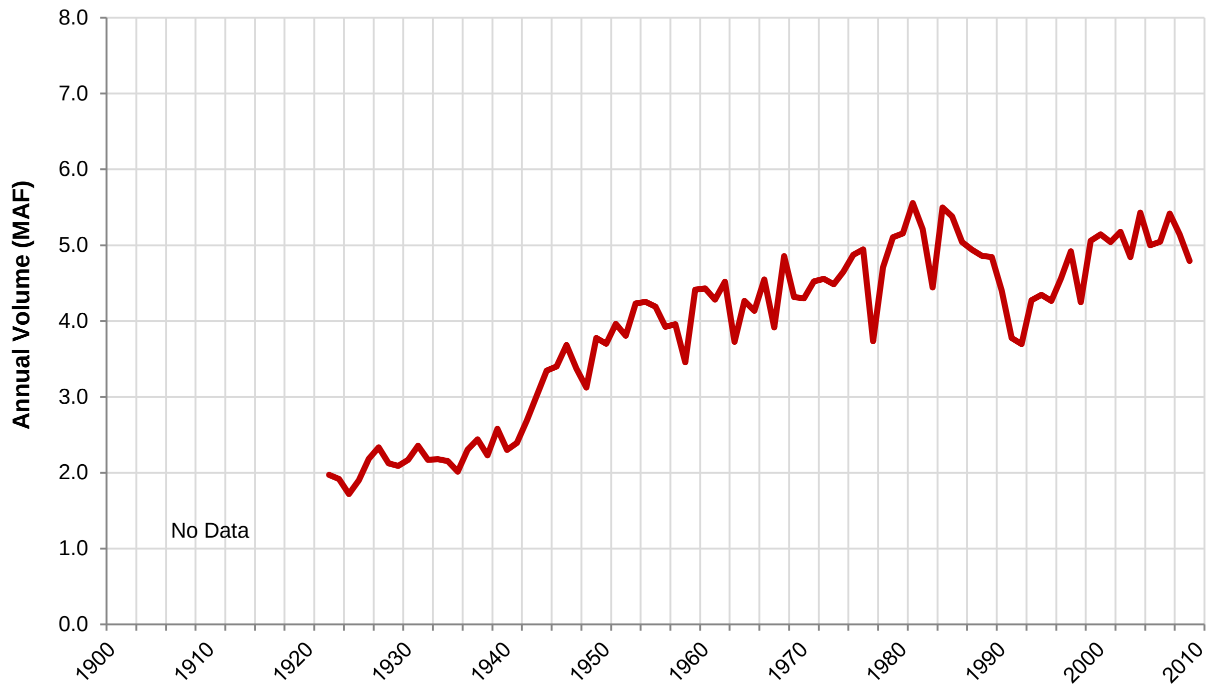


Figure 2-6. Historical Sacramento Valley Stream Diversions

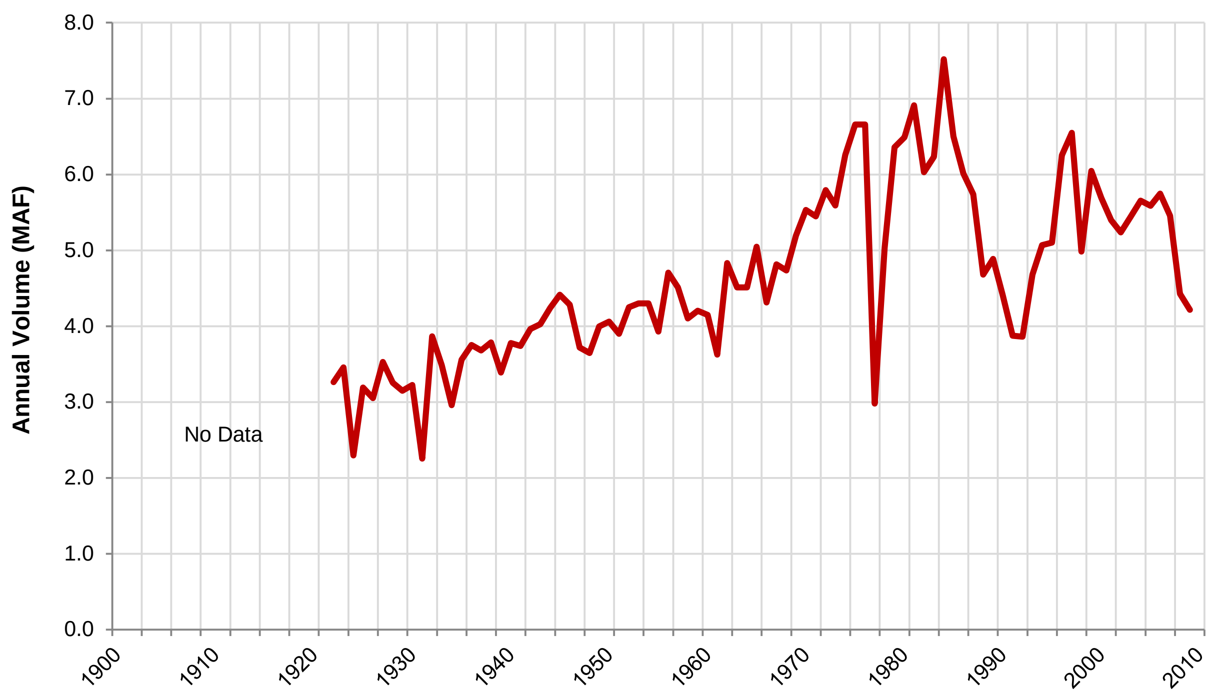


Figure 2-7. Historical San Joaquin Valley Stream Diversions
Does not include Tulare Lake stream diversions

Groundwater

Groundwater inflow is an important component of stream water and significantly affects flows in both the Sacramento and San Joaquin rivers. Over the last nine decades, groundwater extraction for irrigated agriculture and for M&I purposes has lowered groundwater elevations in much of the Central Valley. Because Central Valley streams typically flow over sediments that are hydraulically connected to underlying the aquifer, groundwater inflows to streams have similarly fallen. Estimates of historical changes in groundwater storage and stream gain from groundwater are available from the C2VSim model. **Figure 2-8** presents these changes for the Sacramento Valley, **Figure 2-9** presents these changes for the San Joaquin Valley. In the Sacramento Valley, stream gains from groundwater have decreased from a net inflow of approximately 0.9 MAF per year to a net stream loss of 0.5 MAF per year. In the San Joaquin Valley, stream gains from groundwater have decreased from a net inflow of approximately 0.4 MAF per year to a net stream loss of 0.2 MAF year. **Figure 2-10** presents the monthly stream gain averaged over the period of simulation (Water Years 1922-2009).

There are no reliable estimates of historical groundwater pumping.8 Simulated results for annual groundwater pumping are available from C2VSim and are presented in **Figures 2-11** and **2-12**. Model results suggest that groundwater pumping in the Sacramento Valley has increased by approximately 2.3 MAF over the 88 years of simulation (Water Years 1922-2009). Similarly, model results suggest that groundwater pumping in the San Joaquin Valley has increased by approximately 1.5 MAF over the same period.

[8] Bulletin 26 (DPW, 1931a) estimates that in 1929, 28 percent of the irrigated lands in the Sacramento Valley were irrigated using groundwater.

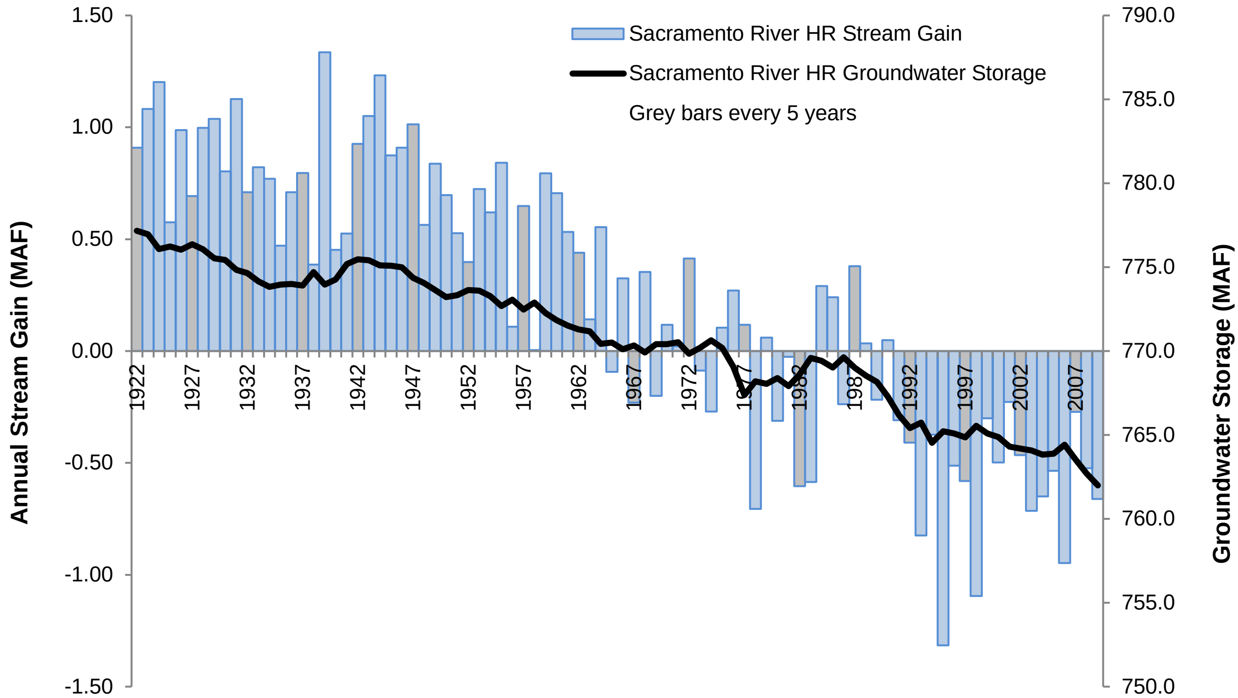


Figure 2-8. Simulated Annual Groundwater Storage and Stream Gain from Groundwater for Sacramento Valley under Historical Conditions

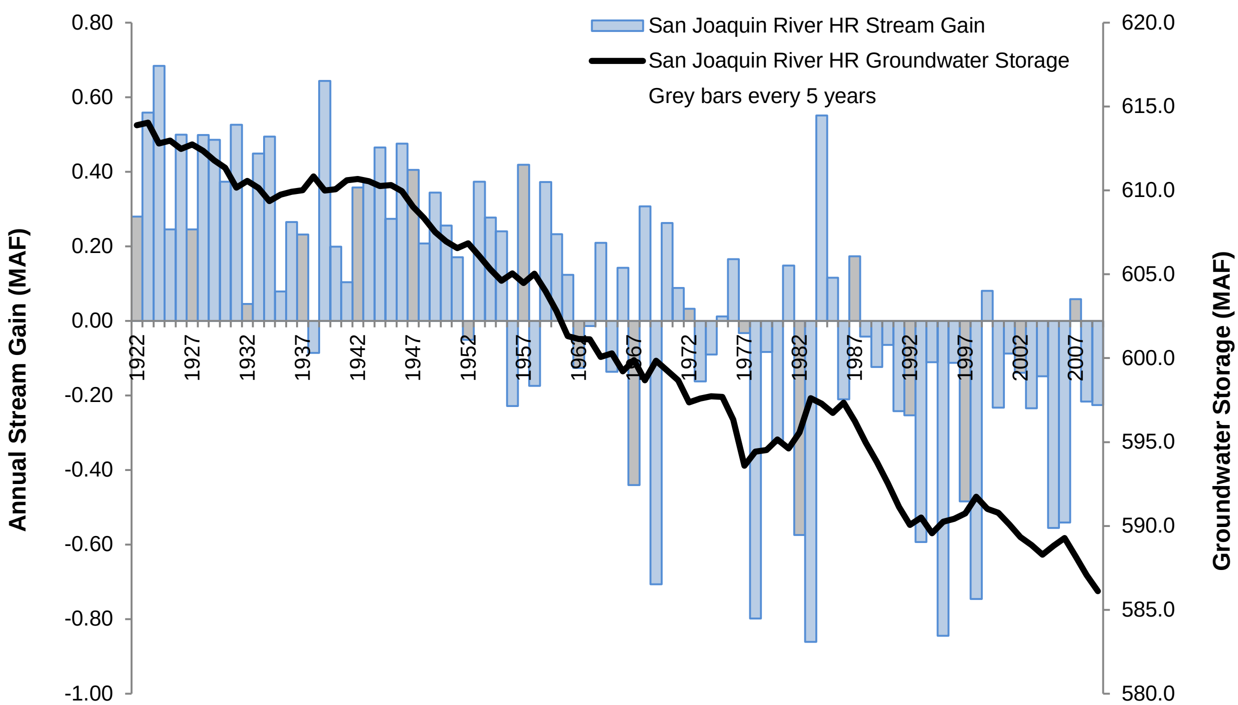


Figure 2-9. Simulated Annual Groundwater Storage and Stream Gain from Groundwater, for San Joaquin Valley under Historical Conditions

Does not include Tulare Lake Hydrologic Region

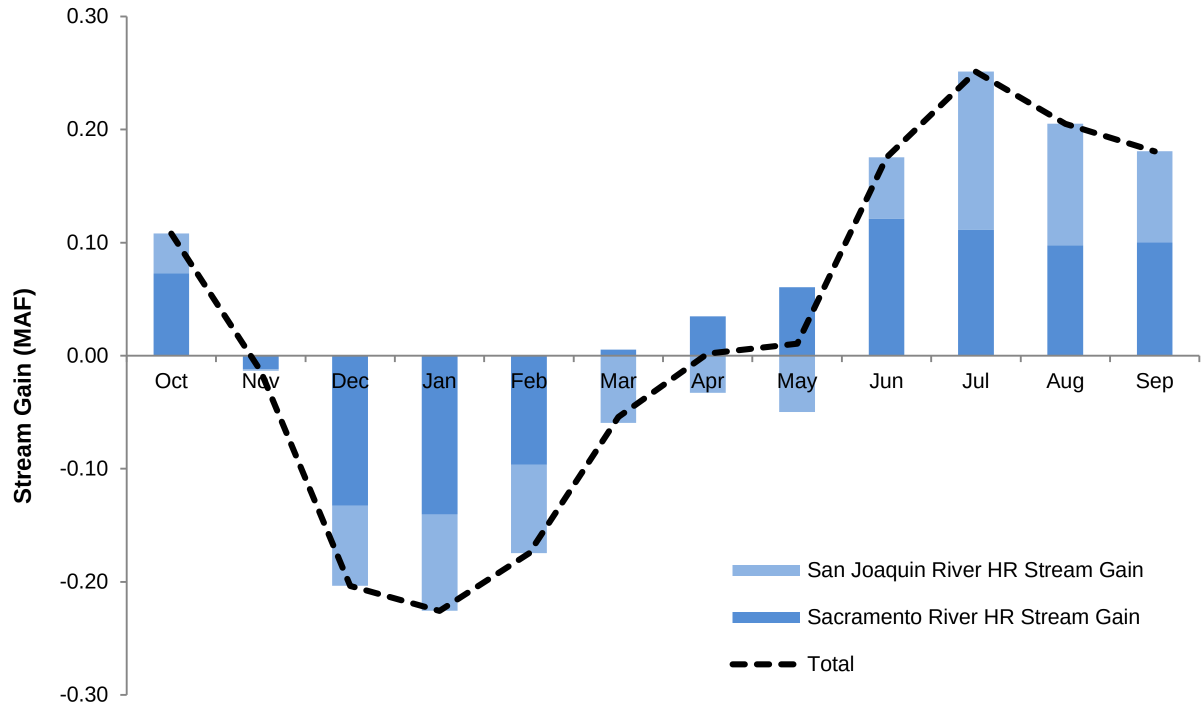


Figure 2-10. Simulated Average Monthly Stream Gain from Groundwater under Historical Conditions

Does not include Tulare Lake Hydrologic Region

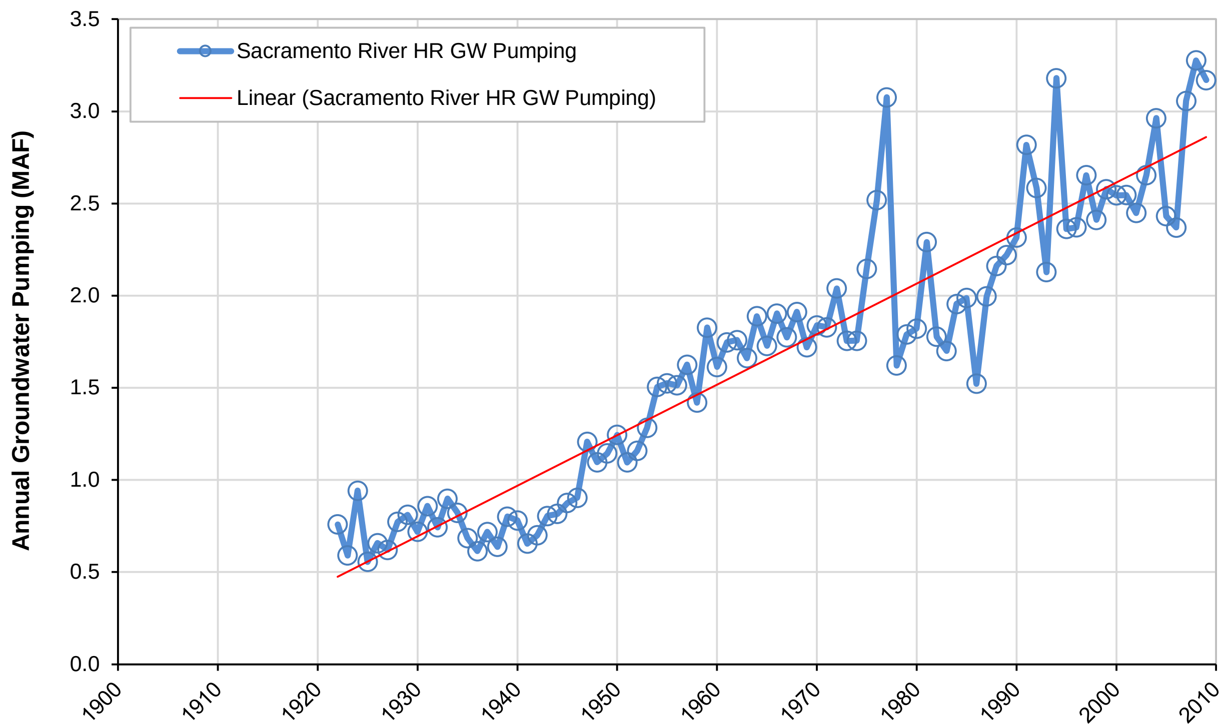


Figure 2-11. Simulated Annual Groundwater Pumping for Sacramento Valley under Historical Conditions

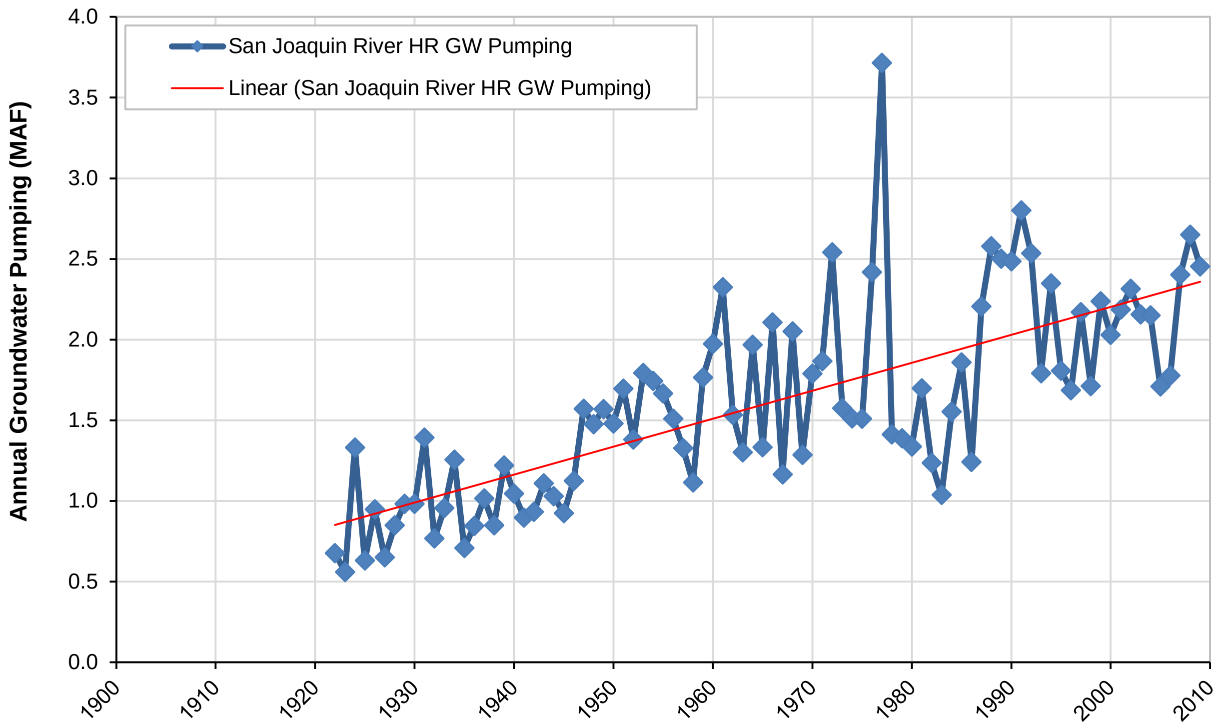


Figure 2-12. Simulated Annual Groundwater Pumping for San Joaquin Valley under Historical Conditions
Does not include Tulare Lake Hydrologic Region

Flood Control

Flood flows are not the focus of this study. Overbank flooding is not represented in the models adopted for this study. However, flood flows and flood control structures are briefly discussed in this section, as during high flow events overbank flooding and inaccurate historical gage records may result in a poor match between historical and simulated flows.

Under natural conditions, the major rivers of the Central Valley had insufficient capacity to carry normal winter rainfall-runoff and spring snowmelt (Grunsky 1929). Rivers overflowed their banks into the natural flood basins flanking both sides of the Sacramento and San Joaquin Rivers (Hall 1880; Grunsky 1929). Important farm and town sites, adjacent to major rivers, were regularly flooded as major rivers overflowed their banks. Regular flooding of these towns led to the formation of levees and reclamation districts by 1860 to raise revenues for flood control. Starting in the 1870s, studies were conducted to determine how to reduce flooding and supply irrigation water. The Office of the State Engineer was established in 1878 to further these plans, and in 1880 the legislature approved the Drainage Act, proposing valley-wide flood control. Following major floods in 1907, it was widely recognized that the system of local levees that had been constructed over the previous 50 years had failed to provide regional flood protection. Subsequently, State and federal authorities, after years of study, developed a set of flood bypasses, channel expansions, and stronger project levees to provide greater relief from large floods.

Sacramento Valley

In the Sacramento Valley, large amounts of rain falling in the surrounding Coastal ranges and the relatively steep Sierra Nevada mountain ranges produces rapid surface water runoff to the Sacramento River. The volume of runoff depends on the amount of rainfall, snow melt, and soil moisture of the watershed. Historically, during high flow events, the relatively shallow grade of the Sacramento River south of the City of Red Bluff would result in overtopping of the river banks.

The flood bypass system for the Sacramento Valley consists of a series of levees, weirs, and bypasses. The system uses three natural depressions to control flows: the Butte, Sutter, and Yolo basins. These basins run parallel to the Sacramento River and receive excess flows from the Sacramento, Feather, and American rivers via natural overflow channels and over weirs. When the Sacramento River is high, the three basins form one continuous waterway connecting the Butte, Sutter, and Yolo Basins. During low stages on the Sacramento, water in these basins can reconnect with the Sacramento River at several points: the Butte Slough Outfall Gates, the terminus of the Sutter Bypass at Verona, and the east levee toe drain at the terminus of the Yolo Bypass above Rio Vista. The Sacramento Weir was completed in 1916 to protect the City of Sacramento from flooding. The Fremont Weir and the Yolo Bypass were completed in 1924. Mouton Weir, the most northerly of the weirs, and Tisdale Weir were completed in 1932, Colusa Weir was completed in the following year. **Figure 2-13** presents the historical monthly flows over the weir. **Figure 2-14** shows the periods of discharge over the Fremont Weir, which is indicative of flood flows valley-wide.

San Joaquin Valley

The Lower San Joaquin River Flood Control Project, constructed between 1959 and 1966, consists of a network of bypass channels, levees, and structures to provide flood protection from Gravelly Ford to the confluence with the Merced River. The project confines flows to the primary San Joaquin River channel and the bypass channels, excluding high flows from the historical network of secondary sloughs and channels. Elements of the project include the Chowchilla Bifurcation Structure, Eastside Bypass Control Structure, the Sand Slough Control Structure, Mariposa Control Structure, and associated bypasses.

Under historical conditions, winter and spring flood flows from the Kings River entered Fresno Slough and were discharged into the San Joaquin River at the Mendota Pool. Since 1954, flood flows on the Kings River have been regulated by Pine Flat Dam, thus reducing the frequency and magnitude of flood spills to Fresno Slough. The Kings River is now operated to convey the first 4,750 cfs of flow to the San Joaquin River.

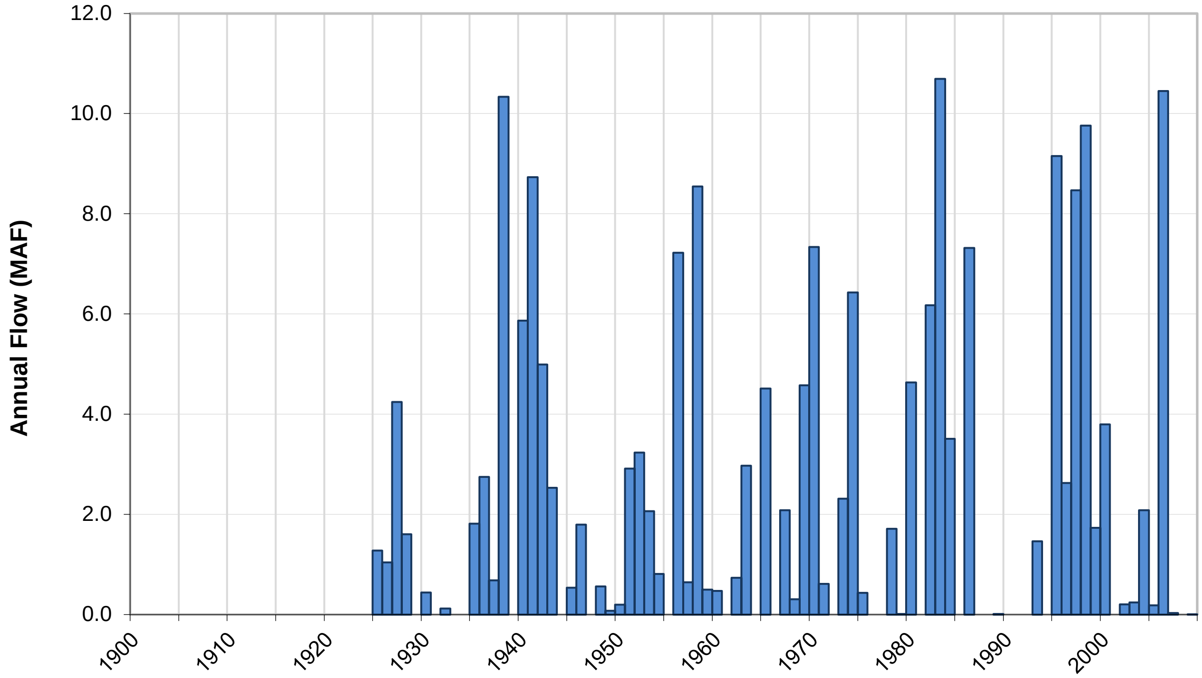


Figure 2-13. Historical Monthly Flows over Fremont Weir

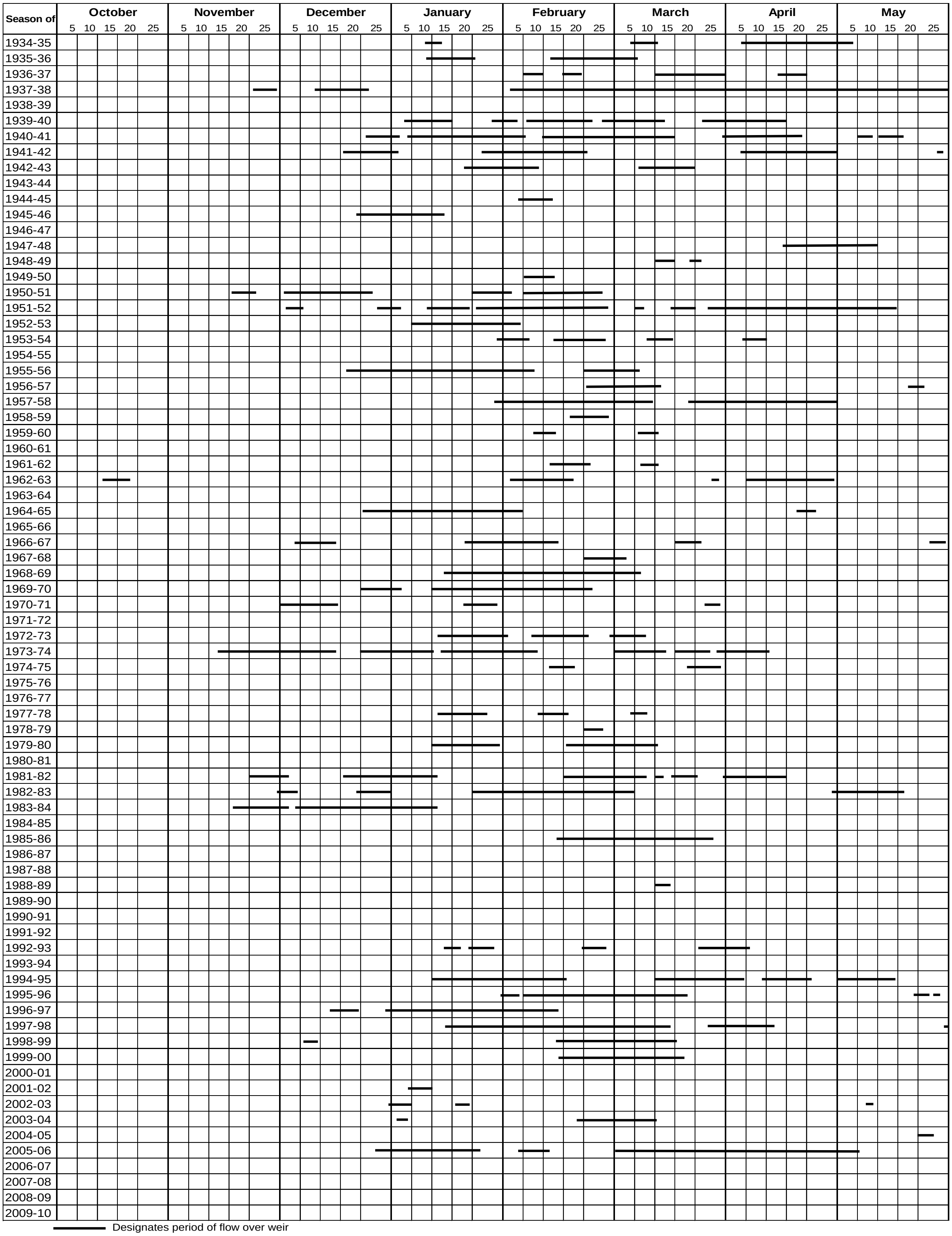
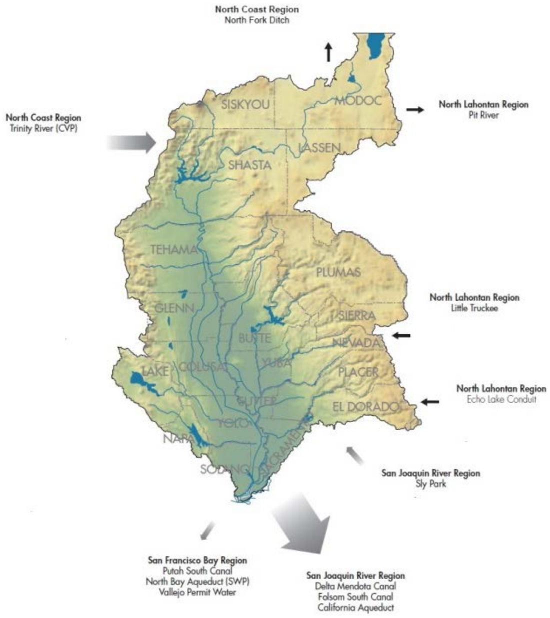


Figure 2-14. Historical Flood Flow Periods for Fremont Weir

Basin Imports and Exports

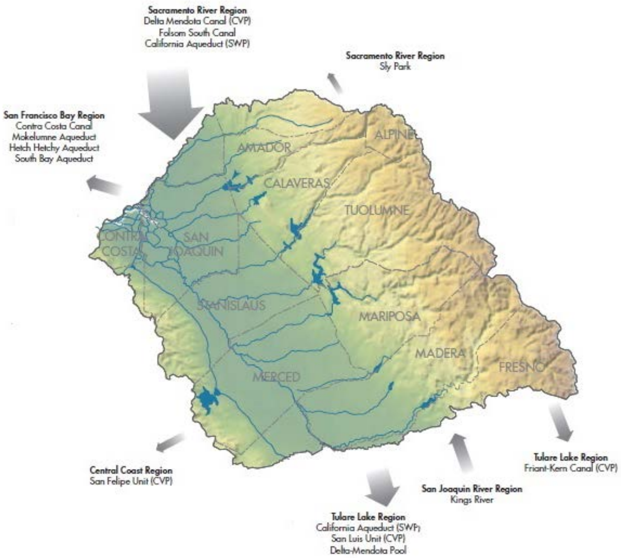
Trans-basin imports and exports for hydropower and water supply purposes directly affects streamflows in both the Sacramento Valley and North San Joaquin Valley.

Sacramento Valley



The largest imports and exports from the Sacramento Valley are associated with the CVP and SWP. Since 1963, the Clear Creek Tunnel has conveyed CVP water from Lewiston Lake on the Trinity River into Whiskeytown Reservoir. CVP exports from the south Delta to the Delta-Mendota Canal began in 1951. SWP exports from the south Delta began in 1968.[9] Additionally, there are several minor interbasin water transfers associated with other public and private entities. Since 1876, Pacific Gas and Electric (PG&E) and has imported approximately 2 TAF annually from Echo Lake in the North Lahontan region to the South Fork of the American River. Sierra Valley imports approximately 6 TAF annually from the Little Truckee River. Shasta Valley water users export 2 TAF from Sacramento Basin to the Klamath River watershed.

[9] Wheeling of SWP water through the Tracy (now Jones) Pumping Plant to the South Bay Aqueduct began in 1962.



North San Joaquin Valley

Similar to the Sacramento Valley, the major imports and exports in to and out of the San Joaquin Valley are associated with the CVP and SWP. Delta water is imported through the Delta-Mendota Canal and California Aqueduct. CVP water is exported from Millerton Lake to the Tulare Lake region through the Friant-Kern Canal. Additionally, the Hetch Hetchy Reservoir system on the Tuolumne River provides water to the southern San Francisco Bay Area and Peninsula. The East Bay Municipal Utility District (EBMUD) diverts water from Pardee Reservoir on the Mokelumne River to supply customers in the East Bay.

CVP Imports and Exports

The CVP (then the State Water Plan) was conceived by the State in 1931 to provide flood control on the Sacramento River, to improve navigation, to prevent saline intrusion in the Delta, and to provide water supplies to contractors in both the Sacramento and San Joaquin valleys.[10] Following congressional approval in 1937, the CVP was built in stages over 40 years. Financed by the federal government, construction of the CVP began in 1937. Shasta Dam was largely completed in 1944 and impounded water created Lake Shasta in April 1944. CVP power was available for sale in the same year. Trinity Dam was completed in 1961. Export of water from the Trinity River watershed through Clear Creek Tunnel to Whiskeytown Reservoir began in 1963. The Corning and Tehama-Colusa canals, which provide irrigation water to approximately 150,000 acres on the west side of the Sacramento Valley, became operational in 1961 and 1976, respectively.

Reclamation completed the Delta Cross Channel in 1951 to aid the transport of high quality water from the Sacramento River, across the Delta to the head of the Contra Costa Canal and Delta-Mendota Canal. The Contra Costa Canal was completed in 1948. The Delta-Mendota Canal and the Jones Pumping Plant were completed in 1951. Construction of CVP-SWP joint use facilities began in 1963. San Luis Reservoir was first filled in 1969.The San Luis Canal, a 102-mile stretch of the California Aqueduct, was completed in 1968. New Melones Dam on the Stanislaus River was completed in 1978. The CVP now includes 20 dams, over 400 miles of conveyance facilities, and 9 MAF of storage capacity.

The following sections describe trans-watershed and trans-basin imports and exports of water associated with the CVP.

Trinity River Watershed

Minimum instream flows for the Trinity River are required to protect and preserve the river's fish and wildlife. Release requirements from Lewiston Lake have varied over four decades as a result of U.S.

[10] Southern California elected to be removed from the plan in order to focus on securing water supplies from the Colorado River.

Department of Interior Secretarial Decisions and the California Department of Fish and Wildlife (CDFW)[11] and CVPIA requests. During the planning phase of the CVP Trinity Division, it was expected that the salmon and steelhead fisheries would be preserved by planned releases from Lewiston Dam and the Trinity River hatchery. The 1955 Trinity River Act authorizing the project foresaw an average annual transbasin diversions of 704 TAF (Reclamation, 1955). A 1957 *Reclamation Plan of Development Report* indicated average annual exports would be approximately 865 TAF. This compares to an unimpaired Trinity River flow at Lewiston of 1,285 TAF (1922–2009). An operating agreement was signed between Reclamation and CDFW in 1959 specifying the amount of water to be provided downstream from Lewiston Dam for fish maintenance. This agreement, partially revised in 1968, called for minimum annual releases of 120 TAF.

Historical flow releases from Lewiston Dam to the Trinity River and exports from Trinity Reservoir through the Clear Creek Tunnel to Whiskeytown Reservoir are presented in **Figure 2-15**. During the first 14 years of operation (1964–1977) transbasin diversions averaged approximately 1,250 TAF per year.

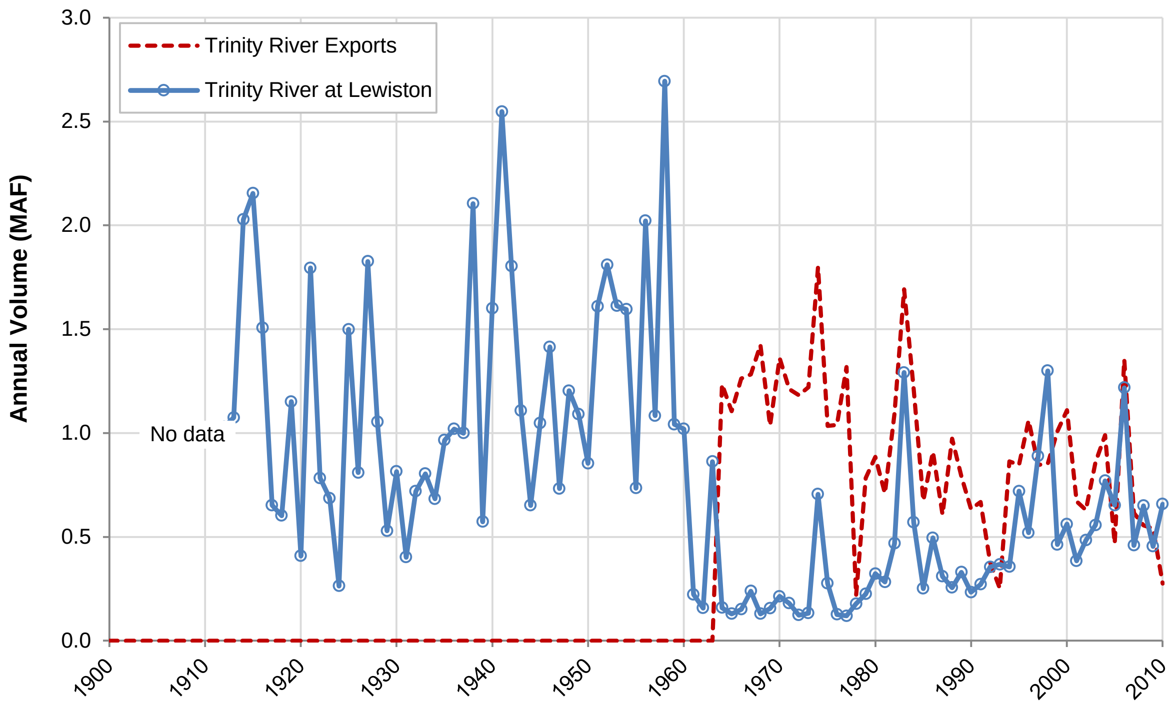


Figure 2-15. Trinity River Unimpaired Flows and Exports

By the 1970s salmon and steelhead populations had fallen far below those that existed before Trinity Dam was completed in 1963. In October 1973, CDFW formerly requested that additional experimental releases be made from Lewiston Dam to prevent further decline in fish populations as part of a 3-year study. The requested release was for 315 TAF per year, however Reclamation was unwilling to release more than

[11] Formerly the California Department of Fish and Game

245 TAF per year. These latter volumes were releases in 1975 and 1976, but not in 1977 because of the extreme drought.

In December 1980, USFWS and Reclamation reached an agreement to increase releases to the Trinity River below Lewiston Dam. This agreement was approved by the Secretary of Interior in January 1981. The agreement specified annual releases from Lewiston Dam of up to 340 TAF in normal water years, 220 TAF in dry years, and 140 TAF in critically dry years. The water year types were defined by the forecasted inflow to Lake Shasta. Under the agreement, USFWS was to conduct a 12-year study to evaluate the effectiveness of the increased flows. In the interim, Reclamation agreed to maintain releases of 287 TAF per year in normal years, with incremental increase of releases to 340 TAF per year as habitat and watershed restoration measures were implemented.

Fishery studies carried-out between 1983 and 1999 culminated in the *Trinity River Flow Evaluation Study* (USFWS, 1999). This study is the foundation of the Trinity River Restoration Program. The Final Environmental Impact Statement/Environmental Impact Report (EIS/EIR) for the program was released in October 2000; the ROD was issued in December 2000. In order to recreate inter-annual flow variability, the ROD defined five water year types with associated minimum annual flow requirements of 369 TAF to 815 TAF, depending on the water year classification. The ROD also defined a minimum carryover storage in Trinity Lake of 600 TAF.

Sacramento-San Joaquin Delta

The Jones Pumping Plant conveys CVP water through the Delta-Mendota Canal to turnouts along the canal, to the Mendota Pool, to San Luis Reservoir, and to the San Luis Canal. The pumping plant has an installed capacity of 5,200 cfs, and a station design capacity of 4,600 cfs. **Figure 2-16** presents annual historical CVP exports from the South Delta through the Jones Pumping Plant. Exports have generally increased since the 1950s, but with significant reductions in 1977 and 1991/92 caused by drought conditions. Since the end of the 1987-1992 six-year drought, CVP exports have varied in response to both hydrologic conditions and changing legal and regulatory requirements, which are discussed later in this chapter.

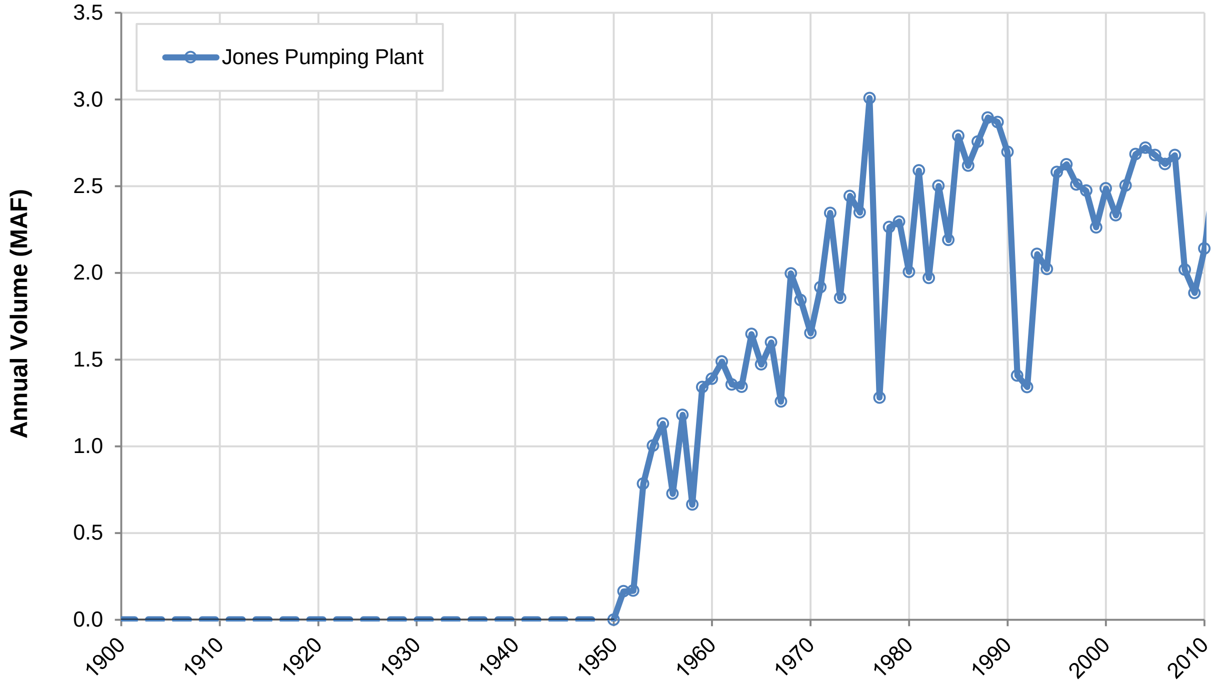


Figure 2-16. Historical CVP Exports from the Delta

CVP water exported from the Delta is primarily used in the North San Joaquin Valley. However, some water is delivered to Santa Clara and San Benito counties through the Pacheco Tunnel from withdrawals from San Luis Reservoir. Historical diversions through the Pacheco Tunnel are presented in **Figure 2-17**. CVP water also is delivered to contractors in the Tulare Lake region, including Westlands WD, the Cities of Avenal, Coalinga, and Huron, and the Kern and Pixley National Wildlife Refuges. Additionally, CVP water is wheeled through Banks Pumping Plant for delivery to Cross Valley Canal contractors. Dos Amigos Pumping Plant, located on the San Luis Canal at Mile Post 87, approximately marks the boundary between the San Joaquin River valley and the Tulare Lake region. The pumping plant conveys both CVP and SWP water. **Figure 2-17** compares historical annual flows through the Jones Pumping Plant to CVP water conveyed through Dos Amigos Pumping Plant.

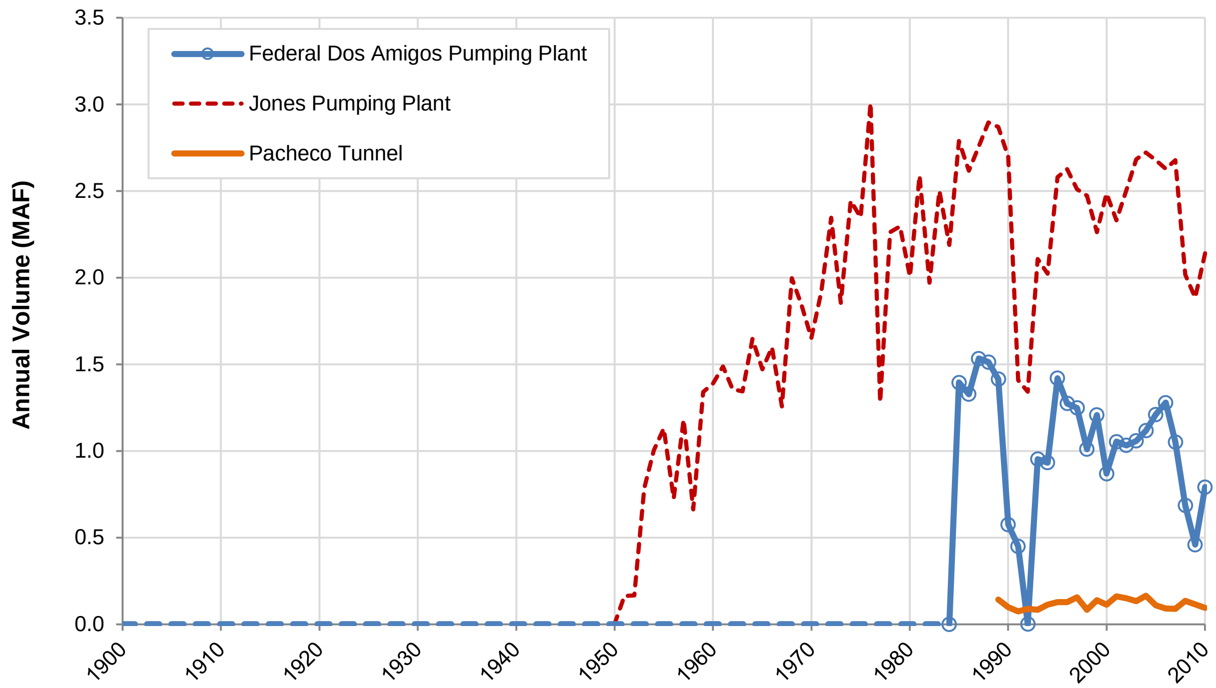


Figure 2-17. Historical Flows Federal Dos Amigos Pumping Plant

San Joaquin River

Similar to Shasta Dam, Friant Dam was one of the initial components of the CVP. Completed in 1942 the dam provides both flood control and conservation storage. Water is released from the dam to meet water requirements above Mendota Pool. Water also is diverted from the dam into the Madera and Friant-Kern canals to meet agricultural water demands and for groundwater recharge in the southern San Joaquin Valley.

The Friant-Kern Canal stretches from Millerton Lake southwards to the Kern River. Canal water is used to support irrigated agriculture in Fresno, Tulare, and Kern counties. Construction of the canal began in 1945 and was completed in 1951. Water is discharged from the canal through a series of wasteways to the Kings, Kaweah, and Tule rivers for downstream diversion. **Figure 2-18** presents annual historical CVP diversions from Millerton Lake to the Friant-Kern Canal. By the mid-1950s, diversions had reached approximately 1.0 MAF, but with significant reductions in dry years (1976-1977, 1987-1992, 1994, 2007-2009).

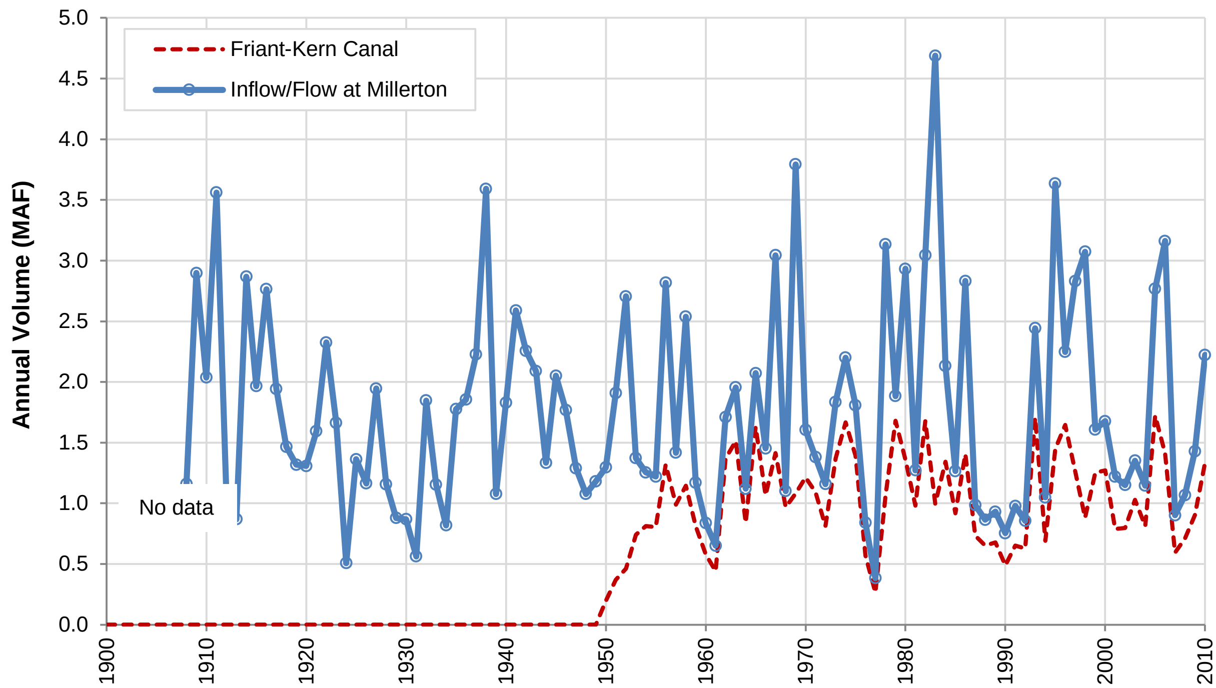


Figure 2-18. Historical Diversions from Millerton Lake to Friant-Kern Canal

SWP Imports and Exports

The SWP was authorized by the California legislature in 1951 for water supply purposes; to capture and store rainfall and snowmelt runoff in Northern California for delivery to areas of need, primarily located to the south of the Delta. The SWP currently includes 33 reservoirs, 29 pumping or generating plants, approximately 700 miles of aqueducts, and 5.8 MAF of storage capacity. DWR administers long-term water supply contracts to 29 local water agencies for water service from the SWP. The SWP made its first deliveries in 1962, using the CVP Jones Pumping Plant to lift water in to Bethany Reservoir. SWP water was delivered to Alameda County WD and Alameda County FCWCD Zone 7 through the partially completed South Bay Aqueduct. Water deliveries to Santa Clara Valley WD began three years later. The first section of the California Aqueduct, ending at the O'Neill Forebay was completed in 1968. The Harvey O'Banks (Banks) Pumping Plant was completed in 1969. SWP deliveries to Central and Southern San Joaquin Valley began in 1968. Deliveries to Southern California began in 1972. Deliveries to the Central Coast began 25 years later in 1997.

As part of the SWP, water is transported across watersheds and basins from water rich areas to areas of water deficit. These imports and exports of water, which are briefly described in the following sections, have profoundly changed river flows in the Sacramento and north San Joaquin valleys.

Sacramento-San Joaquin Delta

Banks Pumping Plant, located in the south Delta, conveys SWP water from the Delta into the head reaches of the California Aqueduct. It also wheels CVP water to San Luis Reservoir and the San Luis Canal, and conveys non-SWP transfer water. During construction (1963-1969) seven pumps were installed with a combined capacity of 6,680 cfs. The installed capacity was expanded in 1992 to 10,670 cfs, with the addition of four more units, and an expanded pumping plant capacity of 10,300 cfs.[12] **Figure 2-19** presents the annual volume of water conveyed through the pumping plant, beginning in 1968.[13] The volume of water conveyed rapidly increased, but with reductions in both wet and very dry years.

The North Bay Aqueduct, part of the SWP, delivers untreated water to the Solano County WA and Napa County FC&WCD. The 27.6-mile aqueduct extends from the Barker Slough Pumping Plant on Barker Slough to the end of the Napa Turnout Reservoir. The Aqueduct was constructed in two phases. Phase I, completed in 1968, began deliveries to Napa County in 1968 using an interim supply from Reclamation's Solano Project. Phase II, completed in 1988, included construction of the Barker Slough Pumping Plant and the North Bay Aqueduct. After the initial year, deliveries to the aqueduct have varied from approximately 30 TAF to 60 TAF per year. These annual volumes also are presented in **Figure 2-19.** However, North Bay Aqueduct diversions are very small compared to those at Banks Pumping Plant.

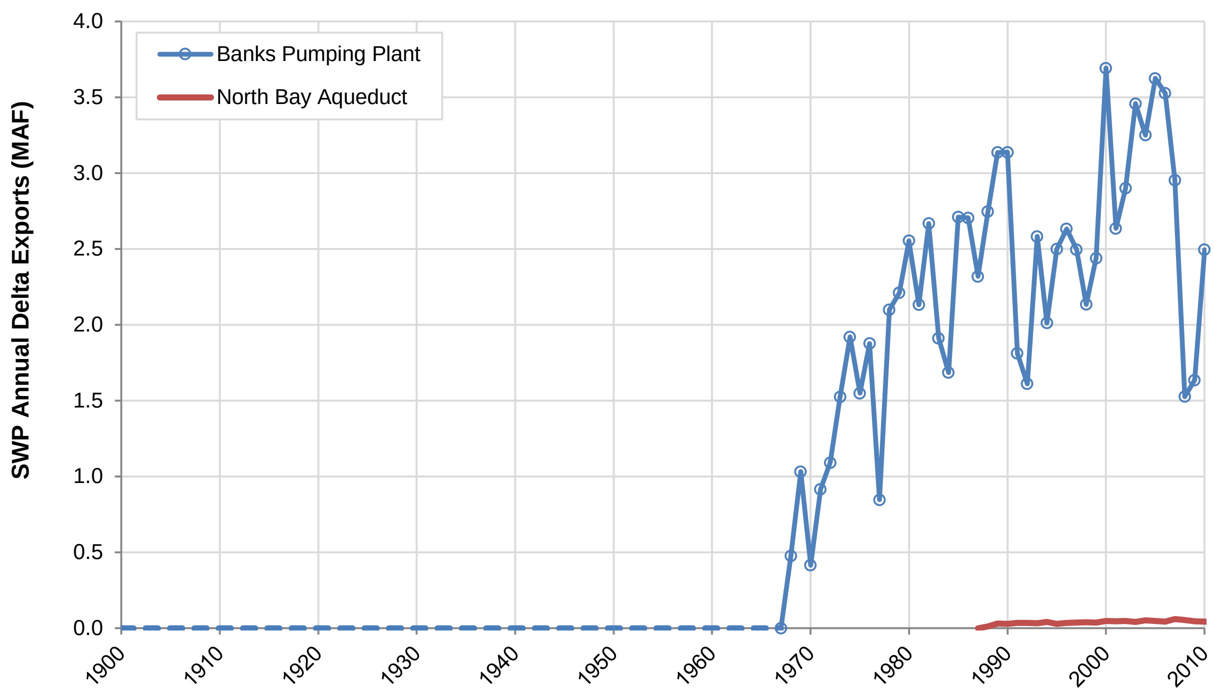


Figure 2-19. Historical SWP Exports from the Delta

California Aqueduct

SWP water diverted into the California Aqueduct is delivered to contractors through the South Bay Aqueduct, the Central Coast Aqueduct, and the East and West Branches.

The SWP made its first deliveries in 1962, using the Jones Pumping Plant to lift water in to Bethany Reservoir. SWP water was delivered to Alameda County WD and Alameda County FCWCD Zone 7

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[12] To protect the Delta waterways in the vicinity of the pumps, the U.S. Army Corps of Engineers (USACE) limited diversions into Clifton Court Forebay to historical rates (Public Notice 5802A, amended October 1981).

[13] Two pump units became operational in September 1967, two additional units became operational in April 1968, and the last unit of the original seven units, began operating in November 1968.

through the partially completed South Bay Aqueduct. Water deliveries to Santa Clara Valley WD began three years later. Deliveries to the aqueduct increased sharply during the initial 20 years, to reach approximately 100 TAF per year, but with considerable year-to-year variation.

The Coastal Aqueduct was built in two phases. The first phase, completed in 1968, served lands on the western edge of the Central Valley. The second phase, completed in 1998, supplies SWP water to San Luis Obispo and Santa Barbara counties. Annual flows are approximately 30 TAF per year, but with considerable year-to-year variation.

Dos Amigos Pumping Plant, located on the San Luis Canal at Mile Post 87, approximately marks the boundary between the north San Joaquin Valley and the Tulare Lake Region. The pumping plant conveys both CVP and SWP water. **Figure 2-20** presents the historical annual flows through the pumping plant, since it was completed it 1966. Annual flows increase steadily since 1970, but with very significant reductions in extremely dry years: 1977 and 1991. Annual flows also are lower in the wet years because of low SWP contractor demands. Annual flows are compared to the historical pumping at Banks Pumping Plant.

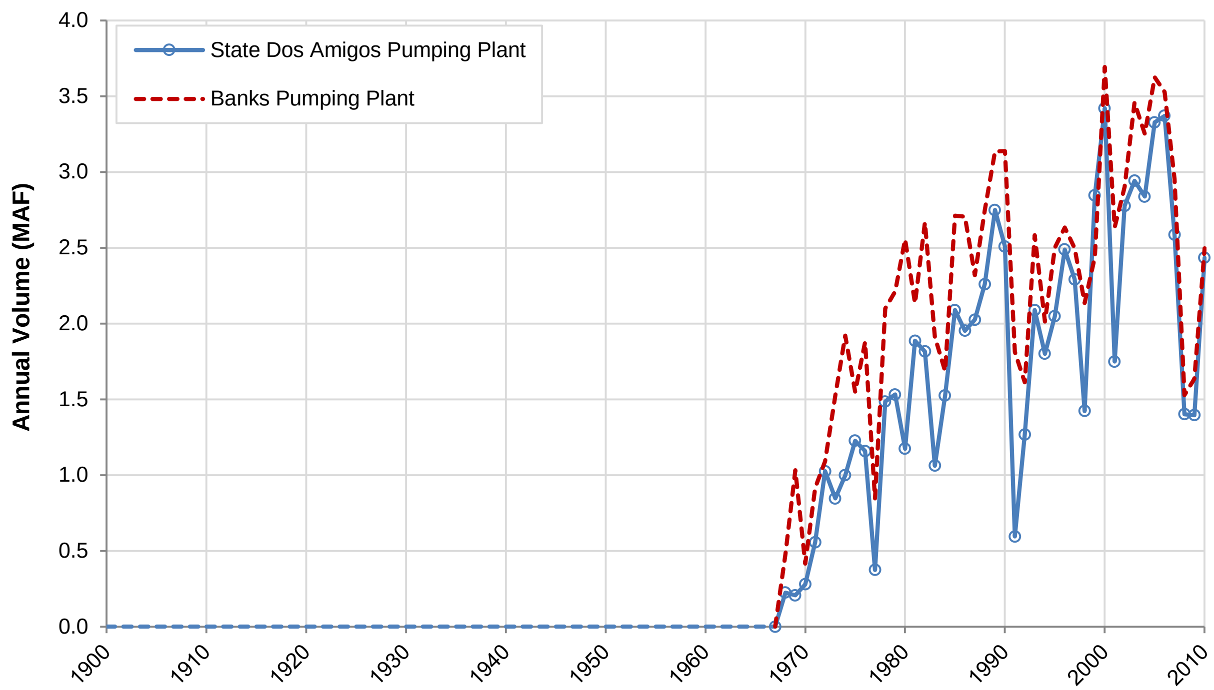

Figure 2-20. Historical Flows Dos Amigos Pumping Plant, San Luis Canal

Other Basin Exports

Mokelumne River Watershed

Since the 1920s, EBMUD's primary source of water to meet water demands in the East Bay has been the Mokelumne River. District facilities include Pardee and Camanche dams on the Mokelumne River and the Mokelumne Aqueduct which convey river water to the East Bay. The two reservoirs are operated in a coordinated manner. EBMUD diverts its municipal supply from Pardee Reservoir, while operating

Camanche Reservoir to satisfy downstream senior rights and regulatory and environmental obligations. Pardee Dam was completed in 1929. Camanche Dam, located 10 miles downstream, was completed in 1964. **Figure 2-21** presents the historical annual exports of Mokelumne River water through the Mokelumne Aqueduct. Exports increased steadily over the first 40 years to reach approximately 200 TAF per year.

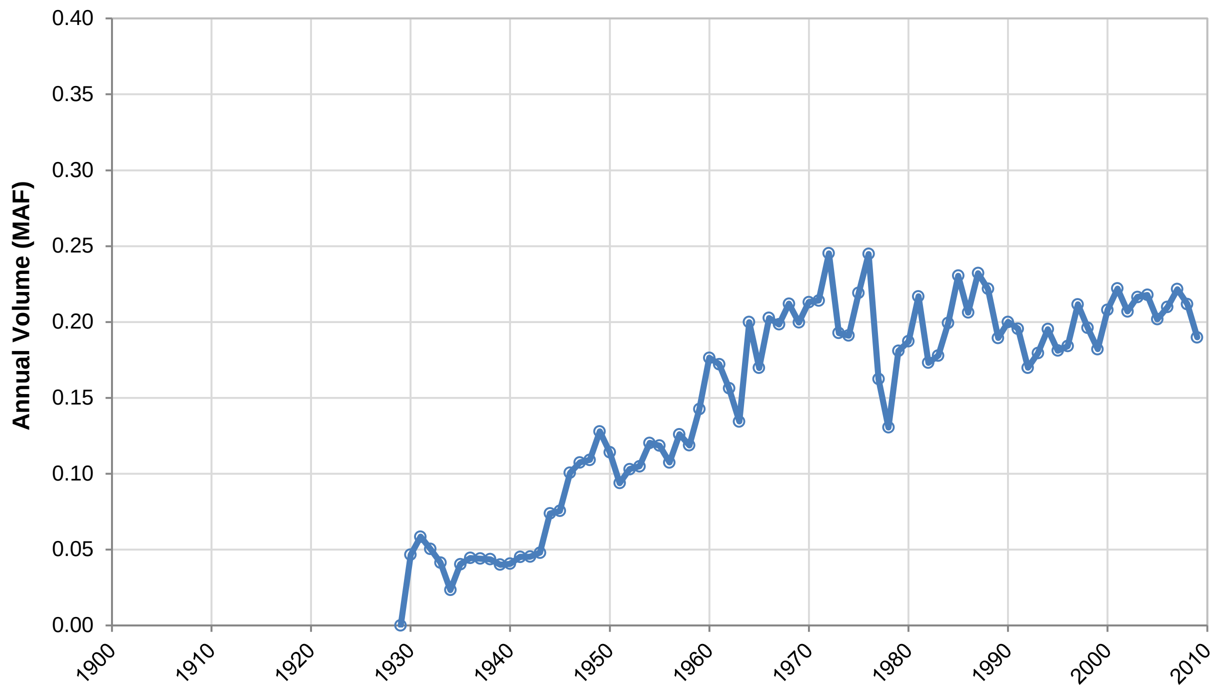

Figure 2-21. Historical Diversions from Pardee Reservoir by East Bay Municipal Utility District

Tuolumne River Watershed

The City of San Francisco withdraws water from Hetch Hetchy Reservoir on the Tuolumne River and from Cherry Creek, which subsequently is conveyed through the Hetch Hetchy Aqueduct to the San Francisco Bay Area to meet local M&I demands. Approval for the Hetch Hetchy Project was granted by the Raker Act of 1913. Construction of the project began in 1914. O'Shaughnessy Dam was completed in 1923; delivery of water through the Hetch Hetchy Aqueduct began in 1934. Since the 1930s, the major additions to the city's water system have included the raising of O'Shaughnessy Dam and the development of Lake Lloyd (Cherry Reservoir); the construction of additional pipelines across the San Joaquin Valley; and construction of local reservoir facilities in the San Francisco Bay Area. **Figure 2-22** presents the historical annual exports of Tuolumne River water through the Hetch Hetchy Aqueduct. Exports increased steadily over the first 50 years to reach approximately 250 TAF per year.

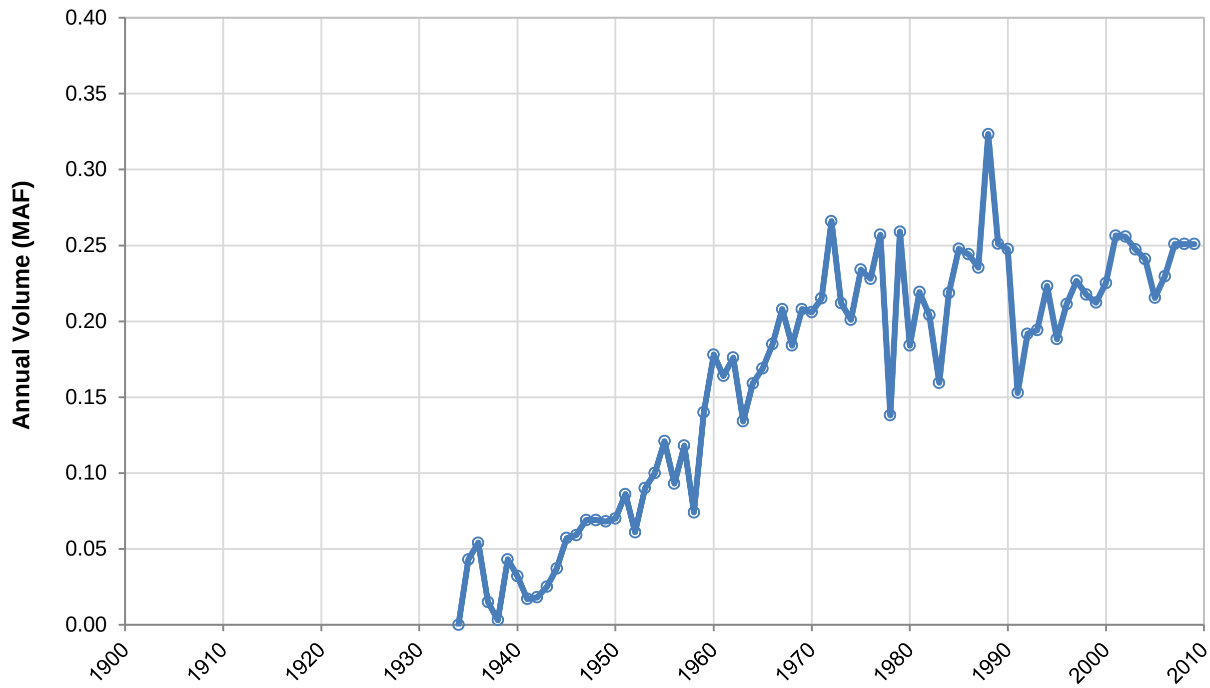

Figure 2-22. Historical Diversions from Hetch Hetchy Reservoir by the City and County of San Francisco

Delta Inflows

Freshwater inflow to the Delta may be calculated as the sum of inflows from the Sacramento River, San Joaquin River, Yolo Bypass, Eastside streams, and miscellaneous minor creeks. Historical records of Delta inflow are available from DWR's DAYFLOW database. The DAYFLOW computer program and associated data was developed by DWR to estimate daily tidally-average, or freshwater, Delta outflow. DAYFLOW data are available beginning water year 1929. However, it is possible to extend the calculation of Delta inflow back to October 1921 using historical gage data. For example, net Delta outflow (described below) for water years 1922 to 1929 was included in DWR testimony for the 1987 Delta Water Rights Hearings. Figure 2-23 presents the extended DAYFLOW data for Delta inflow aggregated to a monthly time step. These inflows are compared to the unimpaired inflows from the rim watersheds to the valley floor. Figure 2-23 also presents the ratio of annual Delta inflow to annual unimpaired rim inflow. This ratio typically varies from 0.9 to 1.6, and exhibits a decreasing trend with time.

Net Delta Outflow

Tidally-averaged Delta outflow, or net Delta outflow, is typically computed from a water balance considering Delta inflows, in-Delta water use, and Delta diversions and exports. Net Delta outflow as calculated by DAYFLOW represents the net flow at the confluence of the Sacramento and San Joaquin rivers, nominally at Chipps Island. The DAYFLOW estimate of Delta outflow is referred to as the net Delta outflow index (NDOI) because it does not account for tidal flows, the fortnight lunar fill-drain cycle of the estuary, or barometric pressure changes. It is an estimate of the net difference between ebbing and flooding tidal flows at Chipps Island (~ + / - 150,000 cfs), transformed to a daily average.

Figure 2-24 presents the extended DAYFLOW data for net Delta outflow aggregated to a monthly time step. These inflows are compared to the unimpaired inflows from the rim watersheds to the valley floor. Figure 2-24 also presents the ratio of annual net Delta outflow to annual unimpaired rim inflow. The ratio typically varies from 0.4 to 1.6, and exhibits a marked decreasing trend with time.

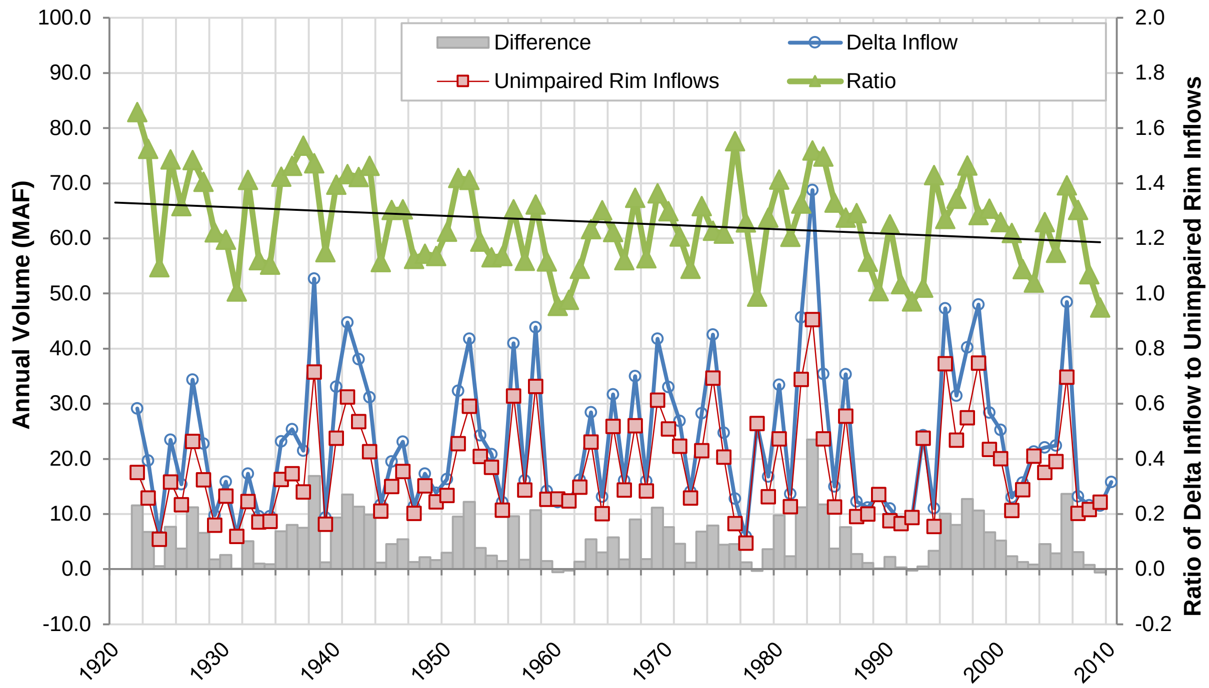

Figure 2-23. Historical Unimpaired Rim Inflows and Delta Inflows

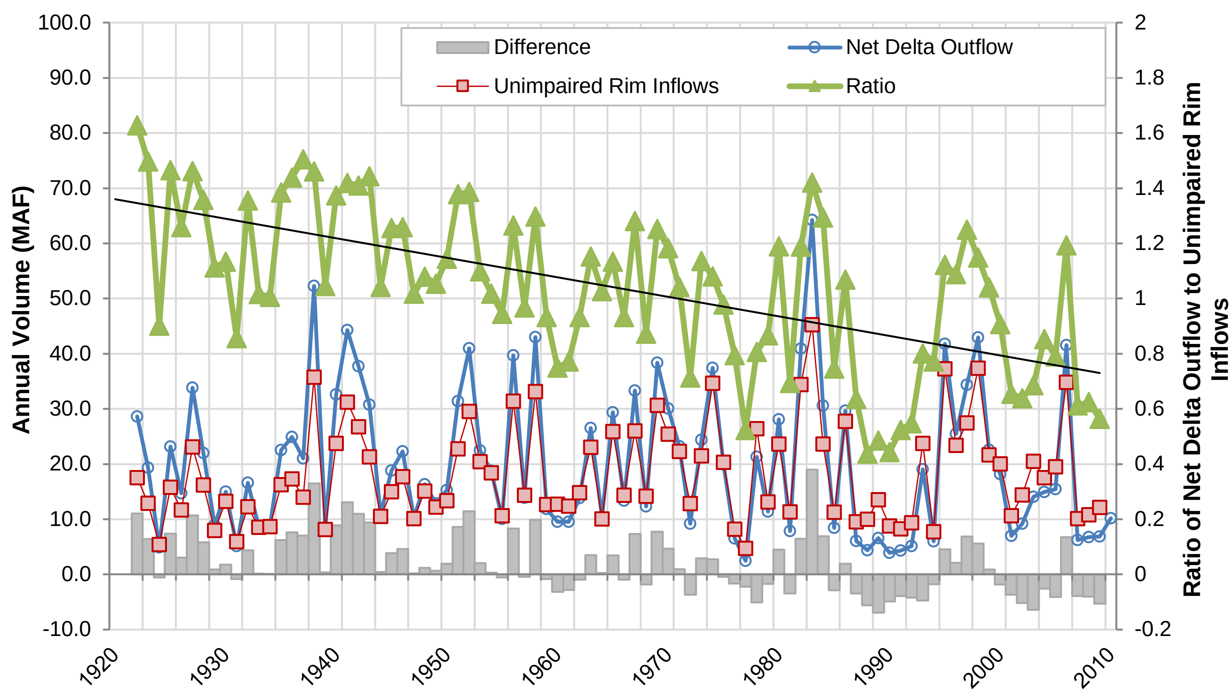

Figure 2-24. Historical Unimpaired Rim Inflows and Net Delta Outflows

Regulatory Environment

Since the inception of the CVP and SWP, the two projects have been operated under changing regulatory requirements and agreements. The major regulatory events are described in the sections below.

Water Right Decision 1485

In November 1976 the State Water Board initiated hearings “to formulate a water quality control plan for the Delta and to determine whether the water-use permits held by the U.S. Bureau and the DWR should be amended to implement the plan.” These hearings culminated in the release of Water Rights Decision 1485 (D-1485) in August 1978 to implement the objectives Water Quality Control Plan for the Sacramento-San Joaquin Delta and Suisun Marsh. Standards for salinity control and for protection of fish and wildlife were based on “without project” conditions and were to provide Delta beneficial uses a level of protection equal to the protection had the CVP and SWP not been constructed. D-1485 required the CVP and SWP to meet the new standards as water rights conditions for the projects. The water quality requirements were the primary regulatory requirements affecting operation of the CVP and SWP. Fish protection at export facilities was based primarily on bypass and approach velocities at the fish collection facilities and on the Four-Pumps Agreement, which mandated maximum take levels. As part of the decision, the State Water Board reserved jurisdiction to revise or formulate additional terms and conditions on permits issued to Reclamation and DWR. During 1979, the CVP and SWP were operated to comply with D-1485 standards (DWR, 1980).

Eight petitions were filed challenging the State Water Board water quality standards and/or its modification of the water rights permits. Litigation was finally settled by the Court of Appeals in May 1986, in what is known as the Racenelli Decision. The Court held that the State Water Board had erred in basing its water quality standards solely to protect Delta water users from the impacts of the SWP and CVP. However, the Court affirmed the State Water Board right to change past water allocation decisions, and amend water rights if necessary to protect fish and wildlife. Consequently, in 1987, the SWRCB began a formal proceeding to reconsider the D-1485 standards, establish new standards if needed, and develop a program of implementation. In the same year as the Racanelli Decision, Reclamation and DWR formalized interim CVP and SWP operations agreements by signing the Coordinated Operations Agreement (COA). The agreement established each projects responsibility for meeting applicable Delta water quality standards and provides the basis operations for sharing available water supplies.

Central Valley Improvement Act

On October 30, 1992, President Bush signed into law the Reclamation Projects Authorization and Adjustment Act of 1992 (Public Law 102-575) that included Title XXXIV, the Central Valley Project Improvement Act (CVPIA). The CVPIA amended the previous authorizations of the CVP to include fish and wildlife protection, restoration, and mitigation as project purposes having equal priority with irrigation and domestic uses. Specific provisions include: the dedication of 800,000 acre-feet per year of CVP yield to fish and wildlife purposes; water transfers provision, including sale of water to users outside the CVP service area; special efforts to restore anadromous fish population by 2002; no new water contracts until fish and wildlife goals achieve; installation of the temperature control device at Shasta Dam; implementation of fish passage measures at Red Bluff Diversion Dam; firm water supplies for Central Valley wildlife refuges; and development of a plan to increase CVP yield.

Interior has been dedicating and managing water pursuant to Section 3406(b)(2) since 1993, the first water year following passage of the CVPIA. Since enactment of the statute, Interior has pursued ways to utilize (b)(2) water in conjunction with reoperation and water acquisitions to meet the goals of the CVPIA.

The CVPIA adopted by reference the water supplies listed in the *Report on Refuge Water Supply Investigations* (Reclamation, 1989a) and *San Joaquin Basin Action Plan/Kesterson Mitigation Plan* (Reclamation, 1989b) as specific quantities of water to be provided to the refuges.[14] "Level 2" is the amount of water required for minimum wetlands and wildlife habitat management, based on historical annual deliveries before 1989. Incremental "Level 4" is additional water required to achieve optimum waterfowl habitat management. Reclamation has signed long-term agreements with USFWS, CDFW, and Grassland Water District (WD) to provide Level 2 and incremental Level 4 water supplies to 19 refuges.[15] Level 2 water supplies include CVP water, non-project water, and groundwater pumping. Reclamation, in partnership with USFWS, has developed a Water Acquisition Program to provide incremental Level 4 refuge water supplies, to be acquired from willing sellers. Between 2000 and 2009, refuge Level 2 annual contract deliveries varied from 338 TAF to 406 TAF.

Endangered Species Act Listings

During the 1987 to 1992 six-year drought, Delta water quality deteriorated, fish populations diminished, and CVP and SWP deliveries were greatly reduced. In 1989, Sacramento River winter-run chinook salmon was listed as a 'threatened' by NMFS and 'endangered' by the California Department of Fish and Game (CDFG)[16], requiring operational changes in the CVP and SWP. In February 1993, NMFS released a long-term BO by for the Sacramento River winter-run Chinook salmon. This BO required a 1.9 MAF carryover storage in Lake Shasta, revised minimum flow requirement downstream of Keswick Dam, Qwest requirements to eliminate reverse flows, and new constraints on the Delta Cross Channel operations. The BO limited incidental total take to less than 1 percent of the out-migration population. In May 1993, Delta smelt was declared a federally threatened species by the USFWS. The agency issued a one-year BO limiting combined project exports to 4,000 cfs in May and 5,000 cfs in June. Additional Qwest standards were also specified. In February 1994, USFWS issued a second one-year BO for Delta smelt. The BO found that CVP and SWP operations were likely to jeopardize continued existence of Delta smelt. Reasonable and prudent alternatives defined the X2 estuarine habitat standard, added additional net Delta outflow criteria, and minimum flows for the San Joaquin at Vernalis. Additional Endangered Species Act (ESA) listings include the Central Valley Steelhead trout in 1998 and the spring run Chinook salmon in 1999. In order to minimize take of listed species, the CVP and SWP exports from the South Delta have been curtailed, typically to 'Health and Safety' levels.

Bay-Delta Accord

In June 1994, state and federal agencies entered into a collaborative agreement with stakeholders to find a long-term, consensus-driven solution to Delta water management and restoration. This marked the formation of the California Water Policy Council and Federal Ecosystem Directorate (CALFED) and a pledge to develop a long-term solution by consensus. The historic Bay-Delta Accord was signed in 1994. The four-year agreement guaranteed a reliable supply of water for the main stakeholders, ensured real time monitoring of water levels, and promised to comply with all environmental regulations through restoration efforts. Compliance with fish take provisions of BOs under ESA were to be achieved at no additional water cost to the CVP and SWP through adjustment of export pumping limits. The Accord also established new standards, including export: inflow (E:I) restrictions on export project pumping, X2,

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[14] Level 2 water supplies include those specifically identified as Level 2 in the *Report on Refuge Water Supply Investigations* (Reclamation, 1989a), and two-thirds of the amount needed for full habitat development per the *San Joaquin Basin Action Plan/Kesterson Mitigation Plan* (Reclamation, 1989b). Level 4 water supplies include those specifically identified as Level 4 in the *Report on Refuge Water Supply Investigations* and the incremental amount needed to provide full habitat development per the *San Joaquin Basin Action Plan/Kesterson Mitigation Plan*. The amount of water diverted to meet these demands at the refuge boundaries will be greater because of loss of water during conveyance.

[15] This includes the Pixley NWR and Kern NWR, located in the Tulare Lake Hydrologic Region. These refuges are represented in CalSim, but are not part of the CalSim 3.0 Hydrology Development Project.

[16] Now the California Department of Fish and Wildlife.

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.

Monterey Agreement

In December 1994, DWR and the majority of the SWP contractors signed the Monterey Agreement. The agreement provided greater flexibility in water operations, created the turn-back pool, allowed storage of water outside of the SWP service area, and use of SWP facilities for transfer of non-SWP water. Under the agreement, water was to be allocated in proportion to contractors' Table A amounts.

Water Right Decision 1641

In 1995, the State Water Board adopted a new water quality control plan based on the Bay-Delta. In December 1999, the State Water Board issued Water Right Decision 1641 (D-1641) and assigned interim responsibility to the CVP and SWP to meet the new flow and water quality objectives. The most significant changes, compared to D-1485, was the introduction of the Sacramento Valley water year index, the introduction of E:I restrictions on Delta pumping, spring X2 Delta outflow requirements, and adoption of the Vernalis Adaptive Management Plan (VAMP). More CVP and SWP water is needed to meet Delta outflow requirements than previously required to meet the standards under D-1485. Phase 8 of the Bay-Delta water right hearings was intended to address the responsibilities of other water-right holders in meeting the objectives in the 1995 water quality control plan. The CVP, SWP, and upstream water right holders reached an agreement on Phase 8 in late December 2002 to stay the Board's Phase 8 proceedings.

CALFED Record of Decision

The CALFED Record of Decision (ROD) describes a 30-year program related to water management focused on the Delta. The principle interconnected components included water supply reliability, water quality, ecosystem restoration, and levee system integrity. Amongst other programs, the ROD established the Environmental Water Account (EWA) to provide water for fishery protection and recovery and assurances against additional water supply losses for urban and agricultural water supplies. The EWA included operational flexibility for the CVP and SWP. This flexibility included exclusive use of a 500 cfs increase in authorized Banks Pumping Plant capacity (between 6,680 and 7,180 cfs) from July through September to move EWA assets.

Operations Criteria and Plan and Biological Opinions

Reclamation periodically updates the CVP Operations Criteria and Plan (CVP-OCAP). The CVP-OCAP, issued in 2004, describes the laws, regulations and other criteria applicable to operations of the CVP that were in effect from 1991 through 2003. Following the release of the BA, USFWS and NMFS issued both jeopardy and no-jeopardy opinions; these biological opinions (BO) were subsequently challenged in court. In 2007, the court held the 2005 FWS BO conclusion that delta smelt were not in jeopardy was arbitrary and capricious and BO was remanded to the agency. In 2008, the court held that the 2004 NMFS BO conclusion that salmon and steelhead were not in jeopardy was arbitrary and capricious and remanded the BO to the agency.

In 2008, Reclamation and DWR released a joint BA for to 'provide a thorough analysis of the continued long-term operations of the CVP and SWP and the effects of those operations on listed species and designated critical habitat.' The USFWS Delta Smelt BO was released on December 15, 2008, in response to Reclamation's request for formal consultation with the agency on the coordinated operations of the CVP and SWP. The BO included RPAs for operations of the CVP and SWP. Specific water management actions include: limitations on exports to meet reverse flow criteria in the Old and Middle rivers; X2 requirements from September through November in wet and above normal years; and delays in installing the spring barrier at the head of the Old River.

The NMFS issued a BO on June 4, 2009 for long-term operations of the CVP and SWP. RPAs contained in the BO included: flow and temperature requirements on Clear Creek, on the Sacramento River above Bend Bridge, on the lower American River and on the Stanislaus River; modified Delta Cross Channel operations; and a San Joaquin River based inflow to export restriction.

In addition to changes in Delta operating criteria, between 1999 and 2010 there have been significant changes in regulations governing upstream operations, addition of new facilities, and increases in water demands. New instream flow requirements for the lower Yuba River were established as part of the lower Yuba River Accord (YCWA, 2007).[17] The Accord also provides water transfers for CVP and SWP contractors south of the Delta. The Feather River settlement agreement, as part of the Federal Energy Regulatory Commission (FERC) relicensing of the Oroville-Thermalito complex, established new instream flow requirements on the lower Feather River (DWR, 2006). Urban water demands steadily increased until the economic downturn in 2007.

Fixed Level of Development Scenarios

The fixed levels of development studies are characterized by assumptions relating to land use, surface water storage, flood control, basin imports and exports, groundwater levels, and regulatory requirements. Assumptions for each level of development are briefly listed in the following sections.

1900 Level of Development

Conditions in the Sacramento and San Joaquin valleys around 1900 were characterized by early flood control measures, drainage of wetlands, and early irrigated agricultural development. Inflows from the mountain and foothill watersheds to the valley floor were not significantly altered by upstream storage. Irrigated agricultural lands covered 13 percent of the Central Valley floor (12.8 million acres total); urban lands covered approximately 1 percent. There were no basin imports, no basin exports, and no Delta regulatory requirements.

1920 Level of Development

By 1920 initial flood control projects were completed, there was a significant increase in irrigated agricultural development, and inflows from the mountain and foothill watersheds to the valley floor were modified by storage regulation in non-project reservoir. Irrigated agricultural lands covered 22 percent of the Central Valley floor, while urban lands covered approximately 1 percent, little changed from 1900.

1940 Level of Development

Between 1920 and 1940, there was significant growth in surface water storage. O’Shaughnessy, Shaver, Almanor, Bucks, and Pardee dams were completed, with a gross combined storage of approximately 2.2 MAF. Basin exports included those by EMBUD from the Mokelumne watershed and those by the City and County of San Francisco from the Tuolumne watershed. Irrigated agricultural lands covered 24 percent of the Central Valley floor and urban lands covered approximately 1 percent.

1960 Level of Development

By 1960, the CVP had begun initial operations, dramatically changing flows in the Sacramento and San Joaquin rivers. Dams in the Sierra Nevada range completed in the preceding 20 years include Shasta, Folsom, Friant, Isabella, Pine Flat, Edison, Cherry, Monticello, Wishon, Courtright, and Mammoth Pool dams. These dams increased the total surface water storage capacity to approximately 13 MAF. Irrigated

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[17] The lower Yuba River flow requirements were established by the State Water Board in Water Right Order 2208 – 0014.

agricultural lands had grown to occupy 45 percent of the Central Valley floor, urban lands had expanded to cover approximately 2 percent of the total area. Although Reclamation operated Shasta and Folsom dams to reduce salinity intrusion in the Delta, there were no statutory Delta regulatory requirements.

1980 Level of Development

By 1980 the CVP had expanded to include dams on the Trinity (Trinity Dam) and Stanislaus (New Melones Dam) rivers, and San Luis Reservoir and Dam (aka B. F. Sisk Dam) – a joint-use facility with the SWP. The SWP has been mostly constructed, although south-of-Delta contract demands were low. Surface water storage capacity in the upper watersheds had grown to 30 MAF. Irrigated agricultural lands covered 58 percent of the Central Valley floor and urban lands had grown to 4 percent of the total land area. In 1978, the State Water Board issued D-1485, requiring the CVP and SWP to meet new Delta water quality standards established in the Water Quality Control Plan of the same year.

2000 Level of Development

By 2000, the pace of development had plateaued. There was no significant increase in surface water storage from 1980. Irrigated agriculture remained little changed from 1980, however, urban lands had approximately doubled to 8 percent of the total land area. In 1999, the State Water Board issued D-1641 assigning responsibilities for meeting Delta standards described in the 1995 Water Quality Control Plan.

2010 Level of Development

Most of the assumptions for the 2000 LOD also apply for the 2010 LOD. The major differences between the two studies are the operational requirements imposed on the CVP and SWP by the USFWS 2008 BO for Delta smelt and the NMFS 2009 BO for chinook salmon, steelhead, and green sturgeon.

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Chapter 3 Modeling Tools and Data

This chapter briefly describes the simulation tools used for the *Historical Level of Development Study* and the major data sources.

Model Selection

The selected simulation model(s) must be capable of simulating both hydrology and water management activities. The model(s) must be capable of simulating storage regulation in the mountain and foothill watersheds of the Central Valley. The model(s) must be capable of simulating the land surface hydrology of the floor of the Central Valley, including irrigation, rainfall-runoff, infiltration, and ET from the root zone. The model(s) must be capable of simulating streamflows, diversions, and return flows. Finally, the model(s) must be capable of simulating the stream-groundwater interaction, as studies have shown that groundwater inflow has been a significant, but evolving component of streamflow. These requirements do not exist in a single model. Therefore, a suite of models was used for the analysis.

C2VSim

The California Central Valley Groundwater-Surface Water Simulation model (C2VSim) is an integrated numerical model that simulates water movement through the linked land surface, groundwater, and stream network of the floor of the Central Valley. It was developed by DWR using the Integrated Water Flow Model (IWFM) code Version 3.02. The code is described by Dogrul (2013). The application to the Central Valley is described by Brush and Dogrul (2013). The model is freely available (DWR, 2014b).

The C2VSim model input files contain, amongst other input data, monthly historical flows at the head of each stream where they enter the valley floor, and downstream surface water diversions. Model input files also include monthly climate data (precipitation and potential ET) and annual land use for water years 1922 through 2009. At runtime, C2VSim dynamically calculates crop water demands, determines water supply contributions from precipitation, soil moisture and surface water diversions, and calculates the groundwater pumping required to meet the remaining water demand. The model simulates the historical response of the Central Valley's groundwater to historical stresses (vertical recharge and groundwater pumping), and determines groundwater outflow (or inflow) to the stream network.

The C2VSim model can be run with either a coarse finite element grid (C2VSim-CG with 1,392 elements, run-time 6 minutes) or with a fine finite element grid (C2VSim-FG with over 35,000 elements, run-time 6 hours). For both versions, the elements are grouped into 21 water budget subregions. Hydrologic parameters were calibrated to match observed surface water flows, groundwater heads, groundwater head differences between well pairs, and stream-groundwater flows for the period between September 1975 and October 2003. The most recent version of the coarse grid C2VSim model is version R374 (C2VSim-CG_R374), released by DWR on June 28, 2013. This version of the model was used for all simulations conducted as part of the *Historical Level of Development Study*.

The advantages of using C2VSim for the Study are as follows:

- Monthly simulation of surface water and groundwater hydrology on the valley floor for water years 1922 – 2009.
- Land-use based irrigation demands.

- Representation of all the major streams of the Central Valley, including Delta inflows and outflows.
- Model output includes detailed stream budgets.
- Publically available, well-documented, peer-reviewed, and easy to use.

The disadvantages of using C2VSim for this Study include:

- No simulation of surface water storage; the model boundary is downstream from the foothill reservoirs.
- No simulation of regulatory requirements.
- Non-standard representation of the Delta.[18]

CalSim II

CalSim II is an application of the Water Resources Integrated Modeling System (WRIMS) developed by DWR's Bay-Delta Office. WRIMS is a generalized water resources modeling software, which is entirely data driven and can be applied to most reservoir-river basin systems. WRIMS represents the physical system (reservoirs, streams, canals, pumping stations, etc.) by a network of nodes and arcs. The model user describes system connectivity and various operational constraints using a modeling language known as Water Resources Simulation Language (WRESL). WRIMS subsequently simulates system operation using optimization techniques to route water through the network based on mass balance accounting. A mixed integer programming solver determines an optimal set of decisions in each monthly time step for a set of user-defined priorities (weights) and system constraints. The model is described by Draper et al. (2004) and DWR (2014a).

CalSim II was jointly developed by DWR and Reclamation and DWR for performing planning studies related to CVP and SWP operations. The primary purpose of CalSim II is to evaluate the water supply reliability of the CVP and SWP at current or future levels of development (e.g., 2005, 2030), with and without various assumed future facilities, and with different modes of facility operations. Geographically, the model covers the drainage basin of the Delta, CVP and SWP deliveries to the Tulare Basin, and SWP deliveries to the San Francisco Bay Area, Central Coast, and Southern California.

CalSim II typically simulates system operations for 82 years 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. The historical flow record of October 1921 to September 2003, adjusted for the influence of land-use change and upstream flow regulation, is used to represent the possible range of water supply conditions. Results from a single simulation may not necessarily correspond to actual system operations for a specific month or year, but are representative of general water supply conditions. Model results are best interpreted using various statistical measures such as long-term or year-type averages.

[18] The Delta, as represented in C2VSim, includes an area of 725,454 acres. DWR's Bay-Delta Office has traditionally treated the Delta as two separate regions, or Depletion Study Areas (DSA), known as the Delta Lowlands (DSA 54) and Delta Uplands (DSA 55). The Delta Lowlands cover the islands and areas of the Delta below the 5-foot mean sea level contour; a total area of 462,100 acres. The Delta Uplands comprise the rest of the Delta Service Area, including portions of the Yolo Bypass, parts of the Cities of West Sacramento and Stockton, and the entire City of Tracy; a total area of 216,100 acres. Combined DSA 54 and 55 cover 678,200 acres. The C2VSim Delta is 47,254 acres larger than the Bay-Delta Office and CalSim II Delta.

The advantages of using CalSim II for this study are as follows:

- Model simulates CVP and SWP operations, including project storage regulation and project exports from the Delta.
- Model represents all major streams of the Sacramento and north San Joaquin valleys.
- Model simulates Delta regulations and outflow requirements.
- Model studies (or applications) are available for D-1485 and D-1641 regulatory environments, albeit at a future level of development.
- Model studies exists for the existing level of development, including simulation of USFWS and NMFS BOs.

The disadvantages of using CalSim II for this Study include:

- Monthly simulation ends October 2003.
- No dynamic simulation of land surface hydrology.
- No simulation of dams and reservoirs located in the High Sierra Nevada watersheds.
- Difficult and time-consuming to modify.

Spreadsheet Models

Spreadsheet-based reservoir operations models were used to address the deficiencies of C2VSim and CalSim II when applied to this Study. Spreadsheet-based models were developed for the majority of the major reservoirs in the Coastal and Sierra Nevada mountain ranges. These models simulate reservoir storage using a monthly time-step. Simulated reservoir releases are dictated by flood space needs, instream flow requirements, and the desire to meet downstream irrigation and M&I demands.

Consumptive Use Model

The primary purpose of C2VSim is the study of the Central Valley's alluvial groundwater aquifers. Efforts to refine the model's portrayal of the Delta have been minimal (Brush, 2015). C2VSim's simulation of in-Delta water use does not account for open water evaporation, neither can the model simulate permanent wetlands that have a constant supply of water through tidal inundation or groundwater uptake.

DWR's Consumptive Use (CU) models were developed to provide hydrologic inputs to DWRSIM and its successor, CalSim II. The CU models incorporate monthly precipitation, evapotranspiration (ET) rates, soil moisture criteria, rooting depth, irrigation indicators, and other factors along with land use to estimate consumptive use of precipitation and irrigation water for different geographic regions within the Central Valley. Two CU models cover the Delta, one for the Delta lowlands (lands below 5-foot elevation) and the other for Delta uplands. The lowlands and uplands models were adopted for the present study as they offer important advantages over C2VSim. First, the CU models are consistent in their Delta representation with CalSim II and DSM2. Second, the CU models account for open water evaporation. Lastly, the CU models may easily be modified to simulate permanent wetlands.

Information Flow between Models

The flow of data and information among the three model types (C2VSim, CalSim II, and spreadsheets) is shown in **Figure 3-1**. The spreadsheet-based models transform historical unimpaired flows at the edge of the valley floor to impaired flows. The CalSim II models define storage releases from CVP and SWP reservoirs and contract allocations. The CV2Sim models simulate streamflows downstream from the foothill reservoirs, stream diversions and return flows, and stream gains from rainfall-runoff and groundwater inflows.

Data Sources

The primary source of historical data is C2VSim-CG_R374, which simulates historical water conditions in the Central Valley. The model input files include historical data relating to streamflows and reservoir releases, stream diversions, and land use.

Inflows

C2VSim-CG_R374 defines 42 surface water inflows at the model boundary. These inflows are fully specified in the input file *CVinflows.dat*. For the *Historical Level of Development Study*, historical inflows must be replaced with flows representing a fixed level of development. **Table 3-1** summarizes the data sources for these fixed level of development inflows. For many of the smaller watersheds that are relatively undeveloped, it is assumed that the historical and fixed level of development flows are the same. Inflows for the fixed level of development can be grouped into three categories:

- **Unimpaired flows –** historical flows adjusted to remove the effects of upstream storage regulation and upstream diversions
- **Historical flows –** for undeveloped watersheds these flows are equivalent to unimpaired flows
- **Impaired flow**s **–** unimpaired flows adjusted for upstream storage regulation and diversions characteristic of a particular level of development.

Land Use

Annual historical land use for the floor of the Central Valley is specified in the C2VSim file *CVlanduse.dat*. However, spatially distributed land use data before 1922 is sparse. Bulletin 27 (DPW, 1931b) provides some regional estimates of irrigated acreage beginning 1879.

Climate Data

Monthly historical precipitation and potential ET for different crops and land cover for the floor of the Central Valley are specified in the C2VSim file *CVprecip.dat* and *CVevapot.dat*. These data have been used without modification for the fixed level of development studies.

Stream Diversions

Except for CVP and SWP contract allocations, no attempt was made to simulate water rights or other legal limitations to surface water diversions. Instead, simulated diversions are determined based on water demands and historical deliveries. C2VSim routes any excess surface water deliveries back to the stream network. Attempts to correlate historical stream diversions to hydrologic conditions or precipitation data were unsuccessful. Monthly historical diversion data are specified in the C2VSim file *CVdiversions.dat*. The source of these data are described by Brush (2013).

Gage Data

Historical streamflow data and reservoir storage data for model validation were collected from several sources, including the U.S. Geological Survey (USGS), the DWR California Data Library, and the California Data Exchange Center (CDEC).

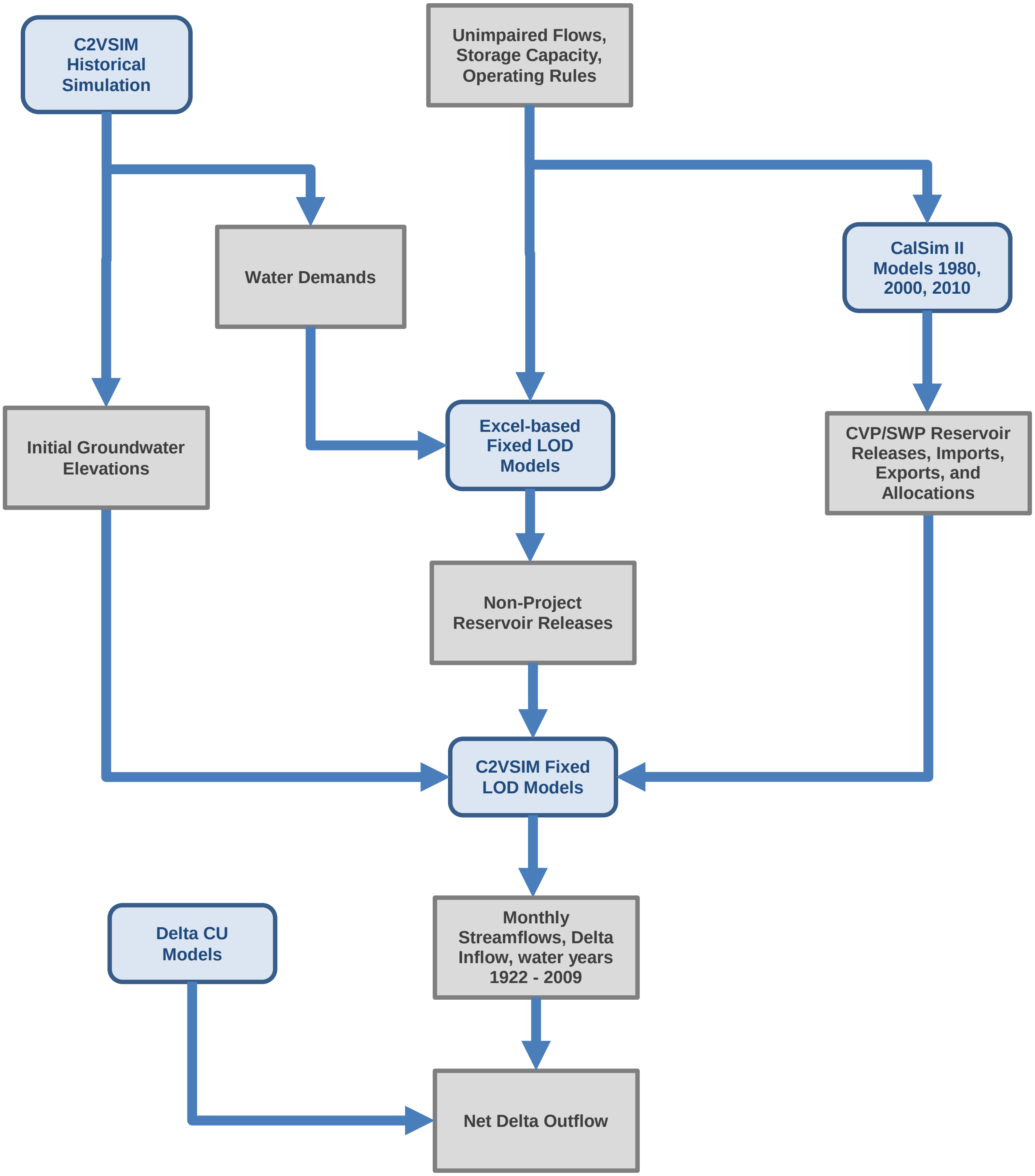

Figure 3-1. Flow of Information between Simulation Models
LOD = Fixed Level of Development

Table 3-1. Data Sources for C2VSim Inflows

<table>
<tr><th>Stream/River</th><th>Model Boundary</th><th>Storage/Flow Regulation</th><th>1900</th><th>1920</th><th>1940</th><th>1960</th><th>1980</th><th>2000</th><th>2010</th></tr>
<tr><td>Sacramento R.</td><td>Sacramento R. at Keswick USGS 11370500</td><td>Storage began in Lake Shasta 11/43.</td><td colspan="3">Unimpaired</td><td>Excel</td><td colspan="3">CalSim II</td></tr>
<tr><td>Cow Ck.</td><td>Cow Ck. near Millville USGS 11374000</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Battle Ck.</td><td>Battle Ck. below Coleman Fish Hatchery USGS 11376550</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Cottonwood Ck.</td><td>Cottonwood Ck. near Cottonwood USGS 113765000</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Paynes and Sevenmile Ck.</td><td>Paynes Ck. near Red Bluff USGS 11377500 and Sevenmile Ck.</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Antelope Ck. Group</td><td>Antelope Ck. near Red Bluff USGS 11379000 * 2.06</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Mill Ck.</td><td>Mill Ck. near Los Molinos USGS 11381500</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Elder Ck.</td><td>Elder Ck. near Paskenta USGS 11379500</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Thomes Ck.</td><td>Thomes Ck. at Paskenta USGS 11382000</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Deer Ck. Group</td><td>Deer Ck. near Vina USGS 11383500* 1.66</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Stony Ck.</td><td>Stony Ck. at Black Butte Dam site/Black Butte Dam release</td><td>Storage began East Park Reservoir 01/11, Stony Gorge Reservoir 11/28, Black Butte Lake 11/63.</td><td>Unimpaired</td><td colspan="6">Excel Operations Study</td></tr>
<tr><td>Big Chico Ck.</td><td>Big Chico Ck. near Chico USGS 11384000</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Butte and Chico Ck.</td><td>Butte Ck. near Chico USGS 11390000*1.24</td><td></td><td colspan="7">Historical Gage Data</td></tr>
<tr><td>Feather R.</td><td>Feather R. at Oroville USGS 11407000/Feather R. below Thermalito Afterbay Release to the Feather R. USGS 11407000 + USGS 11406920</td><td>Lake Almanor 1913, Butte Valley 1924, Mountain Meadows 1924, Bucks Lake 05/27, Little Grass Valley 10/60, Sly Creek 11/61, Frenchman Lake 01/62, Antelope Lake 11/63,Lake Davis 11/66, Oroville-Thermalito 10/67.</td><td>Unimpaired</td><td colspan="3">Excel Operations Study</td><td colspan="3">CalSim II study</td></tr>
<tr><td>Yuba R.</td><td>Yuba R. at Smartville USGS 11419000/Yuba R. below Englebright Dam USGS 11418000 + Deer Ck. near Smartville USGS 11418500</td><td>Lake Spaulding 1911, Old New Bullards Bar 1924, Bowman Lake 12/26, Fordyce Lake 11/26, Englebright 07/41, Scotts Flat 02/48, Merle Collins 01/63, Jackson Meadows 11/64, New Bullards Bar 01/69.</td><td>Unimpaired</td><td colspan="6">Excel Operations Study</td></tr>
<tr><td>Bear R.</td><td>Bear R. near Wheatland USGS 11424000</td><td>Lake Combie 06/28, Rollins 12/64, Camp Far West 11/63.</td><td>Unimpaired</td><td colspan="6">Excel Operations Study</td></tr>
<tr><td>Cache Ck.</td><td>Cache Ck. below Capay Diversion Dam</td><td>Clear Lake 1912, Indian Valley 11/74</td><td>Unimpaired</td><td colspan="6">Excel Operations Study</td></tr>
<tr><td>American R.</td><td>American R. at Fair Oaks USGS 11446500</td><td>Caples 1924, Folsom Lake 02/55, Natoma 04/55, Ice House 10/59, Stumpy Meadows 01/62, Union Valley 05/62, French Meadows 12/64, Loon Lake 1964, Hell Hole 12/65.</td><td>Unimpaired</td><td colspan="3">Excel Operations Study</td><td colspan="3">CalSim II</td></tr>
</table>

Table 3-1. Data Sources for C2VSim Inflows contd.

Stream/River	Model Boundary	Storage/Flow Regulation	1900	1920	1940	1960	1980	2000	2010
Putah Ck.	Putah Ck. near Winters 11454000	Storage began Lake Berryessa 01/57.	Unimpaired Flow			Excel Operations Study			
Cosumnes R.	Cosumnes R. at Michigan Bar USGS 11335000	Storage began Jenkinson Lake 11/54. Diversions by Ranch Murieta.	Unimpaired Flow			Excel Operations Study			
Dry Ck.	Dry Ck. near Galt USGS 11329500 *0.253		Historical Gage Data						
Mokelumne R.	Mokelumne R. below Camanche Dam USGS 11323500	Salt Springs 03/31, Lower Bear River 1952, Pardee 03/29, Camanche 12/63.	Unimpaired Flow		Excel Operations Study				
Calaveras R.	Calaveras R. below New Hogan Dam USGS 11308900	Storage began Old Hogan Reservoir 02/49. Storage began New Hogan Reservoir 12/63.	Unimpaired Flow			Excel Operations Study			
Stanislaus R.	Stanislaus R. below Goodwin Dam USGS 11302000	New Melones Reservoir, Lake Tulloch 11/57, New Spicer Meadow, Beardsley 02/57, Donnell Lake 02/57, Pinecrest Lake, Old Melones 09/26.	Unimpaired Flow less diversions		Excel Operations Study		CalSim II		
Tuolumne R.	Tuolumne R. below LaGrange Dam USGS 11289650	Lake Eleanor 1918, Hetch Hetchy 04/23, Old Don Pedro 01/23, Cherry Lake 1955, New Don Pedro Reservoir 1970.	Unimpaired less div.	Excel Operations Study			CalSim II		
Orestimba Ck.	Orestimba Ck. near Newman USGS 11274500		Historical Gage Data						
Merced R.	Merced R. below Merced Falls Dam USGS 11270900	Storage began Lake McClure 11/30.	Unimpaired Flow less diversions		Excel Operations Study				
Bear Ck. Group	Bear Ck. *3.72		Historical Gage Data						
Deadman Ck.	Bear Ck. Group*0.80		Historical Gage Data						
Chowchilla R.	Chowchilla R. below Buchanan Dam USGS 11259000	Storage began in Lake Eastman 12/75.	Unimpaired Flow				CalSim II		
Fresno R.	Fresno R. below Hidden Dam USGS 11257500	Storage began in Lake Hensley 10/75.	Unimpaired Flow				CalSim II study		
San Joaquin R.	San Joaquin R. below Friant dam USGS 11251000	Storage began in Lake Millerton 10/41.	Unimpaired	Excel Operations Study					
Kings R.	Kings R. below Pine Flat Dam USGS 11221500	Storage began in Pine Flat Lake 12/51. Storage began in Courtright Reservoir 03/58 and Lake Wishon in 12/57.	Unimpaired Flow			Excel Operations Study			
Kaweah R.	Kaweah R. below Terminus Dam USGS 11210950	Storage began in Lake Kaweah 02/62	Unimpaired Flow				Excel Operations Study		
Tule R.	Tule R. below Success Dam USGS 11204900	Storage began in Lake Success 02/62	Unimpaired Flow				Excel Operations Study		
Kern R.	Kern R. near Bakersfield USGS 11194000	Storage began in Lake Isabella 03/52	Unimpaired Flow			Excel Operations Study			
FKC to Kings R, Tule R. Kaweah R.	Friant-Kern Canal discharge	Friant-Kern Canal constructed between 1945-1951	Zero			Excel Operations Study			
Cross-Valley Canal to Kern R.	Cross-Valley Canal discharge	Cross Valley Canal constructed in 1975	Zero				CalSim II		
FKC to Kern R.	Friant-Kern Canal discharge	Friant-Kern Canal constructed between 1945-1951	Zero			Excel Operations Study			

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Chapter 4 C2VSim Model

The C2VSim historical simulation model (C2VSim-CG_R374) (Brush and Dogrul, 2013) is the central model for developing the fixed level of development simulations described in **Chapter 2**. The majority of model inputs are identical across these simulations, with the exception of the following files, which are unique for each level of development:

- CVcropacre.dat
- CVdiversions.dat
- CVinflows.dat
- CVinit_1921.dat
- CVlanduse.dat
- CVurbandem.dat

Initially, it was planned to directly use the version of C2VSim released by DWR in 2013 (C2VSim-CG_R374). However, it was necessary to make several adjustments to this model because of significant discrepancies between simulated historical flows and historical gage data. These adjustments are intended to improve the model's representation of historical inflows to the Delta from the Sacramento and San Joaquin rivers and reduce systematic biases before creating the fixed level of development C2VSim simulations. This chapter describes adjustments to the C2VSim base model and changes to the input files for the fixed level of development simulations. Results from a validation of the C2VSim fixed level of development models also are presented.

Revisions to Historical C2VSim Simulation

The C2VSim historical simulation model (IWFM version 3.02, C2VSim-CG_R374) was modified to correct an error in the stream network, reduce discrepancies between historical gage data and corresponding C2VSim simulated flows (bias correction), and to improve land use data for the Delta. These modifications are discussed in the following sections.

Stream Network

A new inflow was added to the stream network to simulate historical flows from Clear Creek in to the Sacramento River. These inflows were accidentally omitted from C2VSim-CG_R374. The new inflow is located at C2VSim stream node number 208 and is equal to the estimated unimpaired flows from 1922 through 1940 and gaged flows (USGS 11372000) from 1941 through 2009. All references below to the C2VSim historical simulation model refer to the model with the addition of the Clear Creek inflows.

Bias Correction

Separate bias corrections were made to the simulation of the Sacramento River and San Joaquin River flows.

Sacramento River Correction

Following the Clear Creek correction described above, simulated inflows to the Delta from the Sacramento Valley were compared to historical gage data for the Sacramento River at Freeport and the Yolo Bypass at the Lisbon Weir. Historical monthly flows for the Sacramento River at Freeport for water years 1922 through 1948 are based on Table 10 of the *1957 Joint Hydrology Study* (DWR, 1958). Reported flows for water years 1922 and 1923 and the November through March flows for water years 1924 through 1939 were estimated as the Sacramento River at Verona, adjusted for accretions and diversions between Sacramento and Verona. Starting in October 1948, historical flows are from the USGS gages at Sacramento and subsequently at Freeport.[19] An apparent systematic bias was observed in C2VSim, which results in an overestimate of flow for the Sacramento River at Freeport for the entire period of simulation. However, this bias is significantly larger for water years 1922 through 1945. No reliable relationship was found between the discrepancy in simulated and observed flows and an independent variable, e.g., unimpaired flow for the Sacramento River at Shasta.

Historically, south of the town of Chico, the Sacramento River and its major tributaries overtopped their banks during periods of high runoff, spilling water into the Butte, Sutter, American, and Sacramento basins to the east and into the Colusa and Yolo basins to the west. Flows in the Sacramento River are now controlled by the Sacramento River Flood Control Project, constructed by USACE. Shasta Dam, completed in 1945[20], significantly reduced the frequency and amount of downstream flooding. During the 1960's, DWR's planning office (Roos, 2011) identified an apparent change in runoff characteristics for Sacramento Valley flows entering the Delta after 1945. DWR believed that a portion of bank overflow did not return to the river system downstream, but contributed to natural wetlands. This water gradually dissipated through evaporation, evapotranspiration, and seepage. The agency estimated that approximately 4 percent of the Sacramento Valley outflow was "lost" as a result of bank overflow before this date.

To account for overbank flooding, a depletion (treated in the model as a diversion) was added to C2VSim at stream node 383 (Sacramento River above the Freeport gage). For the historical simulation, the depletion is equal to 1,456 TAF per year, applied to water years 1922 through 1943. This depletion also was applied to the 1900, 1920, and 1940 LOD simulations, but for every year of simulation. A second depletion equal to 526 TAF per year was applied to the historical simulation for water years 1944 through 2009. This depletion also was applied to the 1960, 1980, 2000, and 2010 LOD simulations, but for every year of simulation. The reasons for the discrepancy between simulated and observed flows after 1944 were not identified. The monthly depletions are equal to the model bias for that month when averaged over the period 1922-1943 or 1944-2009.

Figures 4-1 through 4-9 compare simulated and historical flows for the Sacramento River at Freeport and the Yolo Bypass at the Lisbon Weir over the period of simulation, before and after making the model modifications described above. There remains large differences between simulated and historical flows for the Sacramento River at Freeport in 1997, 1998, 1999, and 2000. However, these differences are largely offset by equal yet opposite flow differences for the Yolo Bypass at the Lisbon Weir. The source of these discrepancies is probably poor historical gage data for the Yolo Bypass at Woodland.

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[19] Flows for water year 2005 are from CDEC (station ID FPT). Missing data for July 2005 and August 2005 were estimated by linear interpolation of daily flows between July 10, 2005, and September 1, 2005.

[20] Storage began April 1944.

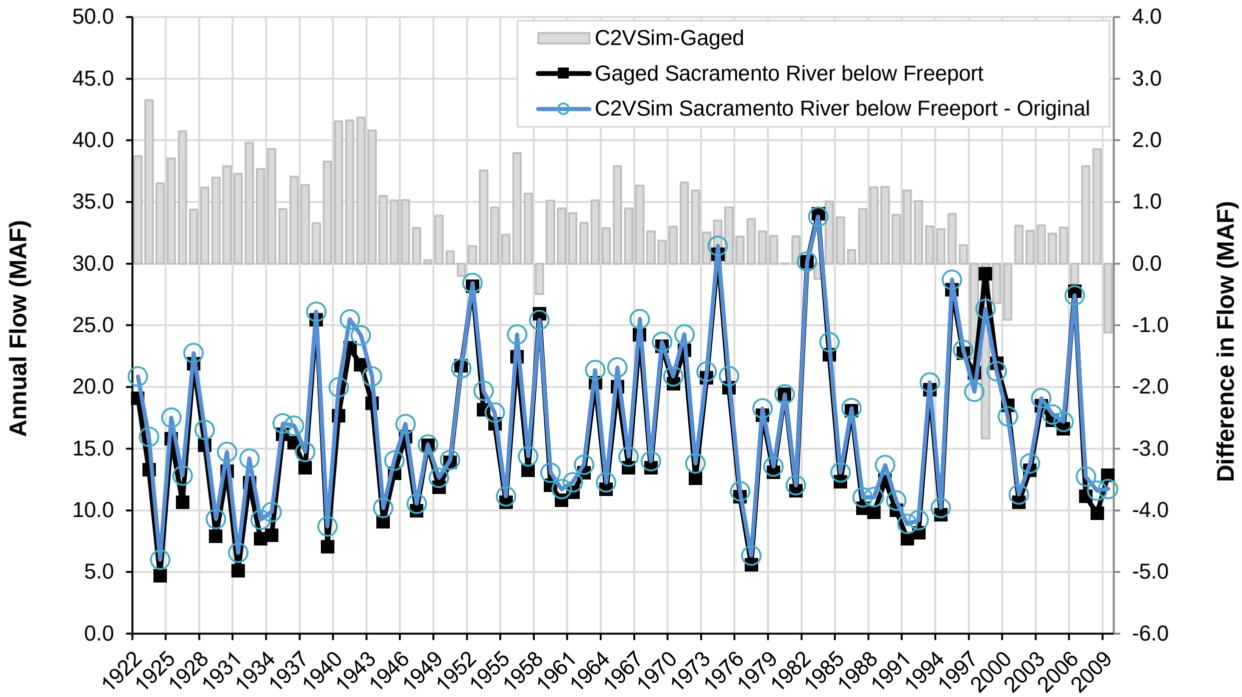


Figure 4-1. Simulated and Gaged Annual Flows for the Sacramento River below Freeport, Water Years 1922-2009, before Model Revisions

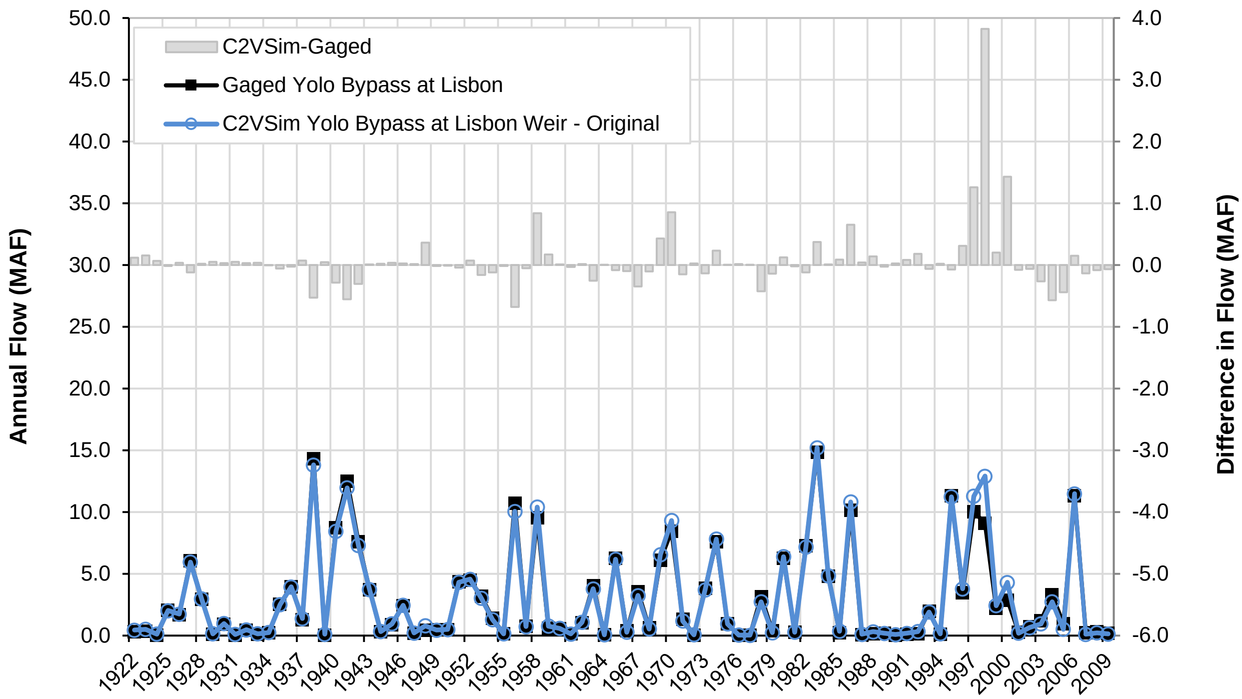


Figure 4-2. Simulated and Gaged Flows Annual Flows for Yolo Bypass at Lisbon, Water Years 1922-2009, before Model Revisions

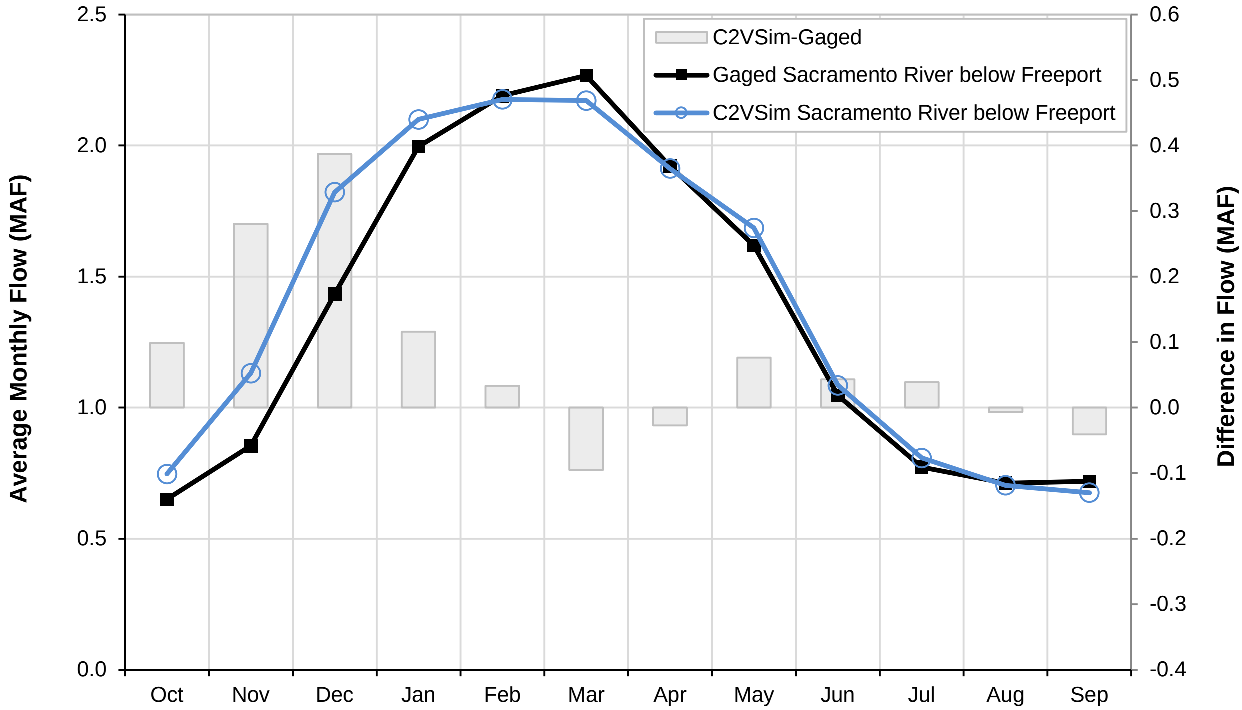


Figure 4-3. Simulated and Gaged Average Monthly Flows for Sacramento River below Freeport, Water Years 1922-2009, before Model Revisions

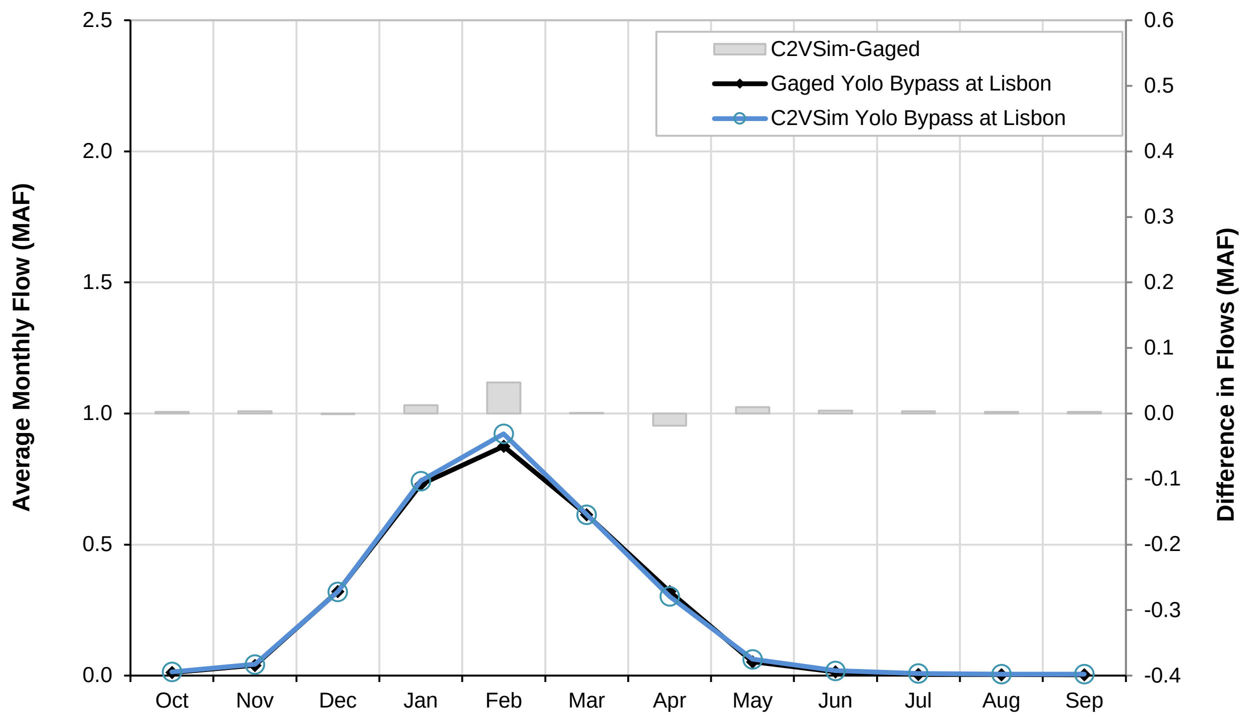


Figure 4-4. Simulated and Gaged Average Monthly Flows for Yolo Bypass at Lisbon Weir, Water Years 1922-2009, before Model Revisions

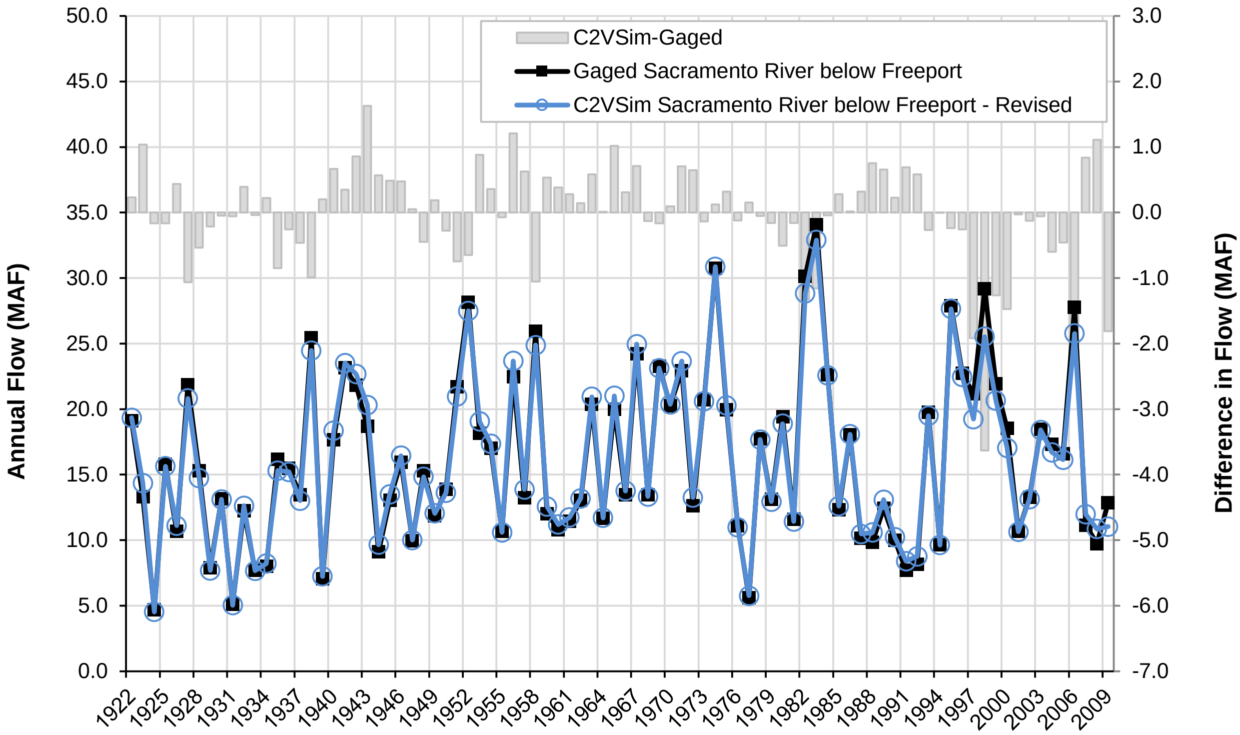


Figure 4-5. Simulated and Gaged Annual Flows for Sacramento River at Freeport, Water Years 1922-2009, after Model Revisions

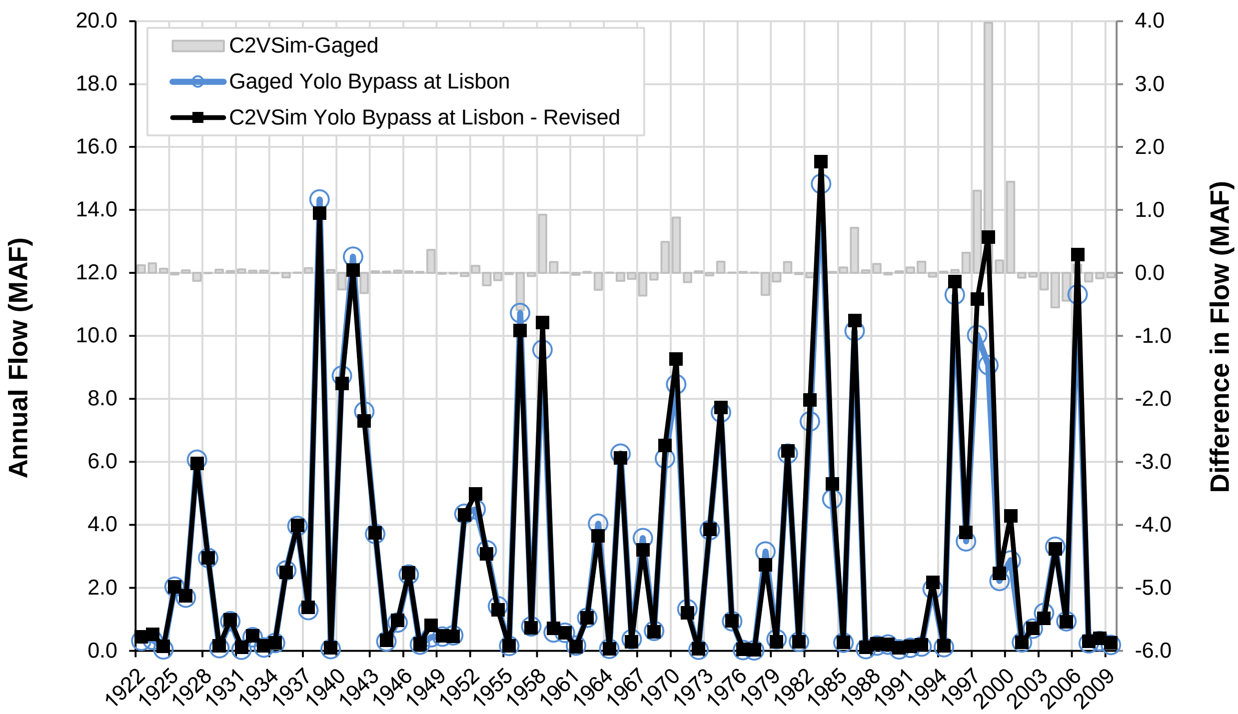


Figure 4-6. Simulated and Gaged Flows Annual Flows for Yolo Bypass at Lisbon, Water Years 1922-2009, after Model Revisions

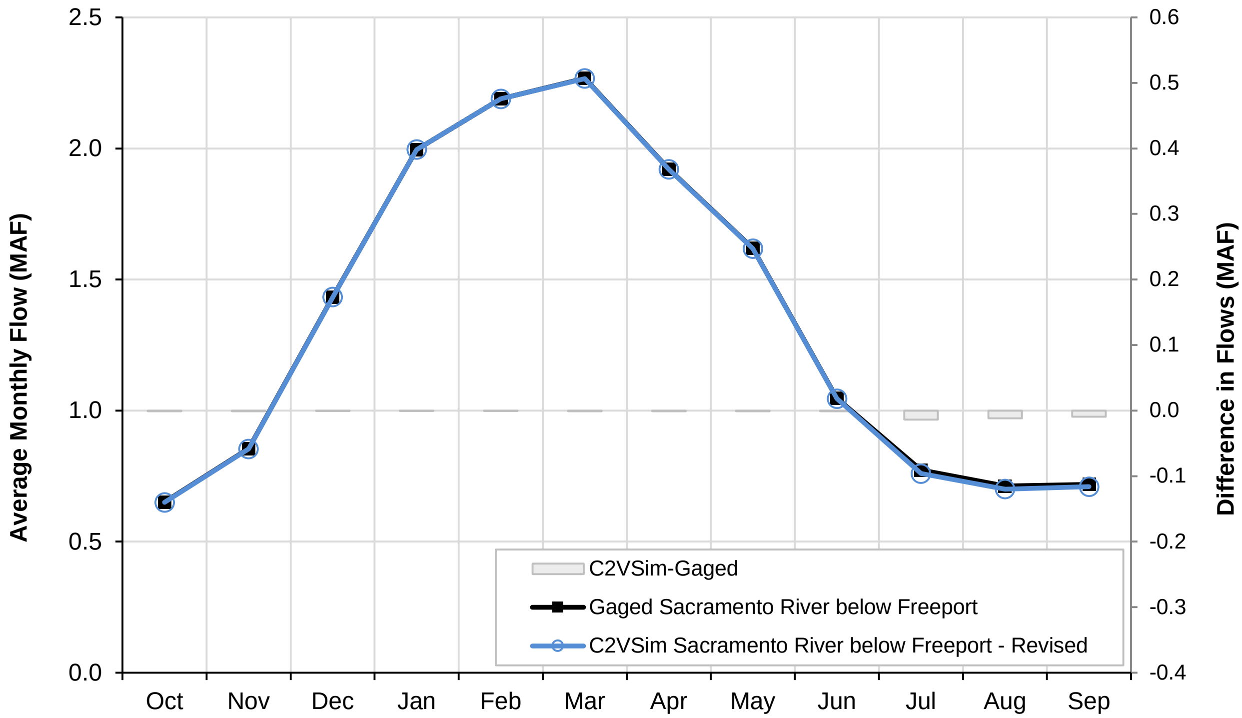


Figure 4-7. Simulated and Gaged Average Monthly Flows for Sacramento River at Freeport, Water Years 1922-2009, after Model Revisions

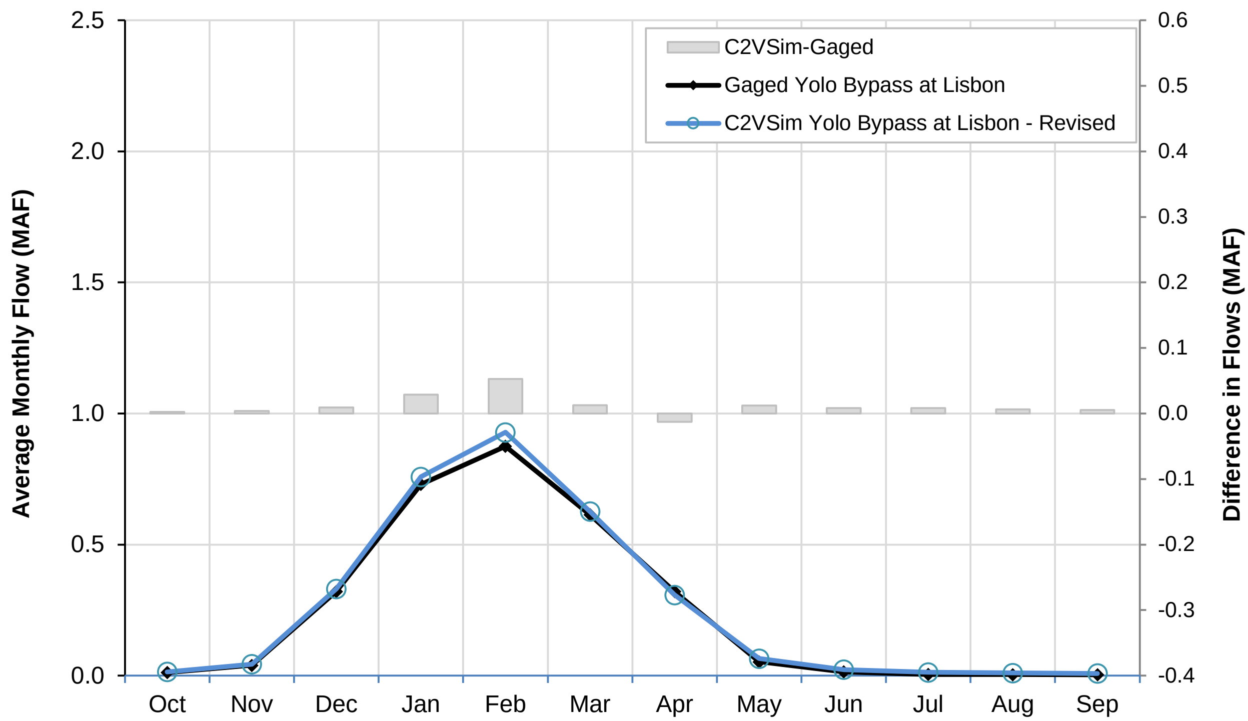


Figure 4-8. Simulated and Gaged Average Monthly Flows for Yolo Bypass at Lisbon, Water Years 1922-2009, after Model Revisions

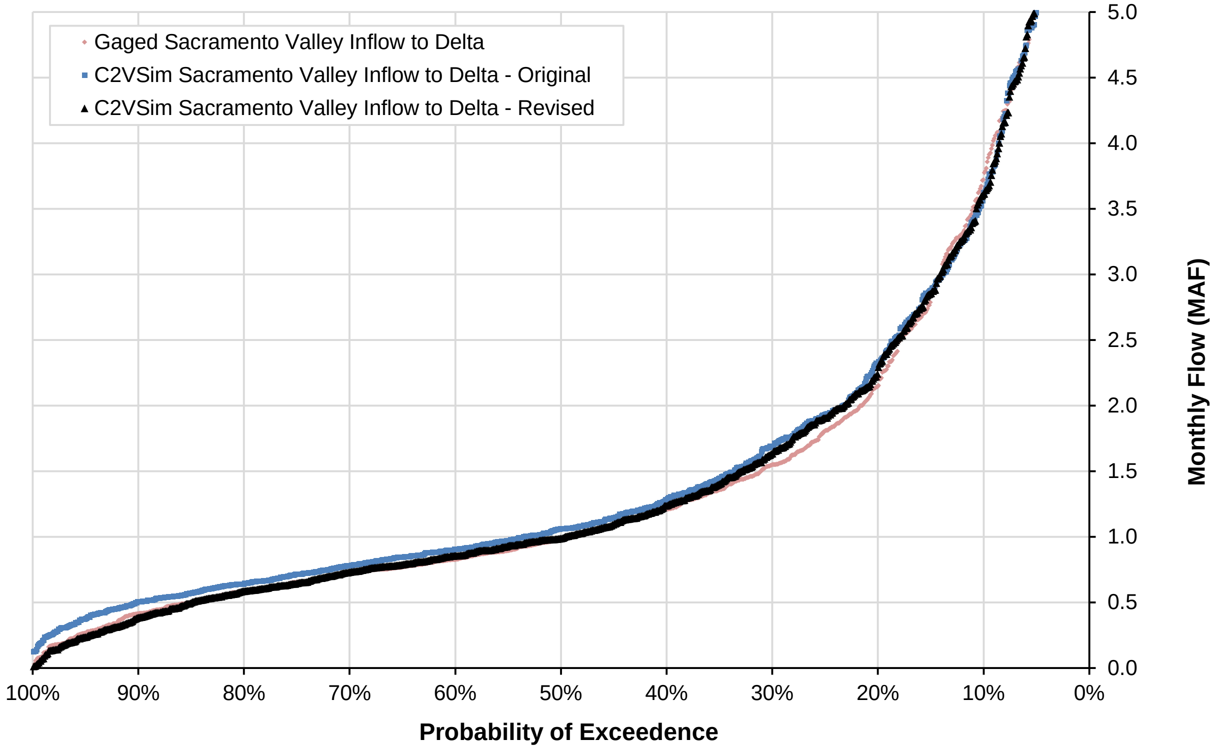


Figure 4-9. Exceedence Plot of Simulated and Gaged Monthly Sacramento Valley Inflows to the Delta, Water Years 1922-2009

San Joaquin River Correction

Simulated inflows to the Delta from the San Joaquin Valley were compared to historical gage data. It was found that C2VSim significantly overestimates flows in the San Joaquin River near Vernalis relative to gage data (USGS 11303500), particularly for the earlier period of simulation. The discrepancy in flow also is apparent for the San Joaquin River at Newman (USGS 11274000). These discrepancies appear to follow two distinct trends, the first covering water years 1922-1941 and the second covering water years 1942-2009. Discrepancies in the early years are attributed to losses associated with overbank flooding at high river flows that occurred seasonally before the construction of Friant Dam and an integrated levee-flood bypass system. These flood events are not simulated in CV2VSim. The reason for discrepancies in the later period of simulation are less clear.

To account for the apparent losses in streamflow, a depletion (treated in the model as a diversion) was added to C2VSim at stream node 134 (San Joaquin River below the Merced River confluence) using logarithmic functions that relate the discrepancies between gaged and simulated flows for the San Joaquin near Vernalis to the historical flow below Friant (USGS 11251000). One function was applied to water years 1922-1941, a second function was applied to the remaining years. The coefficient of determination (r^2) for these relationships are 0.85 and 0.60, respectively. The bias correction for the San Joaquin River averages 1,962 TAF per year for water years 1922-1941 and 866 TAF per year for water years 1942-2009.

For the fixed level of development simulations, the function based on 1922-1941 flow data is applied to develop corrections for the 1900, 1920, and 1940 LOD simulations based on the San Joaquin River unimpaired flow at Friant, not the historical flow. Similarly, the function based on 1942-2009 flow data is used to develop corrections for the 1960, 1980, 2000, and 2010 LOD simulations. These corrections are based on the simulated San Joaquin River flow at Friant.

Figures 4-10 and 4-11 compare simulated and historical annual flows in the San Joaquin River near Vernalis over the period of simulation, before and after the model modifications described above. **Figures 4-12 and 4-13** compare simulated and historical average monthly flows, before and after the model modifications described above. **Figure 4-14** compares simulated and historical monthly flows in the form of an exceedence plot, before and after the modifications.

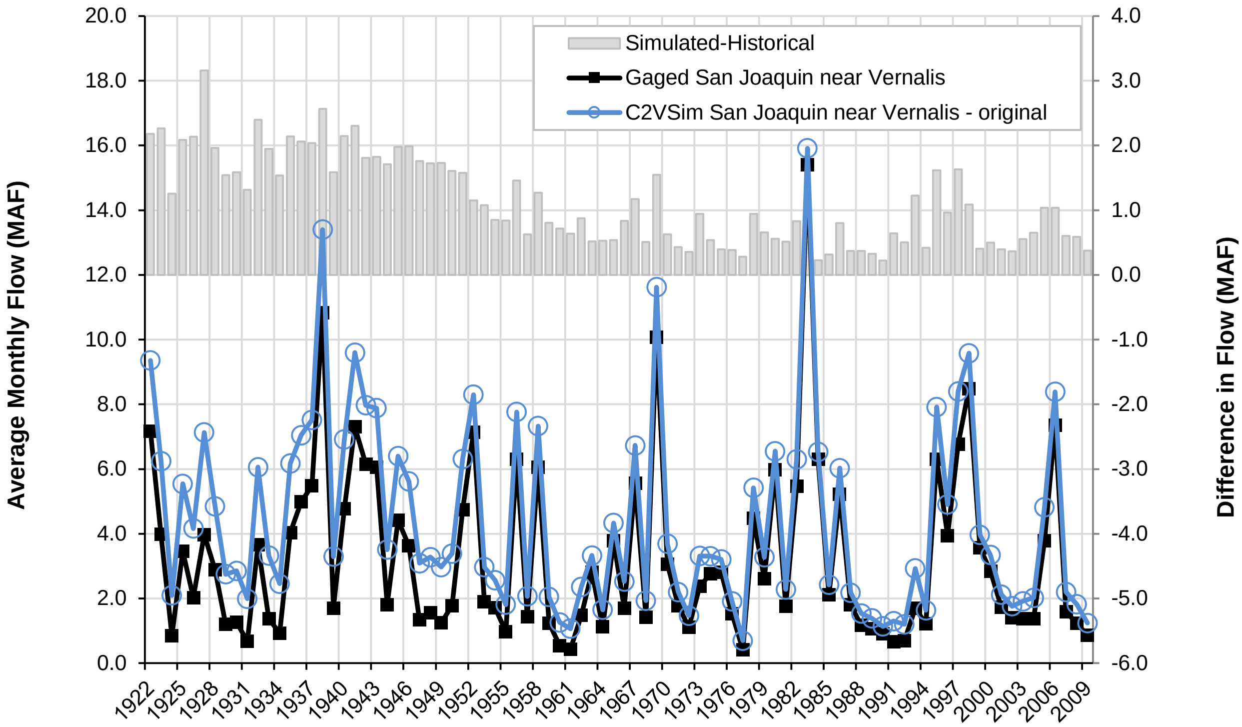


Figure 4-10. Simulated and Historical Annual Flows for San Joaquin River near Vernalis, Water Years 1922-2009, before Model Revisions

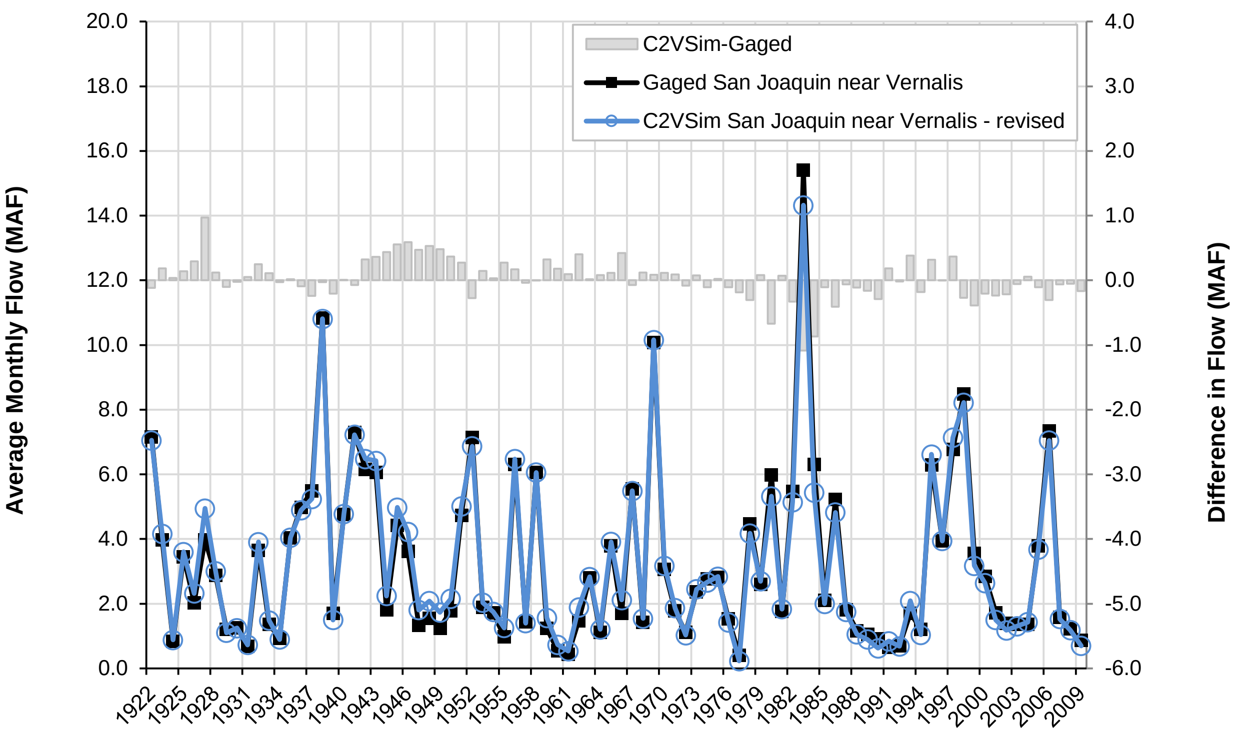


Figure 4-11. Simulated and Historical Annual Flows for San Joaquin River near Vernalis, Water Years 1922-2009, after Model Revisions

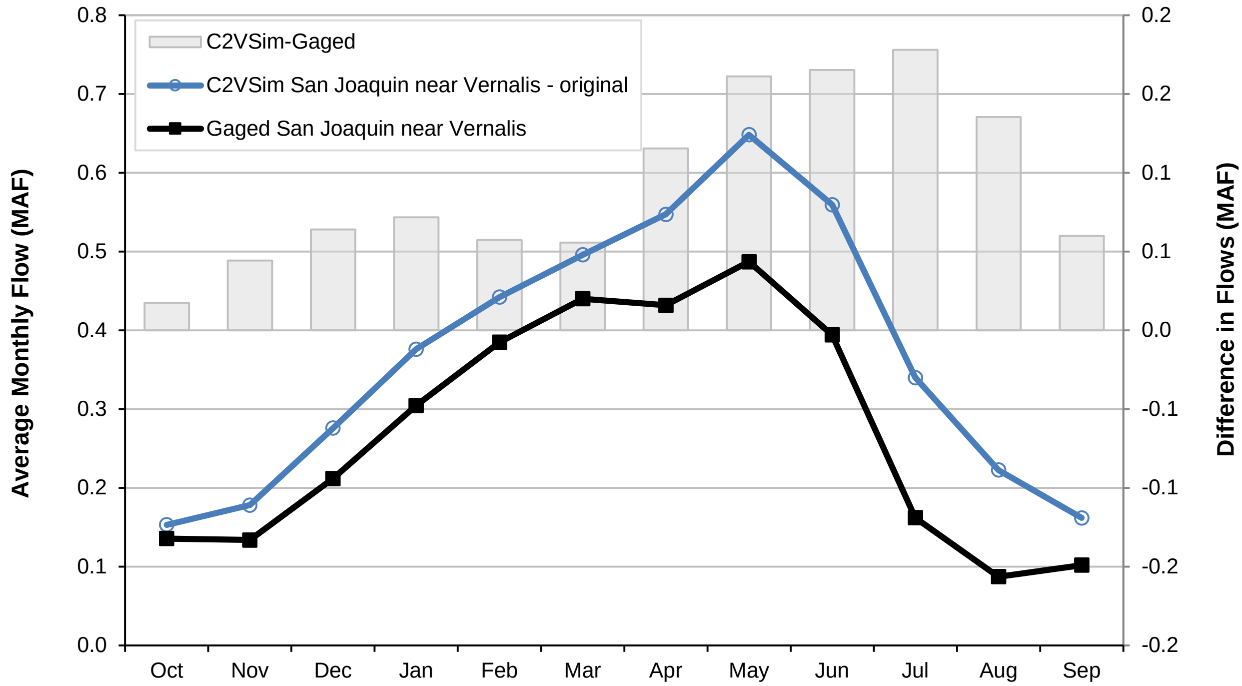


Figure 4-12. Simulated and Historical Average Monthly Flows for San Joaquin River near Vernalis, Water Years 1922-2009, before Model Revisions

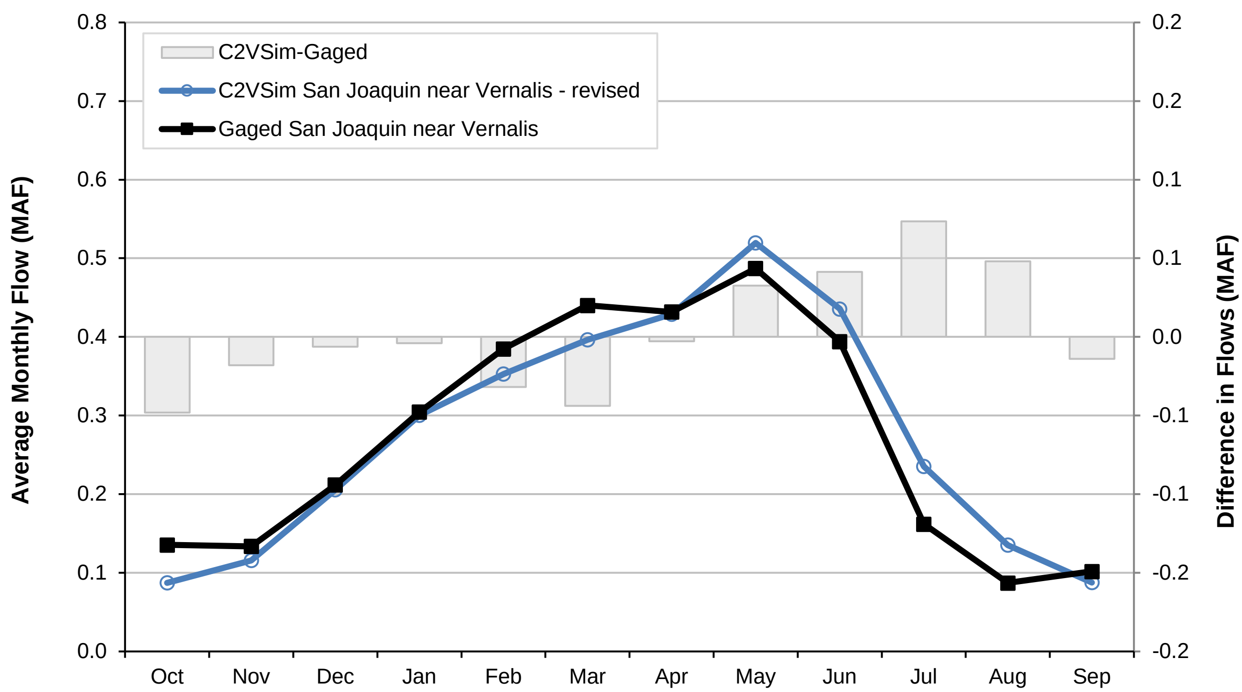


Figure 4-13. Simulated and Historical Average Monthly Flows in the San Joaquin River near Vernalis, Water Years 1922-2009, after Model Revisions

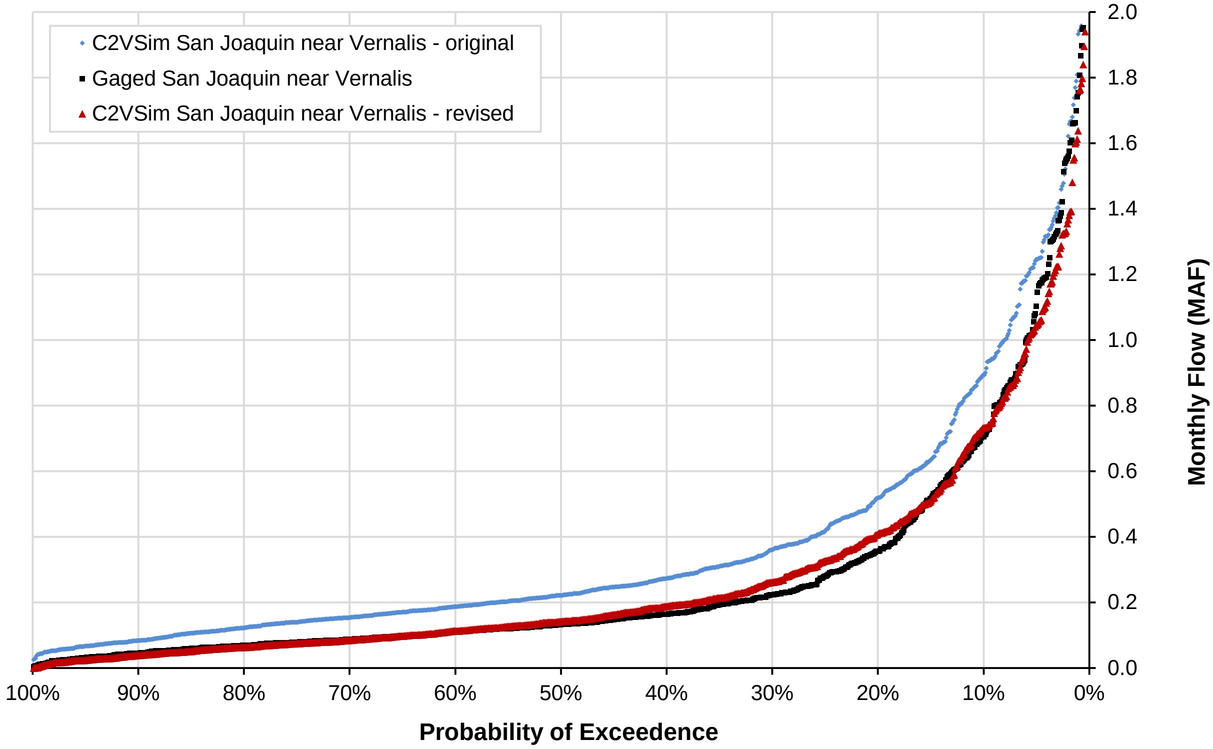
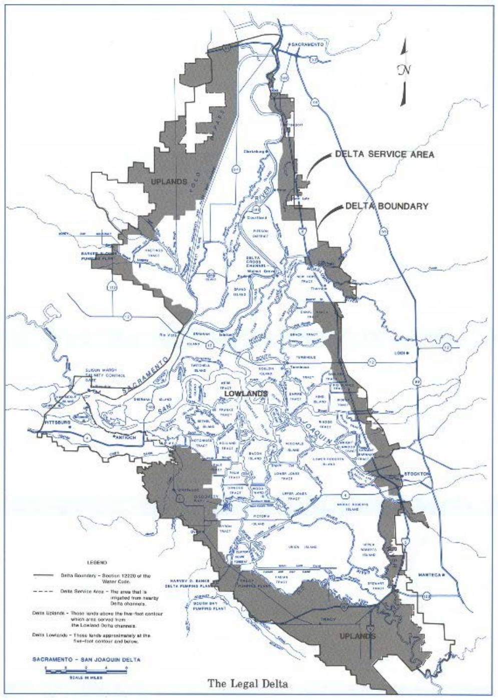


Figure 4-14. Exceedence Plot of Simulated and Historical Monthly Flows for San Joaquin River near Vernalis, Water Years 1922-2009

Sacramento-San Joaquin Delta

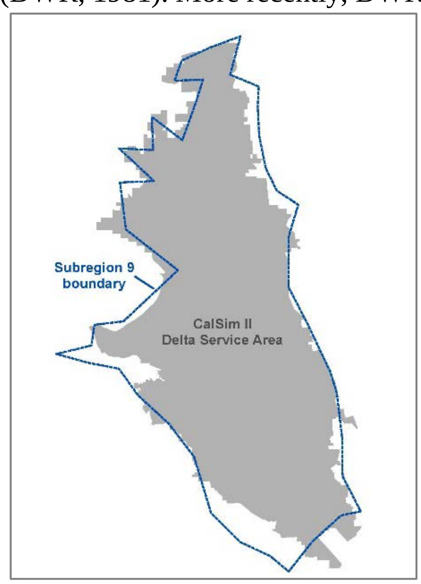
The following sections discuss C2VSim's representation of the Delta and how this representation differs from other models.



Boundary

The official boundary of the Delta, the Legal Delta, was defined in 1959 with the passage of the Delta Protection Act (Section 12220 of the California Water Code). It covers approximately 738,000 acres. C2VSim represents the Delta by Subregion 9 (DSA 55), which covers 725,454 acres. Although the area of Subregion 9 is similar to that of the Legal Delta, differing by less than 2 percent, the boundaries do not match well because of the coarseness of the C2VSim finite element grid.

The Delta, as defined for CalSim II, is known as the "Delta Service Area." The boundary of this area was defined in a DWR Central District Office report called *Sacramento-San Joaquin Delta Area Land Use Survey Data* (DWR, 1965). The most prominent difference between the Legal Delta and Delta Service Area is that the Legal Delta includes the towns of Pittsburg and Antioch; the Delta Service Area does not. Over the years, various estimates of land area for the Delta Service Area have been reported. The Consumptive Use (CU) models,[21] which have been developed for the Delta, use an estimate of 678,200 acres, as reported in *Joint DWR and WPRS Delta Channel Depletion Analysis* (DWR, 1981). More recently, DWR's Bay Delta Office has adopted a value of 679,699 acres; approximately 0.2 percent larger than the previous estimate used for CalSim II (Kadir, 2006). DWR's DAYFLOW program currently assumes a total Delta area of 682,230 acres. However, before October 1980, a larger area of 738,000 was used.



Land Use

Figure 4-15 compares historical Delta agricultural land use from two sources: the CU model and C2VSim. This figure also includes data from a DWR land-use survey conducted in 2007. C2VSim assumes that all agricultural land use is located within the Delta Service Area, so despite the difference in total area, C2VSim and CU model agricultural land use data are identical from 1922 through 1987. After 1987, C2VSim estimates of agricultural land use appear to be rather erratic, including an 89,000 acre decrease in agricultural lands between 1997 and 1998.

For the purposes of the *Historical Level of Development Study,* agricultural land use for the 2000 and 2010 levels of development

[21] The CU computer program, developed by DWR, tracks changes in monthly soil moisture in the root zone caused by precipitation, irrigation, and ET. A CU model was developed for each of two Depletion Study Areas (Delta Lowlands and Delta Uplands) to estimate Delta water demands based on land use, crop ET, precipitation, soil characteristics, and irrigation scheduling.

have been set equal to values reported in the CU model for 2005, i.e., 425,607 acres. Land use data from the CU model are considered more reliable (Kadir, 2015). In comparison, the 2007 DWR land use survey reports an agricultural land area of 400,632 acres. The C2VSim input files CVcropacre.dat and CVlanduse.dat were edited to reflect these changes in land use assumptions. For the 2010 LOD, the changes in land use described above reduced net Delta outflow by approximately 120 TAF/year or by less than 1 percent.

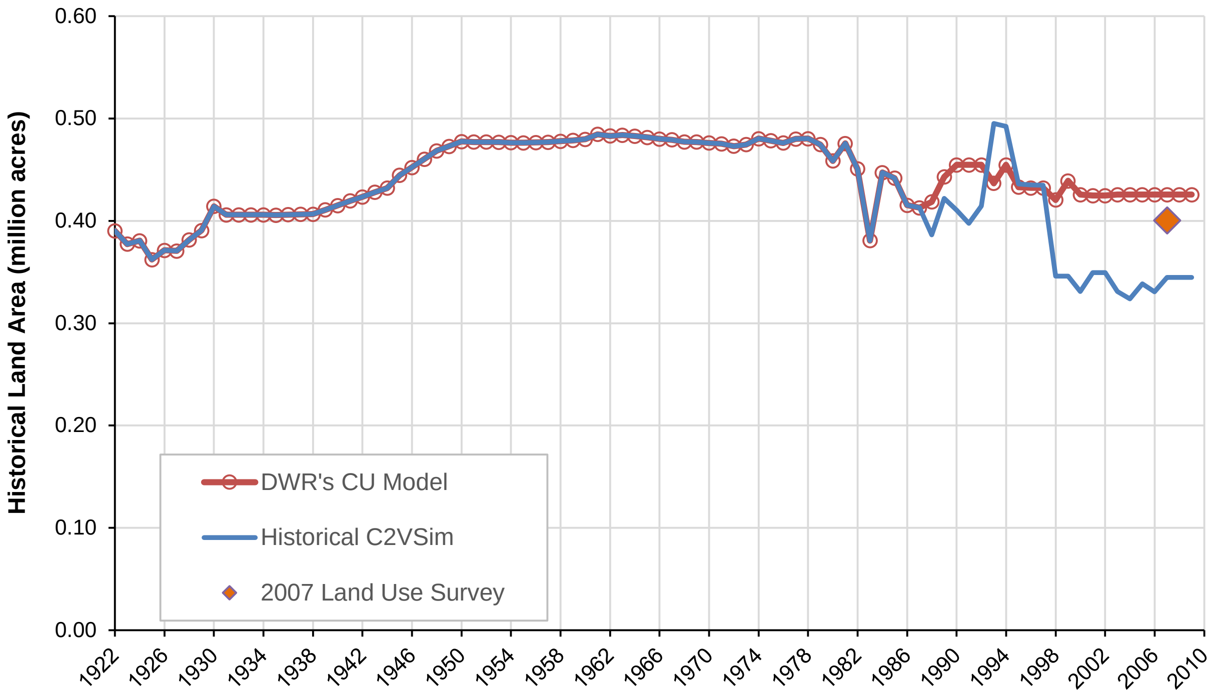


Figure 4-15. Estimates of Historical Delta Agricultural Land Area: Water Years 1922-2009

Net Channel Depletion

The applied water (I_A) needed to meet crop water demands depends on crop potential evapotranspiration (ET_c), irrigation efficiency (η), and the availability of other sources of water, including antecedent soil moisture and precipitation (P). Within the Delta Lowlands, there is an inflow of water from Delta channels to the Delta islands via seepage (S). The seepage rate depends on the head difference between water elevations in the channels and water elevations in drainage ditches in the islands. Seepage rates are approximately constant throughout the year as drainage pumps maintain groundwater levels within the islands relatively constant (Mahadevan, 1995). Within the Delta Lowlands, it is a common practice to periodically leach salts from the root zone through large irrigation applications. Typically, leach water (LW_A) is applied from October through December and drained (LW_D) from January through April (Mahadevan, 1995). Excess water is pumped from the Delta islands back into the Delta. This water consists of excess irrigation water, leach water, and surface runoff (RO) from precipitation.

Delta consumptive use (DCU) is synonymous with gross channel depletions, as described in DAYFLOW documentation.[22] Net channel depletions are the difference between total diversions (D) and total

[22] DAYFLOW is a computer program developed by DWR to estimate daily tidally-average, or freshwater, Delta outflow.

drainage or return flows (R). Net channel depletions are the same as gross channel depletions less Delta precipitation. These relationships are defined by Equations 4-1 through 4-6.

$$\text{Gross Channel Depletion} = D - R + P \qquad \text{Eqn. 4-1}$$

$$\text{Net Channel Depletion} = D - R \qquad \text{Eqn. 4-2}$$

$$D = I_A + LW_A + S \qquad \text{Eqn. 4-3}$$

$$R = (1 - \eta)I_A + LW_D + RO \qquad \text{Eqn. 4-4}$$

$$\text{Gross Channel Depletion} = \eta\, I_A + LW_A + S - LW_D + (P - RO) \qquad \text{Eqn. 4-5}$$

$$\text{Net Channel Depletion} = \eta\, I_A + LW_A + S - LW_D - RO \qquad \text{Eqn. 4-6}$$

ET_c rates for the calculation of crop water use are an input to C2VSim. These input values were taken directly from DWR's CU model. However, DWR has acknowledged that these values may need updating. Revised ET_c were obtained from DWR (Kadir, 2015) based on work conducted by UC Davis (Kadir, 2006; Snyder et al., 2010; Medellin-Azuara and Howitt, 2013). A sensitivity analysis was conducted using revised Delta land use estimates and the original and updated Delta ET_c rates. The updated ET_c rates resulted in an approximate 1 percent decrease in net channel depletions. Changes in net Delta outflow were less than 0.1 percent.

Figures 4-16 and 4-17 compare historical average monthly gross channel depletion and net channel depletion as estimated by DAYFLOW, CU model, and C2VSim. **Figures 4-18 and 4-19** compare annual values as estimated by DAYFLOW, CU model, and C2VSim. **Figure 4-20** compares annual Delta precipitation data as used in the CU model and C2VSim. C2VSim net channel depletions appear to diminish beginning in the mid-1990s compared to the CU model. This discrepancy is caused partly by differences in Delta precipitation and partly by the agricultural land area discussed above. C2VSim's calculation of Delta consumptive use also has the following limitations:

- No land use class for open water; open water evaporation is not considered and open water is lumped with native vegetation.
- No accounting for vegetative uptake from a shallow watertable; simulated ET from native vegetation falls in the early summer as soil moisture becomes depleted.
- No accounting for leaching and seepage which may change the monthly distribution of channel depletions.
- Evaporative losses from bare soil are not limited to the surface 4 to 6 inches as recommended by Allen et al. (1998).

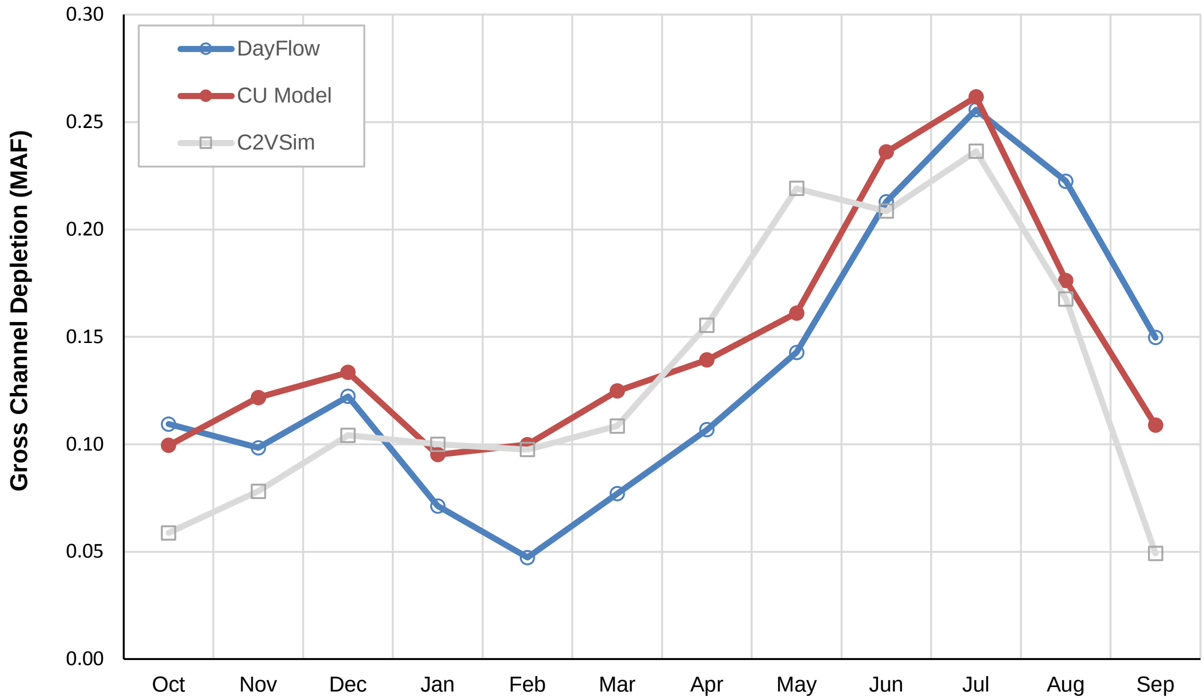


Figure 4-16. Average Monthly Gross Delta Channel Depletion: Water Years 1922-2009

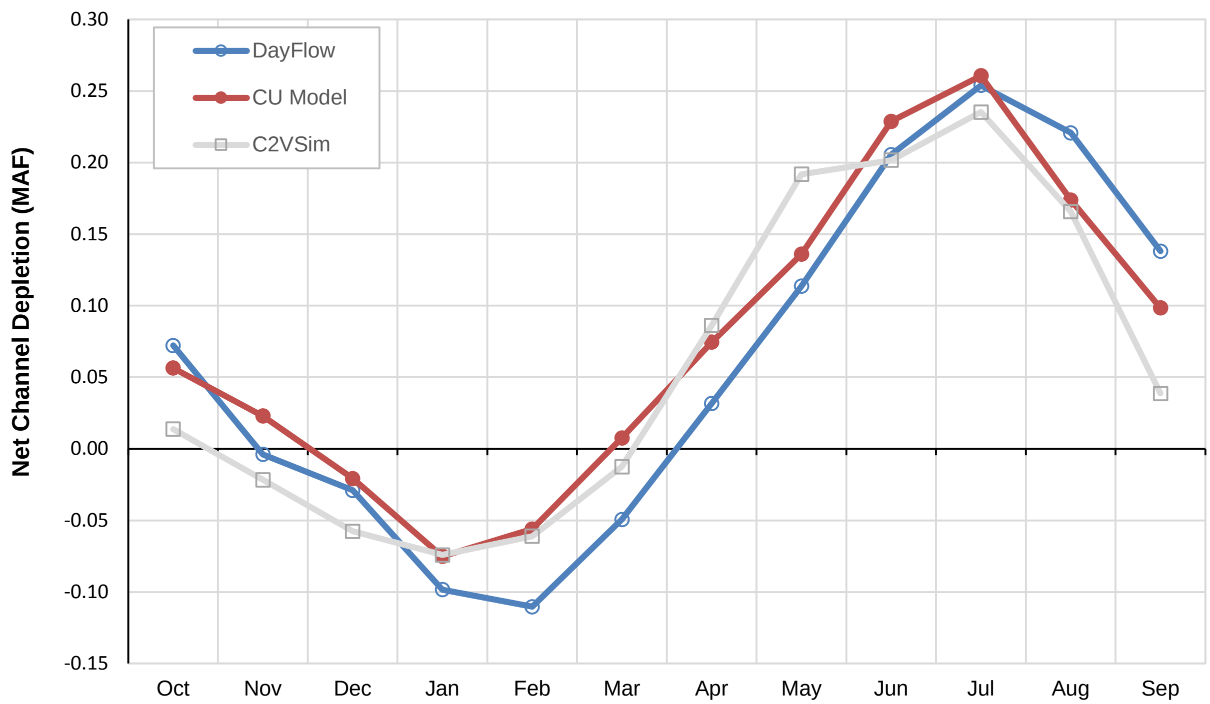


Figure 4-17. Average Monthly Net Delta Channel Depletion: Water Years 1922-2009

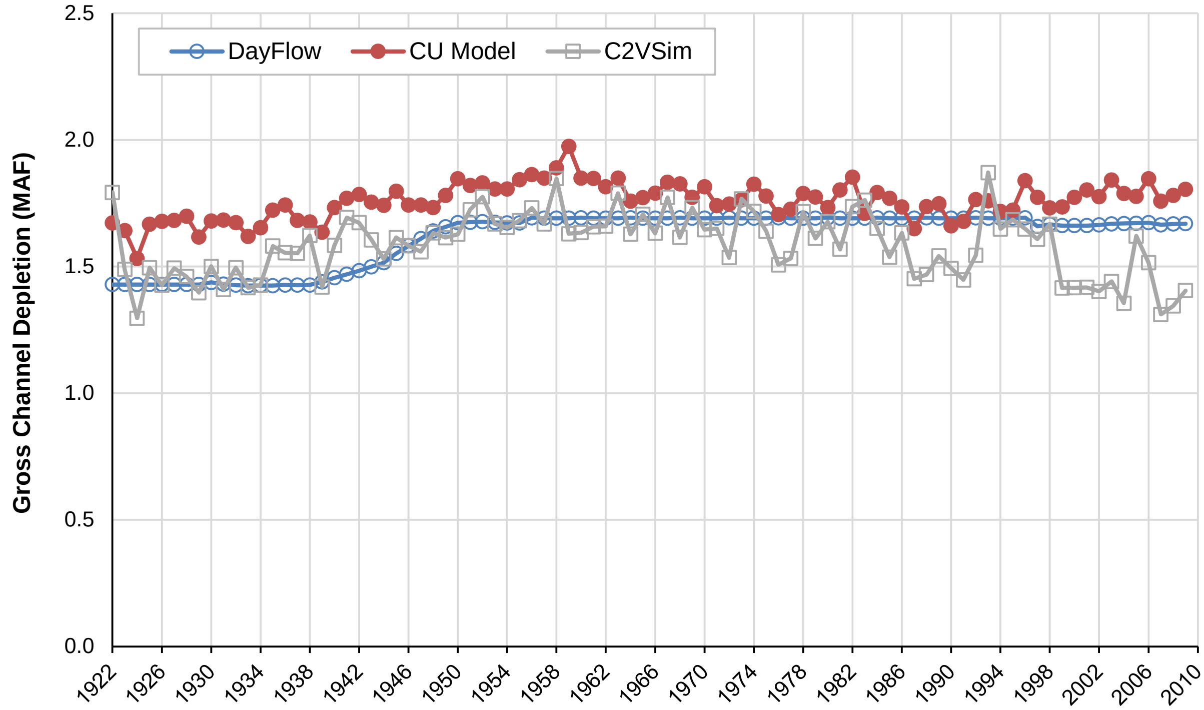


Figure 4-18. Annual Gross Delta Channel Depletion: Water Years 1922-2009

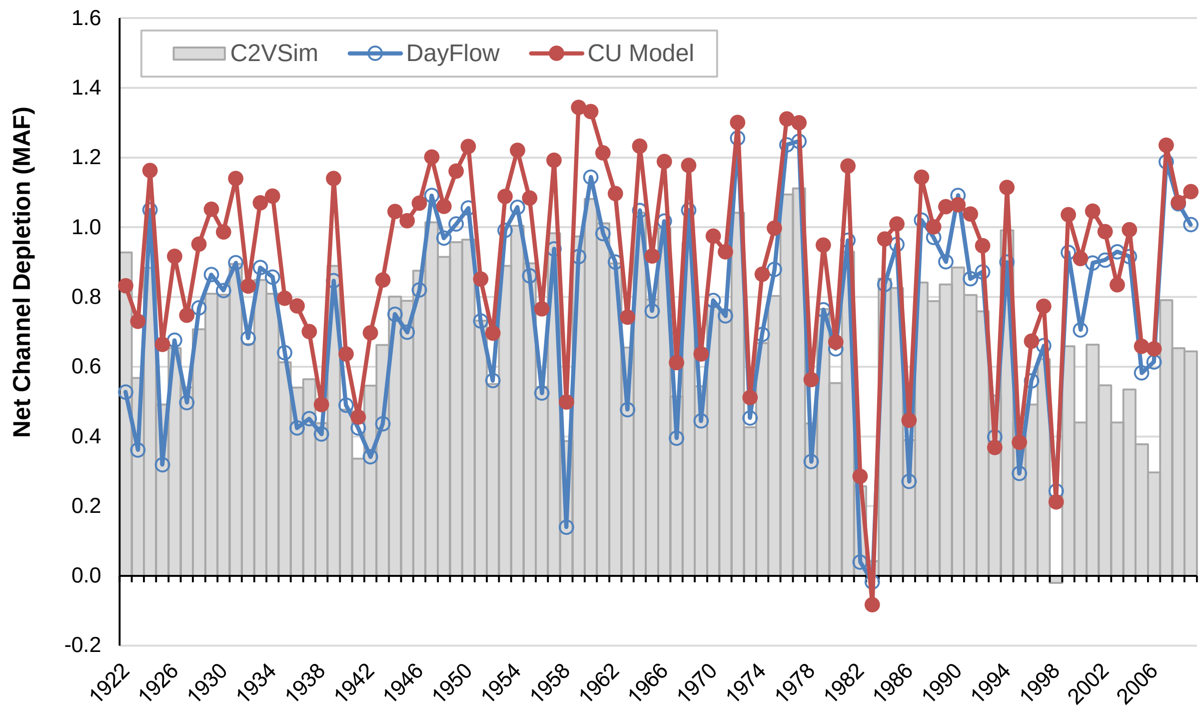


Figure 4-19. Annual Net Delta Channel Depletion: Water Years 1922-2009

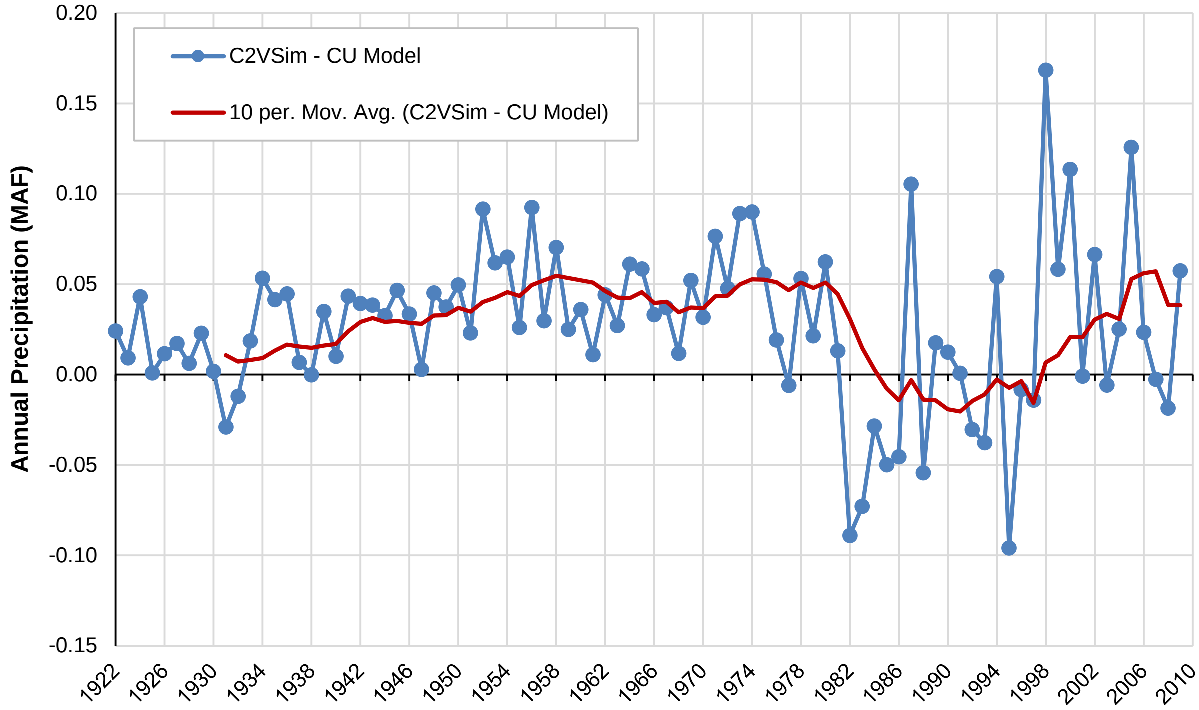


Figure 4-20. Annual Difference in Delta Precipitation: Water Years 1922-2009

Input Files for Fixed Level of Development Simulation

The following sections describe the C2VSim files that were modified for the fixed level of development simulations. All other C2VSim input files remain unmodified from the historical simulation model.

Land Use Category for Fixed Level of Development

Land use is specified in the file *CVlanduse.dat*. For the historical run, this file contains timeseries data specifying the land use distribution for each model element. Four land use categories are considered: agricultural, urban, native vegetation, and riparian vegetation. Land use is specified in units of acres. The total acreage for each row equals the acreage of the listed element.

For most of the fixed level of development simulations, land use is extracted from the C2VSim model of historical conditions (C2VSim-CG_R374) using the year corresponding to the given level of development. For the 1920 LOD, land use data from 1922 is used to represent the level of development. Land use for the 1900 LOD simulation is scaled from land use for the 1920 LOD simulation based on changes in irrigated acreage (from DWR Bulletin 27) between 1900 and 1920 and changes in California's population (from U.S. census data). A single time stamp of 09/30/2500 is specified in the revised *CVlanduse.dat* files to indicate that the specified land use should be applied to all months of the period of simulation.

Crop Acreage for Fixed Level of Development

Irrigated crop acreage is specified in the file *CVcropacre.dat*. For the simulation of historical conditions, the file contains timeseries data for 14 crop types and 3 non-agricultural land classes (urban, native vegetation, and riparian vegetation) for 21 subregions. Land use is specified in acres and for each water year.

For most fixed level of development simulations, crop acreage is extracted from C2VSim-CG_R374 for the year corresponding to the given level of development. Crop acreage data from 1922 is used to represent the 1920 LOD simulation. Crop acreage for the 1900 LOD simulation is scaled from crop acreage for the 1920 LOD simulation, based on changes in crop acreages between 1900 and 1920 (from USDA agricultural census data). A single time stamp of 09/30/2500 is specified in the revised *CVlanduse.dat* files to indicate that the specified land use should be applied to all years of the period of simulation.

Urban Demand for Fixed Level of Development

The input file *CVurbandem.dat* contains the urban water demand for each of 21 subregions as monthly timeseries data. For most fixed level of development simulations, urban demands are extracted from C2VSim-CG_R374 for the year corresponding to the given level of development. Urban demand data from 1922 is used to represent the 1920 LOD simulation, and urban demand in the 1900 LOD simulation is scaled from urban demand in the 1920 LOD simulation, based on relative changes in California population between 1900 and 1920 (from USDA agricultural census data). Only 12 time periods are specified in the revised *CVlanduse.dat* files for water year 4000 to indicate that the specified urban demands should be applied to all years of the period of simulation.

Initial Conditions for Fixed Level of Development

The input file *CVinit_1921.dat* contains initial conditions for the simulation, corresponding to October 1, 1921. Data inputs include the initial aquifer head values, the initial soil moisture for the root zone, initial moisture values for the unsaturated zone, and initial moisture values for the small-stream watersheds.

For each fixed level of development simulation, the initial head at each groundwater node for each of 3 layers is set equal to the simulated head under historical conditions for the end of the year corresponding to the given level of development (from the C2VSim file *CVGWheadall.out*). For the 1900- and 1920 LOD simulation, initial conditions from C2VSim-CG_R374 (based on assumed 1921 conditions) are applied; simulated groundwater conditions before October 1921 are not available. In addition, for the 1900 LOD, the initial soil moisture specified for the root zone was adjusted to eliminate model instabilities resulting from changing the land use acreages relative to historical 1921 conditions.

Diversions for Fixed Level of Development

Surface water diversions are specified in the file *CVdivspec.dat*. Data inputs include the locations, properties, and recharge zones for surface water diversions and bypasses. The original C2VSim model (C2VSim-CG_R374) has 246 surface water diversions and 12 bypasses. These diversions are bypasses are listed in **Table 4-1**. Three additional diversions were added as part of the revisions to the historical model, as previously described. Monthly timeseries of diversion data for C2VSim-CG_R374 are contained in the input file *CVdiversions.dat*. For the fixed level of development simulations, the diversion and bypass flows are stored in an HEC-DSS file (USACE, 1995).

For the 1900- through 1960 LOD simulations, the source of diversion data for input to the C2VSim models includes the Excel-based reservoir operations models and C2VSim historical data. Diversions explicitly simulated in the reservoir operations models are stored directly in the input HEC-DSS file. Other diversion data are developed from the historical C2VSim diversion data. For the latter, diversions at each node are fixed as a repeating monthly pattern that is equal to average of historical C2VSim diversions at that node for each month in the 10-year period centered around the given level of development. For the 1920 LOD, the diversion data are based on the average of 1922-1931 historical diversions. For the 1900 LOD, diversions are scaled from the computed 1920 LOD diversions, based on the either the relative change in population from 1900 to 1920 for M&I diversions (from U.S. census data), or the relative change in agricultural diversions from 1900 to 1920 (from DWR Bulletin 17).

Table 4-1. C2VSim Model Diversions and Bypasses

ID	Diversion/Bypass	ID	Diversion/Bypass
1-2	Whiskeytown and Shasta imports	82	Cosumnes River riparian diversions
3-5	Sacramento River to Bella Vista conduit	83-84	Mokelumne River diversions
6-7	Sacramento River diversions Keswick to Red Bluff	85	Calaveras River diversions
8	Cow Creek riparian diversions	86	Delta agricultural diversions
9	Battle Creek riparian diversions	87	Delta M&I diversions
10	Cottonwood Creek riparian diversions (import)	88-90	North Bay Aqueduct diversions
11	Clear Creek riparian diversions	91	Delta to Contra Costa Canal export
12	Sacramento River diversions to Corning Canal	92	Delta to CVP export
13-14	Stony Creek to North and South Canals	93	Delta to SWP export
15	Stony Creek to the Tehama-Colusa Canal	94-95	Stanislaus River to South San Joaquin Canal
16	Stony Creek to the Glenn-Colusa Canal	96-97	Stanislaus River to Oakdale Canal
17	Sacramento River to Subregion 2 for Ag	98-99	Stanislaus River riparian diversions
18	Antelope Creek riparian diversions	100-102	Tuolumne River to Modesto Canal
19	Mill Creek riparian diversions	103-107	Tuolumne River riparian diversions
20	Elder Creek riparian diversions	108-109	Tuolumne River to Turlock Canal
21	Thomes Creek riparian diversions	110-111	Merced River to Merced ID Northside Canal
22	Deer Creek diversions	112-115	Merced River riparian diversions
23-24	Sacramento River to Tehama-Colusa Canal	116-117	Merced River to Merced ID Main Canal
25-26	Sacramento River to Glenn-Colusa Canal	118	Chowchilla River to Chowchilla WD
27-28	Sacramento River diversions Red Bluff to KL.	119	Chowchilla River riparian diversions
29	Little Chico Creek (import)	120	Chowchilla River for groundwater recharge
30	Tarr Ditch (import)	121	Fresno River to Madera ID
31	Miocene and Wilenor Canals (import)	122	Fresno River riparian diversions
32	Palermo Canal from Oroville Dam (import)	123	Fresno River for groundwater recharge
33	Forbestown Ditch (import)	124-131	San Joaquin River riparian diversions
34	Little Dry Creek (import)	132-145	Kings River diversions
35	Bangor Canal (import)	146-155	Kaweah River diversions
36	Thermalito Afterbay (import)	156-157	Tule River diversions
37	Feather River (replaced by Thermalito)	158-170	Kern River diversions
38	Feather River to Thermalito ID (import)	171-176	Delta-Mendota Canal deliveries and seepage
39-41	Lower Feather River diversions	177-183	Mendota Pool deliveries
42-43	Yuba River diversions	184-186	O'Neill Forebay deliveries
44-46	Bear River to Camp Far West ID/South Sutter WD	187-209	San Luis Canal deliveries and seepage
47	Bear River Canal to South Sutter WD (import)	210-211	Madera Canal deliveries
48	Boardman Canal (import)	212-235	Friant-Kern Canal deliveries
49	Combie (Gold Hill) Canal deliveries (import)	236-243	Cross-Valley Canal deliveries
50	Cross Canal deliveries (import)	244	Kings River to Friant-Kern Canal
51-55	Butte Creek diversions	245	Kaweah River to Friant-Kern Canal
56	Butte Slough diversions	246	Tule River to Friant-Kern Canal
57-61	Sutter Bypass East & West Borrow Pit diversions	*247*	*San Joaquin R Seepage Correction*
62-63	Colusa Basin Drain diversions	*248*	*Sac R Historical Correction (Nov/Dec)*
64	Knights Landing Ridge Cut diversions	*249*	*Sac R Historical Correction (other months)*
65	Sacramento River RB KL to Sacramento	1	Moulton Weir spill to Butte Basin
66	Sacramento River to City of West Sacramento	2	Colusa Weir spill to Butte Basin
67	Sacramento River LB, KL to Sacramento	3	Tisdale Weir near Grimes
68	Sacramento River to City of Sacramento	4	Freemont Weir spill to Yolo Bypass
69	Cache Creek diversions	5	Sacramento Weir spill to Yolo Bypass
70	Yolo Bypass diversions	6	Knights Landing Ridge Cut flood flow to Yolo Bypass
71-73	Putah South Canal deliveries	7	Kings River to South Fork Kings River
74	Putah Creek riparian diversions	8	Kaweah River to groundwater recharge
75-76	Folsom Lake diversions (import)	9	Tule River to groundwater recharge
77-79	Folsom South Canal deliveries	10	Kern River Flood Channel to groundwater recharge
80	American River to Carmichael WD	11	South Fork Kings River to groundwater recharge
81	American River to the City of Sacramento	12	Kern River to Buena Vista Lake

For the 1980-, 2000-, and 2010 LOD simulations, the source of diversion data includes: (a) the Excel-based reservoir operations models, (b) results from CalSim II simulations, (c) individual rules assigned to specific diversion nodes, and (d) C2VSim historical data. Diversions or deliveries explicitly simulated in the reservoir operations models are directly stored in the HRC-DSS input file. Next, certain C2VSim diversion nodes were mapped to CalSim II diversion arcs or were associated with CalSim II annual allocations, and the CalSim results were used to develop the C2VSim diversions based on either the CalSim diversion data or the CalSim annual allocation multiplied by the contract amount and the monthly diversion pattern (from C2VSim historical data). Additionally, some nodes were assigned individual rules applying historical data to account for arcs not explicitly simulated by CalSim but bound by specific restrictions not reflected in the C2VSim data. For C2VSim diversions not covered by one of the above cases, diversions at each node are fixed as a repeating monthly pattern, equal to the average historical C2VSim diversions at that node, for each month in the 10-year period centered around the given level of development. For the 2010 LOD simulation, the diversion data are based on the average of 2000-2009 historical diversions because the historical C2VSim diversion data ends in 2009.

Inflows for Fixed Level of Development

Inflows for each fixed level of development simulation are derived from the corresponding reservoir operations model or CalSim II study, as described in **Chapter 3**. All timeseries inflow data are stored in a single HEC-DSS file, C2VSim_LOD_Inflows.dss. The filename and path are specified in the input file *CVinflows.dat*. **Table 4-2** lists the inflow data for each level of development.

Table 4-2 C2VSim Model Boundary Inflows

ID	Inflow	ID	Inflow
1	Sacramento River	23	Calaveras River
2	Cow Creek	24	Stanislaus River
3	Battle Creek	25	Tuolumne River
4	Cottonwood Creek	26	Orestimba Creek
5	Paynes and Sevenmile Creek	27	Merced River
6	Antelope Creek Group	28	Bear Creek Group
7	Mill Creek	29	Deadmans Creek
8	Elder Creek	30	Chowchilla River
9	Thomes Creek	31	Fresno River
10	Deer Creek Group	32	San Joaquin River
11	Stony Creek	33	Kings River
12	Big Chico Creek	34	Kaweah River
13	Butte and Chico Creek	35	Tule River
14	Feather River	36	Kern River
15	Yuba River	37	FKC Wasteway Deliveries to Kings River
16	Bear River	38	FKC Wasteway Deliveries to Tule River
17	Cache Creek	39	FKC Wasteway Deliveries to Kaweah River
18	American River	40	Cross-Valley Canal deliveries to Kern River
19	Putah Creek	41	Friant-Kern Canal deliveries to Kern River
20	Cosumnes River	42	Madera Canal spills to Fresno River
21	Dry Creek	43	Madera Canal spills to Chowchilla River
22	Mokelumne River		

1900 Level of Development

The 1900 fixed level of development C2VSim model includes the following:

- Inflows from 1900 LOD spreadsheet models.
- Diversions from the 1900 LOD spreadsheet models or average 1922-1931 diversions from the C2VSim historical model, scaled to a 1900 LOD based on the relative change in California population and irrigated acreage between 1900 and 1920.
- Land use, crop acreage, and urban demand from year 1922 of the C2VSim historical model, scaled to a 1900 LOD based on the relative change in irrigated acreage, crop use, and California population between 1900 and 1920.
- Initial groundwater heads based on assumed 1921 conditions from C2VSim historical model, with modified initial root zone soil moisture.

1920 Level of Development

The 1920 fixed level of development C2VSim model includes the following:

- Inflows from 1920 LOD spreadsheet models.
- Diversions from the 1920 LOD spreadsheet models or average 1922-1931 diversions from the C2VSim historical model.
- Land use, crop acreage, and urban demand from year 1922 of the C2VSim historical model.
- Initial groundwater heads based on assumed 1921 conditions from C2VSim historical model.

Inflows for the 1920 LOD are identical to the 1900 LOD, except for Stony Creek, Feather River, Yuba River, Bear River, Cache Creek, American River, Stanislaus River, Tuolumne River, Merced River, and San Joaquin River.

1940 Level of Development

The 1940 fixed level of development C2VSim model includes the following:

- Inflows from 1940 LOD spreadsheet models.
- Diversions from 1940 LOD spreadsheet models or average 1936-1945 diversions from the C2VSim historical model.
- Land use, crop acreage, and urban demand from year 1940 of the C2VSim historical model.
- Initial groundwater heads based simulated conditions at the end of September 1940 from C2VSim historical model.

1960 Level of Development

The 1960 fixed level of development C2VSim model includes the following:

- Inflows from 1960 LOD spreadsheet models.
- Diversions from 1960 LOD spreadsheet models or average 1956-1965 diversions from the C2VSim historical model.
- Land use, crop acreage, and urban demand from year 1960 of the C2VSim historical model.

- Initial groundwater heads based simulated conditions at the end of September 1960 from C2VSim historical model.

1980 Level of Development
The 1980 fixed level of development C2VSim model includes the following:

- Inflows from 1980 LOD spreadsheet models or the 1980 LOD CalSim II simulation.
- Diversions from 1980 LOD spreadsheet models, the 1980 LOD CalSim II simulation, individual rules based on historical or CalSim flows and year 1980 contract conditions, or average 1976-1985 diversions from the C2VSim historical model.
- Land use, crop acreage, and urban demand from year 1980 of the C2VSim historical model.
- Initial groundwater heads based simulated conditions at the end of September 1980 from C2VSim historical model.

2000 Level of Development
The 2000 fixed level of development C2VSim model includes the following:

- Inflows from 2000 LOD spreadsheet models or the 2000 LOD CalSim II simulation.
- Diversions from 2000 LOD spreadsheet models, the 2000 LOD CalSim II simulation, individual rules based on historical or CalSim flows and year 2000 contract conditions, or average 1996-2005 diversions from the C2VSim historical model.
- Land use, crop acreage, and urban demand from year 2000 of the C2VSim historical model.
- Initial groundwater heads based simulated conditions at the end of September 2000 from C2VSim historical model.

2010 Level of Development
The 2010 fixed level of development C2VSim model includes the following:

- Inflows from 2010 LOD spreadsheet models or the 2010 LOD CalSim II simulation.
- Diversions from 2010 LOD spreadsheet models, the 2010 LOD CalSim II simulation, individual rules based on historical or CalSim flows and year 2010 contract conditions, or average 2000-2009 diversions from the C2VSim historical model.
- Land use, crop acreage, and urban demand from year 2009 of the C2VSim historical model.
- Initial groundwater heads based simulated conditions at the end of September 2009 from C2VSim historical model.

Model Validation
The fixed level of development C2VSim simulations are a hypothetical construct. Simulated monthly flows are not expected to match historical flows, except for the water year that is equal to the level of development, and for adjacent water years. For example, simulated flows for the 1940 LOD should match historical flows in 1940, and be reasonably close to historical flows for the 10-years 1936 through 1945.

The C2VSim models were validated by comparing average monthly simulated Delta inflows from the fixed level of development models and from the historical simulation to gaged Delta inflows across the 10-year period of record centered on each level of development. For the purposes of model validation, historical inflows to the Delta from the Sacramento Valley are calculated as the sum of flows in the Sacramento River at Freeport, discharge from the Sacramento Regional Wastewater Treatment Plant, flows in the Yolo Bypass near Woodland and Putah Creek near Davis, and spills over the Sacramento Weir. For the purposes of model validation, historical inflows to the Delta from the San Joaquin Valley are assumed equal to the San Joaquin River near Vernalis. For the validation, historical Delta inflows are calculated as the sum of the Sacramento and San Joaquin Valley inflows, as described above, combined with the Mokelumne River flow at Woodbridge. No reliable complete historical data set is available for the lower reaches of the Calaveras River or the Cosumnes River upstream from its confluence with the Mokelumne River, so these flows were not considered in the validation. For model validation purposes, other minor inflows (e.g., Marsh Creek) were ignored. **Figures 4-21 through 4-27** show results for the Sacramento Valley Delta inflows. **Figures 4-28 through 4-34** show results for the San Joaquin Valley Delta inflows. **Figures 4-35 through 4-41** show results for the total Delta inflow. The figures also show the difference between the fixed level of development C2VSim simulation and the revised C2VSim simulation of historical conditions in the form of a bar chart.

Use of Models in a Stand-Alone Analysis

The fixed level of development C2VSim models can be used in two ways. The first is in a comparative analysis and the second is in an absolute analysis. The comparative analysis consists of comparing output from two model runs. Differences in simulated inflows to the Delta are explained by differences in inflows at the boundary of the model domain (e.g., Feather River below Oroville Dam), differences in diversions and return flows, differences in rainfall-runoff (differences are typically small), and differences in groundwater inflows. In the comparative analysis, it is expected that some, but not all, of the errors in the underlying models will cancel out (e.g., errors in precipitation, evapotranspiration, unregulated inflows). In an absolute analysis, the results of one model run are considered directly. Conclusions drawn from a comparative analysis are deemed to be more reliable. Conclusions drawn from an absolute analysis of output from a single model should be carefully reviewed.

Model output is best analyzed as indicated in the following equation:

$$Q'_{LOD} = Q_{obs} + (Q_{LOD} - Q_{sim}) \qquad \text{Eqn. 4-7}$$

where:

Q_{obs} = Observed (gaged) historical flow

Q_{sim} = Simulated flow from C2VSim simulation of historical conditions (i.e., varying land use)

Q_{LOD} = Simulated flow from C2VSim simulation of fixed level of development (i.e., constant land use)

Q'_{LOD} = Adjusted simulated flow in an attempt to remove model bias/errors

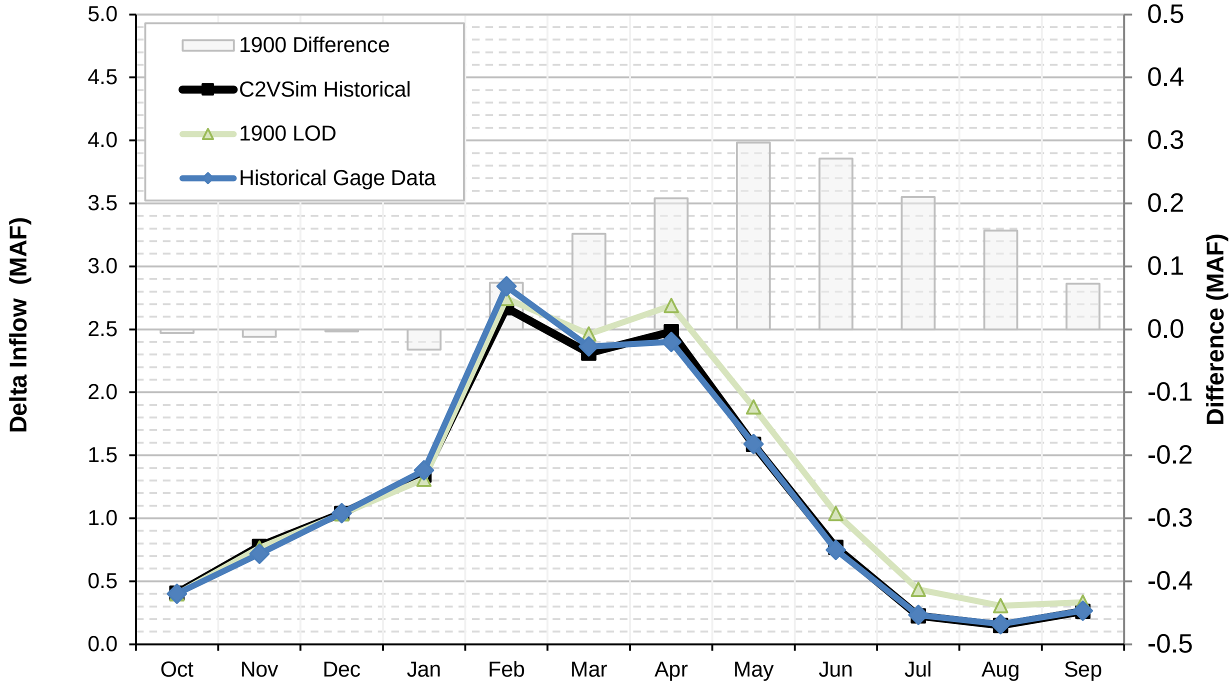


Figure 4-21. Simulated 1900 LOD and Historical Average Monthly Delta Inflows from Sacramento Valley: Water Years 1922-1931

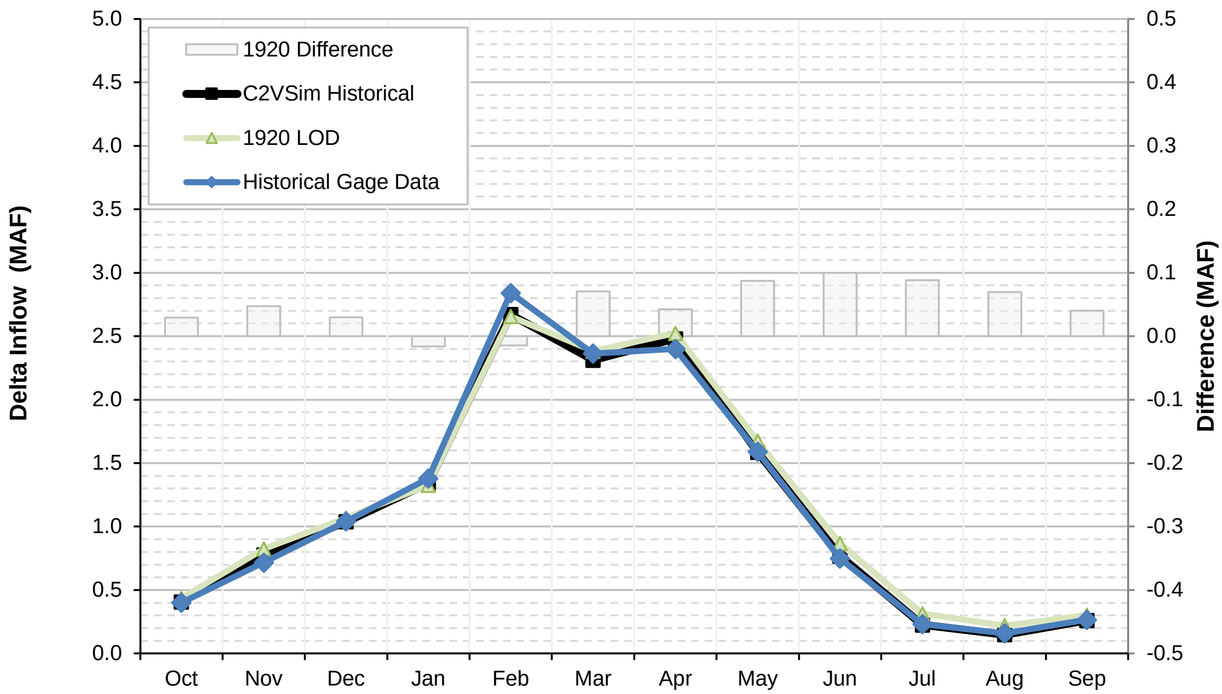


Figure 4-22. Simulated 1920 LOD and Historical Average Monthly Delta Inflows from Sacramento Valley: Water Years 1922-1931

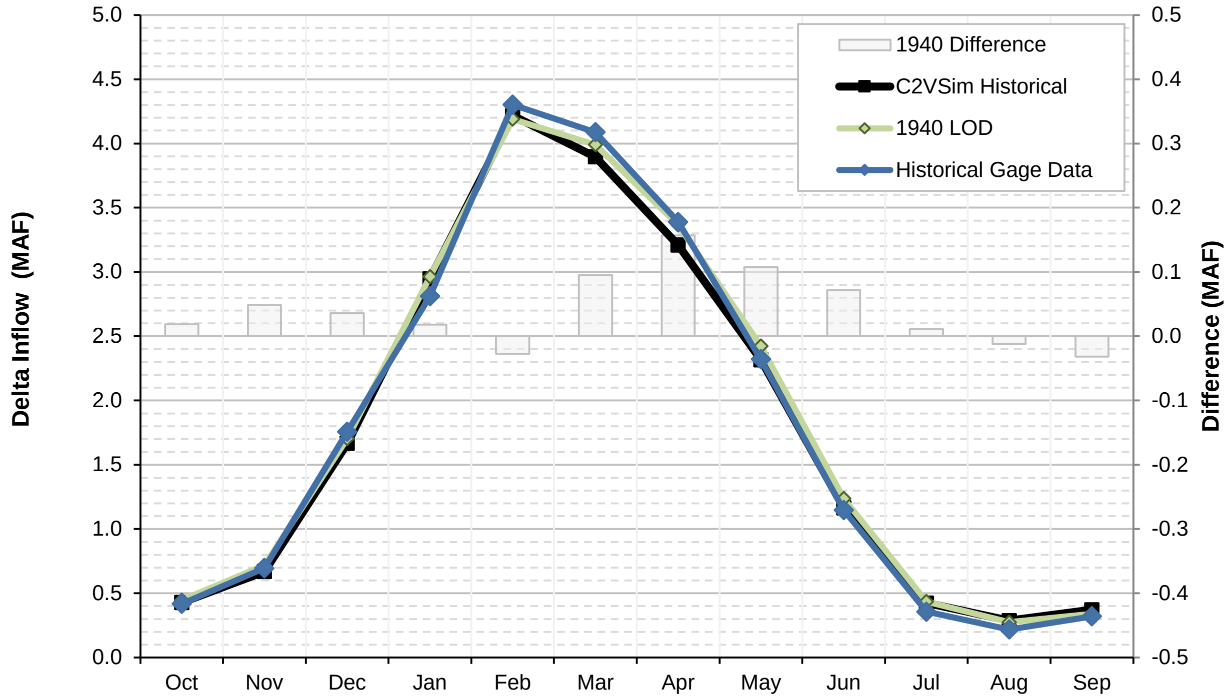


Figure 4-23. Simulated 1940 LOD and Historical Average Monthly Delta Inflows from Sacramento Valley: Water Years 1936-1945

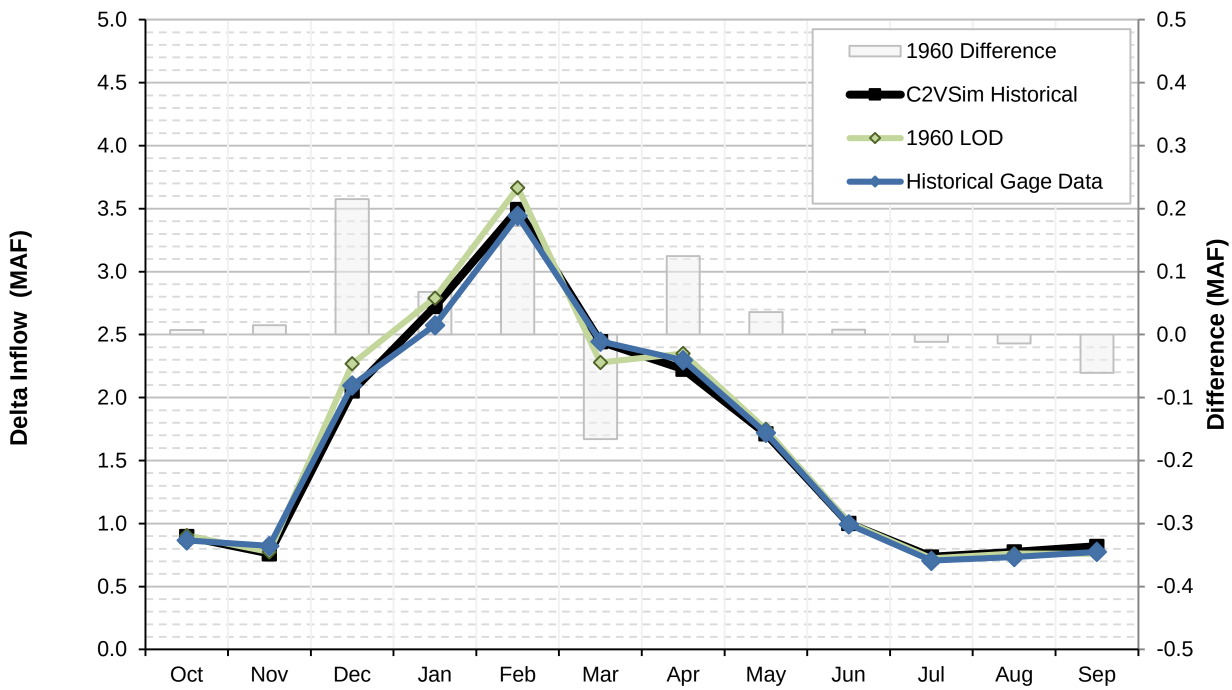


Figure 4-24. Simulated 1960 LOD and Historical Average Monthly Delta Inflows from Sacramento Valley: Water Years 1956-1965

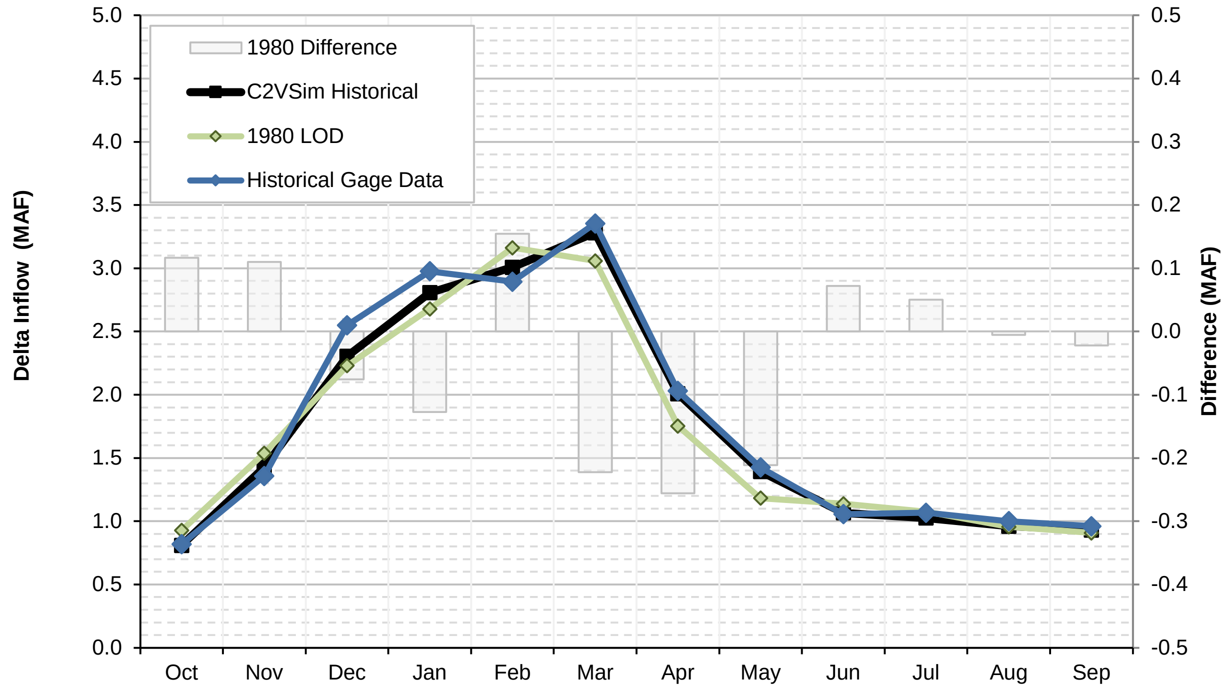


Figure 4-25. Simulated 1980 LOD and Historical Average Monthly Delta Inflows from Sacramento Valley: Water Years 1976-1985

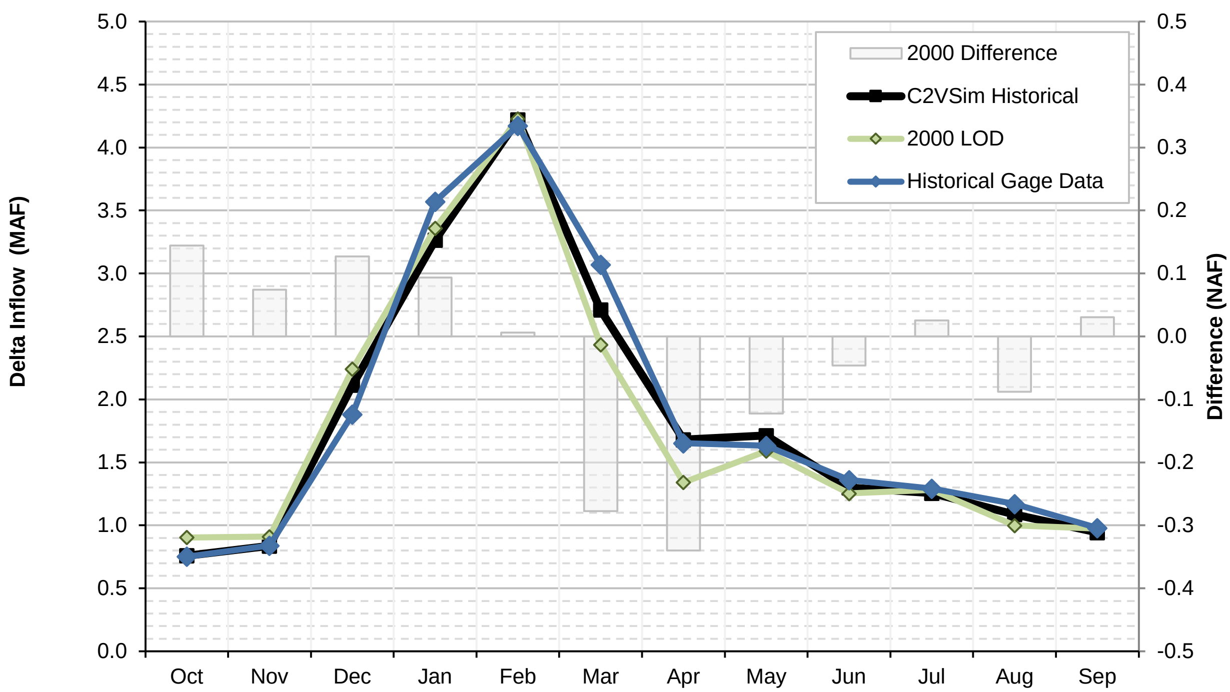


Figure 4-26. Simulated 2000 LOD and Historical Average Monthly Delta Inflows from Sacramento Valley: Water Years 1996-2005

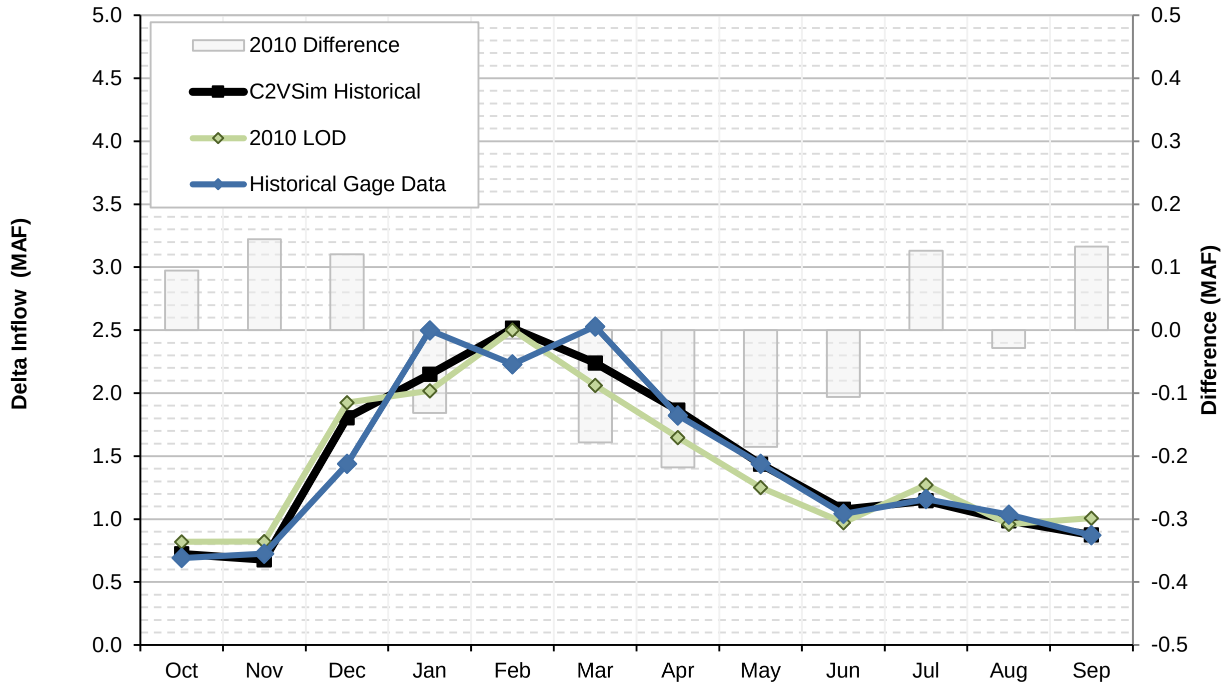


Figure 4-27. Simulated 2010 LOD and Historical Average Monthly Delta Inflows from Sacramento Valley: Water Years 2000-2009

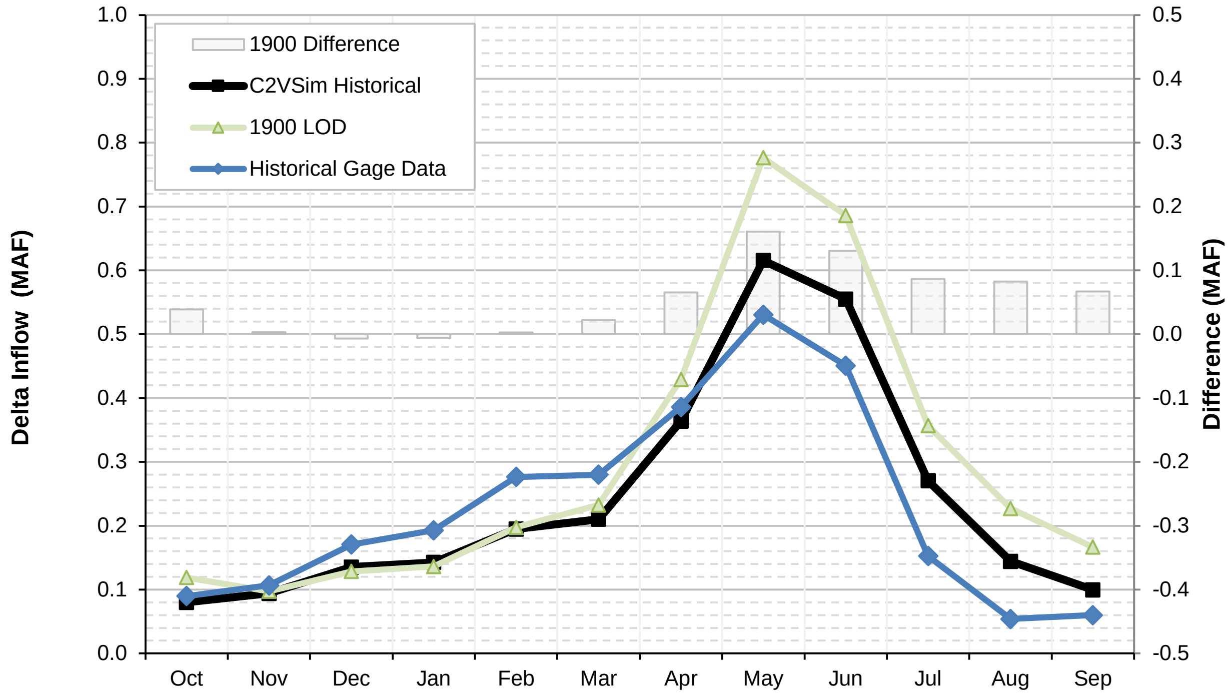


Figure 4-28. Simulated 1900 LOD and Historical Average Monthly Delta Inflows from San Joaquin Valley: Water Years 1922-1931

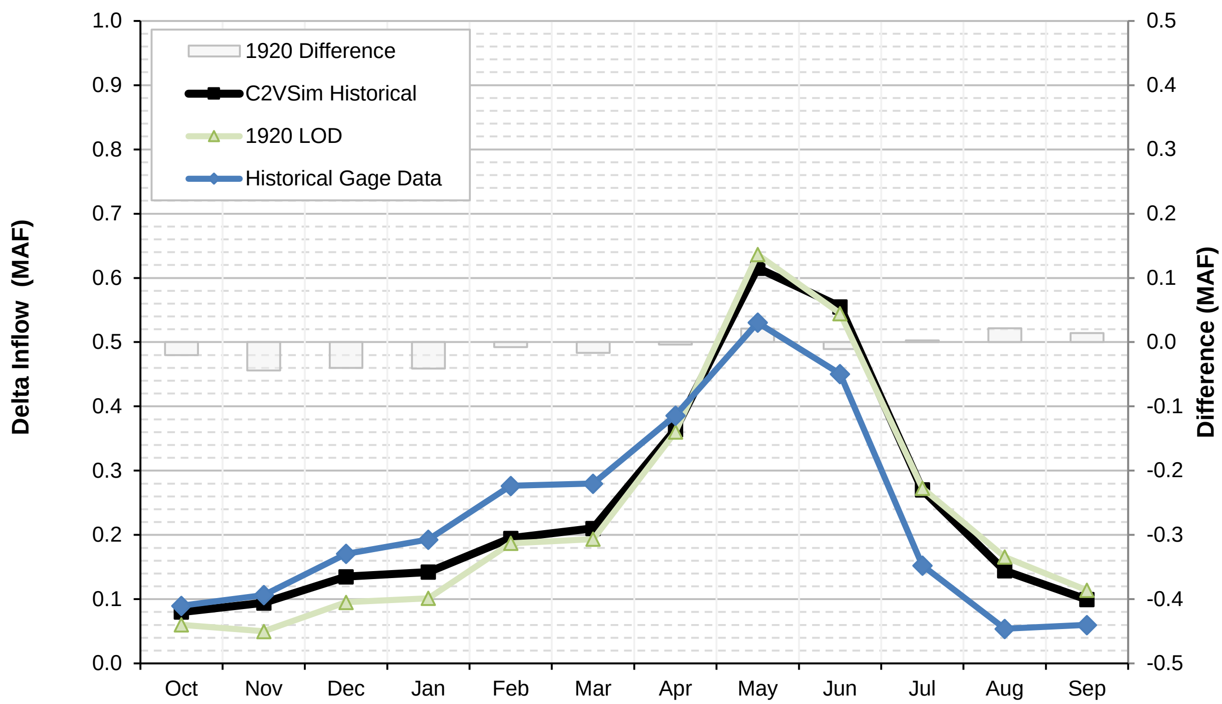


Figure 4-29. Simulated 1920 LOD and Historical Average Monthly Delta Inflows from San Joaquin Valley: Water Years 1922-1931

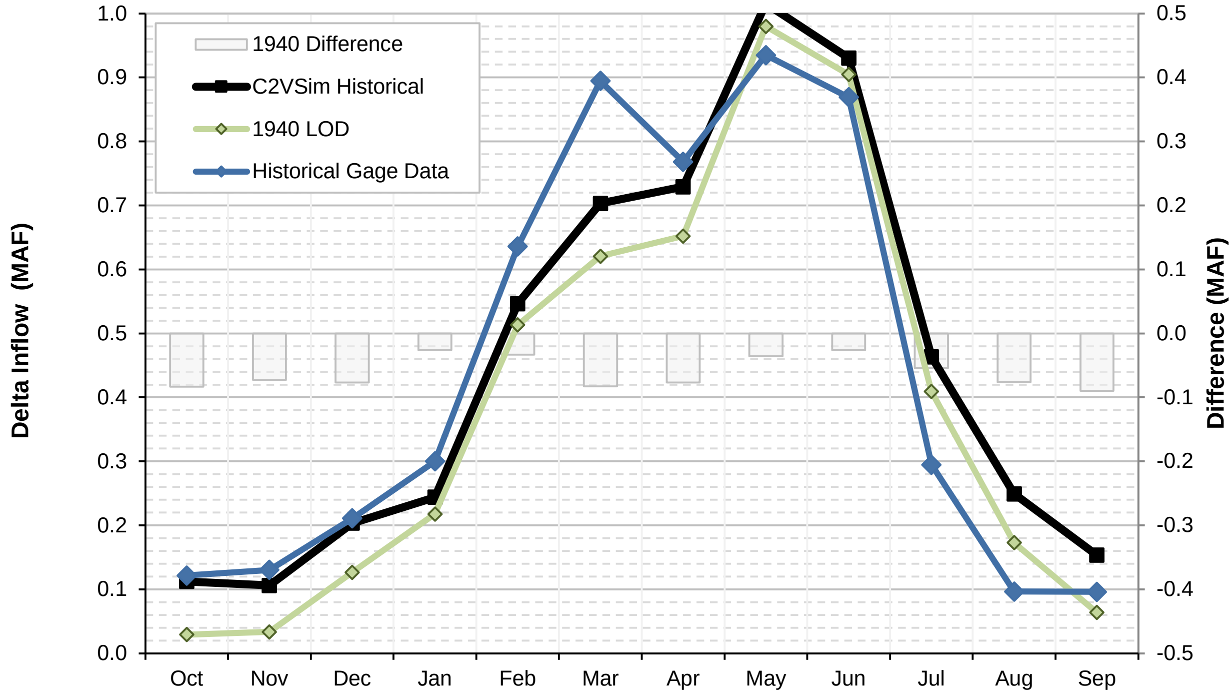


Figure 4-30. Simulated 1940 LOD and Historical Average Monthly Delta Inflows from San Joaquin Valley: Water Years 1936-1945

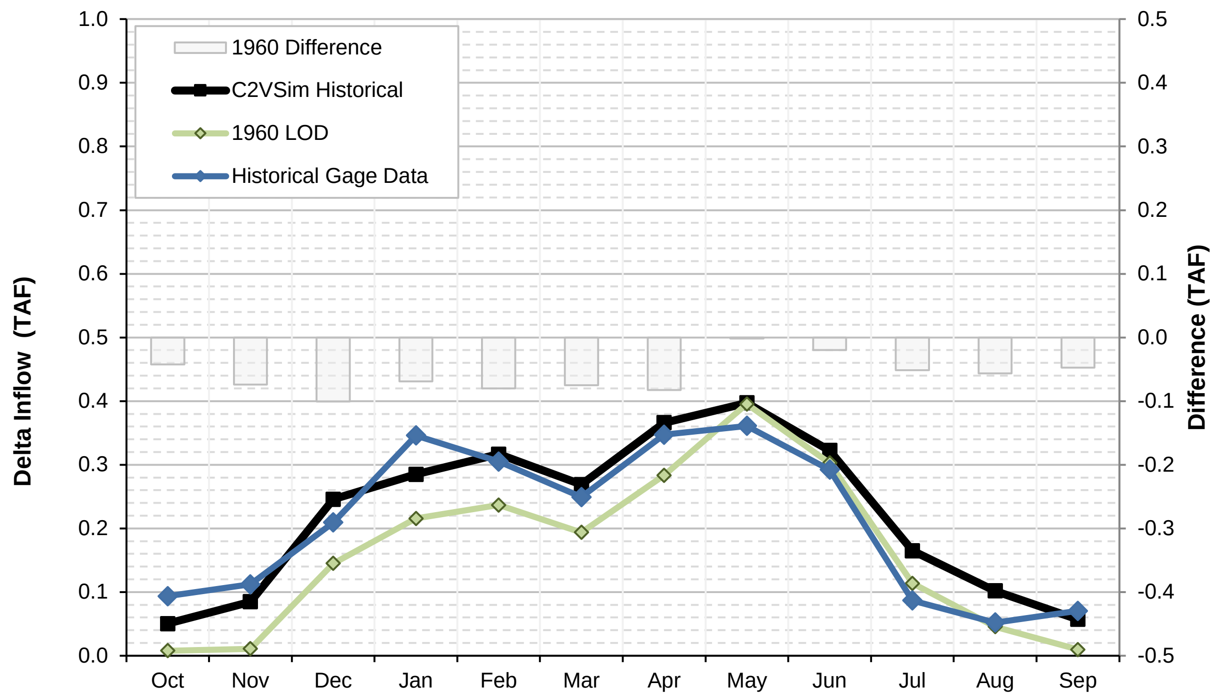


Figure 4-31. Simulated 1960 LOD and Historical Average Monthly Delta Inflows from San Joaquin Valley: Water Years 1956-1965

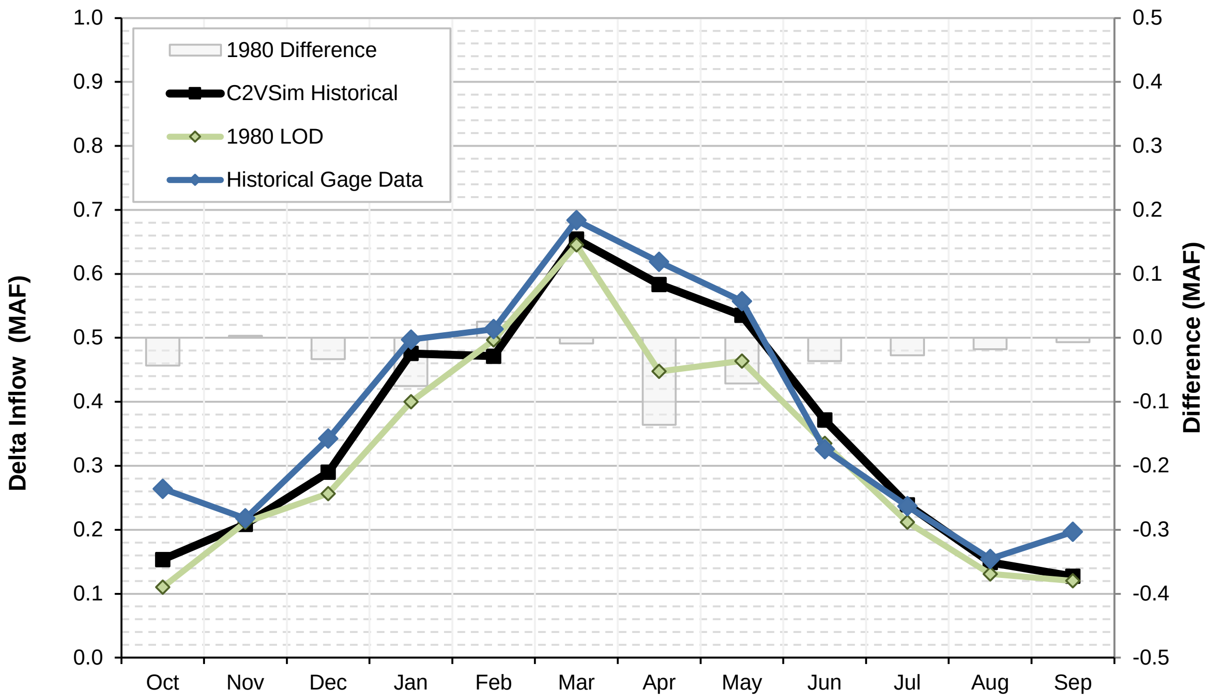


Figure 4-32. Simulated 1980 LOD and Historical Average Monthly Delta Inflows from San Joaquin Valley: Water Years 1976-1985

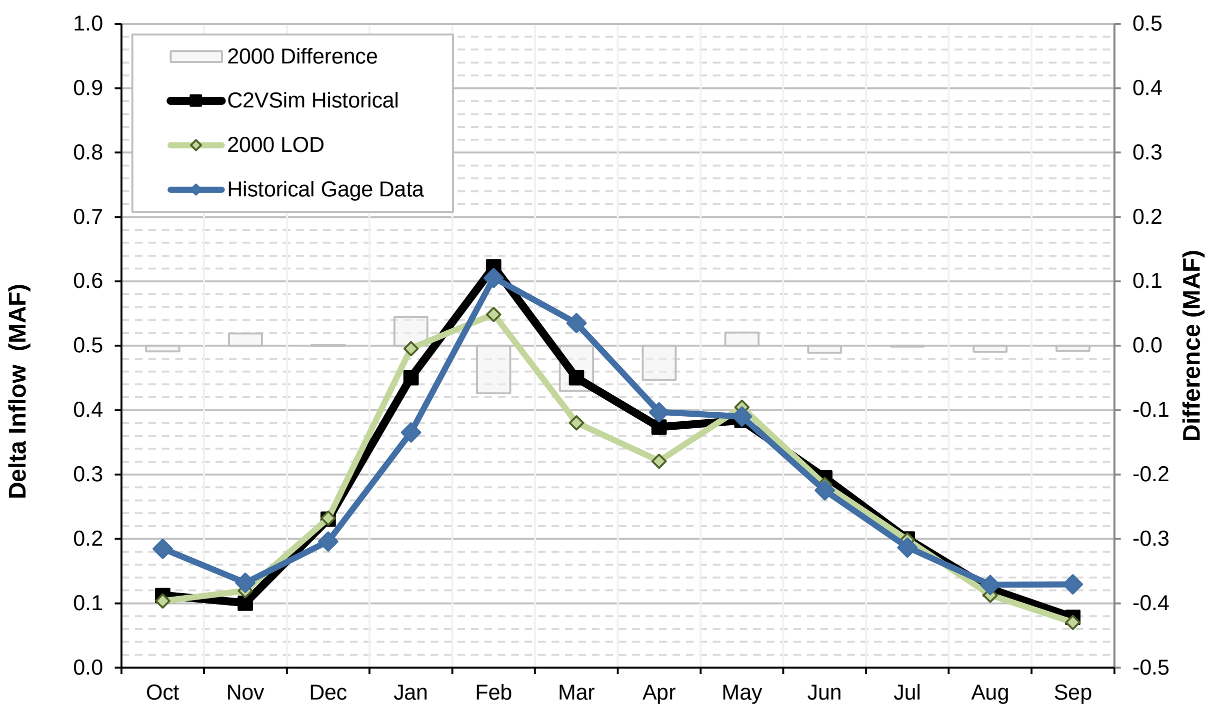


Figure 4-33. Simulated 2000 LOD and Historical Average Monthly Delta Inflows from San Joaquin Valley: Water Years 1996-2005

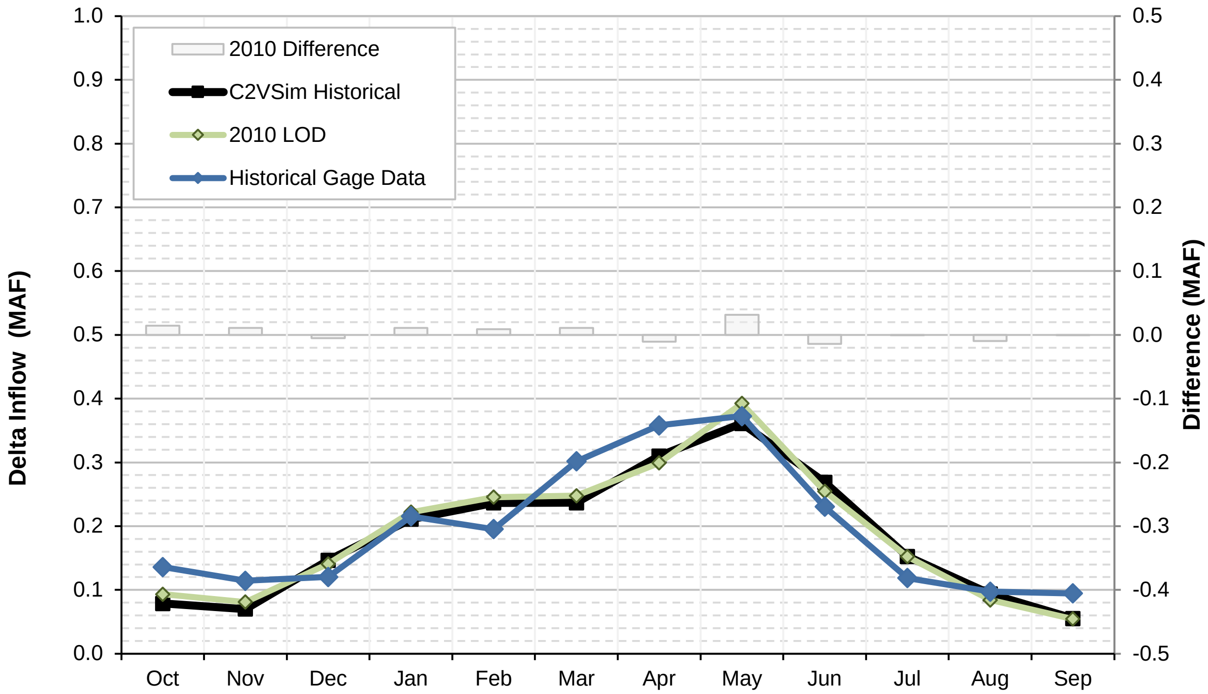


Figure 4-34. Simulated 2010 LOD and Historical Average Monthly Delta Inflows from San Joaquin Valley: Water Years 2000-2009

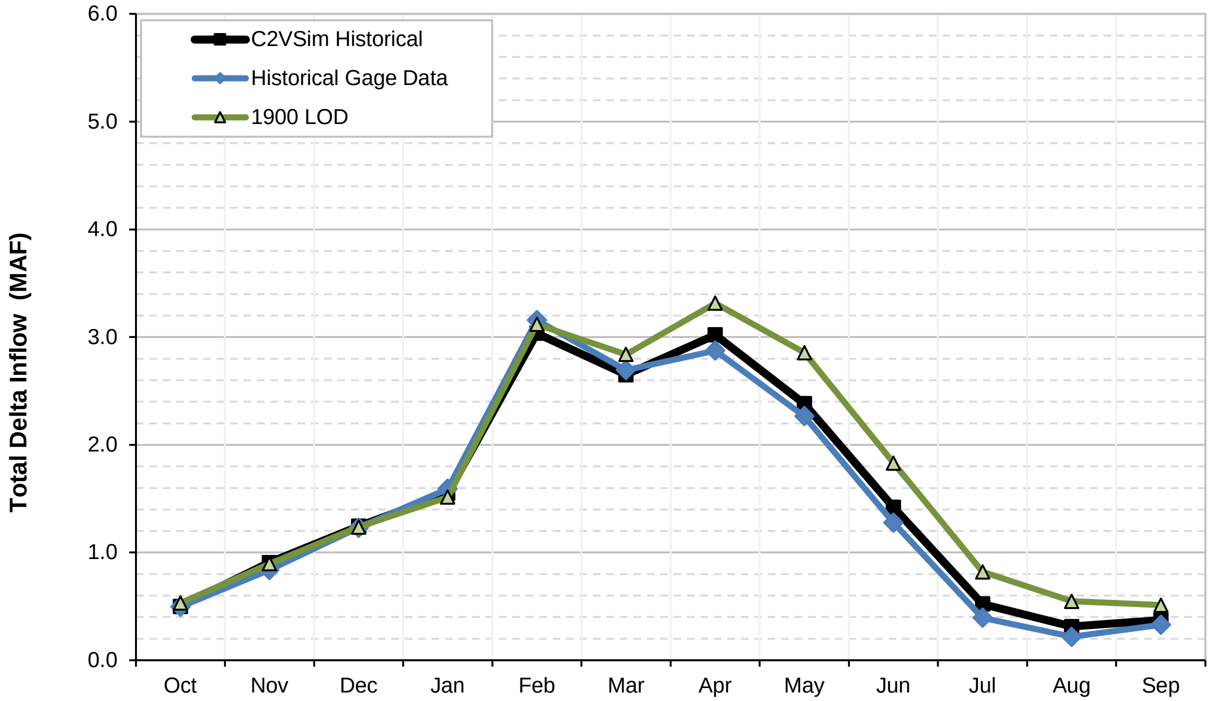


Figure 4-35. Simulated 1900 LOD and Historical Average Monthly Delta Inflows: Water Years 1922-1931

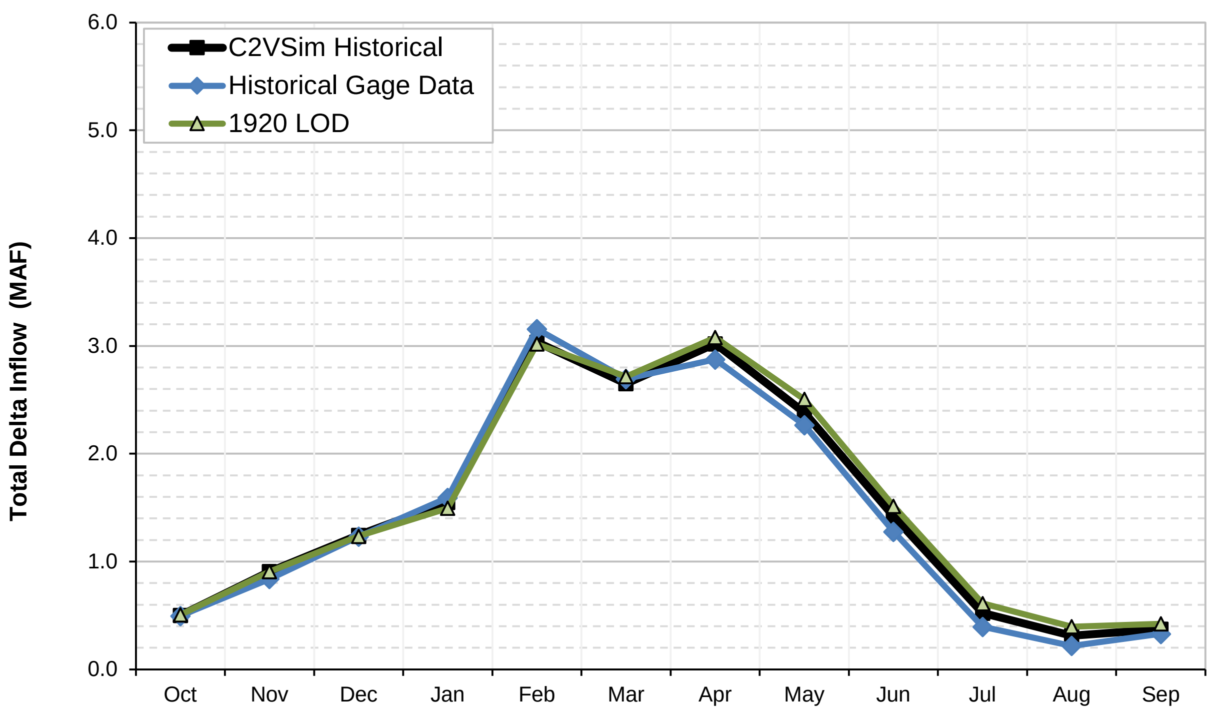


Figure 4-36. Simulated 1920 LOD and Historical Average Monthly Delta Inflows: Water Years 1922-1931

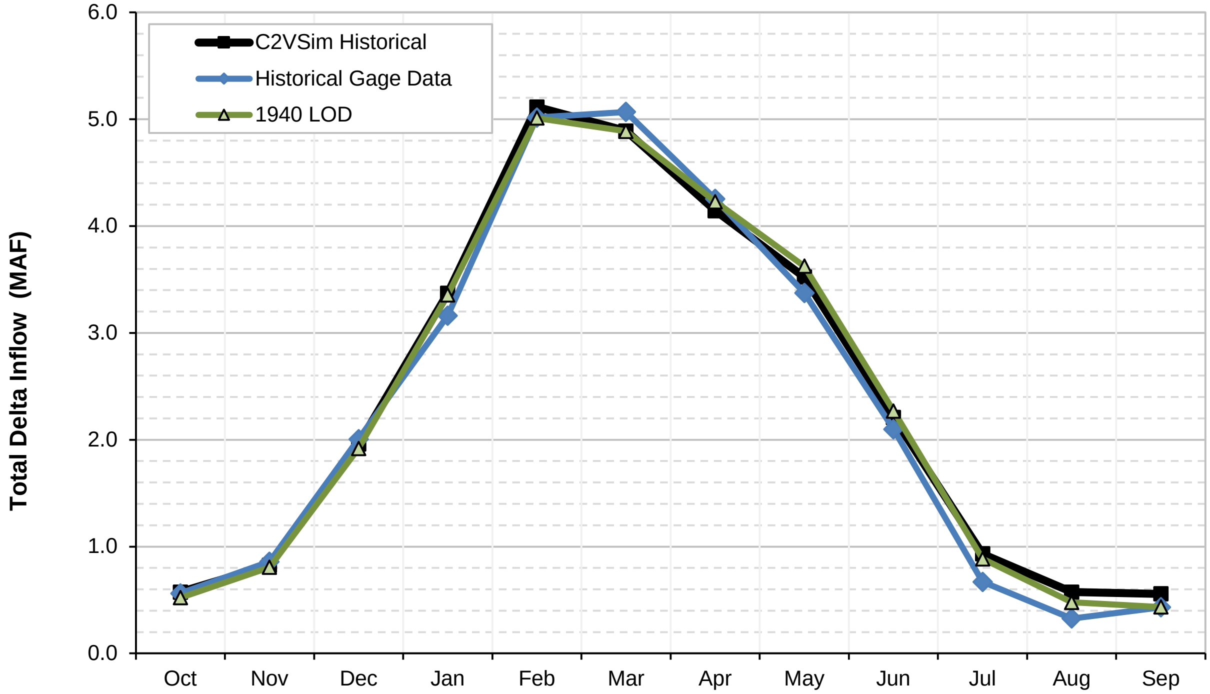


Figure 4-37. Simulated 1940 LOD and Historical Average Monthly Delta Inflows: Water Years 1936-1945

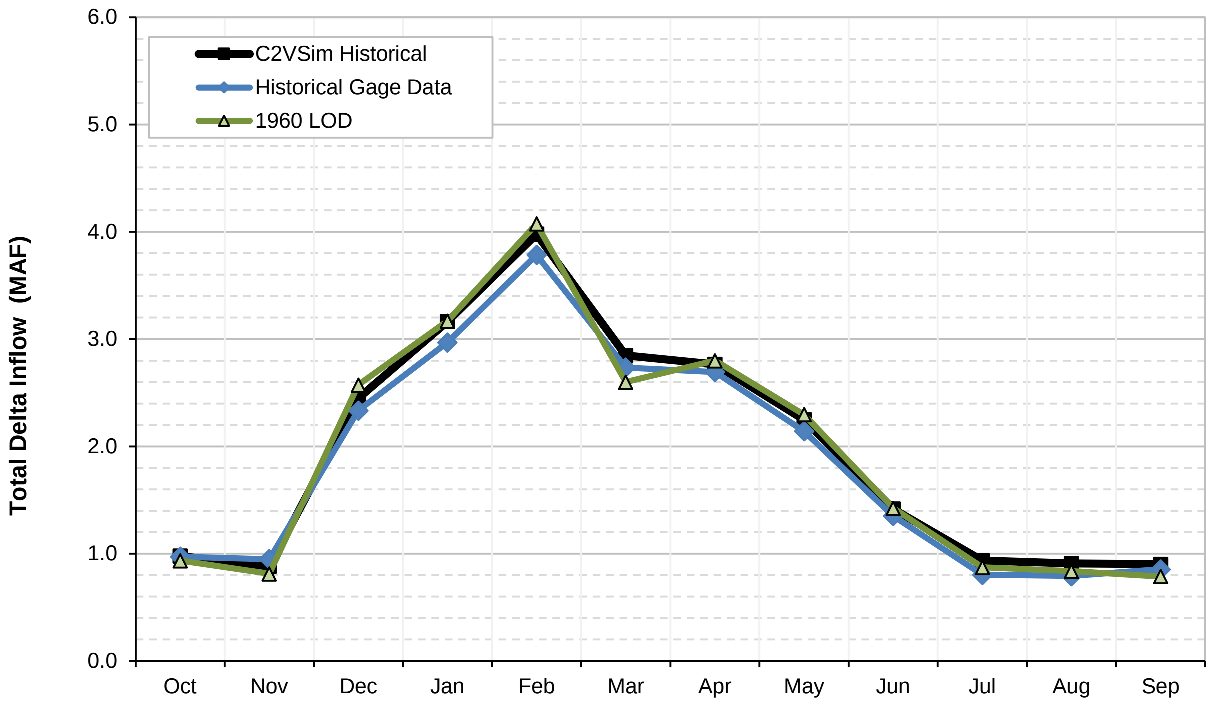


Figure 4-38. Simulated 1960 LOD and Historical Average Monthly Delta Inflows: Water Years 1956-1965

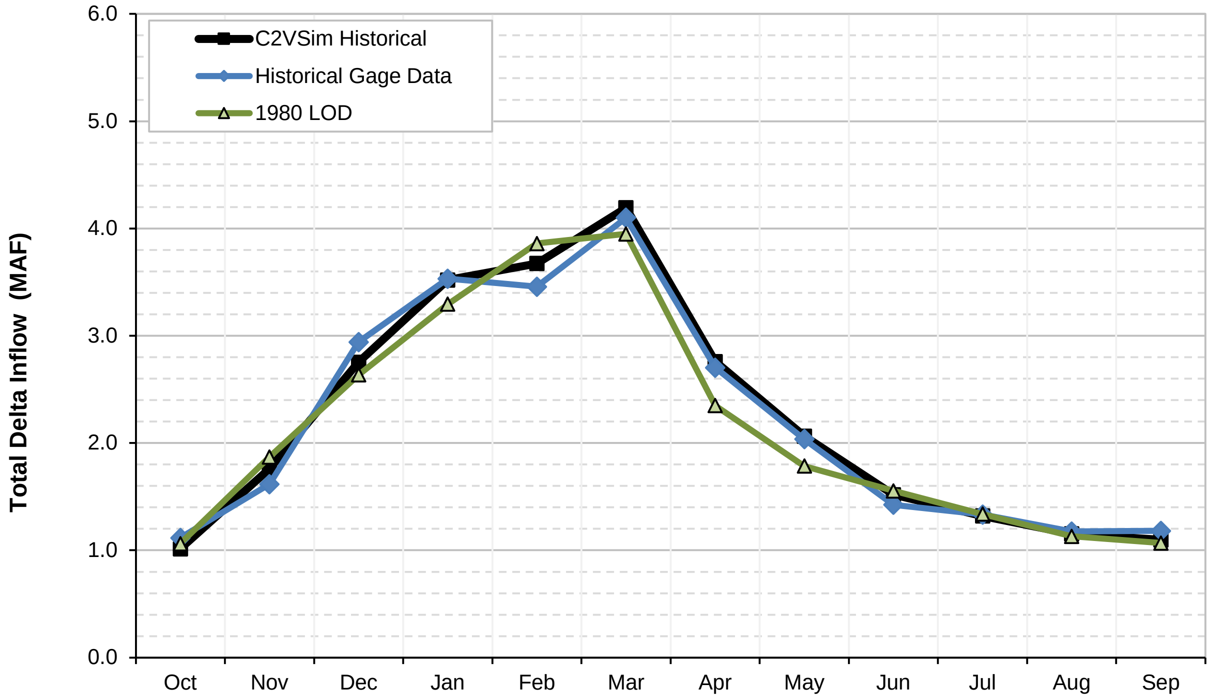


Figure 4-39. Simulated 1980 LOD and Historical Average Monthly Delta Inflows: Water Years 1976-1985

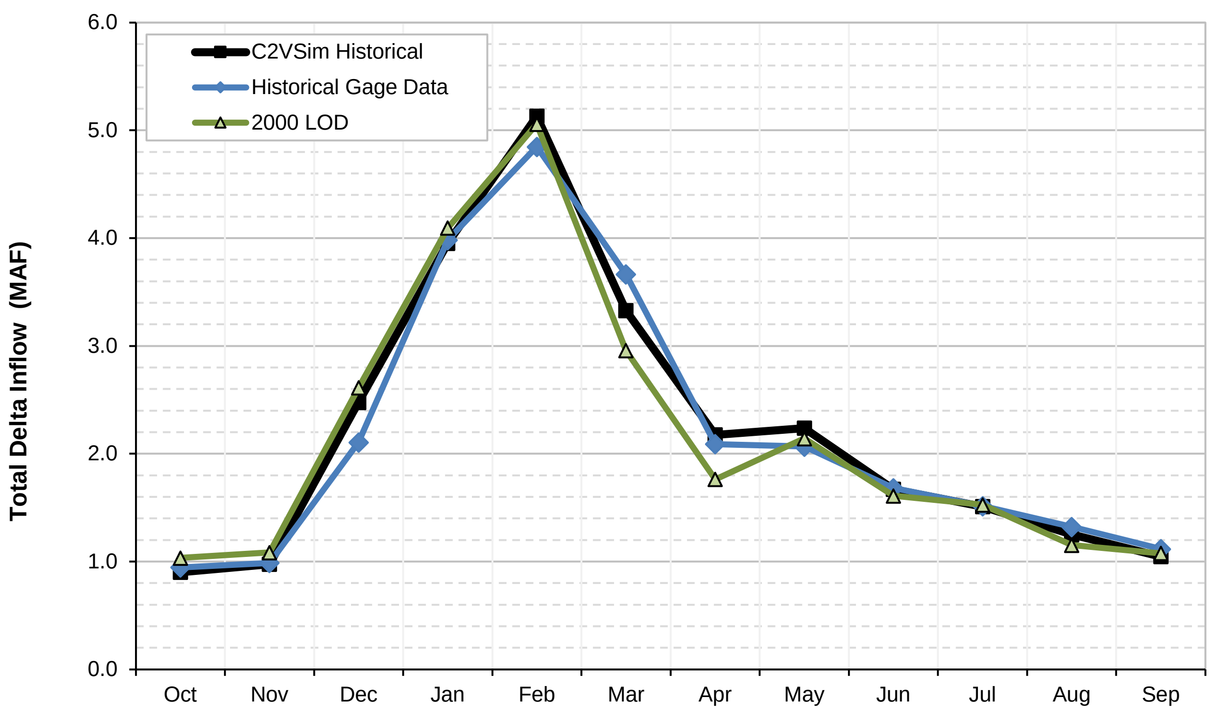


Figure 4-40. Simulated 2000 LOD and Historical Average Monthly Delta Inflows: Water Years 1996-2005

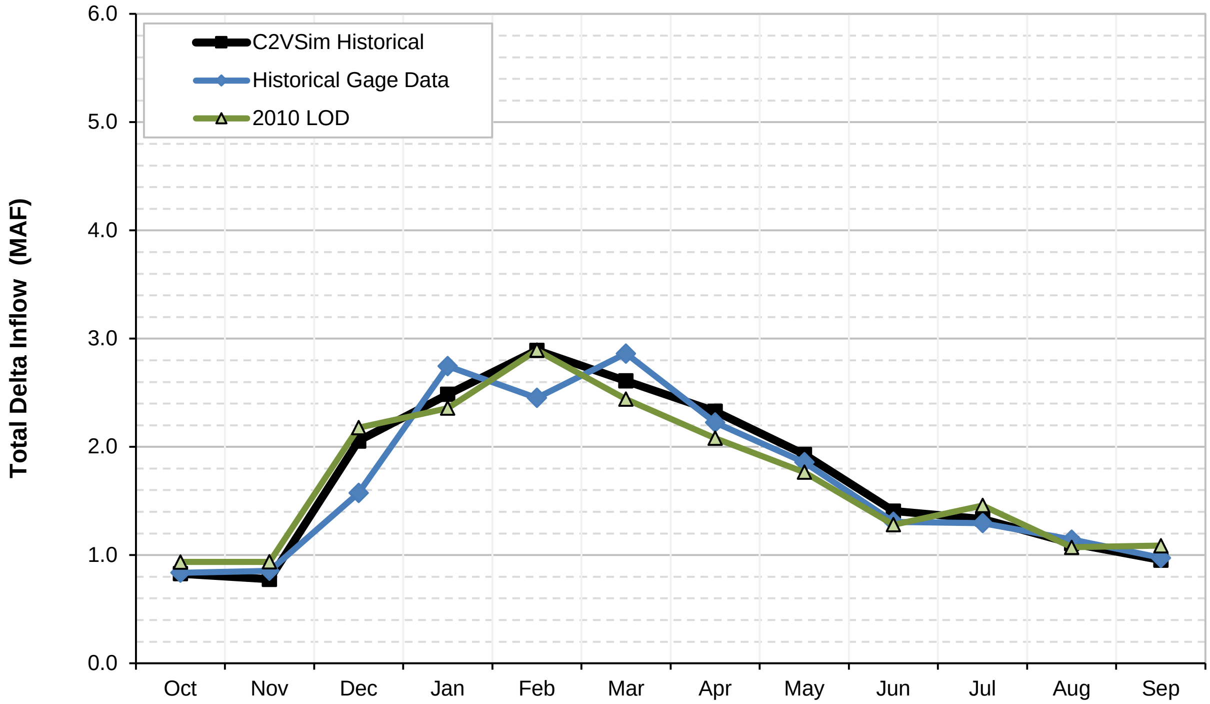


Figure 4-41. Simulated 2010 LOD and Historical Average Monthly Delta Inflows: Water Years 2000-2009

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Chapter 5 CalSim II Models

The purpose of using CalSim II for the *Historical Level of Development Study* is to simulate CVP and SWP operations under different levels of development and different regulatory requirements. CalSim II simulated releases from project reservoirs and simulated water allocations and deliveries to CVP and SWP contractors are inputs to the C2VSim fixed level of development models. This chapter briefly describes the CalSim II models used for the 1980, 2000, and 2010 levels of development.[23]

CalSim II Fixed Level of Development Models

The fixed level of development models are briefly described in the following sections. The discussion is limited to the features that differentiate the three models. A full description of CalSim II assumptions and inputs is presented by DWR (2014a).

1980 Level of Development

By 1980 the CVP was complete, the SWP was implemented but with low water demands, and State Water Board D-1485 governing Delta standards was in effect. The version of CalSim II used to represent the 1980 LOD was developed by Reclamation in 2014 as part of the Reclamation *Cost Allocation Study* (Parker, 2015). The Cost Allocation model developed by Reclamation known as "D1485" is for a future level of development (nominally 2020), but it represents operation of the CVP and SWP under the regulatory requirements of D-1485.

As part of the *Historical Level of Development Study*, the D1485 model was converted to a 1980 LOD by changing timeseries data stored in the HEC-DSS input files and changing paired data contained in the CalSim II lookup tables.[24] CalSim II "wresl" files were modified to remove certain projects that did not exist in 1980. These projects include the Barker Slough Pumping Plant and the North Bay Aqueduct,[25] Freeport Regional Water Project, Los Vaqueros Project, Delta Water Supply Project, and South Bay Aqueduct Enlargement Project. **Appendix A** describes specific files that were modified. Accounting for SWP facilities located south of the Delta that did not exist in 1980 (e.g., Coastal Branch Phase II) was undertaken indirectly by changing the associated Table A demands.

The D1485 CalSim II model includes the COA for sharing unstored water and for meeting the Delta flow and salinity requirements specified in D-1485. Although COA was not signed until 1986, DWR and Reclamation had coordinated activities under interim annual letter agreements since 1968, and as defined

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[23] Although many of the CVP facilities existed by 1960, it was not considered practical to develop a CalSim II model of these facilities' operations given the available time and budget. Instead, the early CVP facilities are simulated in a spreadsheet model, which is described in **Chapter 6**.

[24] The "SV" and "init" HEC-DSS files from DRR2013_Existing_FullDem_082313 were adopted, except for timeseries data describing CVP and SWP contract demands south of the Delta.

[25] Under Phase I of the North Bay Aqueduct, completed in 1968, water was provided to Napa County using an interim supply of water from Reclamation's Solano Project.

in the 1971 "Supplemental Agreement between the United States of America and the State of California for Coordinated Operation of the Central Valley Project and State Water Project."

2000 Level of Development

The version of CalSim II used to represent the 2000 LOD was developed by Reclamation in 2014 as part of the Reclamation *Cost Allocation Study* (Parker, 2014). The CalSim II model, called "D1641wTrinityROD", is for a future level of development (nominally 2020), but it represents operation of the CVP and SWP before the issuance of the 2008 and 2009 BOs. The D1641wTrinityROD study simulates the regulatory environment of D-1641 and includes Trinity River flow requirements established in the ROD for the Trinity River Mainstem Fishery Restoration Final EIS/EIR (USDI, 2000).[26]

Versions of CalSim II released in 2002 (DWR and Reclamation, 2002) and 2004 (Reclamation, 2004) incorporated new procedures for dynamic modeling of CVPIA 3406(b)(2) water. Based on the October, 1999 Reclamation (b)(2) decision and the subsequent February, 2002 decision, CVPIA 3406(b)(2) accounting procedures were based on system conditions under operations associated with D-1485 and D-1641 regulatory requirements. CVPIA 3406(b)(2) allocated 800 TAF (600 TAF in Shasta critical years) of CVP project water to targeted fish actions, including support for D-1641 implementation. In CalSim II, discretionary 3406(b)(2) actions were dynamically selected based on hydrologic conditions and the amount of (b)(2) water remaining. The (b)(2) actions simulated in CalSim II included:

- Anadromous Fish Restoration Program (AFRP) instream flow requirements on Clear Creek below Whiskeytown Dam, Sacramento River below Keswick Dam, and American River below Nimbus Dam.
- CVP export restrictions during December and January.
- CVP export restrictions during VAMP (April 15 – May 15).
- CVP export restrictions during VAMP shoulder (May 16 – May 31).
- CVP summer export restrictions during (June 1 – June 30).
- CVP export restrictions during VAMP shoulder (April 1 – April 14).
- CVP winter export restrictions (February 1 – March 31).

These actions have <u>not</u> been included in the 2000 LOD version of CalSim II. Firstly, (b)(2) accounting procedures changed significantly following a 2003 Ninth Circuit Court ruling that allowed Reclamation to use (b)(2) water to satisfy either the 1995 Water Quality Control Program or post-CVPIA ESA requirements. CalSim II is not set-up to simulate the pre-2003 accounting procedures. Secondly, excluding (b)(2) actions from the 2000 LOD presents a clearer picture of the "cost" of the 1995 Water Quality Control Plan requirements and its implementation in D-1641 compared to D-1485. The D1641wTrinityROD does not simulate operation of the EWA.

As part of the *Historical Level of Development Study*, the D1641wTrinityROD model was converted to a 2000 LOD by changing timeseries data stored in the HEC-DSS input files and paired data contained in the CalSim II lookup tables.[27] CalSim II "wresl" files were modified to remove certain projects that did

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[26] The D1641wTrinityROD model does not include additional flow releases and export limits of the 2008 OCAP B2 actions.

[27] The "SV" and "init" HEC-DSS files from DRR2013_Existing_FullDem_082313 were adopted, except for timeseries data describing CVP and SWP contract demands south of the Delta.

not exist in 2000. These projects include the Freeport Regional Water Project, Los Vaqueros Project Expansion, Delta Water Supply Project, and South Bay Aqueduct Enlargement Project. **Appendix A** describes specific files that were modified.

2010 Level of Development

The version of CalSim II used to represent the 2010 LOD was developed by DWR for the *2013 State Water Project Delivery Reliability Report* (DWR, 2014a. The CalSim II model that represents existing conditions is named “DRR2013_Existing_FullDem_082313” and is available for download from DWR’s Bay-Delta Office web site. The model includes simulation of the RPAs contained in BOs issued by USFWS and NMFS on CVP and SWP operations for the protection of federally listed threatened and endangered species and their critical habitat.[28]

The RPAs included in the 2008 and 2009 USFWS and NMFS BOs have made certain (b)(2) actions redundant. Implementation of (b)(2) actions in this version of CalSim II is limited to meeting the AFRP flows on Clear Creek below Whiskeytown Dam and on the Sacramento River below Keswick Dam.

South of Delta Demands

South of Delta demands for the CVP and SWP are key determinants of simulated Delta exports, which in-turn drive CVP and SWP reservoir operations. **Table 5-1** lists CVP contractors, the date they first received CVP water, and their contract amounts at various levels of development. **Table 5-2** lists long-term SWP contractors, the date they first received SWP water, and their full Table A amount.

For modeling purposes, it is assumed that CVP contractors request their full contract amount for the 1980, 2000, and 2010 LOD studies. It is assumed that SWP contractors request their full Table A amount for the 2000 and 2010 LOD studies. However, SWP contractor demands for the 1980 LOD are based on a review of historical contractor request and delivery data, as presented in **Table 5-3**. Additional details are presented in **Appendix C**.

[28] USFWS released a new BO in December 2008, and NMFS released a new BO in June 2009.

Table 5-1. Central Valley Project Contract Amounts

Contractor	Year of First Delivery[4]	CVP Contract (TAF)				Water Rights
		1960	1980	2000	2010	
Banta Carbona ID	1957	5.000	25.000	25.000	20.000	0.000
Broadview WD	1956	16.000	27.000	27.000	0.000	0.000
Bryron-Bethany ID (inc. former Plain View WD)	1953	17.250	20.600	20.600	20.600	0.000
Centinella WD		2.500	2.500	2.500	0.000	0.000
City of Tracy		10.000	10.000	10.000	20.000	0.000
Del Puerto WD (consolidation in 1995)	1953	138.150	138.150	140.210	140.210	0.000
Department of Veteran Affairs		0.000	0.000	0.450	0.850	0.000
Eagle Field WD	1953	4.550	4.550	4.550	4.550	0.000
Mercy Springs WD	1956	13.300	13.300	2.842	2.842	0.000
Oro Lomo WD	1953	4.600	4.600	4.600	0.600	0.000
Pacheco WD		0.000	0.000	0.000	0.000	0.000
Pajaro Valley WMA		0.000	0.000	6.260	6.260	0.000
Panoche WD	1953	93.988	0.000	0.000	0.000	0.000
Patterson WD	1954	16.500	16.500	16.500	16.500	6.000
San Luis WD	1953	93.300	0.000	0.000	0.000	0.000
Westlands WD DD No. 1		0.000	0.000	0.000	2.500	0.000
Westlands WD DD No. 1		0.000	0.000	0.000	2.990	0.000
Westlands WD DD No. 1		0.000	0.000	0.000	27.000	0.000
Westlands WD DD No. 2		0.000	0.000	4.198	4.198	0.000
West Side ID	1958	0.000	5.000	5.000	5.000	0.000
West Stanislaus ID	1953	20.000	50.000	50.000	50.000	0.000
Widren WD	1954	2.990	2.990	2.990	0.000	0.000
Central California ID		0.000	0.000	0.000	0.000	110.000
TOTAL Delta-Mendota Canal		**438.128**	**320.190**	**322.700**	**324.100**	**116.000**
Terra Linda Farms (formerly Coelho Family Trust)	1955	0.000	5.200	2.080	2.080	1.332
Dudley & Indart/Coelho/Hansen	1960	0.000	0.000	0.000	0.000	2.280
Fresno Slough WD	1955	4.000	4.000	4.000	4.000	0.866
Grasslands WD	1956	0.000	0.000	0.000	0.000	0.000
James ID	1955	0.000	35.300	35.300	35.300	9.700
Laguna WD	1956	0.800	0.800	0.800	0.800	0.000
Meyers Farm Family Trust		0.000	0.000	0.000	0.000	0.210
Reclamation District 1606	1955	0.000	0.228	0.228	0.228	0.342
Department of Fish and Wildlife		0.000	0.000	3.120	3.120	1.321
Tranquility ID	1955	13.800	13.800	13.800	13.800	20.200
Tranquility PUD	1955	0.000	0.070	0.070	0.070	0.093
Westlands WD - Pool		0.000	0.000	0.000	4.000	0.000
Central California ID		0.000	0.000	0.000	0.000	422.400
Columbia Canal Company		0.000	0.000	0.000	0.000	59.000
Westlands WD - Pool		0.000	0.000	0.000	4.000	0.000

Table 5-1. Central Valley Project South-of-Delta Contract Amounts contd.

Contractor	Year of First Delivery[4]	CVP Contract (TAF)				Water Rights
		1960	1980	2000	2010	
Central California ID	1951	0.000	0.000	0.000	0.000	422.400
Columbia Canal Company	1951	0.000	0.000	0.000	0.000	59.000
Firebaugh Canal Company	1951	0.000	0.000	0.000	0.000	85.000
San Luis Canal Company	1951	0.000	0.000	0.000	0.000	163.600
TOTAL Mendota Pool		**18.600**	**59.398**	**59.398**	**63.398**	**766.344**
City of Avenal		0.000	3.500	3.500	3.500	0.00
Department of Fish and Wildlife		0.000	0.000	0.010	0.010	0.00
Parks and Recreation		0.000	2.250	2.250	2.250	0.00
City of Coalinga		0.000	10.000	10.000	10.000	0.00
City of Huron		0.000	3.000	3.000	3.000	0.00
Pacheco WD		0.000	10.080	10.080	10.080	0.00
Panoche WD		0.000	94.000	94.000	94.000	0.00
San Luis WD		0.000	125.080	125.080	125.080	0.00
Westlands WD		0.000	1,008.000	1,150.000	1150.000	0.00
Total San Luis Canal		**0.000**	**1255.910**	**1397.920**	**1397.920**	**0.000**
San Benito County WD		0.000	0.000	43.800	43.800	0.000
Santa Clara Valley WD		0.000	0.000	152.500	152.500	0.000
Total San Felipe Division		**0.000**	**0.000**	**196.300**	**196.300**	**0.000**
Cross Valley Canal		**0.000**	**128.300**	**128.300**	**128.300**	**0.000**
TOTAL		**438.128**	**1704.400**	**2045.220**	**2110.018**	**882.344**
Merced NWR		0.000	0.000	0.000	13.500	
San Luis NWR – East Bear Creek Unit		0.000	0.000	0.000	8.863	
Volta WA		1.000	0.000	0.000	13.000	
San Luis NWR – Kesterson Unit		0.000	0.000	0.000	10.000	
San Luis NWR – Freitas Unit		0.000	0.000	0.000	5.290	
San Luis NWR – San Luis Unit		0.000	0.000	0.000	19.000	
San Luis NWR – West Bear Creek Unit		0.000	0.000	0.000	7.207	
Los Banos WA		0.000	0.000	0.000	16.670	
North Grasslands WA – Salt Slough Unit		0.000	0.000	0.000	6.680	
North Grasslands WA – China Island Unit		0.000	0.000	0.000	6.967	
Grassland WD/RCD		53.500	0.000	0.000	125.000	
Mendota WA		0.000	0.000	0.000	27.594	
Kern NWR		0.000	0.000	0.000	9.950	
Pixley NWR		0.000	0.000	0.000	1.280	
Refuges - Level 2		**54.500**	**0.000**	**0.000**	**271.001**	

Notes:
1. Deliveries to the Delta-Mendota Canal began June 1951. The construction of the San Luis Canal was completed in 1967.
2. The construction of the Cross Valley Canal was completed in 1975.
3. The construction of the San Felipe Division was completed in 1987.
4. Blank values indicate that the date of first delivery was not identified.

Key:
DD = Distribution District, ID = Irrigation District, NWR = National Wildlife Refuge,
PUD = Public Utility District, RCD = Resource Conservation District
WA = Wildlife Area, WD = Water District

Table 5-2. State Water Project Annual Table A Amounts

Long-term Contractor	Year of First Delivery	Table A Amount (TAF)			
		1980[5]	2000	2010	Maximum Entitlement
Alameda County FCWCD, Zone 7	1962	22.000	68.000	80.619	80.619
Alameda County Water District	1962	24.800	42.000	42.000	42.000
Antelope Valley-East Kern Water Agency	1972	69.200	138.400	141.400	141.400
Castaic Lake Water Agency	1968	17.700	95.200	95.200	95.200
City of Yuba City	1984	0.000	9.600	9.600	9.600
Coachella Valley Water District	1973	10.884	23.100	138.350	138.350
County of Butte	1968	1.100	2.890	27.500	27.500
County of Kings	1968	2.200	4.000	9.305	9.305
Crestline-Lake Arrowhead Water Agency	1972	2.900	5.800	5.800	5.800
Desert Water Agency	1973	17.000	38.100	55.750	55.750
Dudley Ridge Water District	1968	41.000	53.370	50.343	43.343
Empire West Side Irrigation District	1968	3.000	3.000	3.000	3.000
Kern County Water Agency	1968	634.500	1,020.730	982.730	982.730
Littlerock Creek Irrigation District	1972	1.150	2.300	2.300	2.300
Metropolitan Water District of Southern California	1972	1,057.000	2,011.500	1,911.500	1,911.500
Mojave Water Agency	1972	27.200	75.800	82.800	89.800
Napa County FCWCD	1968	0.000	16.325	29.025	29.025
Oak Flat Water District	1968	5.700	5.700	5.700	5.700
Palmdale Water District	1985	(11.180)[4]	21.300	21.300	21.300
Plumas County FCWCD	1970	0.710	1.510	2.160	2.700
San Bernardino Valley Municipal Water District	1972	65.500	102.600	102.600	102.600
San Gabriel Valley Municipal Water District	1974	17.400	28.800	28.800	28.800
San Gorgonio Pass Water District	2003	(6.800)[4]	3.000	17.300	17.300
San Luis Obispo County FCWCD	1997	(1.000)[4]	25.000	25.000	25.000
Santa Barbara County FCWCD	1997	(1.200)[4]	45.486	45.486	45.486
Santa Clara Valley Water District	1965	88.000	100.000	100.000	100.000
Solano County Water Agency	1986	(0.500)[4]	39.620	47.506	47.756
Tulare Lake Basin Water Storage District	1968	66.500	118.500	88.922	88.922
Ventura County Watershed Protection District	1990	(1.000)[4]	20.000	20.000	20.000
Devils Den Water District	1968	12.700	N/A	N/A	N/A
Hacienda Water District	1969	5.200	N/A	N/A	N/A
TOTAL		**2,193.344**	**4,121.631**	**4,171.996**	**4,172.786**

Notes:

1. SWP 1980 water supplies were sufficient to meet all water contractor delivery requests, including carryover entitlements and surplus water (Article 21).
2. Hacienda Water District merged with Tulare Lake Basin Water Storage District January 1, 1981.
3. Devils Den Water District merged with Castaic Lake Water District January 3, 1991
4. No deliveries at the 1980 LOD. Table A amount not included in total.
5. Source: Bulletin 132-81.

Table 5-3. SWP Table A Requests Assumed for Modeling Purposes, 1980 LOD

Long-term Contractor	Historical Table A Entitlement (TAF)			Historical Table A Deliveries (TAF)			Assumed Demand for Modeling Purposes	
	1976	1980	1985	1976	1980	1985	(TAF)	(% Table A)
Alameda County FCWCD, Zone 7	17.200	22.000	27.000	17.200	16.790	15.072	22.000	100%
Alameda County Water District	21.300	24.800	30.800	21.300	11.034	19.016	24.800	100%
Antelope Valley-East Kern Water Agency	44.000	69.200	40.000	27.782	63.075	37.064	62.280	90%
Castaic Lake Water Agency	9.500	17.700	29.100	0	1.210	12.410	1.770	10%
Coachella Valley Water District	7.600	10.884	16.989	7.600	10.884	16.989	10.884	100%
County of Butte	1.400	1.100	1.200	0.527	0.267	0.308	0.275	25%
County of Kings	1.600	2.200	3.400	1.600	2.200	3.400	2.200	100%
Crestline-Lake Arrowhead Water Agency	1.740	2.900	4.350	1.002	1.239	1.422	1.160	40%
Desert Water Agency	12.000	17.000	27.000	12.000	17.000	27.000	17.000	100%
Dudley Ridge Water District	28.300	41.000	47.200	30.921	41.000	46.251[1]	41.000	100%
Empire West Side Irrigation District	3.000	3.000	3.000	3.000	0.716	5.197	3.000	100%
Kern County Water Agency	386.050	563.400	821.100	386.050	563.400	821.100	634.500	100%
Kern County Water Agency	56.100	71.100	93.900	56.100	71.100	67.796	634.500	100%
Littlerock Creek Irrigation District	0.640	1.150	1.730	0.589	0.191	0	0.230	20%
Metropolitan Water District of Southern California	655.600	1,057.000	1,558.700	628.951	531.727	698.484	528.500	50%
Mojave Water Agency	17.800	27.200	39.000	0	4.000	0	27.200	0%
Oak Flat Water District	3.500	5.700	4.900	4.039	5.700	5.433[1]	5.700	100%
San Bernardino Valley Municipal Water District	55.000	65.500	81.500	12.273	0	7.390	6.550	10%
San Gabriel Valley Municipal Water District	14.000	17.400	21.800	6.071	1.085	5.028	17.400	25%
Santa Clara Valley Water District	88.000	88.000	88.000	88.000	88.000	88.000	88.000	100%
Tulare Lake Basin Water Storage District	50.800	66.500	45.549	57.807	66.500	109.791[1]	66.500	100%
Devils Den Water District	11.700	12.700	12.700	11.700	12.700	12.099	12.700	100%
Hacienda Water District	3.900	5.200	0.000	3.900	5.200	N/A[2]	5.200	100%
TOTAL	**1,481.380**	**2,192.634**	**2,998.918**	**1,378.412**	**4,121.631**	**1,999.250**	**1,578.849**	

Notes:
1. Deliveries include entitlement deferred from prior year.
2. Hacienda Water District merged with Tulare Lake Basin Water Storage District January 1, 1981.

Chapter 6
Spreadsheet Models

This chapter briefly describes the spreadsheet-based reservoir operations and watershed models that were developed for Central Valley rivers and streams that have significant storage regulation as part of local projects owned and operated by local water agencies.

Model Template

Table 6.1 lists the spreadsheet-based watershed and reservoir operations models. Each model or file has a common structure and includes the following:

- A "ReadMe" worksheet documenting the file revision history and summarizing the assumptions for the different levels of development.
- Dark brown colored tabs for user input inflows to reservoir operations models.
- A white colored tab labeled 'Inflow Modification Factors' which can be used to scale inflows based on a fraction of the unimpaired flow (used for climate change simulations only; all factors are set to 1 for the non-climate change scenarios, which is equivalent to no flow modification)
- Light brown colored tabs for CalSim II results for 1980, 2000, and 2010 LODs (only for spreadsheet models using CalSim II results for 1980-2010 LOD flows).
- Dark green colored tabs containing the data to be written to the C2VSim inflow or diversion input files.
- Pink colored tabs containing the reservoir/river operations models, and charts comparing simulated and historical reservoir storage and/or streamflow data for the 10 year period centered on each simulated LOD.
- Blue colored tabs containing flow, storage, or evaporation data referenced by the reservoir / river operations models.
- Light green colored tabs containing diversion or demand data referenced by the reservoir / river operations models.
- Light brown colored tabs used to extend the CalSim II results from 2004-2009, by correlating CalSim II and CalSim 3.0 results from 1922-2003 for each arc, then applying the resulting correlation factors to the 2004-2009 CalSim 3.0 results (only for spreadsheet models using CalSim II results for 1980-2010 LOD flows).
- Grey colored tabs containing generic reference data, including water year type classifications and unit conversion factors.

Table 6-1. Spreadsheet-Based Watershed Models

File Name	Model Output	Storage/Flow Regulation
MWD1_I1_Shasta	Sacramento River at Keswick	Shasta
MWD1_I2_CowCreek	Cow Creek near Millville	None
MWD1_I3_BattleCreek	Battle Creek below Coleman Hatchery	None
MWD1_I4_CottonwoodCreek	Cottonwood Creek near Olinda	None
MWD1_I5_PaynesCreek	Paynes and Sevenmile creeks outflow	None
MWD1_I6_AntelopeCreekGroup	Antelope Creek near Red Bluff multiplied by 2.06	None
MWD1_I7_MillCreek	Mill Creek near Los Molinos	None
MWD1_I8_ElderCreek	Elder Creek near Paskenta	None
MWD1_I9_ThomesCreek	Thomes Creek at Paskenta	None
MWD1_I10_DeerCreekGroup	Deer Creek near Vina multiplied by 1.66	None
MWD1_I11_StonyCreek	Black Butte Dam release	East Park, Stony Gorge, Black Butte
MWD1_I12_BigChicoCreek	Big Chico Creek near Chico	None
MWD1_I13_Butte&ChicoCreek	Butte Creek near Chico multiplied by 1.24	None
MWD1_I14_FeatherRiver	Feather River at Oroville plus release from Thermalito Afterbay to Feather River	Almanor, Butte Valley, Mountain Meadows, Bucks, Little Grass Valley, Sly Creek, Frenchman, Antelope, Davis,
MWD1_I15_MiddleYuba	Middle Fork Yuba at mouth	Jackson Meadows
MWD1_I15_SouthYuba	South Fork Yuba at mouth	Spaulding, Bowman, Fordyce, Scotts Flat
MWD1_I15_YubaRiver	Yuba River near Smartville	New Bullards Bar, Englebright, Merle Collins
MWD1_I16_BearRiver	Bear River near Wheatland	Rollins, Combie, Rollins, Camp Far West
MWD1_I17_CacheCreek	Cache Creek below Capay Dam	Clear Lake, Indian Valley
MWD1_I18_AmericanRiver	American River at Fair Oaks	Folsom
MWD1_I19_PutahCreek	Putah Creek near Winters	Berryessa (Monticello Dam)
MWD1_I20_CosumnesRiver	Cosumnes River at Michigan Bar	Jenkinson (Sly Park Dam)
MWD1_I21_DryCreek	Dry Creek near Galt	Amador
MWD1_I22_MokelumneRiver	Mokelumne River below Camanche	Lower Bear, Salt Springs, Pardee, Camanche
MWD1_I23_StanislausRiver	Stanislaus River below Goodwin	Alpine, Beardsley, Donnell, Lyons, Pinecrest, Relief, Utica, Union, Melones
MWD1_I25_TuolumneRiver	Tuolumne River below LaGrange	Eleanor, Hetch Hetchy, Don Pedro
MWD1_I26_OrestimbaCreek	Orestimba Creek near Newman	None
MWD1_I27_MercedRiver	Merced River below Merced Falls	Lake McClure
MWD1_I28_BearCreekGroup	Bear, Burns, Mariposa, Owens creeks	None
MWD1_I29_DeadmanCreek	Deadman Creek	None
MWD1_I30_ChowchillaRiver	Chowchilla below Buchanan	Eastman (Buchanan Dam)
MWD1_I31_FresnoRiver	Fresno River below Hidden	Hensley (Hidden Dam)
MWD1_I32_37_38_39_41_ UpperSanJoaquinRiver	San Joaquin River below Friant	Friant Dam, Millerton Lake
MWD1_I33_KingsRiver	Kings River below Pine Flat	Pine Flat Improve simulation of Pine Flat
MWD1_I34_KaweahRiver	Kaweah River below Terminus	Kaweah (Terminus Dam)
MWD1_I35_TuleRiver	Tule River below Success	Success Dam
MWD1_I36_KernRiver	Kern River near Bakersfield	Lake Isabella
MWD1_I40_CVCtoKern	Cross Valley Canal outflow	None
MWD1_I42_ClearCreek	Clear Creek near Igo	Whiskeytown
MWD1_1_18_32_CVP_1960 LOD	Dam releases	Shasta, Folsom, Millerton

Sacramento Valley Models

The sections below briefly describe the spreadsheet models used to develop C2VSim inflow data for Sacramento Valley at each level of development.

Trinity River

Trinity Dam and Lake, components of the CVP Trinity Division, regulate flows in the Trinity River. Construction of the dam began in 1957 and was completed in 1962. Lewiston Dam and Lake, located immediately downstream from Trinity Dam, reregulate upstream dam releases and provide a forebay for exports from the Trinity River through Clear Creek Tunnel to the Sacramento Valley. Diversions through Clear Creek Tunnel to Whiskeytown Reservoir began in April 1963.

No spreadsheet model was developed for the Trinity River. Trinity River imports are zero for the 1900-, 1920-, 1940-, and 1960 LOD models. For the 1980-, 2000-, and 2010 LOD models, imports from the Trinity River are simulated using CalSim II.

Clear Creek

The Clear Creek watershed is located between Trinity Reservoir and Shasta Lake in Shasta County. Flows in the creek are regulated by Whiskeytown Dam and Reservoir, which were completed in 1963, as part of the CVP Trinity Division. Natural inflows to the reservoir are supplemented by Trinity River water imported through the Clear Creek Tunnel and Judge Francis Carr Powerhouse (USGS 11525430). Water stored in Whiskeytown Reservoir is subsequently released to Clear Creek, diverted directly from the reservoir for irrigation and municipal water supplies, or is diverted through the Spring Creek Tunnel and Spring Creek Powerhouse (USGS 11371600) and released into Keswick Reservoir.

The C2VSim input represent the Clear Creek inflows to the Sacramento River below Keswick Dam. These inflows were estimated as follows:

- **1900 LOD**: unimpaired Clear Creek flow near Igo (USGS 11371000), less average historical 1922-1930 Clear Creek diversions.
- **1920 LOD**: as 1900 LOD.
- **1940 LOD**: unimpaired Clear Creek flow near Igo (USGS 11371000), less average historical 1936-1945 Clear Creek diversions.
- **1960 LOD**: unimpaired Clear Creek flow near Igo (USGS 11371000), less average historical 1956-1965 Clear Creek diversions.
- **1980 LOD**: Whiskeytown Reservoir releases from CalSim II study,[29] plus stream accretions below Whiskeytown Dam, less average historical 1976-1985 Clear Creek diversions.
- **2000 LOD**: Whiskeytown Reservoir releases from CalSim II study,[8] plus stream accretions below Whiskeytown Dam, less average historical 1996-2005 Clear Creek diversions.
- **2010 LOD**: Whiskeytown Reservoir releases from CalSim II study,[8] plus stream accretions below Whiskeytown Dam. At the 2010 LOD, it is assumed that there are no diversions from Clear Creek.

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[29] CalSim II simulates water years 1922 through 2003. Simulated data for water years 2004 through 2009 are based on unpublished CalSim 3.0 simulations.

Sacramento River below Keswick Dam

Shasta Lake and Dam, located upstream from Keswick Dam are the principal features of the CVP Shasta Division. The dam is operated for flood control, water supply, and maintenance of downstream water temperature. Storage in Shasta Dam began in November 1943. Shasta Lake has a capacity of approximately 4,552,000 acre-feet. Keswick Dam represents the northern boundary of the C2VSim model domain. The dam, completed in 1949, is part of the CVP Shasta Division and is used both to reregulate releases from Shasta Dam and for power generation. Keswick Reservoir has a capacity of approximately 24,000 acre-feet.

The watershed upstream from Keswick Dam includes the northern-most portion of the Sacramento River, the Pit River, and McCloud River. Historical streamflow data for the Sacramento River at Keswick (USGS 11370500) are available beginning October 1938. Before this date, historical flows are based on the *1957 Joint Hydrology Study* (DWR, 1958) and two discontinued gages: Sacramento River at Kennett (USGS 11369500) and Sacramento River at Red Bluff (USGS 113780000). Natural accretions to the Sacramento River from Shasta Dam to Keswick Dam were calculated as the difference between Shasta Lake inflow and the unimpaired flow at Keswick. The latter is calculated by adjusting the observed flow to remove the effects of upstream storage regulation, reservoir evaporation, and imports from the Spring Creek Tunnel.

C2VSim inflows represent the releases from Keswick Dam. These inflows were calculated as follows:

- **1900 LOD**: Full natural flow at Shasta Dam, plus natural accretions from Shasta to Keswick.
- **1920 LOD**: As 1900 LOD.
- **1940 LOD**: As 1900 LOD.
- **1960 LOD**: Simulated releases from Shasta Dam, plus natural accretions between Shasta Dam and Keswick Dam. Shasta Dam is operated to meet minimum flow requirements at Keswick and at the Sacramento River Navigation Control Point. Operations are coordinated with Folsom Dam to meet Delta outflow requirements and CVP exports.
- **1980 LOD**: Flow below Keswick Dam as simulated by the *D1485* CalSim II model (arc C5), adjusted for historical accretions between Shasta Dam and Keswick Dam, which are not represented in CalSim II.
- **2000 LOD**: Flow below Keswick Dam as simulated by the *D1641wTrinityROD* CalSim II model (arc C5), adjusted for historical accretions between Shasta Dam and Keswick Dam, which are not represented in CalSim II.
- **2010 LOD**: Flow below Keswick Dam as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C5), adjusted for historical accretions between Shasta Dam and Keswick Dam, which are not represented in CalSim II.

Cow Creek

The Cow Creek watershed is situated in Shasta County, south-east from Lake Shasta. The watershed stretches from the foothills of Mount Lassen, in a southwest direction, to the Sacramento River. Historical streamflow data are available for Cow Creek near Millville (USGS 11374000) beginning October 1949. The gage is located approximately 2.9 miles upstream from the mouth of the river, and approximately 7 miles downstream from the C2VSim model boundary. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flows. Streamflow data before October 1949 were estimated by linear regression with the gage data Mill Creek near Los Molinos (USGS 11381500).

Battle Creek

The Battle Creek watershed is located in Shasta and Tehama counties and is bordered by the Bear Creek watershed to the north and Paynes Creek to the south. Historical streamflow data are available for Battle Creek below the Coleman Fish Hatchery (USGS 11376550) beginning October 1961. The gage is located approximately one mile downstream from the C2VSim model boundary. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flow. Streamflow data before October 1961 were estimated by linear regression with the gage data Mill Creek near Los Molinos (USGS 11381500). Inflows to C2VSim were adjusted so as to account for inflows to the Sacramento River from Bear Creek, which are not explicitly simulated in C2VSim.

Cottonwood Creek

The Cottonwood Creek watershed is located within both Shasta and Tehama counties. It is bordered to the north by the Anderson Creek and Lower Clear Creek watersheds and to the south by the Red Bank Creek and Thomes Creek watersheds. Streamflows for Cottonwood Creek near Cottonwood (USGS 11376000) are available beginning October 1940. Before this date, flows were estimated by USACE as the sum of flows for Cottonwood Creek at the Dutch Gulch dam site (drainage area 394 square miles), South Fork Cottonwood Creek at the Tehama dam site (drainage area of 371 square miles) and Cottonwood Creek local area (drainage area 162 square miles). The Cottonwood gage is located approximately 3 miles upstream from the mouth of the creek and a significant distance within the model domain. Therefore, the inflows at the edge of the model domain were calculated as the sum of the South Fork Cottonwood Creek near Olinda (USGS 11375870) and Cottonwood Creek near Olinda (USGS 11375810). Streamflow data for these discontinued gages were estimated by linear regression with the gage data Cottonwood Creek near Cottonwood. The same flows were used for each level of development.

Paynes and Sevenmile Creeks

Paynes Creek and Sevenmile Creek are adjacent watersheds located in Tehama County, and bordered by Battle Creek to the north and Antelope Creek to the south. Streamflow data are available for Paynes Creek near Red Bluff (USGS 11377500, discontinued); the gage located approximately 1 mile upstream from the mouth, corresponds to the C2VSim model boundary. No streamflow data are available for Sevenmile Creek. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flow at the site of the Paynes Creek gage, multiplied by a factor of 1.10 to account for Sevenmile Creek. Streamflow data for Paynes Creek were extended by linear regression with the gage data Mill Creek near Los Molinos (USGS 11381500).

Antelope Creek Group

The Antelope Creek watershed is located in Tehama County and lies between the Paynes Creek and Sevenmile Creek watersheds to the north and the Mill Creek watershed to the south. Historical streamflow data are available for Antelope Creek near Red Bluff (USGS 11379000, discontinued). The gage was located approximately 11 miles upstream from the mouth and 1 mile downstream from the C2VSim model boundary. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flow, multiplied by a factor of 2.06 to account for inflows from adjacent ungaged watersheds. Streamflow data before October 1940 and after September 1982 were estimated by linear regression with the gage data Mill Creek near Los Molinos (USGS 11381500).

Mill Creek

The Mill Creek watershed is located mostly in Tehama County and is bordered by the Battle Creek and Antelope Creek watersheds to the north and the Deer Creek watershed to the south. Streamflow data are available for Mill Creek near Los Molinos (USGS 11381500) beginning October 1928. The gage is located approximately 5.5 miles upstream from the mouth and 1 mile downstream from the C2VSim model boundary. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flow. Streamflow data before October 1928 were estimated by linear regression with Deer Creek near Vina (USGS 11383500).

Elder Creek

The Elder Creek watershed is located in Tehama County adjacent to and north of the Thomes Creek watershed. Historical monthly streamflow data are available for Elder Creek near Paskenta (USGS 11379500) from October 1948 to the present. The gage corresponds approximately to the C2VSim model boundary. Streamflow data before October 1948 were estimated by linear regression with the gage data Thomes Creek at Paskenta (USGS 11382000). The same flows are used for each level of development.

Thomes Creek

The Thomes Creek watershed is located in Tehama County adjacent to and south of the Elder Creek watershed. Historical monthly streamflow data are available for Thomes Creek at Paskenta (USGS 11382000) from October 1920 to September 1996. The gage corresponds approximately to the C2VSim model boundary. Streamflow data after September 1996 were estimated by linear regression with the gage data Elder Creek near Paskenta (USGS 11379500). The same flows are used for each level of development.

Deer Creek Group

The Deer Creek watershed lies in Tehama and Butte counties and is bordered to the north by the Mill Creek watershed and to the south by the North Fork and Middle Fork Feather River, Big Chico Creek, and Butte Creek watersheds. The Deer Creek watershed is one of the rare watersheds for which streamflow data exist for the entire period of simulation. Historical monthly streamflow data are available for Deer Creek near Vina (USGS 11383500) beginning October 1911. The gage is located 1.5 miles upstream from the C2VSim boundary. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flow, multiplied by a factor of 1.66 to account for inflows from adjacent ungaged watersheds.

Stony Creek

The Stony Creek watershed is located in the Coastal Range, north of Cache Creek. Flows in the creek are regulated by 3 dams, operated for both flood control and water supply purposes. East Park Dam was completed in 1910 as part of Reclamation's Orland Project and has a storage capacity of 51,000 acre-feet. Stony Gorge Dam, which is located approximately 18 miles downstream, was completed in 1928, and is also part of the Orland Project. It has a storage capacity of 50,000 acre-feet. Operations of East Park and Stony Gorge dams are coordinated with operation of Black Butte Dam, which was completed in 1963 as part of the CVP. Black Butte Dam has a storage capacity of 144,000 acre-feet.

C2VSim inflows represent the combined releases from Black Butte Dam to Stony Creek and into the South Canal. These flows were calculated as follows:

- **1900 LOD**: Full natural flow at East Park dam site, plus local inflows to Stony Gorge and Black Butte dam sites
- **1920 LOD**: Simulated storage regulation in East Park Reservoir, plus local accretions at the Stony Gorge and Black Butte dam sites. East Park Reservoir is operated to meet downstream water demands based on the 1922-1931 historical deliveries to the Orland Project North and South canals and to the Glenn-Colusa Canal.
- **1940 LOD**: Simulated storage regulation in East Park and Stony Gorge reservoirs, plus local accretions to the Black Butte dam site. The reservoirs are collectively operated to meet downstream water demands based on the 1936-1945 historical deliveries to the Orland Project North and South canals and to the Glenn-Colusa Canal.

- **1960 LOD**: As 1940 LOD, but with reservoirs operated to meet water demands based on the 1956-1964 deliveries to the Orland Project North and South canals and the Glenn-Colusa Canal.
- **1980 LOD**: Simulated storage regulation in East Park, Stony Gorge, and Black Butte reservoirs. The reservoirs are collectively operated to meet water demands based on the 1976-1985 deliveries to Orland Project North and South canals and to the Glenn-Colusa Canal.
- **2000 LOD**: As 1980 LOD, but with reservoirs operated to meet water demands based on the 1996-2005 deliveries to the Orland Project North and South canals, Glenn-Colusa Canal, and Tehama-Colusa Canal.
- **2010 LOD**: As 2000 LOD, but with reservoirs operated to meet water demands based on the 2000-2009 deliveries to the Orland Project North and South canals, Glenn-Colusa Canal, and Tehama-Colusa Canal.

Big Chico Creek

The Big Chico Creek watershed is a long and narrow strip of land located between Deer Creek to the north-west and Butte Creek to the south-east. Historical monthly streamflow data are available for Big Chico Creek near Chico (USGS 11384000) from October 1930 to September 1986. Additionally, since September 1975, DWR has measured flows in Big Chico Creek at Chico (A04250), in the Lindo Channel near Chico (A00615), and at the Mud Creek diversion at Chico (A00928). For water years 1922 through 1930, monthly flows are published in the *1957 Joint Hydrology Study* (DWR, 1958). Streamflows for water years 1987 through 2009 were derived through linear regression of historical annual streamflow data for Big Chico Creek near Chico with corresponding annual streamflow data for the sum of the three DWR gages.

Butte and Chico Creeks

The Butte Creek watershed and the adjacent ungaged watersheds of Little Chico Creek and Little Dry Creek lie between Big Chico Creek to the north and the West Branch Feather River watershed to the south. Historical monthly streamflow data are available for Butte Creek near Chico (USGS 11390000) from October 1930 to the present. The gage is located approximately 4 miles upstream from the C2VSim boundary. Upstream from the gage, water is imported by PG&E from the West Branch of the Feather River as part of the DeSabla Hydropower Project. For all levels of development the C2VSim inflows were set equal to the historical flows for Butte Creek near Chico multiplied by a factor of 1.24 to account for the ungaged watersheds of Little Chico Creek and Little Dry Creek. Historical streamflows before October 1930 are taken from the *1957 Joint Hydrology Study*.

Feather River

The upper Feather River watershed drains in to Lake Oroville, one of the major water storage facilities of the SWP. The upper watershed includes the West Branch, North Fork, Middle Fork, and South Fork Feather River. All of these watersheds have been developed for water supply and hydropower. Historical monthly streamflow data are available for the Feather River at Oroville (USGS 11407000) from October 1901 to the present. The gage is currently located 300 feet upstream from the Fish Barrier Dam. Since November 1967, flows have been completely regulated by Lake Oroville.

C2VSim inflows represent the flows in the Feather River below Oroville Dam after diversions by Western Canal WD and the Joint Water District Board. This is equivalent to the sum of Feather River at Oroville (USGS 11407000) and the Thermalito Afterbay release (USGS 11406920). These inflows were calculated as follows:

- **1900 LOD**: Full natural flow Feather River near Oroville, as published by CDEC.

- **1920 LOD**: Full natural flow, impaired to account for storage regulation and evaporation in Lake Almanor.
- **1940 LOD**: Historical flow Feather River near Oroville, adjusted after 1940 to remove the effects of storage regulation and reservoir evaporation in reservoirs built after 1940 (Little Grass Valley, Sly Creek, Frenchman Lake, Antelope Lake, Lake Davis) and imports /exports beginning after 1940 (Slate Creek imports and Kelly Ridge exports).
- **1960 LOD**: As 1940 LOD.
- **1980 LOD**: Flow below the Thermalito Afterbay return as simulated by the *D1485* CalSim II model (arc C203).
- **2000 LOD**: Flow below the Thermalito Afterbay return as simulated by the *D1641wTrinityROD* CalSim II model (arc C203).
- **2010 LOD**: Flow below the Thermalito Afterbay return as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C203).

Yuba River

The upper watersheds of the North, Middle, and South Yuba rivers have been extensively developed for hydropower and water supply by Yuba County WA, Nevada ID, and PG&E. Storage facilities on the Middle Yuba and South Yuba rivers and associated diversion facilities enable Nevada ID and PG&E to export approximately 400,000 acre-feet per year from the Yuba River watershed to the Bear River and American River watersheds. In addition, the South Feather Water and Power Agency exports an average of approximately 70,000 acre-feet per year from Slate Creek (a tributary to the North Yuba River) to the South Fork Feather River watershed. The lower Yuba River refers to the 24-mile-long section of the river between Englebright Dam and its confluence with the Feather River southwest of Marysville.

- **1900 LOD**: Unimpaired Yuba River flow at Smartville (DWR data, 5th edition)
- **1920 LOD**: As 1900 LOD, but includes simulated operations for Lake Spaulding on the South Fork Yuba River.
- **1940 LOD**: As 1920 LOD, but includes simulated operations for Old Bullards Bar Reservoir on the North Fork, the Milton-Bowman development on the Middle Fork, and Lake Fordyce on the South Fork.
- **1960 LOD**: As 1940 LOD, but with revised water demands.
- **1980 LOD**: As 1940 LOD, but includes simulated storage operations for New Bullards Bar on the North Fork and Jackson Meadows Reservoir on the Middle Fork. Also accounts for export of water from Slate Creek to the South Fork Feather watershed.
- **2000 LOD**: As 1980 LOD, but with diversions at Daguerre Point Dam based on average historical 1996–2005 diversions.
- **2010 LOD**: As 1980 LOD, but with New Bullards Bar operated to meet instream flow standards established as part of the lower Yuba River Accord 2010, and diversions at Daguerre Point Dam based on average historical 2000–2009 diversions.

Bear River

The Bear River watershed is highly regulated. River flows are dominated by trans-watershed imports from the Yuba watershed, and to a lesser extent from the American River, and exports to the American Basin. Water also is stored in three reservoir Lake Rollins, Lake Combie, and Camp far West Reservoir. The flow below Camp Far West Dam (site) for each level of development is calculated as follows:

The Lake Valley Canal diverts from the North Fork of the North Fork American River to supplement the Drum Canal in the Yuba-Bear River watershed. Diversions began in 1911. Flows in the canal are exported from the American River watershed in the vicinity of Emigrant Gap. Winter flows in the North Fork of the North Fork American River are stored and regulated upstream by Kelly Lake and Lake Valley Reservoir.

- **1900 LOD**: Unimpaired Bear River flow near Wheatland (DWR data, 5th edition)

- **1920 LOD**: Simulated Bear River flow at Wheatland, equal to the sum of inflows and diversions above the Bear River Canal, less Bear River diversions, plus inflows and diversions between the Bear River Canal and Combie Canal, less Combie Canal diversions, plus inflows and diversions between the Combie Canal and Wheatland.

  Inflows and diversions above the Bear River Canal are equal to the sum of unimpaired flow at the Rollins Reservoir dam site (I_RLLNS), imports to the Bear River system from Lake Spaulding via the Drum Canal (CalSim 3.0 arc D_SPLDG_DRM000), historical imports to the Bear River System from the North Fork American River via the Lake Valley Canal (USGS gage data), inflows to the Bear River from the South Yuba Canal (calculated as the difference between gaged flow at head of canal and gaged flow at Deer Creek Powerhouse), less average 1922-1931 diversions to the Boardman Canal (based on CalSim 3.0 data).

  Flow in the Bear River above the Combie Canal is equal to Bear River flow above the Bear River canal, less diversions to the Bear River Canal (with demands based on average 1922-1931 USGS gage data), plus local inflows at the Combie Reservoir dam site (from CalSim 3.0 I_CMBIE).

  Flow in the Bear River at Wheatland is equal to the Bear River above the Combie Canal, less diversions to the Combie Canal (based on average 1922-1931 historical diversions), plus local inflows at Camp Far West (CalSim 3.0 arc I_CMPFW), Wolf Creek (CalSim 3.0 arc I_WLF013), and Garden Bar (I_BRR023), less average 1922-1931 historical diversions to the Camp Far West Irrigation District (ID).

- **1940 LOD**: Simulated storage regulation in Combie Reservoir, with Combie inflows calculated similar to 1920 LOD flows above Combie Canal (inflows and average 1936-1945 diversions above the Bear River Canal, less average 1936-1945 Bear River Canal diversions, plus local inflows to Combie Reservoir). Combie Reservoir is operated to meet average 1936-1945 Combie Canal demands plus average 1936-1945 Camp Far West ID demands. Flows from Combie Reservoir to Wheatland are calculated as in the 1920 LOD simulation, except with diversions to the Camp Far West ID based on deliveries from Combie Reservoir.

- **1960 LOD**: As 1940 LOD, with deliveries and diversions based on average 1956-1965 demands.

- **1980 LOD**: Simulated storage regulation in Rollins, Combie, and Camp Far West reservoirs. Inflow to Rollins Reservoir is calculated as 1920 LOD flows above the Bear River Canal, except with average 1976-1985 diversions to the Boardman Canal. Rollins reservoir is operated to release for minimum instream flows below the Bear River Canal (based on requirements in

CalSim II), plus average 1976-1985 demands in the Bear River Canal, Combie Canal, and Camp Far West ID and South Sutter WD. Inflow to Combie Reservoir is equal to releases from Rollins Reservoir, less diversions to the Bear River Canal based on average 1976-1985 demands, plus local inflows to Combie. Combie reservoir is operated to release to the Bear River for minimum instream flows below Combie Reservoir (based on requirements in CalSim II), plus average 1976-1985 demands for Camp Far West ID and South Sutter WD. Combie Canal demands are also withdrawn directly from the reservoir, based on average 1976-1985 demands.

Inflow to Camp Far West Reservoir is calculated as the release from Combie Reservoir, plus local inflows at Camp Far West as in the 1920 LOD simulation. Camp Far West Reservoir is operated to release for minimum instream flows below Camp Far West (based on requirements in CalSim II), plus average 1976-1985 demands for Camp Far West ID and South Sutter WD.

- **2000 LOD**: As 1980 LOD, with deliveries and diversions based on average 1996-2005 demands.
- **2010 LOD**: As 1980 LOD, with deliveries and diversions based on average 2000-2009 demands.

American River

The American River watershed is divided into the upper watershed above Folsom Lake and Dam, and the lower watershed, consisting primarily of the 29-mile-long river reach between Folsom Dam and the Sacramento River. The upper watershed has been extensively developed for both power generation and water supply. Placer County WA's Middle Fork Project, within the Middle Fork American River watershed, was completed in 1967. The major storage facilities are French Meadows Reservoir on the Middle Fork and Hell Hole Reservoir on the Rubicon River. The reservoirs have a combined storage capacity of 343,000 acre-feet. Placer County WA seasonally stores water to meet irrigation and M&I demands within Western Placer County and for power generation. Water released from the project is diverted at the American River Pump Station located on the North Fork American River near the City of Auburn, and at Folsom Dam.

The Upper American River Project, built in the 1970s by the Sacramento Municipal Utility District (SMUD) consists of 11 dams and eight powerhouses. The project generates hydropower from the South Fork American River and its tributaries. The reservoirs have a combined storage capacity of 430,000 acre-feet.

C2VSim inflows represent the flows in the lower American River below Natoma Dam. These flows were calculated as follows:

- **1900 LOD**: Full natural flow for the American River at Fair Oaks, as published by CDEC.
- **1920 LOD**: As 1900 LOD, except flows impaired to account for storage regulation in Lake Valley and Loon Lake reservoirs, imports from PG&E South Canal, exports to the Lake Valley Canal and Georgetown Divide PUD Ditch, and M&I and agricultural diversions in the vicinity of Folsom based on the 1922–1931 historical diversions.
- **1940 LOD**: As 1920 LOD, except diversions are based on 1936–1945 historical data.
- **1960 LOD**: Simulated releases from Natoma Dam. Upstream storage regulation includes Lake Valley, Loon Lake, and Ice House reservoirs.
- **1980 LOD**: Flow below Folsom Dam as simulated by the *D1485* CalSim II model (arc C9).
- **2000 LOD**: Flow below Folsom Dam as simulated by the *D1641wTrinityROD* CalSim II model (arc C9).

- **2010 LOD**: Flow below Folsom Dam as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C9).

Cache Creek

The Cache Creek watershed, located predominantly in Lake County, includes Clear Lake, one of California's largest natural lakes. Since 1914, lake levels have been regulated by Cache Creek Dam, located approximately 3 miles downstream from the natural outlet of the lake. Water is released from the lake to meet downstream agricultural demands. Indian Valley Dam, located on the North Fork Cache Creek, was completed by Yolo County Flood Control and Water Conservation District (FCWCD) in 1974. The reservoir provides water for both agricultural and municipal purposes. Water is diverted from Cache Creek by Yolo County FCWCD at the Capay Diversion Dam for irrigation.

The C2VSim Cache Creek inflow represents the flow in the creek below the Capay Diversion Dam. These inflows were estimated as follows:

- **1900 LOD**: unimpaired Cache Creek flows near Capay Diversion Dam, developed from historical Cache Creek flows at Rumsey, modified to remove effects of Clear Lake and Indian Valley storage regulation and evaporation.
- **1920 LOD**: simulated releases from Clear Lake to Cache Creek, plus inflows from the North Fork of Cache Creek, Bear Creek, and downstream local accretions. Clear Lake is operated to meet average 1922-1931 agricultural demands for agricultural diversions from Cache Creek, and is operated to meet Gopcevic Decree requirements.
- **1940 LOD**: as 1920 LOD, with Clear Lake operated to meet average 1936-1945 demands for agricultural demands at the Capay Diversion Dam.
- **1960 LOD**: as 1920 LOD, with Clear Lake operated to meet average 1956-1965 demands for agricultural demands at the Capay Diversion Dam.
- **1980 LOD**: sum of simulated releases from Clear Lake, simulated releases from Indian Valley Reservoir, Bear Creek natural inflows to Cache Creek, and local accretions to Cache Creek. Clear Lake and Indian Valley are collectively operated to meet average 1976-1985 historical agricultural demands at the Capay Diversion Dam. Indian Valley is assumed to release up to 250 cfs to meet these demands, and remaining demands are met by Clear Lake. Clear Lake is also operated to meet Gopcevic Decree requirements.
- **2000 LOD**: as 1980 LOD, with Clear Lake and Indian Valley Reservoir operated to meet 1996-2005 average historical agricultural demands at the Capay Diversion Dam.
- **2010 LOD**: as 1980 LOD, with Clear Lake and Indian Valley Reservoir operated to meet 2000-2009 average historical agricultural demands at the Capay Diversion Dam.

Putah Creek

Lake Berryessa and Monticello Dam separate the upper and lower Putah Creek watersheds in the Coast Ranges. Monticello Dam was completed in 1957 as part of Reclamation's Solano Project. Downstream, at the Putah Diversion Dam, Solano County Water Agency diverts water from Putah Creek into the Putah South Canal for irrigation and municipal and industrial purposes. About 1 mile upstream from I-80, the channel departs from the natural creek channel and flows directly to the Yolo Bypass. This artificial channel, known as the South Fork of Putah Creek, was constructed over a period of decades, beginning in the 1870s, and, for practical purposes, is the main channel of Putah Creek.

The C2VSim Putah Creek inflow represents the flow in the creek above the Putah South Canal diversion at the gage Putah Creek near Winters (USGS 11454000). These inflows were estimated as follows:

- **1900 LOD**: Putah Creek near Winters, unimpaired for storage regulation is Lake Berryessa.
- **1920 LOD**: as 1900 LOD.
- **1940 LOD**: as 1900 LOD.
- **1960 LOD**: unimpaired flow Putah Creek near Winters, impaired by simulated operation of Lake Berryessa to meet average 1956-1965 Putah South Canal demands.
- **1980 LOD**: unimpaired flow Putah Creek near Winters, impaired by simulated operation of Lake Berryessa to meet average 1976-1985 Putah South Canal demands.
- **2000 LOD**: unimpaired flow Putah Creek near Winters, impaired by simulated operation of Lake Berryessa to meet average 1996-2005 Putah South Canal demands.
- **2010 LOD**: unimpaired flow Putah Creek near Winters, impaired by simulated operation of Lake Berryessa to meet average 2000-2009 Putah South Canal demands and instream flow requirements.

Sacramento Valley Floor

C2VSim simulates flows through various flood channels and bypasses within the Sacramento Valley, including the Knights Landing Ridge Cut and the Yolo Bypass.

Knights Landing Ridge Cut

The Knights Landing Ridge Cut was constructed to provide an outlet from the Colusa Basin when high Sacramento River stage prevents discharge of excess water through the Knights Landing Outfall Gates. It was completed in 1915. The amount of water flowing through the Knights Landing Ridge Cut depends on downstream irrigation demands, stage in the Sacramento River, flows in the Colusa Basin Drain, and setting at the Wallace Weir, located at the confluence of the Knights Landing Ridge Cut and Yolo Bypass. Flows through the Knights Landing Ridge Cut are not gaged. However, estimates of historical flows through the channel were developed based on gaged flows for the Colusa Basin Drain at Highway 20 and at the Knights Landing Outfall Gates.

Flows through the Knights Landing Ridge Cut for the different LODs were determined as follows:

- **1900 LOD**: no flow.
- **1920 LOD**: estimated historical flows based on gaged flows in the Colusa Basin Drain.
- **1940 LOD**: as 1920 LOD.
- **1960 LOD**: as 1920 LOD.
- **1980 LOD**: flow as simulated by the *D1485* CalSim II model (arc C184B).
- **2000 LOD**: flow as simulated by the *D1641wTrinityROD* CalSim II model (arc C184B).
- **2010 LOD**: flow as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C184B).

Fremont Weir

The Fremont Weir, together with the Yolo Bypass, were completed in 1924 as part of the Sacramento River Flood Control Project providing flood relief for the City of Sacramento. The weir is the first overflow structure on the Sacramento River's right bank. Water spilling over the weir is conveyed 41 miles through the bypass to Cache Slough. Historical flows over the weir were developed from several sources. From October 1921 through December 1946, historical flow data are available from Table 51 of the *1957 Joint Hydrology Study*. From January 1947 through September 1975 gage records are available from USGS (station 11391021). Beginning October 1975, flows data are available from DWR Division of Flood Management.

Flows over the Fremont Weir for the different LODs were determined as follows:

- **1900 LOD**: historical flows.
- **1920 LOD**: as 1900 LOD.
- **1940 LOD**: as 1900 LOD.
- **1960 LOD**: as 1900 LOD.
- **1980 LOD**: flow as simulated by the *D1485* CalSim II model (arc D160).
- **2000 LOD**: flow as simulated by the *D1641wTrinityROD* CalSim II model (arc D160).
- **2010 LOD**: flow as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc D160).

For the 1900 LOD it is assumed that over-bank spills are of similar magnitude and frequency as controlled spills over Fremont weir.

Northern San Joaquin Valley Models

The San Joaquin River drains approximately 13,500 square miles, at the Vernalis gage, bounded by the Sierra Nevada Mountains to the east, the Coast Range to the west, and the Tulare Lake basin to the south. The Vernalis gage is regarded as the boundary that separates the San Joaquin Valley from the Delta, since it is the most downstream flow measurement station on the river not subject to tidal influence. This section briefly describes the spreadsheet models used to provide C2VSim inflow data for this part of the San Joaquin Valley at each level of development.

Cosumnes River

The Cosumnes River watershed is located between the American River watershed to the north and east, the Mokelumne watershed to the south, and the Delta to the west. Historical streamflow data are available for the Cosumnes River at Michigan Bar (USGS 11335000) beginning October 1907. The most significant development in the Cosumnes River watershed is the Sly Park Unit. Originally part of the CVP, the unit was transferred to El Dorado ID as part of the district’s water supply system. Located in the North Fork Cosumnes watershed, Sly Park Unit includes Jenkinson Lake and Sly Park Dam on Sly Park Creek, Camp Creek Diversion Dam on Camp Creek, and the Sly Park-Camino Conduit. Jenkinson Lake is the largest reservoir in the Cosumnes watershed, providing approximately 41,000 acre-feet of active storage. Storage began in January 1955.

The C2VSim inflow represents the Cosumnes River approximately one mile downstream from the USGS gage at Michigan Bar. These flows were estimated as follows:

- **1900 LOD**: Full natural flow for the Cosumnes River at Michigan Bar as published by CDEC.
- **1920 LOD**: As 1900 LOD.
- **1940 LOD**: As 1900 LOD.

- **1960 LOD**: unimpaired flow Cosumnes River near Michigan Bar, impaired by simulated operation of Jenkinson Lake and exports through the Camino Conduit to meet average 1956-1965 El Dorado ID demands.
- **1980 LOD**: unimpaired flow Cosumnes River near Michigan Bar, impaired by simulated operation of Jenkinson Lake and exports through the Camino Conduit to meet average 1976-1985 El Dorado ID demands.
- **2000 LOD**: unimpaired flow Cosumnes River near Michigan Bar, impaired by simulated operation of Jenkinson Lake and exports through the Camino Conduit to meet average 1996-2005 El Dorado ID demands.
- **2010 LOD**: unimpaired flow Cosumnes River near Michigan Bar, impaired by simulated operation of Jenkinson Lake and exports through the Camino Conduit to meet average 2000-2009 El Dorado ID demands.

Dry Creek

Dry Creek is a tributary of the Mokelumne River, which it joins approximately 8 miles upstream from the river's mouth. Historical streamflow data are available for Dry Creek near Galt (USGS 11329500) for water years 1927 – 1933 and 1945 – 1987. For all levels of development, inflows were taken from the historical run of C2VSim (C2VSim-CG_R374, inflow no. 21). Storage regulation in Lake Amador, imports from Lake Pardee, and imports from the North fork Mokelumne River are ignored as the effects on downstream flows in Dry Creek are considered to be small and because of lack of historical data.

Mokelumne River

The Mokelumne River watershed incudes lands in Alpine, Amador, and Calaveras counties. The majority of the watershed is undeveloped. Inflows to Pardee Reservoir are partially controlled by seven upstream reservoirs, which are owned and operated by PG&E. The PG&E reservoirs have a combined capacity of 220,000 acre-feet. The "old" PG&E reservoirs (Upper and Lower Blue Lakes, Meadow Lake, Twin Lakes, and Upper Bear) were constructed before October 1921 and are relatively small. Salt Springs Reservoir was constructed in 1931, enlarged in 1946, and now has a storage capacity of approximately 142,000 acre-feet. Lower Bear Reservoir was constructed in 1952 and has a storage capacity of approximately 49,000 acre-feet. Pardee Dam was completed in 1929. It is owned and operated by East Bay Municipal Utility District (EBMUD) for water supply and hydropower generation. Camanche Dam was completed in 1963, with a storage capacity of 417,000 acre-feet. Historical streamflow data are available for the Mokelumne River near Mokelumne Hill (USGS 11319500) from October 1927 to the present.

For internal planning studies, EBMUD has developed a monthly simulation model of its facilities within the Mokelumne River watershed. The model is known as EBMUDSIM.

For this study, analysis ignores storage regulation in the old PG&E reservoirs in the upper watershed. These reservoirs were built between 1881 and 1903 and have a combined gross storage of 26,560 acre-feet. The C2VSim inflow represents the Mokelumne River below Camanche Dam (or dam site). These flows were estimated as follows:

- **1900 LOD**: The full natural flow for the Mokelumne River at Mokelumne Hill as published by CDEC, plus local river accretions between the gage and Camanche dam site.
- **1920 LOD**: As 1900 LOD.
- **1940 LOD**: Simulated release from Pardee Dam to meet flood control, downstream agricultural demands, instream flow requirements, and seepage losses. Inflows to Pardee Reservoir adjusted

for storage regulation in Salt Springs Reservoir. Diversions from Pardee Reservoir include those to Mokelumne Aqueduct.

- **1960 LOD**: Simulated release from Pardee Dam to meet flood control, downstream agricultural demands, instream flow requirements, and seepage losses. Inflows to Pardee Reservoir adjusted for storage regulation in Salt Springs and Lower Bear reservoirs. Diversions from Pardee Reservoir include those to Mokelumne Aqueduct.
- **1980 LOD**: Simulated release from Pardee and Camanche dams to meet flood control, downstream agricultural demands, instream flow requirements, and seepage losses. Inflows to Pardee Reservoir adjusted for storage regulation in Salt Springs and Lower Bear reservoirs. Diversions from Pardee Reservoir include those to Mokelumne Aqueduct. EBMUD water demands are based on aqueduct diversions for water years 1976 and 1979-1984. Water years 1977 and 1978 were excluded because of limited water supplies.
- **2000 LOD**: Flow below Camanche Dam as simulated by EBMUDSIM (EBMUD's simulation tool) and reported in *Permit 10478 Time Extension Project*, *Draft Environmental Impact Report*, September 2013. For the 2000 LOD, a demand of 215 MGD was assumed.
- **2010 LOD**: Flow below Camanche Dam as simulated by EBMUDSIM. EBMUD's demand for water varies from year to year, due to a mix of factors, including weather, the local economy, and development. From calendar year 2000 to 2003, demand was relatively constant, ranging from 214 to 216 MGD. In 2004, demand increased to 219 MGD, in part because of a hot summer and strong economic growth. Subsequently, demand dropped in 2005 to 208 MGD and stayed low due to the economic recession. However, for the 2010 LOD, demand is unchanged from the 2000 LOD.

Calaveras River

The Calaveras River watershed is located in Calaveras and San Joaquin counties between the Mokelumne and Stanislaus rivers. It includes to New Hogan Dam and Reservoir. The City of Stockton constructed the original Hogan Dam in 1931 for flood control. The reservoir had a storage capacity of 78,000 acre-feet. USACE completed construction of New Hogan Dam in 1963 at the same site. The expanded reservoir has a storage capacity of 317,100 acre-feet and provides flood control and water supply for irrigation and municipal and industrial use. Historical monthly streamflow data are available for the Calaveras River at Jenny Lind (USGS 11309500) from January 1907 to September 1966. Data are available for the Calaveras River below New Hogan Dam near Valley Springs (USGS 11308900) from February 1961 to September 1990.

The C2VSim inflow represents the Calaveras River below the dam or dam site. These inflows were estimated as follows:

- **1900 LOD**: Full natural Calaveras River flow at New Hogan dam site derived from the unimpaired flow of the Calaveras River at Jenny Lind.
- **1920 LOD**: As 1900 LOD
- **1940 LOD**: As 1900 LOD
- **1960 LOD**: Simulated releases from (Old) Hogan Reservoir for flood control and to meet downstream riparian rights, and Stockton East WD and Calaveras County WD demands, accounting for river seepage losses. Demands based on 1956-1965 deliveries.
- **1980 LOD**: Simulated releases from New Hogan Reservoir for flood control and to meet downstream riparian rights, and Stockton East WD and Calaveras County WD demands,

accounting for river seepage losses. Demands based on 1976-1985 deliveries including M&I deliveries to the Dr. Joe Waidhofer water treatment plant, which began operation in 1978.

- **2000 LOD**: As 1980 LOD, but with demands based on 1996-2005 deliveries.
- **2010 LOD**: As 1980 LOD, but with demands based on 2000-2009 deliveries.

Stanislaus River

The upper and lower watersheds of the Stanislaus River are divided by New Melones Reservoir and Dam. New Melones Reservoir, Dam, and Powerplant are located about 60 miles upstream from the confluence of the Stanislaus River with the San Joaquin River. Construction of New Melones Dam was completed in 1979 by USACE. The dam, now operated by Reclamation as part of the CVP, impounds a reservoir with a gross storage capacity of 2.4 million-acre feet. The dam is operated for flood control, irrigation and municipal water supplies, peak use period hydroelectric production, recreation, and fish and wildlife enhancement. Tulloch Dam, Reservoir, and Powerplant, located approximately 6 miles downstream from New Melones Dam provide afterbay storage for reregulating power releases from New Melones Powerplant under contractual arrangements between Reclamation and Oakdale and South San Joaquin irrigation districts, which own and operate Tulloch Dam as part of the Tri-Dam Project. Goodwin Diversion Dam is located approximately 3 miles downstream from Tulloch Dam. The dam was constructed by Oakdale and South San Joaquin irrigation districts in 1913 to divert Stanislaus River water into the district's canals. USGS maintains streamflow gages downstream from Goodwin Diversion Dam (USGS 11302000) and at Ripon (USGS 11303000).

The upper watershed covers approximately 904 square miles. It includes New Spicer Meadow Reservoir, Beardsley Reservoir, Donnell Lake, and Pinecrest Lake.

- **1900 LOD**: Full natural flow at New Melones dam site, plus accretions between the New Melones dam site and Goodwin Dam, less diversions to Oakdale and San Joaquin Canals. Diversions to Oakdale and San Joaquin canals are based on average 1922-1931 canal flows, scaled to a 1900 level of demand using the relative volumes of agricultural diversions in the San Joaquin basin in 1900 and 1920 (from DWR Bulletin 27). Accretions between the New Melones dam site and Goodwin Dam are equal to the local inflow to Tulloch Reservoir (CalSim 3.0 arc I_TULOC) and the local inflow to Goodwin Dam (CalSim 3.0 arc I_STS059).

- **1920 LOD**: As 1900 LOD, except inflow at New Melones dam site is modified by upstream storage regulation in Alpine, Pinecrest, Relief, Utica, and Union reservoirs, and diversions to Oakdale and San Joaquin Canals are based on average 1922-1931 canal flows. - missing historical storage data

- **1940 LOD**: Simulated storage regulation in Old Melones Reservoir, plus accretions between the New Melones dam site and Goodwin Dam, less average 1936-1945 diversions to Oakdale and San Joaquin Canals. Inflow to Old Melones Reservoir is full natural flow modified by upstream storage regulation in Alpine, Lyons, Pinecrest, Relief, Utica, and Union reservoirs - missing historical storage data

- **1960 LOD**: Simulated storage regulation in Old Melones Reservoir, plus accretions between the New Melones dam site and Goodwin Dam, less average 1936-1945 diversions to Oakdale and San Joaquin Canals. Inflow to Old Melones Reservoir is full natural flow modified by upstream storage regulation in Alpine, Beardsley, Donnell, Lyons, Pinecrest, Relief, Utica, and Union reservoirs - missing historical storage data

- **1980 LOD**: Flow below Goodwin Dam as simulated by the *D1485* CalSim II model (arc C520).

- **2000 LOD**: Flow below Goodwin Dam as simulated by the *D1641wTrinityROD* CalSim II model (arc C520).
- **2010 LOD**: Flow below Goodwin Dam as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C520).

Tuolumne River

The Tuolumne River is one of the major San Joaquin River tributaries, located between the Stanislaus River to the north and the Merced River to the south. River flows are regulated by New Don Pedro Reservoir and Dam. The new dam was completed in 1971 replacing the older dam that was built in 1923. The upstream watershed has been developed for both water supply and hydropower. Inflows to New Don Pedro Reservoir are significantly affected by the operations of the City and County of San Francisco's Hetch Hetchy Water and Power Project. Eleanor Dam was completed in 1918, Hetch Hetchy Dam was completed in 1923, and Cherry Dam was completed in 1955.

Below New Don Pedro Dam, Modesto ID and Turlock ID divert water at La Grange Dam, immediately upstream from the C2VSim model domain. Historical flows downstream from New Don Pedro Dam are reported directly may be estimated as the sum of the Tuolumne River below LaGrange Dam (USGS 11289650) or Tuolumne River above LaGrange Dam (USGS 11288000) and upstream diversions through the Modesto Canal (USGS 11289000) and through the Turlock Canal (USGS 11289500).

The C2VSim inflows representing the Tuolumne River below LaGrange Dam were estimated as follows:

- **1900 LOD**: Full natural flow at New Don Pedro dam site, plus accretion between New Don Pedro and LaGrange Dam, less diversions to Modesto Canal and Turlock Canal.
- **1920 LOD**: As 1920 LOD, except flow at New Don Pedro dam site impaired for Lake Eleanor storage and evaporation.
- **1940 LOD**: Simulated releases from (Old) Don Pedro Dam, plus accretion between New Don Pedro and LaGrange Dam, less diversions to Modesto Canal and Turlock Canal. Inflow to Don Pedro Reservoir calculated as full natural flow impaired for Lake Eleanor and Hetch Hetchy Reservoir storage and evaporation, and diversions to the City of San Francisco.
- **1960 LOD**: Simulated releases from (Old) Don Pedro Dam, plus accretion between New Don Pedro and LaGrange Dam, less diversions to Modesto Canal and Turlock Canal. Inflow to Don Pedro reservoir calculated as full natural flow impaired for Lake Eleanor, Hetch Hetchy Reservoir, and Cherry Lake storage and evaporation, and diversions to the City of San Francisco.
- **1980 LOD**: Flow below LaGrange Dam as simulated by the *D1485* CalSim II model (arc C540).
- **2000 LOD**: Flow below LaGrange Dam as simulated by the *D1641wTrinityROD* CalSim II model (arc C540).
- **2010 LOD**: Flow below LaGrange Dam as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C540).

Orestimba Creek

Orestimba Creek provides the only significant inflow from the westside of the San Joaquin Valley. The creek joins the San Joaquin River just south of the City of Patterson. During the wet season flows in the creek can be substantial and sustained after prolonged precipitation. However, the creek is mostly dry for the rest of the year, except for irrigation return flows. Historical streamflow records are available for Orestimba Creek near Newman (USGS 11274500) from October 1932 to the present. The gage is located approximately one mile downstream from the C2VSim model boundary. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flow. Streamflow data before October 1932 were estimated by linear regression with Fresno River near Knowles (USGS 11257500).

Merced River

The Merced River is one of the major San Joaquin River tributaries, located to the south of the Tuolumne River. River flows are regulated by Lake McClure and New Exchequer Dam. The new dam was completed in 1960 replacing the original dam that was completed in 1926. New Exchequer Dam is operated for both water supply and hydropower. Historical monthly streamflow data are available for Merced River at Exchequer (USGS 11270000) from April 1901 to September 1964. The Exchequer gage was located approximately 0.65 miles below New Exchequer Dam. Merced ID has historical records for the Merced River at Exchequer beginning October 1965. Storage records for Lake McClure Reservoir (USGS 11269500) are available from November 1930 to the present. USACE also maintains records of lake inflows. From October 1921 to September 1994, historical inflows to Lake McClure were calculated from a mass balance based on gaged flows for the Merced River at Exchequer and accounting for changes in reservoir storage and reservoir evaporation. Beginning October 1994, lake inflows were taken from USACE data.

Merced ID's McSwain Development includes McSwain Reservoir, Dam and Powerhouse, and is operated by the district for hydropower generation. The dam is located 6.3 miles below Exchequer Dam. McSwain Reservoir has a storage capacity of approximately 9,700 acre-feet. Located below McSwain Dam, PG&E's Merced Falls Project consists of Merced Falls Dam and Powerhouse. The dam was constructed in 1901 for hydropower generation. There is no significant storage regulation at the dam.

Merced ID diverts water from the Merced River to supply irrigation water to approximately 164,000 acres in Merced County and drinking water for the City of Merced. Water is diverted at the Merced Falls Dam into the Northside Canal and at the Crocker-Huffman Dam (located downstream from the Merced Falls Dam) into the Main Canal.

The C2VSim inflows, which represent the Merced River below Merced Falls Dam (but upstream from the Crocker-Huffman Dam) were estimated as follows:

- **1900 LOD**: Gaged Merced River flow at Exchequer dam site, plus accretion between Exchequer and Crocker-Huffman diversion dam, less diversions to the Merced ID North Canal. Merced ID North Canal diversions are based on average 1922-1931 canal flows, scaled to a 1900 level of demand using the relative volumes of agricultural diversions in the San Joaquin basin in 1900 and 1920 (from DWR Bulletin 27). Accretions between Exchequer and Crocker-Huffman diversion dam are based on gage data.
- **1920 LOD**: As 1900 LOD, with Merced ID North Canal diversions based on average 1922-1931 canal flows
- **1940 LOD**: Simulated storage regulation in Old Exchequer Dam, plus accretions between Exchequer and Crocker-Huffman diversion dam, less diversions to Merced ID North Canal. Old Exchequer Dam inflows are calculated from a mass balance on downstream gaged flows, change in storage, and reservoir evaporation. Old Exchequer Dam is operated to meet average 1936-1945 flows in Merced ID North and Main Canals, as well as Cowell Agreement flows. Releases for Merced ID canal diversions are allocated in April of each year, based on forecasted April through September water supplies. Flood control rules are based on the maximum historical storage in Old Exchequer Dam.
- **1960 LOD**: As 1940 LOD, with Old Exchequer Dam operated to meet 1956-1965 average demands in Merced ID North and Main Canals.

- **1980 LOD**: Simulated storage regulation in Lake McClure and New Exchequer Dam, plus accretions between Exchequer and Crocker-Huffman diversion dam, less diversions to Merced ID North Canal. New Exchequer Dam is operated to meet flood control requirements, downstream agricultural demands, based on 1976-1985 the North and Main Canal flows, and instream flow requirements as specified in the Cowell Agreement and Davis-Grunsky Agreement.
- **2000 LOD**: As 1980 LOD, except water based on 1996-2005 historical North Canal and Main Canal flows, as well as new FERC flow requirements and VAMP flows.
- **2010 LOD**: As 1980 LOD, except water based on 2000-2009 historical North Canal and Main Canal flows, FERC flow requirements, and required flows under the Memorandum of Understanding with the California Department of Fish and Game.

Bear Creek Group

The Bear Creek group of streams, usually referred to as the Merced Stream Group, are located south of the Merced River. The group includes Bear Creek, Burns Creek, Mariposa Creek, and Owens Creek. The creeks drain the foothills of Mariposa County. Flows are unregulated except for temporary storage in flood detention basins. Historical flow data are available from USACE at the outlet from these basins. Historical streamflow data was extended through linear regression with Fresno River near Knowles (USGS 11257500). For all levels of development, C2VSim inflows were set equal to the (estimated) historical flows.

Deadman Creek

Deadman Creek is located south of Mariposa Creek and is typically considered as one of the Merced Stream Group. No gage data are available other than for 1942. Inflows from the watershed were estimated by scaling flows for the Chowchilla River at the Buchanan dam site/Eastman Lake inflows (USGS 11259000) using factors to account for differences in watershed drainage area and precipitation. For all levels of development, C2VSim inflows were set equal to the (estimated) historical flows.

Chowchilla River

The Chowchilla River watershed is located in Madera and Mariposa counties, south of the Merced Stream Group and north of the Fresno River. River flows are regulated by Buchanan Dam and Eastman Lake, which has a gross capacity of 150,000 acre-feet. The dam was completed in 1975 by USACE for both flood control and water supply purposes. Historical streamflow data are available for Chowchilla River near Raymond (USGS 1125890) are available for water years 1971 – 1980. Reservoir inflow, release, storage and evaporation data are available from USACE beginning October 1975. Flow records before this date typically cover a relatively short period. Unimpaired flows at the dam site were extended through linear correlation with the Fresno River near Knowles (USGS 11257500).

The C2VSim inflow represents the Chowchilla River below the dam or dam site. These inflows were estimated as follows:

- **1900 LOD**: Full natural Chowchilla River flow at dam site.
- **1920 LOD**: As 1900 LOD
- **1940 LOD**: As 1900 LOD
- **1960 LOD**: As 1900 LOD
- **1980 LOD**: Releases from Buchanan Dam as simulated by the *D1485* CalSim II model (arc C53).
- **2000 LOD**: Releases from Buchanan Dam as simulated by the *D1641wTrinityROD* CalSim II model (arc C53).

- **2010 LOD**: Releases from Buchanan Dam as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C53).

Fresno River

The watershed of the Fresno River is located in Madera County, located between the Chowchilla and San Joaquin rivers. It includes Hidden Dam and Hensley Lake, which has a gross capacity of 90,000 acre-feet. The dam was completed in 1975 by USACE to provide flood protection to the City of Madera and adjacent agricultural lands and for water supply. Historical streamflow data are available both upstream and downstream from Hidden Dam. Data for Fresno River near Knowles (USGS 11257500) are available for water years 1911 – 1990. The gage was located approximately 11 miles upstream from Hidden Dam. Data for the Fresno River below Hidden Dam, near Daulton (USGS 11258000) are available for water years 1941 – 1990. The gage was located less than one mile from the dam. Reservoir inflow, release, storage and evaporation data are available from USACE beginning October 1975. Unimpaired flows at the dam site were extended through linear correlation with the Fresno River near Knowles (USGS 11257500).

The C2VSim inflow represents the Fresno River below the dam or dam site. These inflows were estimated as follows:

- **1900 LOD**: Full natural Fresno River flow at dam site.
- **1920 LOD**: As 1900 LOD
- **1940 LOD**: As 1900 LOD
- **1960 LOD**: As 1900 LOD
- **1980 LOD**: Releases from Hidden Dam as simulated by the *D1485* CalSim II model (arc C52).
- **2000 LOD**: Releases from Hidden Dam as simulated by the *D1641wTrinityROD* CalSim II model (arc C52).
- **2010 LOD**: Releases from Hidden Dam as simulated by the *DRR2013_Existing_FullDem* CalSim II model (arc C52).

San Joaquin River

The C2VSim inflow for the San Joaquin River represents the river flow below Friant Dam, or below the dam site. These inflows were estimated as follows:

- **1900 LOD**: Full natural flow of the San Joaquin River at Millerton, as published by CDEC.
- **1920 LOD**: Simulated inflow from modified USAN model for 1920 LOD, which impairs the full natural flow at Friant to account for storage regulation in Huntington Lake, Shaver Lake, and Bass Lake. Storage in these lakes began in 1912, 1927, and 1910.[30]
- **1940 LOD**: Simulated inflow from modified USAN model for 1940 LOD, which impairs the full natural flow at Friant to account for storage regulation in Florence Lake, Huntington Lake, Shaver Lake, and Bass Lake. Storage in Florence Lake began in 1925.
- **1960 LOD**: Simulated storage regulation in Millerton Lake. Reservoir inflow is from the modified USAN model for 1960-2010 LODs, which impairs the full natural flow at Millerton to account for storage regulation in Lake Thomas Edison, Florence Lake, Huntington Lake, Shaver

[30] The original dam for Bass Lake was built in 1896, but was enlarged in 1910.

Lake, Mammoth Pool, and Bass Lake. Millerton Lake releases to the San Joaquin River are made to meet CalSim II assumed depletions (diversions plus seepage and evaporation losses) between Friant Dam and Gravely Ford (in the form of a repeating monthly pattern which is the same for each LOD), as well as flood operations which account for the Mammoth Pool Credit (required Millerton flood space is reduced based on available storage in Mammoth Pool) and conditional flood releases based on forecasted inflows and demands. The model is linked to the 1960 LOD model of Delta operations Shasta and Folsom Reservoirs, such that the demand for Delta exports is reduced by the monthly volume of Millerton flood spills diverted at Mendota Pool (equal to the smaller of either the demands at Mendota Pool or the total Millerton flood spill).

Releases are also made to the Friant-Kern and Madera Canals based on 1976-1985 average canal flows, and an allocated annual supply based on an assumed carryover target for Millerton Lake. Friant-Kern Wasteway deliveries to the Kings, Tule, Kaweah, and Kern Rivers are based on the total simulated release from Millerton to the Friant-Kern Canal, and a correlation between the historical flow at the head of the FKC and historical deliveries to each river (historical delivery records from original C2VSim inflow data).

- **1980 LOD**: Simulated storage regulation in Millerton Lake/Friant Dam. Reservoir inflow is from the modified USAN model for 1960-2010 LODs, which impairs the full natural flow at Millerton to account for storage regulation in Lake Thomas Edison, Florence Lake, Huntington Lake, Shaver Lake, Mammoth Pool, and Bass Lake. Millerton Lake releases to the San Joaquin River are made to meet CalSim II assumed depletions (diversions plus seepage and evaporation losses) between Friant Dam and Gravely Ford (in the form of a repeating monthly pattern which is the same for each LOD), as well as flood operations which account for the Mammoth Pool Credit (required Millerton flood space is reduced based on available storage in Mammoth Pool) and conditional flood releases based on forecasted inflows and demands. Releases are also made to the Friant-Kern and Madera canals to meet water demands based on 1976-1985, and an allocated annual supply based on an assumed carryover target for Millerton Lake.
- **2000 LOD**: As 1980 LOD, with Millerton Lake/Friant Dam operated to meet water demands based on 1996-2005 deliveries to the Friant-Kern and Madera canals.
- **2010 LOD**: As 1980 LOD, with Millerton Lake/Friant Dam operated to meet water demands based on 2000-2009 deliveries to the Friant-Kern and Madera canals.

Southern San Joaquin Valley

This sections briefly describes the spreadsheet models used to provide C2VSim inflow data for the southern portion of the San Joaquin Valley at each level of development. This part of the valley, known as the Tulare Lake region, is internally drained by the Kings, Kaweah, Tule, and Kern rivers. Historically, these rivers flowed into the former Tulare, Buena Vista, and Kern lakes. Streamflows in the Tulare Lake region do not directly affect flows in the San Joaquin River, except in wetter years when floodwater flows from the Kings River through the James Bypass into the Mendota Pool. Additionally, there may be some subsurface groundwater flow from the Tulare Lake basin to the San Joaquin River basin. Streamflows in the Tulare Lake basin are only of minor importance to the Study. Therefore, less effort was directed towards developing spreadsheet models for the four major rivers and the resulting spreadsheet models remain coarse and approximate.

Kings River

The Kings River originates in the Sierra Nevada mountains in and around Kings Canyon National Park. The watershed has been developed for both hydropower and water supply purposes. As part of the Kings

River Project, PG&E completed the construction of Courtright and Wishon dams in 1958 for power generation. In the foothills, the river is impounded by Pine Flat Dam before flowing onto the valley floor south of the City of Fresno. Pine Flat Dam was completed in 1954 by USACE for flood control and water supply purposes.

C2VSim input data for the Kings River represent the river flows below Pine Flat Dam (USGS 11221500). These inflows were estimated as follows:

- **1900 LOD**: Unimpaired Kings River flow at Pine Flat Dam as computed by DWR and published on CDEC (ID = KFG).
- **1920 LOD**: As 1900 LOD.
- **1940 LOD**: As 1900 LOD (storage regulation in Black Rock Reservoir, completed in 1927, is ignored).
- **1960 LOD**: Unimpaired Kings River flows at Pine Flat Dam adjusted for simulated storage regulation in Courtright, Pine Flat, and Wishon reservoirs; reservoir evaporation is ignored.
- **1980 LOD**: As 1960 LOD.
- **2000 LOD**: As 1960 LOD.
- **2010 LOD**: As 1960 LOD.

Little effort was made to accurately simulate storage regulation in Pine Flat Lake as downstream river flows have limited effect on inflows to the Delta.

Kaweah River

The Kaweah River watershed is located in Tulare County, south of the Kings River. In the foothills, the river is impounded by Kaweah Dam before flowing onto the valley floor north-east of the City of Visalia. Kaweah Dam was completed in 1962 by USACE for flood control and water supply purposes.

The C2VSim input data for the Kaweah River represent the river flows below Terminus Dam (USGS 11210950). These inflows were estimated as follows:

- **1900 LOD**: Unimpaired for Kaweah River at Kaweah Dam, as computed by DWR and published on CDEC (ID=KWT)
- **1920 LOD**: As 1900 LOD.
- **1940 LOD**: As 1900 LOD.
- **1960 LOD**: As 1900 LOD.
- **1980 LOD**: Simulated releases from Kaweah Dam, are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 1976-1985; reservoir evaporation is ignored.
- **2000 LOD**: As 1980 LOD, except releases from Kaweah Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 1996-2005.
- **2010 LOD**: As 1980 LOD, except releases from Kaweah Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 2000-2009.

Little effort was made to accurately simulate storage regulation in Lake Kaweah as downstream river flows have limited effect on inflows to the Delta.

Tule River

The Tule River watershed is located in Tulare County, south of the Kaweah River. Success Dam, located at the junction of the north and south forks was completed by the USACE in 1961 for flood control and water supply purposes. Downstream, the river flows onto the valley floor near the City of Porterville.

The C2VSim input data for the Tule River represent the river flows below Success Dam (USGS 11204900). These inflows were estimated as follows:

- **1900 LOD**: Unimpaired Tule River at Success Dam, as computed by DWR and published on CDEC (ID=KWT) and extended by correlation.
- **1920 LOD**: As 1900 LOD.
- **1940 LOD**: As 1900 LOD.
- **1960 LOD**: As 1900 LOD.
- **1980 LOD**: Releases from Success Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 1976-1985; reservoir evaporation is ignored.
- **2000 LOD**: as 1980 LOD, except releases from Success Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 1996-2005.
- **2010 LOD**: as 1980 LOD, except releases from Success Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 2000-2009.

Little effort was made to accurately simulate storage regulation in Lake Success as downstream river flows have limited effect on inflows to the Delta.

Kern River

The Kern River is the most southerly of the four rivers represented in C2VSim in the southern San Joaquin Valley. The river is impounded by Lake Isabella and Dam. The dam was built by USACE for flood control and water supply purposes, and completed in 1961. Downstream, the river flows onto the valley floor near the City of Bakersfield.

The C2VSim input data for the Kern River represent the river flows near Bakersfield (USGS 11194000). These inflows were estimated as follows:

- **1900 LOD**: Unimpaired Kern River near Bakersfield, as computed by DWR and published on CDEC (ID=KWT) and extended by correlation.
- **1920 LOD**: As 1900 LOD.
- **1940 LOD**: As 1900 LOD.
- **1960 LOD**: Flows near Bakersfield are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage in Lake Isabella, 1976-1985.

- **1980 LOD**: As 1960 LOD, except releases from Isabella Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 1976-1985.
- **2000 LOD**: As 1960 LOD, except releases from Isabella Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 1996-2005.
- **2010 LOD**: As 1960 LOD, except releases from Isabella Dam are calculated as the unimpaired flows less storage regulation based on the average monthly change in historical storage, 2000-2009.

Little effort was made to accurately simulate storage regulation in Lake Isabella as downstream river flows have limited effect on inflows to the Delta.

Other Inflow Data

In addition to streamflows at the model domain boundary, C2VSim inflow data include canal flows that originate outside of the model domain, but discharge to the C2VSim stream network. Canal inflows include deliveries from the Friant-Kern Canal and the Cross Valley Canal.

Friant-Kern Canal

The Friant-Kern Canal, part of CVP Friant Division, was completed in 1951. The canal conveys water from Millerton Lake to agricultural lands in the Tulare Lake region. Deliveries are made through a series of wasteways from the canal to the Kings, Tule, Kaweah, and Kern rivers.

C2VSim canal inflows to the four rivers for the 1900-, 1920-, and 1940 LOD are zero. Canal inflows for the 1960-, 1980-, 2000-, and 2010 LOD are taken from a spreadsheet model of Millerton Lake. The model calculates the releases from the lake into the head of the Friant-Kern Canal for each level of development. Subsequently, flows from the Friant-Kern Canal wasteways to the Kings, Tule, Kaweah, and Kern Rivers are calculated based on historical flow at the head of the canal compared to the historical discharge to each river.

Cross Valley Canal

The Cross Valley Canal was constructed by Kern County Water Agency in 1975 to convey CVP and SWP water from the California Aqueduct to the City of Bakersfield for M&I water supply and for irrigation of agricultural lands in the east of the county. Some of the canal water is discharged into the Kern River for downstream diversion.

The C2VSim canal flows for the Cross Valley Canal for the 1900-, 1920-, 1940-, and 1960 LOD are zero. Canal flows for the 1980-, 2000-, and 2010 LOD are taken from CalSim II, as represented by model arc D855. Based on C2VSim historical data, it is assumed that 8 percent of Cross Valley Canal flows are discharged into the Kern River.

Chapter 7
Model Results

This chapter summarizes C2VSim model results for the seven levels of development. These results do not account for the effects of climate change, which is the subject of Chapter 8.

C2VSim Output Files

All model results are contained in the C2VSim budget files (*.bud) and output (*.out) files, located in the *C2VSim\results folder*. Key files are described in the sections below.

Streamflow Budget, CVstream.bud

In C2VSim, each reach of a river is assigned to one of 21 subregions. Stream budget information is reported by subregion in the CVstream.bud file. The last table, labeled ‘subregion 22’, presents values for the entire model domain. The stream budget components are: (a) the upstream and downstream flows at the boundary of the subregion; and (b) the interior inflows and outflows to the stream, including surface runoff (including flows from small watersheds outside the model domain), surface water diversions and return flows, inflows and outflows to flood bypasses, flows to and from groundwater. The CVstream.bud file also lists any unmet irrigation demands, reported as a diversion shortage (Brush and Dogrul, 2013).

Stream Reach Budget, CVstreamrch.bud

CVstreamrch.bud lists the outflows for each of 75 pre-defined stream reaches. Stream reaches in the vicinity of the Delta are shown in **Figure 7-1**. The layout of each table is identical to the CVstream.bud file (Brush and Dogrul, 2013).

Sacramento River at Freeport

C2VSim stream Reach 65 represents the Sacramento River from the Feather to the American confluences. Reach 66 represents the lower American River. Reach 67 represents the lower Sacramento River between the American River and the inflow from Cache Slough. The sum of the outflows from Reach 65 and Reach 66 equals the headflow in Reach 67. The confluence of the American and Sacramento rivers is represented by a group of 3 stream nodes: 373, 380, and 381. Node 384 represents the Sacramento River below Freeport (i.e., below the USGS gage 11447650 and the wastewater treatment discharge). The Sacramento River flow at Node 384, as output to the file *CVSWhyd.out*, is on average 679 TAF per year less than the headflow in Reach 67. This decrease in flow is caused by: (a) the bias correction of 666 TAF per year diversion applied at Node 384 in the months of November and December, (b) a second bias correction of 1,125 TAF per year applied for the 1900, 1920, and 1940 LODs, and (c) diversions by the City of Sacramento at Node 381.

Yolo Bypass at the Lisbon Weir

C2VSim stream Reach 68 represents lower Cache Creek and the Yolo Bypass from the mouth of the creek to the confluence with Putah Creek. Reach 69 represents lower Putah Creek. Reach 70 represents the Yolo Bypass downstream from Putah Creek and subsequently Cache Slough. The sum of the outflows from Reach 68 and Reach 69 equals the headflow in Reach 70. The confluence of Putah Creek and Yolo Bypass is represented by a group of 3 stream nodes: 399, 405, and 406. Node 378 in Reach 68 represents

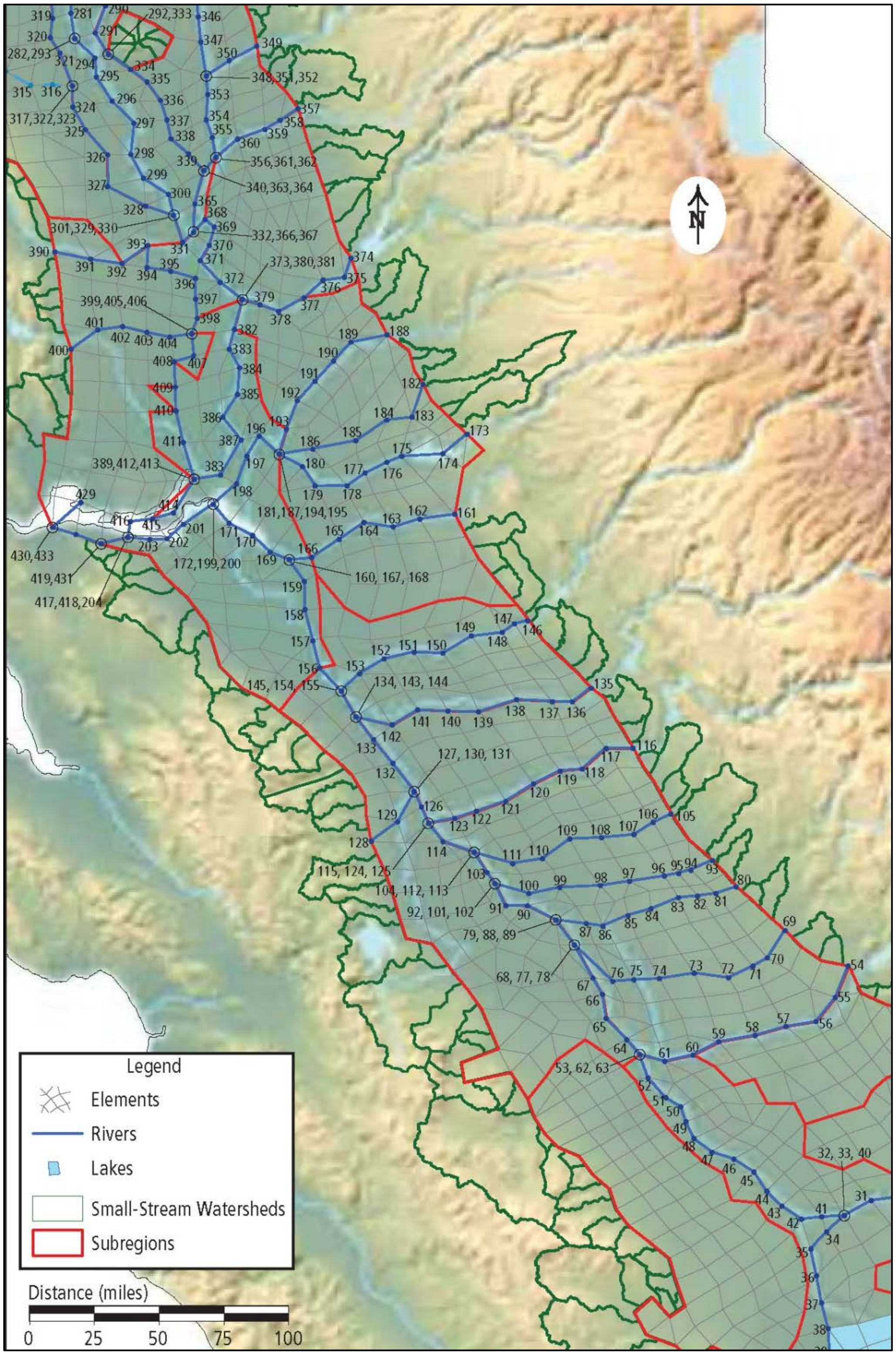

Figure 7-1. C2VSim Stream Network and Stream Nodes in the Vicinity of the Sacramento-San Joaquin Delta

Reproduced from Integrated Water Flow Model IWFM v3.02. User's Manual (Brush and Dogrul, 2013).

the gaged flow Yolo Bypass near Woodland (USGS 11453000). Simulated inflow from the Sacramento Weir enters Reach 68 at Node 397. Node 406 in Reach 70 represents the Lisbon Weir.

San Joaquin River near Vernalis

C2VSim stream Reach 22 represents the San Joaquin River from the Tuolumne to the Stanislaus confluences. Reach 23 represents the lower Stanislaus River. Reach 24 represents the lower San Joaquin River between the Stanislaus and Calaveras rivers. The sum of the outflows from Reach 22 and Reach 23 equals the headflow in Reach 24. The confluence of the Stanislaus and San Joaquin rivers is represented by a group of 3 stream nodes: 145, 154, and 155. Node 155 also represents the San Joaquin River near Vernalis (USGS 11303500). The San Joaquin River flow at Node 155, as output to the file *CVSWhyd.out*, is on average 13 TAF/year greater than the headflow in Reach 24 because of minor river accretions between the mouth of the Stanislaus River at Node 155.

Surface Water Deliveries, CVdiverdtl.bud

Information relating to stream diversions and deliveries is listed in the *CVdiverdtl.bud*. Diversion information is reported by subregion; no table is produced for the entire model domain. Diversions are listed by diversion number and associated stream node. A river node value of zero for a delivery indicates the water was imported from outside the model domain; a river node value for a diversion indicates water was exported to an area outside the model domain (Brush and Dogrul, 2013).

Groundwater Budget, CVground.bud

Information on groundwater flows and storage is reported in the *CVground.bud* file. This information is reported by subregion, and for the entire model domain (table labeled ‘subregion 22’). The groundwater budget includes the groundwater storage at the beginning and end of each timestep. Inflows to groundwater include vertical recharge from precipitation and irrigation, seepage from streams, and lateral flows from adjacent groundwater basins or small watersheds outside of the model domain. Inflows also include water from injection wells, which is reported as ‘recharge’. Vertical recharge from precipitation and irrigation is divided into deep percolation form the root zone to the unsaturated zone, and net deep percolation from the unsaturated zone to the groundwater. Outflows from groundwater include groundwater pumping, discharge to streams, and lateral flow to adjacent groundwater basins (Brush and Dogrul, 2013).

Land and Water Use Budget, CVlandwater.bud

Model results from the land surface hydrology simulation are reported in the file *CVlandwater.bud*. This file contains 21 subregion tables, and a summary table for the entire model domain (subregion 22). Information is presented by land use category: agriculture and urban. The tables report only information related to developed water and not precipitation, so that the native vegetation category is not considered. For both agriculture and urban categories, the tables present the land use, the water demands (supply requirement), surface water and groundwater supplies, and any water shortage. Because irrigation efficiencies are less than 100 percent, water supplies typically exceed the potential consumptive use of applied water (CUAW), which is also listed. The regional imports are the sum of surface water diversions and groundwater pumping originating outside the subregion or outside the model boundary, and the regional exports are the sum of surface water diversions and groundwater pumping exported to other subregions or outside the model domain (Brush and Dogrul, 2013).

Root Zone Budget, CVrootzn.bud

Model results for the land surface and root zone are reported in the file *CVrootzn.bud*. Results are presented by subregion and for the entire model domain (subregion 22). For each subregion, results are subdivided by land use: agriculture, urban, and native and riparian vegetation. For each land use category, tables list the land area, precipitation, ET, runoff, deep percolation, and beginning and end of storage for each timestep. Additionally, for the agricultural and urban categories, irrigation and M&I waters supplies are reported and associated return flows (Brush and Dogrul, 2013).

Streamflow Hydrograph, CVSWhyd.out

The model user may specify addition print options so as to output monthly timeseries of streamflows at particular stream nodes. These print options are specified in the input file *CVprint.dat* (Brush and Dogrul, 2013). Stream nodes associated with Delta inflows and outflows are listed in **Table 7-1**. The original file was modified so as to output flows at all major locations (e.g., gage locations, Delta boundary flows). For the fixed level of development simulations, a total of 84 locations are specified. These are listed in **Table 7-2**.

Table 7-1. Model Nodes and Arcs Associated with Delta Inflows and Outflows

C2VSim			CalSim II	Description
Stream Node	Groundwater Node	Subregion	Arc	
406	414	6	C157	Yolo Bypass at Lisbon Weir, below Putah Creek confluence
384	451	9	C169	Sacramento River at Freeport plus discharge from Sacramento Regional Wastewater Treatment Plant
385	463	9	C400	Sacramento River at Hood
N/A	N/A	N/A	C401B_DXC	Flow through the Delta Cross Channel
N/A	N/A	N/A	C401B_GEO	Flow through Georgiana Slough
194	479	8	C501	Cosumnes River at mouth
181	479	8	I504	Mokelumne River above Cosumnes River
Diversion No. 86				In-Delta agricultural water use
Diversion No. 87				In-Delta M&I water use
Diversion No's 88, 89, 90			C402B	Barker Slough Pumping Plant
419	530	9	C406	Net Delta outflow
Diversion No 91 (part)			D416	Contra Costa Canal Pumping Plant No. 1
Diversion No 91 (part)			D408_OR	Contra Costa WD intake on Old River
Diversion No 91 (part)			D408_VC	Contra Costa WD intake on Victoria Canal
N/A	N/A	N/A	C408	Old and Middle River
155	615	10	C639	San Joaquin River near Vernalis
167	558	9	C508	Calaveras River at mouth
Diversion No. 92			D418	Jones Pumping Plant
Diversion No. 93			D419	Banks Pumping Plant

Table 7-2. Specified Streamflows for Output

Stream Node	Description	Stream Node	Description
33	Army Weir - Flows to Kings River North Fork	292	Butte Creek outflow
40	Crescent Weir - to Kings River South Fork	298	Sacramento River below Wilkins Slough
53	James Bypass flow to Mendota Pool	301	Sacramento River above Colusa Basin Drain
54	San Joaquin River at Friant	329	Colusa Basin Drain outflow
59	San Joaquin River near Biola	330	Sacramento River at Knights Landing
64	San Joaquin River near Mendota	340	Sutter Bypass Outflow
67	San Joaquin River near Dos Palos	344	Feather River near Gridley
77	Fresno River at mouth	348	Feather River at Yuba City
88	Chowchilla River at mouth	349	Yuba River at Daguerre Point Dam
89	San Joaquin River near El Nido	350	Yuba River at Marysville
115	San Joaquin River at Newman	351	Yuba River at mouth
119	Merced River at Schaffer Bridge	353	Feather River at Olivehurst
122	Merced River near Livingston	357	Bear River below Camp Far West
124	Merced River at Stevinson	359	Bear River at Wheatland
130	Orestimba Creek at River Road	361	Bear River at mouth
131	San Joaquin River at Crows Landing	363	Feather River near Nicolaus
135	Tuolumne River at La Grange Dam	366	Feather River at mouth
141	Tuolumne River at Merced	367	Sacramento River below Fremont Weir
143	Tuolumne River at mouth	369	Sacramento River at Verona
144	San Joaquin River below Tuolumne	374	Folsom Dam Release
146	Stanislaus River below Goodwin	375	American River below Natomas
153	Stanislaus River at Ripon	376	American River at Fair Oaks
154	Stanislaus River at mouth	379	American River at Sacramento
155	San Joaquin River near Vernalis	384	Sacramento River at Freeport
156	San Joaquin River at Vernalis	385	Sacramento River at Hood
167	Calaveras River at mouth	389	Sacramento River Upstream of Cache Slough
179	Mokelumne River at Woodbridge	393	Cache Creek at Yolo
181	Mokelumne River above Cosumnes	396	Yolo Bypass near Woodland
186	Dry Creek near Galt	399	Yolo Bypass above Putah Creek
187	Dry Creek at mouth	401	Putah Creek at Winters
192	Cosumnes River at McConnell	403	Putah Creek at Davis
194	Cosumnes River at mouth	405	Putah Creek near Davis
204	San Joaquin River u/s from CVP/SWP Exports	406	Yolo Bypass below Putah Creek
205	Sacramento River at Keswick	412	Yolo Bypass above Cache Slough
224	Sacramento River above Bend Bridge	413	Sacramento River below Cache Slough
230	Sacramento River at Red Bluff	414	Sacramento River above Rio Vista
259	Sacramento River at Vina	417	Sacramento River u/s from CVP/SWP Exports
261	Sacramento River at Hamilton	418	Delta d/s from CVP/SWP Exports
267	Stony Creek near Hamilton City	419	Delta Outflow
275	Sacramento River at Ord Ferry	430	Suisun Marsh
279	Sacramento River at Butte City	432	SJR TO Carquinez Straight
282	Sacramento River at Colusa	433	Model Outflow

Key: u/s = upstream, d/s = downstream, CVP = Central Valley Project, SWP = State Water Project

Average Annual Flows

Figure 7-2 presents long-term average annual Delta inflows and outflows for each level of development. The level of development is plotted on the x-axis. These flows are discussed in the following sections.

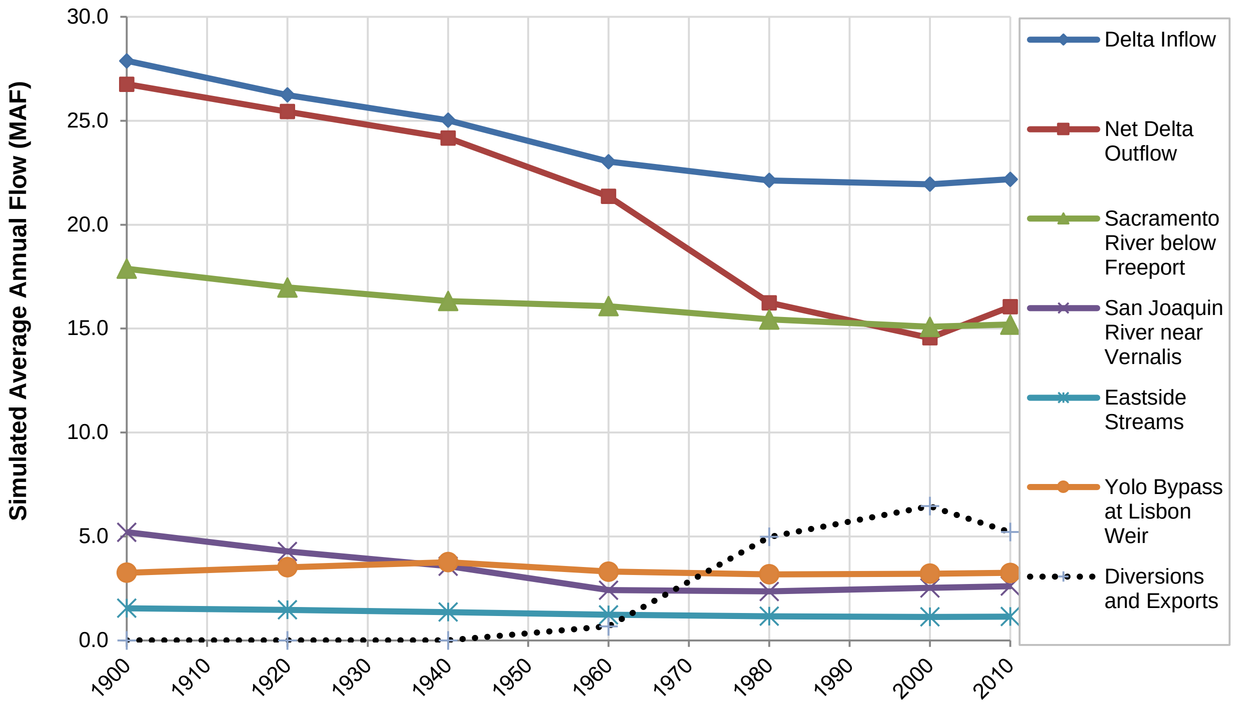

Figure 7-2. Average Annual Simulated Flows at Different Levels of Development

Sacramento below Freeport

Figure 7-2 presents the long-term average annual flows for the Sacramento River below Freeport. Simulated long-term flows decrease from 17.6 MAF to 15.1 MAF across the seven levels of development. This gradual reduction is due to the increase in irrigated agricultural on the valley floor, and to a lesser extent increased evaporative losses from reservoirs in the upstream watersheds. For the 1980, 2000, and 2010 LODs, Sacramento River flows are supplemented by Trinity River water. Average annual imports from Lewiston Dam through Clear Creek Tunnel are 0.8 MAF, 0.5 MAF, and 0.5 MAF, respectively.

Yolo Bypass at Lisbon Weir

Figure 7-2 presents the long-term average annual flows for the Yolo Bypass downstream from its confluence with Putah Creek, and just upstream from the Lisbon Weir. Flows are primarily flood flows, and consist of water diverted through the Knights Landing Ridge, water spilled over the Fremont and Sacramento weirs, and inflows from Cache Creek and Putah Creek. The Knights Landing Ridge Cut was completed in 1915 as an outlet for Colusa Basin flood water during periods of high river stage in the Sacramento River. The Fremont Weir was built in 1924. The Sacramento Weir was built in 1916. Flows through flood bypasses are not modeled dynamically in C2VSim, but are inputs to the model. For modeling purposes, flood flows directed through the ridge cut and spills over the weirs are assumed to be equal to the historical flows for all levels of development. Flows in the Yolo Bypass have diminished over time because of increased agricultural diversions from Cache Creek, the completion of Indian Valley Dam on the North Fork Cache Creek in 1974, and the completion of Monticello Dam on Putah Creek in 1957 and the associated construction of Reclamation's Solano Project. Simulated long-term average annual flows for the Yolo Bypass at Lisbon Weir decrease from 3.3 MAF to 3.1 MAF across the seven levels of development.

San Joaquin near Vernalis

Figure 7-2 presents the long-term average annual flows for the San Joaquin near Vernalis, where the river enters the Delta. Simulated long-term average annual flows decrease from 6.2 MAF to 3.4 MAF across the seven levels of development. This gradual reduction in flows is caused by growth in upstream exports (e.g., Friant Dam to the Friant-Kern Canal, Hetch Hetchy Dam to the Hetch Hetchy Aqueduct) and increased agricultural water use. Friant Dam, which impounds Millerton Lake, was completed in 1941. At the 2010 LOD exports average nearly 1.1 MAF.

Eastside Streams

The Eastside Streams as modeled in C2VSim include the Calaveras, Cosumnes, and Mokelumne rivers. **Figure 7-2** shows the flow for the Mokelumne River below the mouth of the Cosumnes River, at a point where the river enters the Delta (streamnode 196). Simulated long-term average annual flows slowly decrease from 1.5 MAF to 1.2 MAF across the seven levels of development as diversions for M&I water supply increase (e.g., by EBMUD and Stockton East Water District), and as greater amounts of water are diverted for agricultural purposes (e.g., by Woodbridge Irrigation District and Stockton East Water District). Pardee Dam, on the Mokelumne River was completed in 1929, Camanche Dam, located 10 miles downstream, was completed in 1964. New Hogan Dam on the Calaveras River was completed in 1963.

Delta Net Channel Depletions

Table 7-3 presents a summary of the net channel depletion as calculated by the CU model for each level of development. Average annual values range from a high of 1.1 MAF at the 1900 LOD to 0.8 MAF at the 1920 LOD. These values are approximate only. For the 1900 LOD, it is assumed that the Delta is only partially reclaimed and that unclaimed lands consist of permanent wetlands supplied by precipitation, tidal flows, and groundwater uptake. Areas of reclaimed lands from 1860 through 1930 are reported in Bulletin 27 (DPW, 1931b) .

Table 7-3. Simulated Net Channel Depletions

LOD	Land Use (acres)						Average Annual Flows (MAF)		
	Agriculture	Urban	Native Vegetation	Permanent Wetland	Open Water	Total	Precipitation	Consumptive Use	Net Channel Depletion
1900	243,359	12,065	167,275	206,600	50,400	679,699	0.85	1.98	1.13
1920	408,400	13,900	206,999	0	50,400	679,699	0.85	1.65	0.80
1940	433,000	15,300	180,999	0	50,400	679,699	0.85	1.70	0.85
1960	499,000	19,700	108,599	0	52,400	679,699	0.85	1.85	1.00
1980	461,400	34,310	129,489	0	54,500	679,699	0.85	1.75	0.90
2000	428,335	53,604	143,260	0	54,500	679,699	0.85	1.78	0.93
2010	428,335	53,604	143,260	0	54,500	679,699	0.85	1.78	0.93

Key: LOD = level of development, MAF = million acre-feet

Delta Diversions and Exports

Beginning with the 1960 LOD, CVP exports are part of the Delta flow balance. SWP exports are included in the 1980, 2000, and 2010 LODs. Combined, the CVP and SWP south of Delta exports average 0.7 MAF for the 1960 LOD, 5.8 MAF for the 1980 LOD, 5.6 MAF for the 2000 LOD, and 5.2 MAF for the 2010 LOD. Exports initially grow with increasing export demands and contract amounts, but at the 2000 and 2010 LOD are curtailed to meet Delta flow and salinity standards and biological opinion requirements.

Net Delta Outflow

Net Delta outflow is calculated from a flow balance between Delta inflows, in-Delta net channel depletions, and Delta exports. Net channel depletions are taken from CU models for Delta lowlands and Delta uplands. The average annual net Delta outflow for the 2010 LOD is 16.7 MAF, compared to a CalSim II value of 15.7 MAF. This discrepancy is primarily caused by differences in simulated surface runoff and simulated surface water - groundwater interactions. Of the difference of 1.0 MAF, 0.2 MAF is ascribed to the Sacramento Valley, 0.3 MAF to the San Joaquin Valley, and 0.4 MAF to the eastside streams. The large discrepancy for the eastside streams appears to be partially caused by the omission in CalSim II of inflows from Dry Creek, a tributary of the Mokelumne River.

Delta Inflow Hydrographs

Figures 7-3 and 7-4 compare the magnitude and timing of average monthly Delta inflows (1922–2009) across all level of development simulations. For the purposes of these figures, the inflow from the Sacramento Valley is the sum of flows for the Sacramento River at Freeport, discharge from the Sacramento Regional Wastewater Treatment Plant, and the Yolo Bypass and Toe Drain at the Lisbon Weir. The inflow from the San Joaquin Valley is the flow for the San Joaquin River near Vernalis. Total Delta inflow, as presented in **Figure 7-5**, is the sum of flows from the Sacramento and San Joaquin valleys, as described, combined with inflows from the Cosumnes, Mokelumne, and Calaveras rivers. Other minor inflows, e.g., from Marsh Creek, have been ignored. **Figures 7-6** through **7-10** present total Delta inflows by water year type (D-1641 Sacramento Valley Index). CalSim II data is included in these figures. Discrepancies between CalSim II output and C2VSim output for the 2010 LOD highlight inconsistencies in the modeling approach. Ideally, these discrepancies would be addressed in a further phase of model refinement.

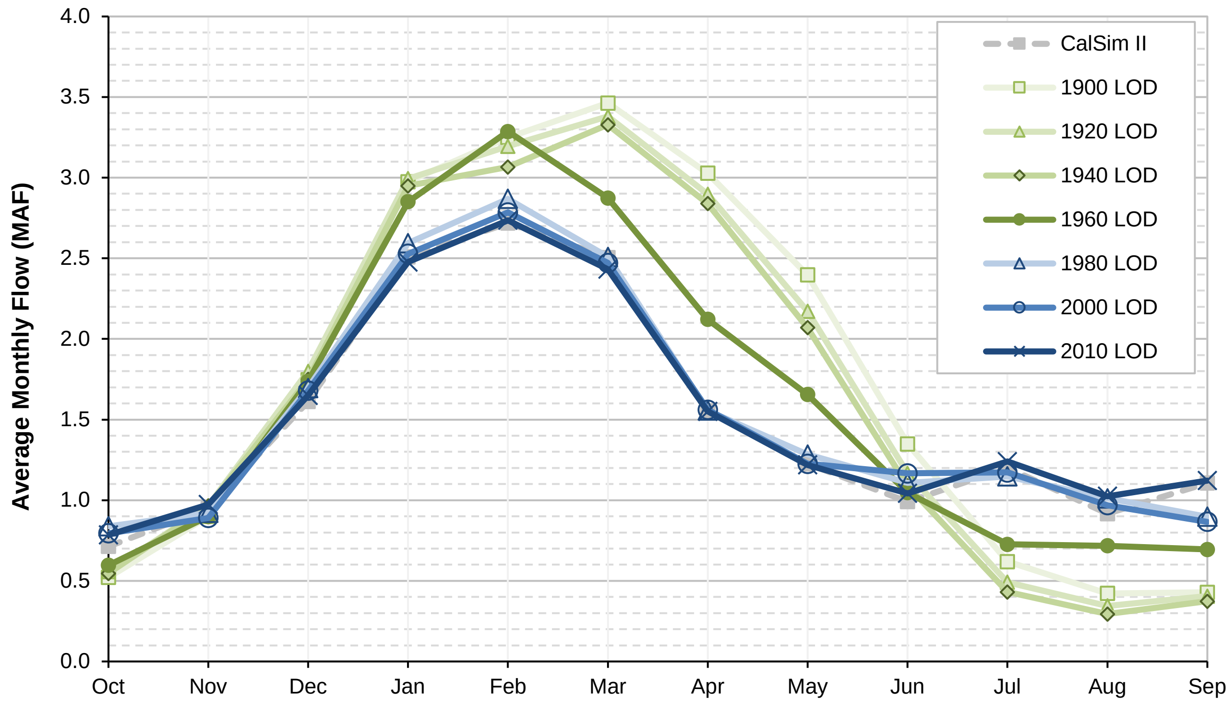

Figure 7-3. Average Monthly Simulated Delta Inflow from Sacramento Valley: All Water Years 1922-2009

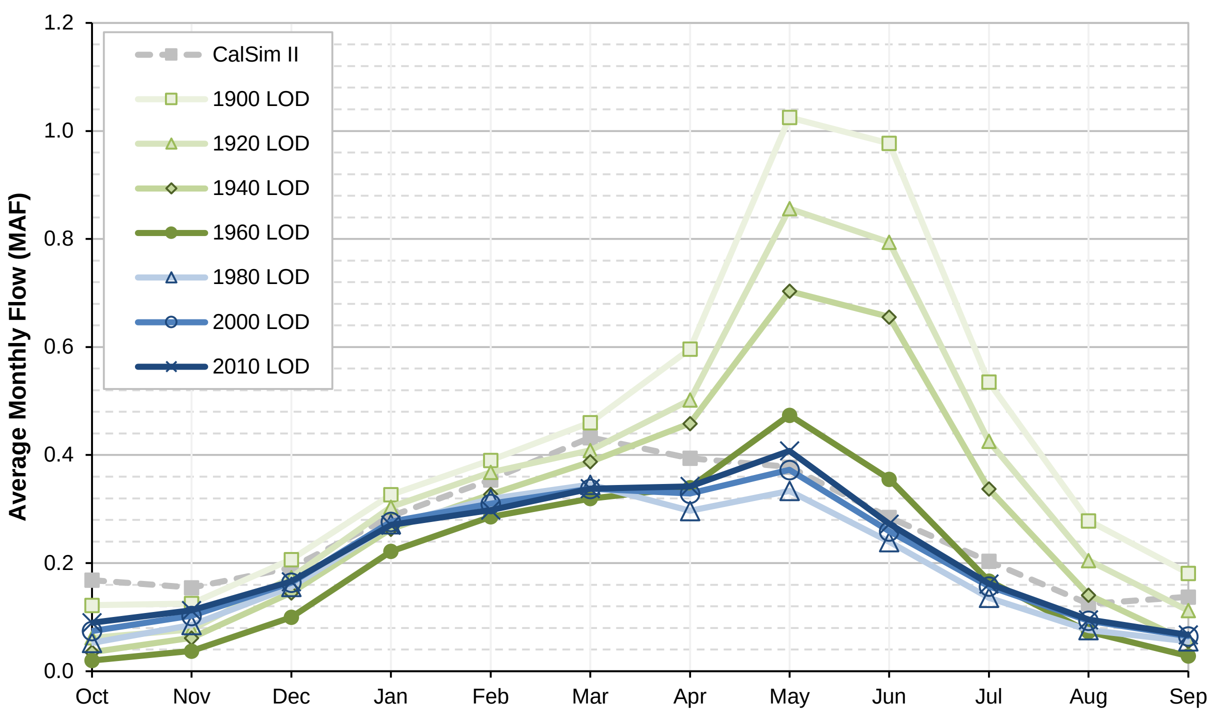

Figure 7-4. Average Monthly Simulated Delta Inflows from San Joaquin Valley: All Water Years 1922-2009

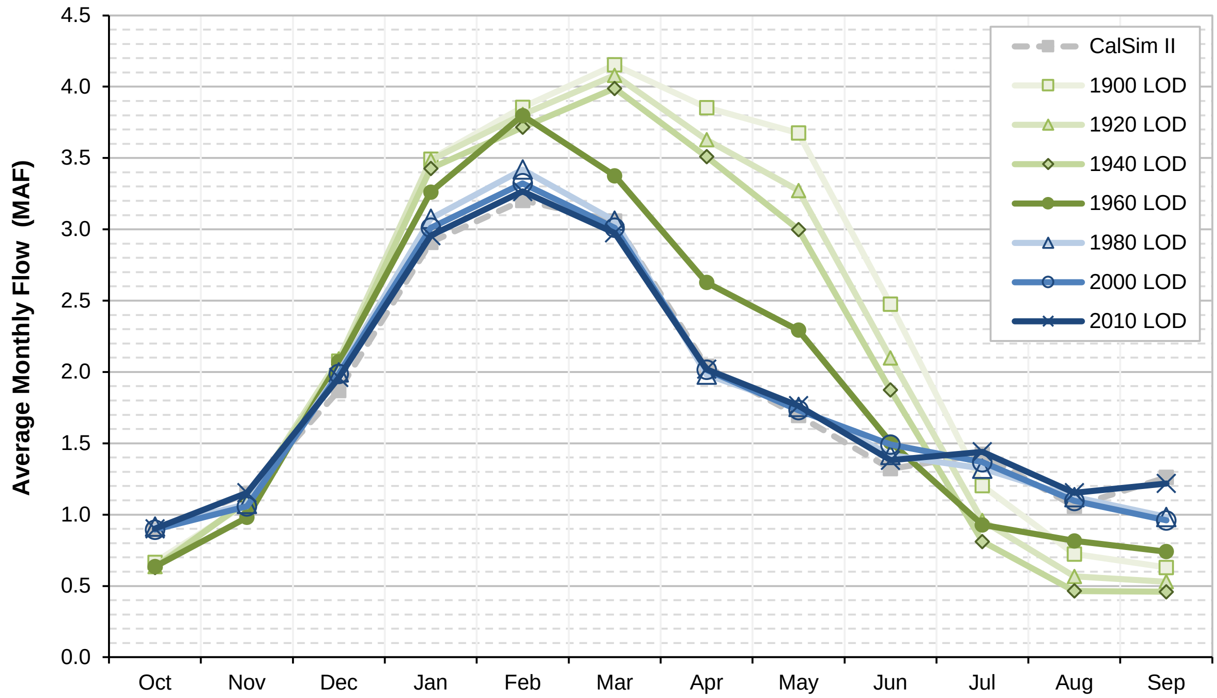

Figure 7-5. Average Monthly Simulated Total Delta Inflow: All Water Years 1922-2009

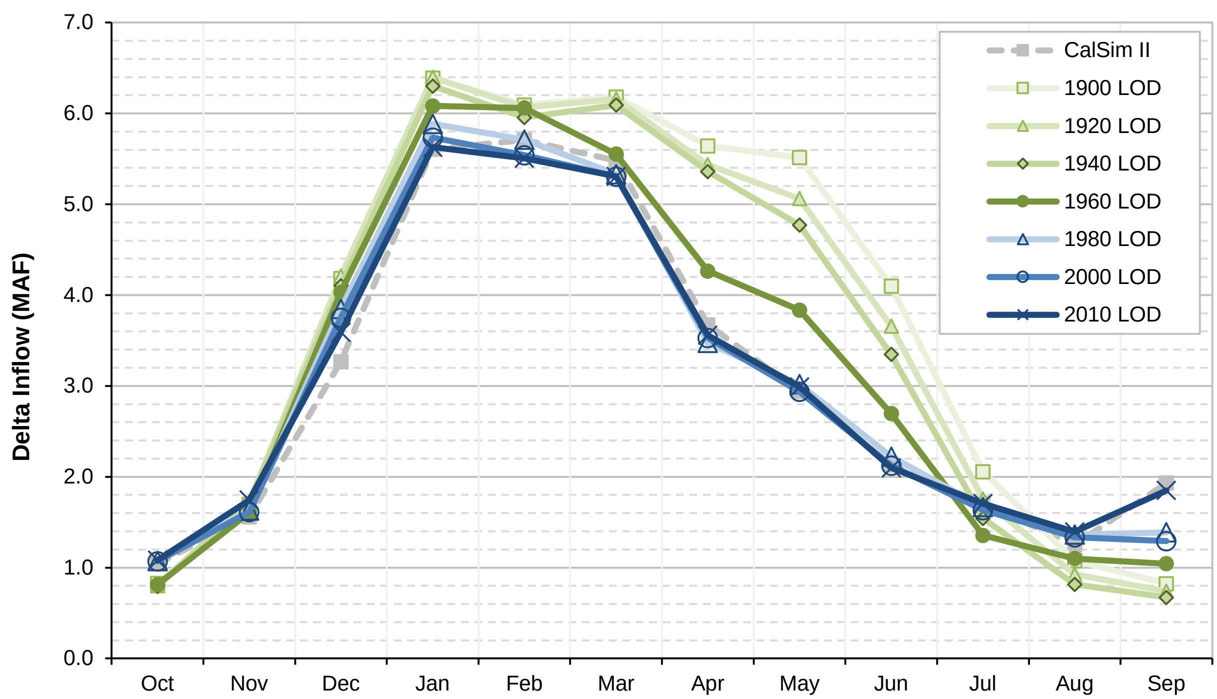

Figure 7-6. Average Monthly Simulated Total Delta Inflow: Wet Water Years 1922-2009

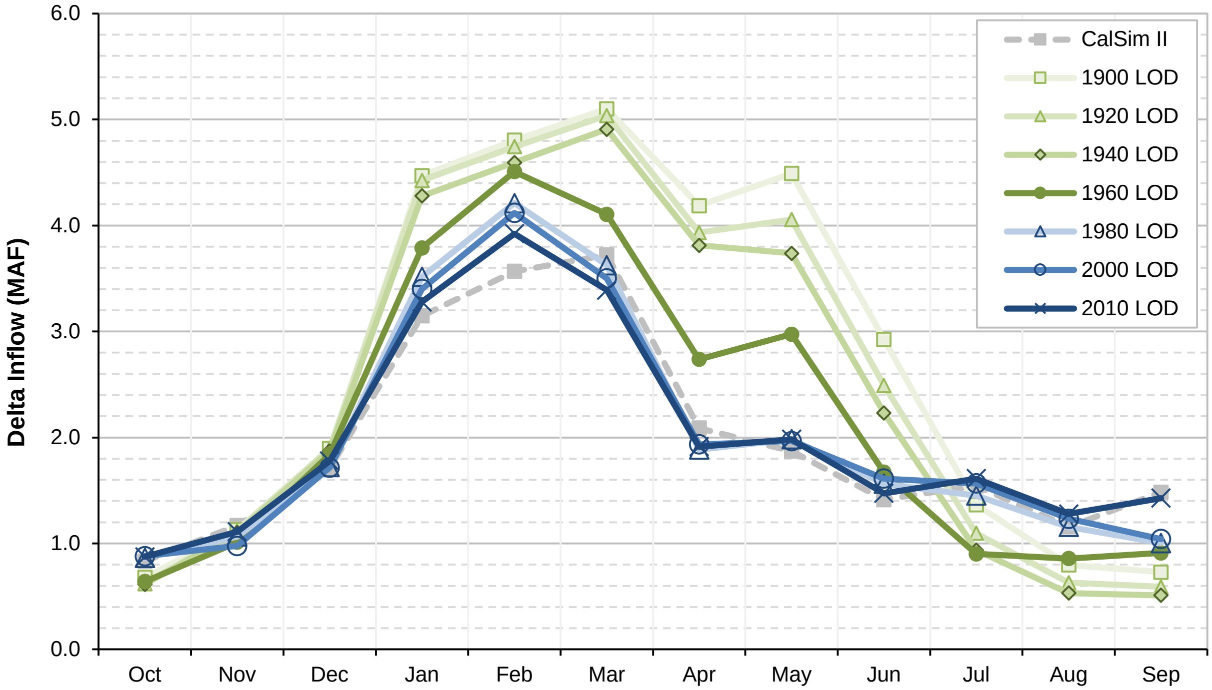

Figure 7-7. Average Monthly Simulated Total Delta Inflow: Above Normal Water Years 1922-2009

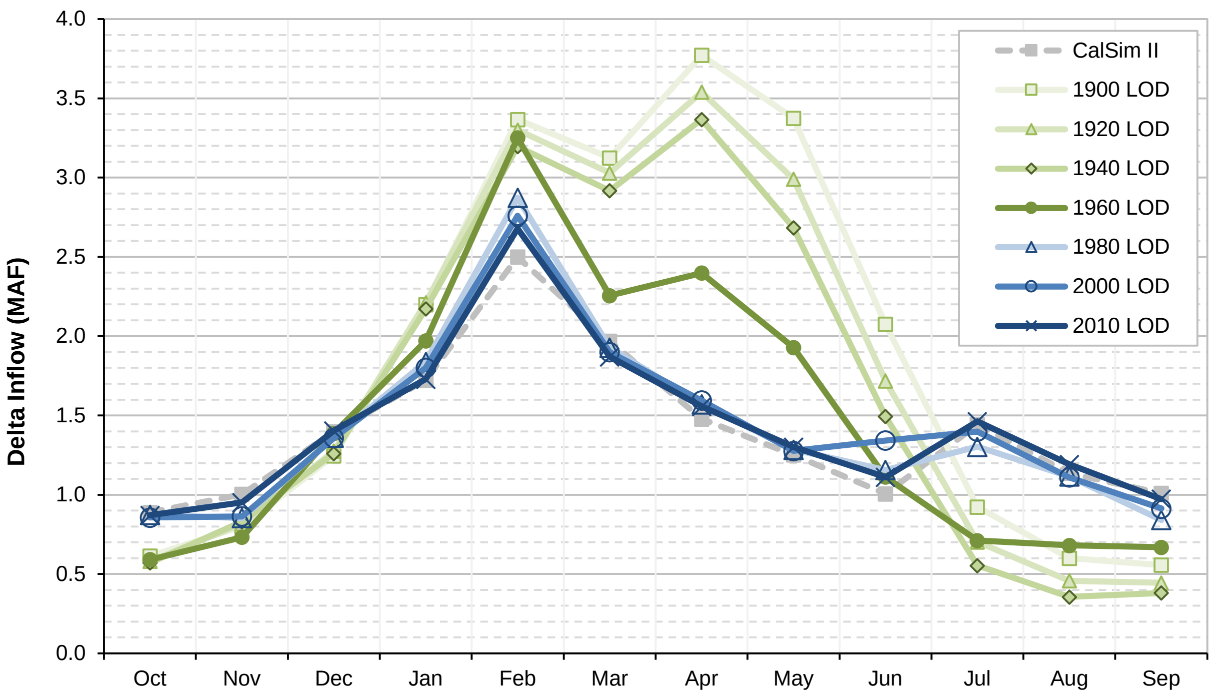

Figure 7-8. Average Monthly Simulated Total Delta Inflow: Below Normal Water Years 1922-2009

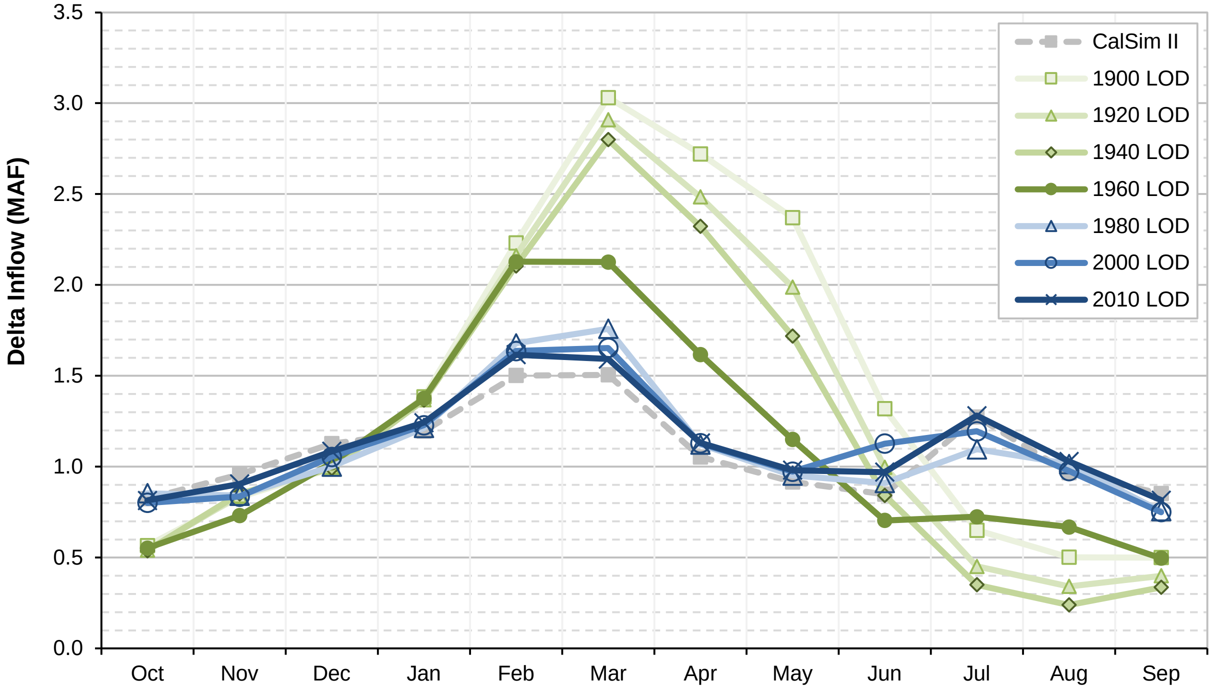

Figure 7-9. Average Monthly Simulated Total Delta Inflow: Dry Water Years 1922-2009

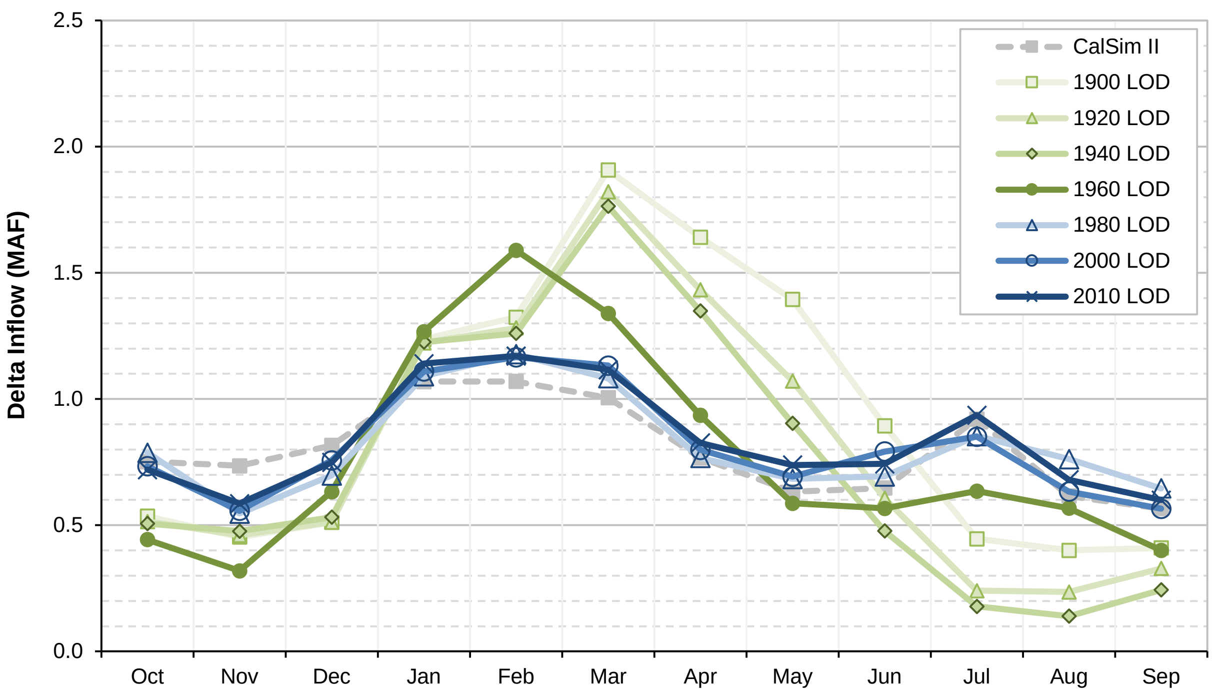

Figure 7-10. Average Monthly Simulated Total Delta Inflow: Critical Water Years 1922-2009

Delta Consumptive Use

Figure 7-11 compares the magnitude and timing of average monthly net channel depletions (1922–2009) across all the level of development simulations.

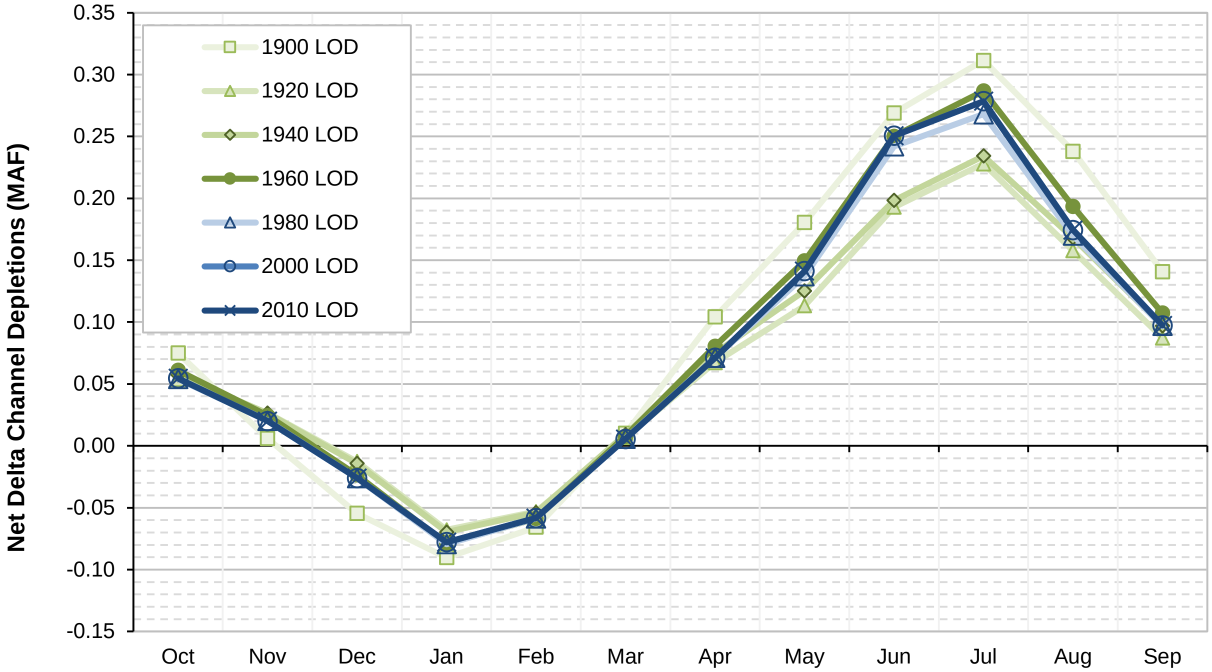

Figure 7-11. Average Monthly Simulated Net Channel Depletions: All Water Years 1922-2009

Delta Outflow Hydrographs

Figure 7-12 compares the magnitude and timing of average monthly net Delta outflows (1922–2009) across all the level of development simulations. **Figures 7-13** through **7-17** disaggregates these flow hydrographs into wet, above normal, below normal, dry, and critical years (D-1641 Sacramento Valley 40-30-30 index). Discrepancies between CalSim II output and C2VSim output for the 2010 LOD highlight inconsistencies in the modeling approach. Ideally, these discrepancies would be addressed in a further phase of model refinement.

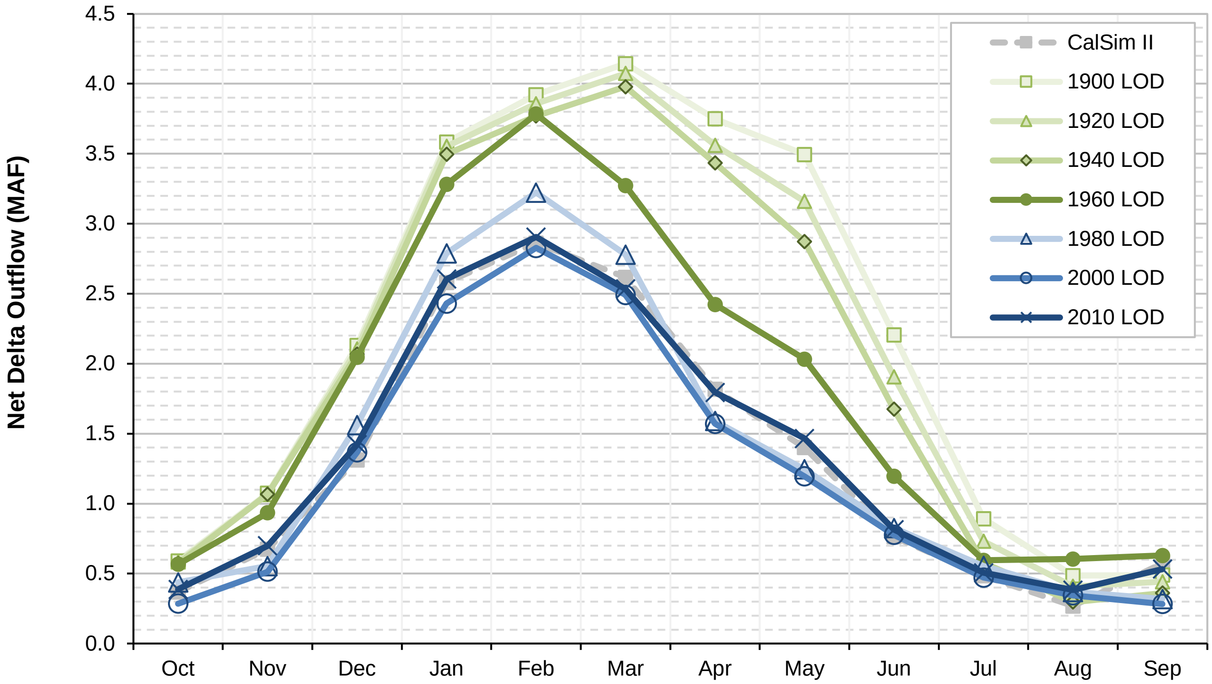

Figure 7-12. Average Monthly Simulated Net Delta Outflow: All Water Years 1922-2009

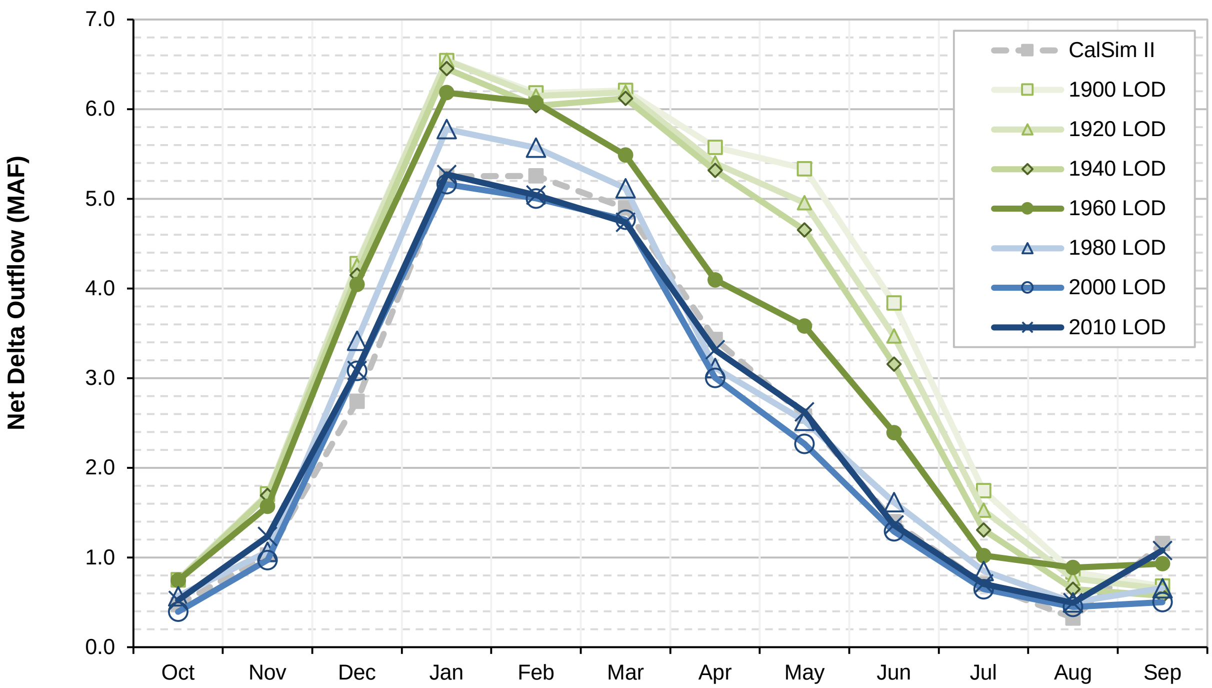

Figure 7-13. Average Monthly Simulated Net Delta Outflow: Wet Water Years 1922-2009

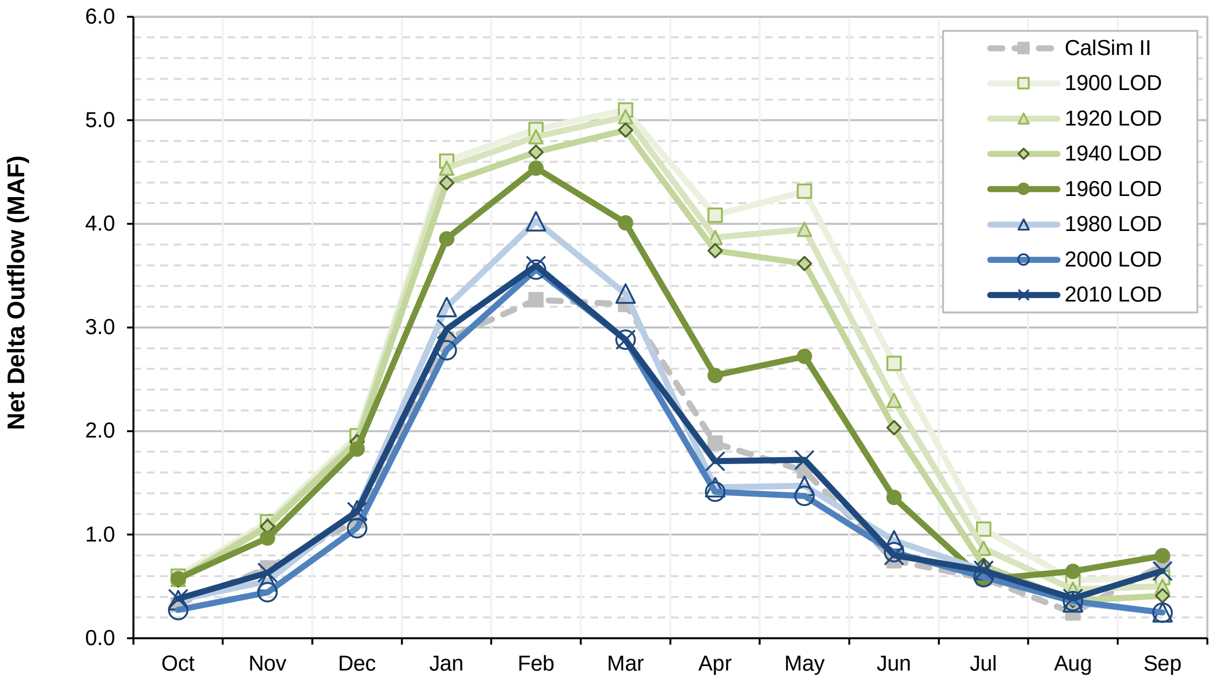

Figure 7-14. Average Monthly Simulated Net Delta Outflow: Above Normal Water Years 1922-2009

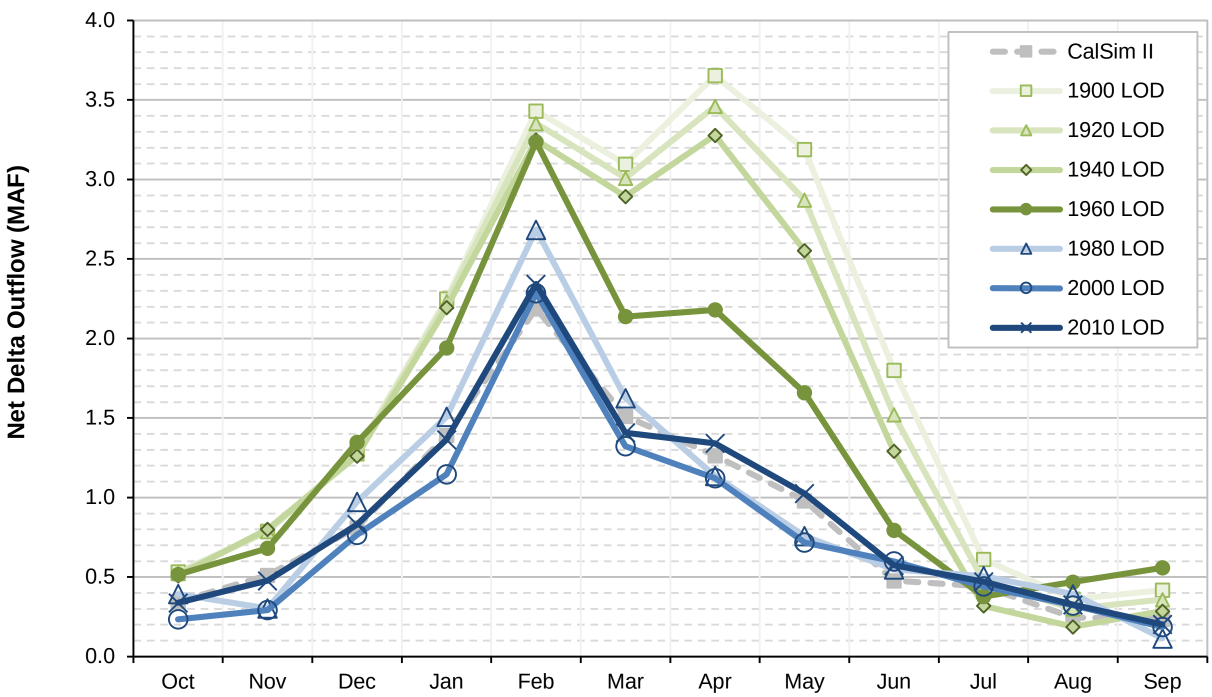

Figure 7-15. Average Monthly Simulated Net Delta Outflow: Below Normal Water Years 1922-2009

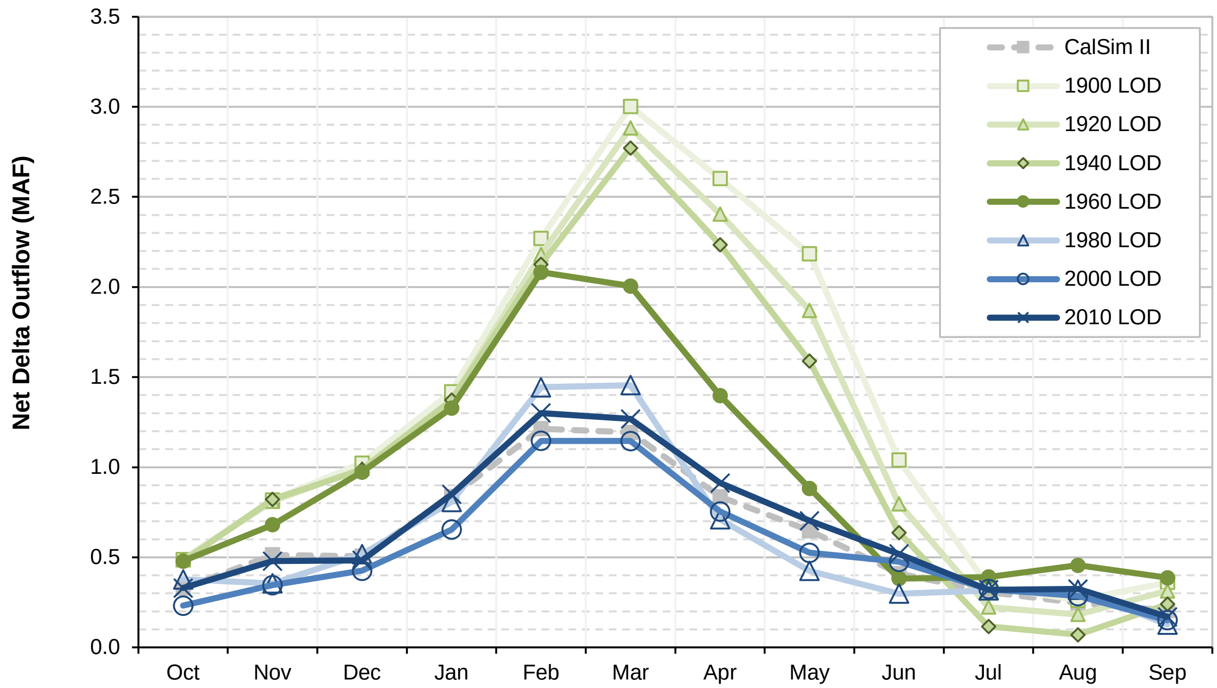

Figure 7-16. Average Monthly Simulated Net Delta Outflow, Dry Water Years 1922-2009

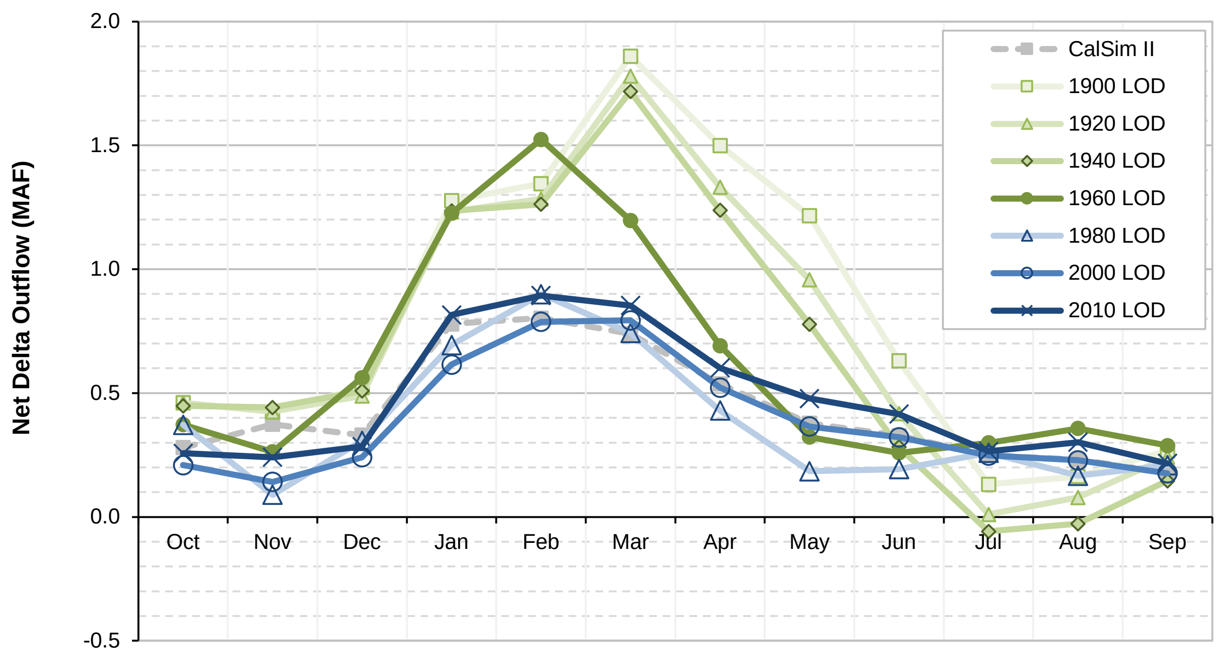

Figure 7-17. Average Monthly Simulated Net Delta Outflow, Critical Years 1922-2009

Groundwater

Historically, groundwater inflows have augmented and sustained river flows. The Sacramento River gained water from the underlying aquifer for most of the study period. Bryan (1923) reports that groundwater feeds the Sacramento River as far south as Hamilton City. However, over the 20th century, groundwater extraction and falling groundwater levels has reduced these inflows. **Figure 7-17** presents the long-term average annual stream losses for each level of development for the Sacramento Valley and San Joaquin Valley. At the 1900 LOD, groundwater contributes approximately 1.3 MAF per year to streamflow. At the 2010 LOD, the flow direction has reversed and streams lose approximately 1.2 MAF per year to groundwater. **Figure 7-18** presents the average monthly flow hydrographs for this stream-groundwater interaction. Streams lose water in the winter and spring, as rivers are swollen by runoff and snowmelt, and stream stage is high. Conversely, streams gain water in the summer and late fall. However, development over the 20th century has changed this seasonal cycle, so that stream losses have grown greater in the winter and spring and stream gains in the summer have diminished to almost zero, or negative.

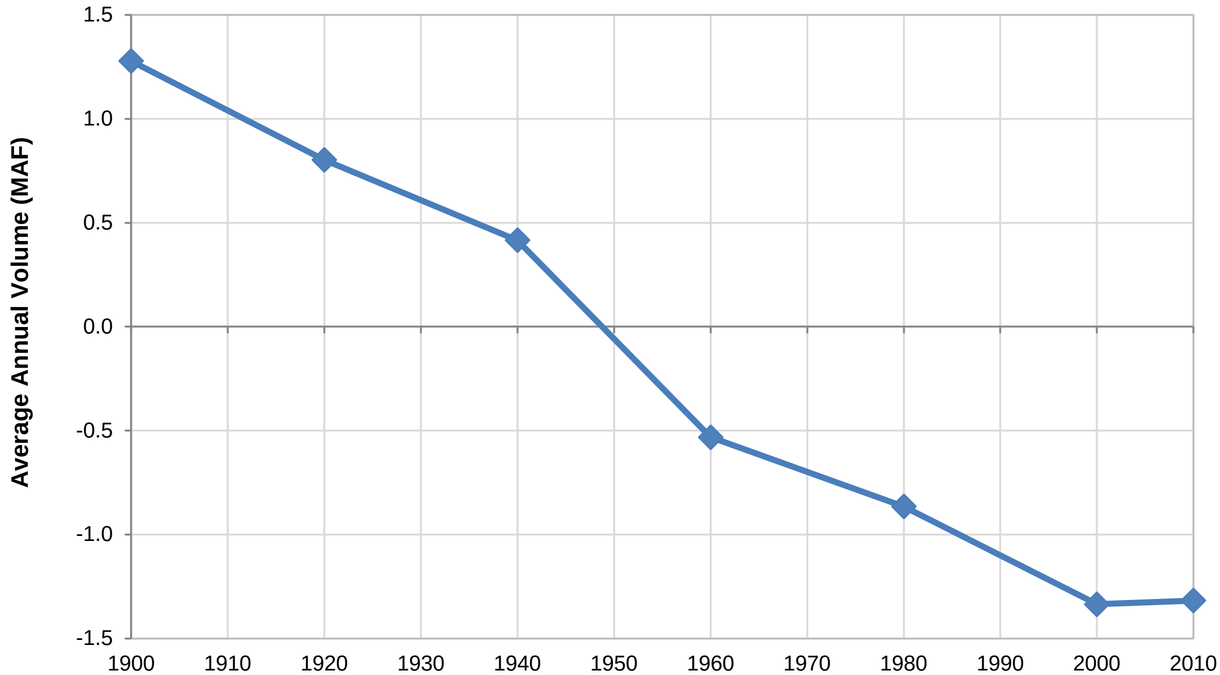

Figure 7-18. Average Annual Simulated Stream Gains from Groundwater at Different Levels of Development

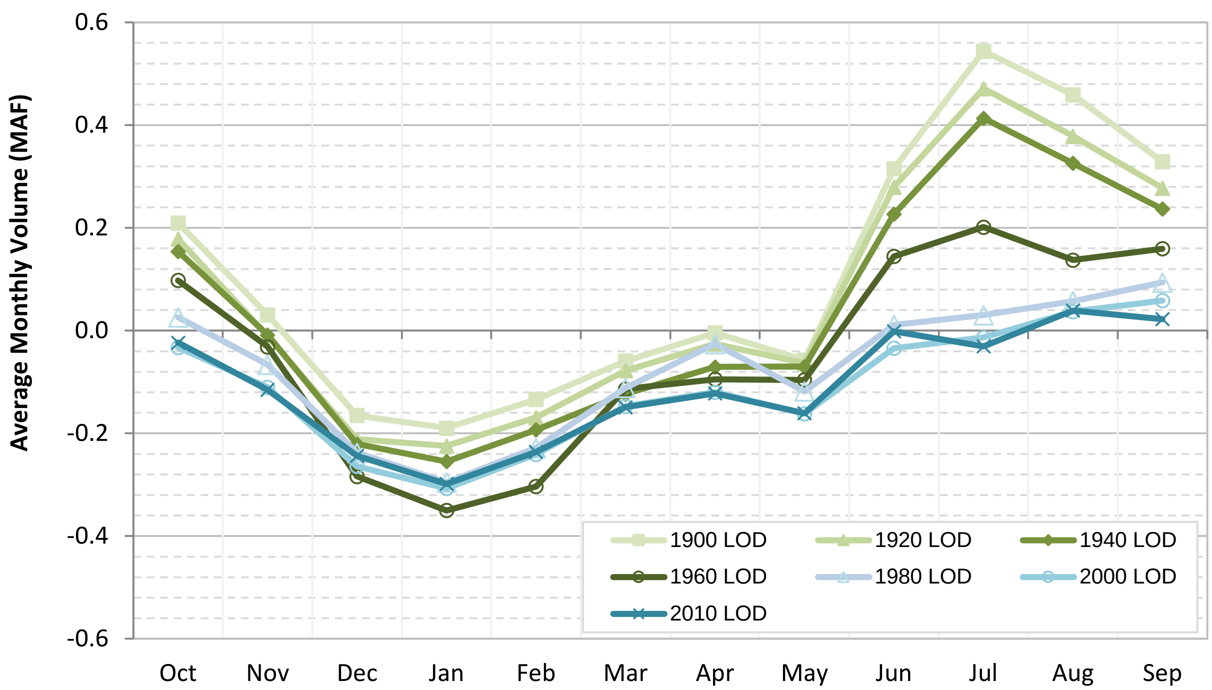

Figure 7-19. Average Monthly Simulated Stream Gains from Groundwater: All Years 1922-2009

Chapter 8
Climate Change

Since the beginning of the 20th century, the average daily surface temperatures for California have risen approximately 1.5 °F, changing the snow accumulation and snow melt regime in the Sierra Nevada, Trinity, and Cascade mountains, and the rainfall-runoff pattern of watersheds at lower elevations. The purpose of the analysis presented in this chapter is to investigate the impacts of historical temperature changes on Delta inflows and inform ongoing studies about why Delta flows and salinity have changed over time.

Climate Transformed Flows

The study of changing runoff caused by long-term changes in temperature was conducted by RMC (2015). Temperature averages and trends were imposed on the historical temperature data from 1922 through 2009. The original and modified temperature data were used in the VIC hydrologic model (Liang and Lettenmaier, 1994) to develop streamflow timeseries with and without the temperature modifications. The three-step perturbation method (Wang, Hongbing, and Chung, 2011) was used to develop monthly timeseries of perturbation factors that define the impacts of temperature-driven climate change on streamflows. A set of perturbation factors was defined for each level of development. Applied to the historical unimpaired flow data, the perturbation factors remove the effects of temperature trends and impose a fixed climate change effect (relative to a 1900 baseline) for each level of development.

To account for the effects of climate change at a particular level of development, unimpaired flows were adjusted using monthly perturbation factors. These factors are the ratio of the climate transformed flow to the historically observed full natural flow. Pertubation factors were available for only a subset of Central Valley watersheds. Therefore, each model inflow was associated with an 'indicator' watershed. **Table 8-1** lists the transformed flows and the source (watershed) of the perturbation factors. All calculations are contained in the Excel workbook *MWD1_ClimateChangeFactors_ CalSimInflows.xlsx*.

Unregulated flows were transformed directly, using the timeseries of perturbation factors for the 'indicator' watershed. However, in some cases model inputs reflect impaired, rather than unimpaired flows. For example, the CalSim II inflow "I6" represents the inflow to Lake Oroville at a particular level of development. Inflows to the lake are affected by upstream storage regulation on the North, Middle, and South Forks of the Feather River and by exports from the West Branch Feather River to Butte Creek. For impaired flows, a four-step approach was adopted, as follows:

1. Unimpaired flows for the watershed were obtained from DWR, or determined based on available flow and storage data.
2. An impairment was calculated as the impaired flow (from the CalSim II input file) less the unimpaired flow.
3. The unimpaired flows were transformed using the appropriate timeseries of perturbation factors.
4. The impairment from Step 2 was added to the transformed unimpaired flow.

This approach assumes that climate change has not significantly affected operation of water facilities in the upper watersheds.

CalSim II Results

Although CalSim II is an intermediate model in this study, CalSim model results are presented here to illustrate the effects climate change has on CVP and SWP operations and on Delta flows. Annual CalSim II inflows, with and without the climate transformation, are presented in **Figure 8-1**. Flows from the rim watersheds on to the valley floor or into rim reservoirs, as represented by CalSim II, average 31.42 MAF per year. Climate transformed inflows for the 2010 LOD average 31.37 MAF per year. Thus, at an annual time scale, the climate transformed inflows are approximately equal to untransformed flows. This is expected as the transformation represents only the effects of long-term temperature changes and not potential changes to precipitation. **Figure 8-2** illustrates the effects of the climate transformation on seasonal inflows for the 2010 LOD for the beginning years (1922-1931) of the period of simulation. Winter flows increase with a corresponding decrease in summer flows. **Figure 8-3** illustrates the effects of the climate transformation on seasonal inflows for the 2010 LOD for the ending years (1994-2003) of the period of simulation. For this latter period, the two hydrographs are very similar, as expected. **Figure 8-4** presents the percent change in flow for the entire period of simulation for the months of January and June. Flows increase in January because of less snow accumulation. Flow decrease in June because of earlier snow melt. **Figure 8-5** illustrates the damping effect of storage regulation on temperature induced changes to streamflows. The figure presents the average monthly inflows and releases from CVP and SWP reservoirs over the period of simulation, with and without climate change. The reservoirs include Trinity, Shasta, Whiskeytown, Oroville, Folsom, New Melones, and Millerton. Storage regulation removes most of the seasonal effects of climate change. Finally, **Figure 8-6** shows the seasonal effects of climate change on Delta inflows, exports (Banks Pumping Plant and Jones Pumping Plant), and net Delta outflows. The seasonal effects of climate change on Delta inflows and net Delta outflows are more pronounced than the effects on flows downstream of CVP and SWP reservoirs as a significant portion of the inflows from the rim watersheds are unregulated. However, there is no significant effects on Delta exports. This is partly explained by the many regulatory constraints that limit export pumping.

C2VSim Model Results

Climate-transformed unimpaired flows were input to CalSim II and the spreadsheet models to obtain simulated releases from the major reservoirs. Subsequently, these releases were input to C2VSim to simulate streamflows on the valley. **Figures 8-7 and 8-8** show the average monthly (1922–2009) Delta inflow hydrographs under with- and without- climate change conditions for the 1920 LOD and the 2010 LOD. These figures suggest that temperature-driven, climate change effects on Delta flows are not significant when compared to the effects of human actions in the upstream watersheds. Possible reasons for the lack of a climate signal are as follows:

- Climate change modeling did not address changing patterns of precipitation.
- Climate change modeling did not address changes to evaporative demand on the valley floor.
- Rising temperature trends before 1970 are muted.
- Low elevation watersheds are relatively unaffected by rising temperatures.
- The timing of the climate-change signal from high elevation watersheds varies with elevation; e.g., the seasonal shift in flows from the Lake Shasta watershed is very different from that for the Lake Oroville watershed.
- Storage regulation dampens the climate change signal.

The analysis presented in this chapter considers the climate change effects of the 20th and early 21st

century. Conclusions from this analysis should not detract from the very serious effects of climate change that are expected to occur during the middle and late parts of the 21st century,

Table 8-1. Source of Climate Transformed Inflows for C2VSim and CalSim II

Stream/River	Model Boundary/Data Source for Historical Flow	Indicator Watershed[1]
Inputs needed for C2VSim		
Sacramento River	Sacramento River at Keswick USGS 11370500	Shasta
Clear Creek	Clear Creek near Igo USGS 11372000	Clear
Cow Creek	Cow Creek near Millville USGS 11374000	Bear
Battle Creek	Battle Creek below Coleman Fish Hatchery USGS 11376550	Bear
Cottonwood Creek	Cottonwood Creek near Cottonwood USGS 113765000	Cottonwood
Paynes Creek	Paynes Creek near Red Bluff USGS 11377500 and Sevenmile Creek	Bear
Antelope Creek Group	Antelope Creek near Red Bluff USGS 11379000 * 2.06	Bear
Mill Creek	Mill Creek near Los Molinos USGS 11381500	Bear
Elder Creek	Elder Creek near Paskenta USGS 11379500	Cottonwood
Thomes Creek	Thomes Creek at Paskenta USGS 11382000	Cottonwood
Deer Creek Group	Deer Creek near Vina USGS 11383500* 1.66	Bear
Stony Creek	Stony Creek at Black Butte Dam site/Black Butte Dam release	Cottonwood
Big Chico Creek	Big Chico Creek near Chico USGS 11384000	Bear
Butte and Chico Creek	Butte Creek near Chico USGS 11390000*1.24	Bear
Feather River	Feather River at Oroville USGS 11407000	Oroville
Yuba River	Yuba River at Smartville USGS 11419000	Yuba
Bear River	Bear River near Wheatland USGS 11424000	Bear
Cache Creek	Cache Creek below Capay Diversion Dam	Cottonwood
American River	American River at Fair Oaks USGS 11446500	Folsom
Putah Creek	Putah Creek near Winters 11454000	Cottonwood
Cosumnes River	Cosumnes River at Michigan Bar USGS 11335000	Cosumnes
Dry Creek	Dry Creek near Galt USGS 11329500 *0.253	Cosumnes
Mokelumne River	Mokelumne River below Camanche Dam USGS 11323500	Mokelumne
Calaveras River	Calaveras River below New Hogan Dam USGS 11308900	Calaveras
Stanislaus River	Stanislaus River below Goodwin Dam USGS 11302000	Stanislaus
Tuolumne River	Tuolumne River below LaGrange Dam USGS 11289650	Tuolumne
Orestimba Creek	Orestimba Creek near Newman USGS 11274500	Calaveras
Merced River	Merced River below Merced Falls Dam USGS 11270900	Merced
Bear Creek Group		Calaveras
Deadman Creek		Calaveras
Chowchilla River	Chowchilla River below Buchanan Dam USGS 11259000	Calaveras
Fresno River	Fresno River below Hidden Dam USGS 11257500	Calaveras
San Joaquin River	San Joaquin River below Friant Dam USGS 11251000	San Joaquin
Kings River	Kings River below Pine Flat Dam USGS 11221500	Kings
Kaweah River	Kaweah River below Terminus Dam USGS 11210950	Kings
Tule River	Tule River below Success Dam USGS 11204900	Kings
Kern River	Kern River near Bakersfield USGS 11194000	Kings
Additional inputs needed for CalSim II		
Trinity River	Inflow to Trinity Reservoir	Trinity
Clear Creek	Inflow to Whiskeytown Reservoir	Clear Creek
Sacramento River	Inflow to Shasta	Shasta

Note: Perturbation factor for transforming unimpaired flows based on VIC model for watershed listed.

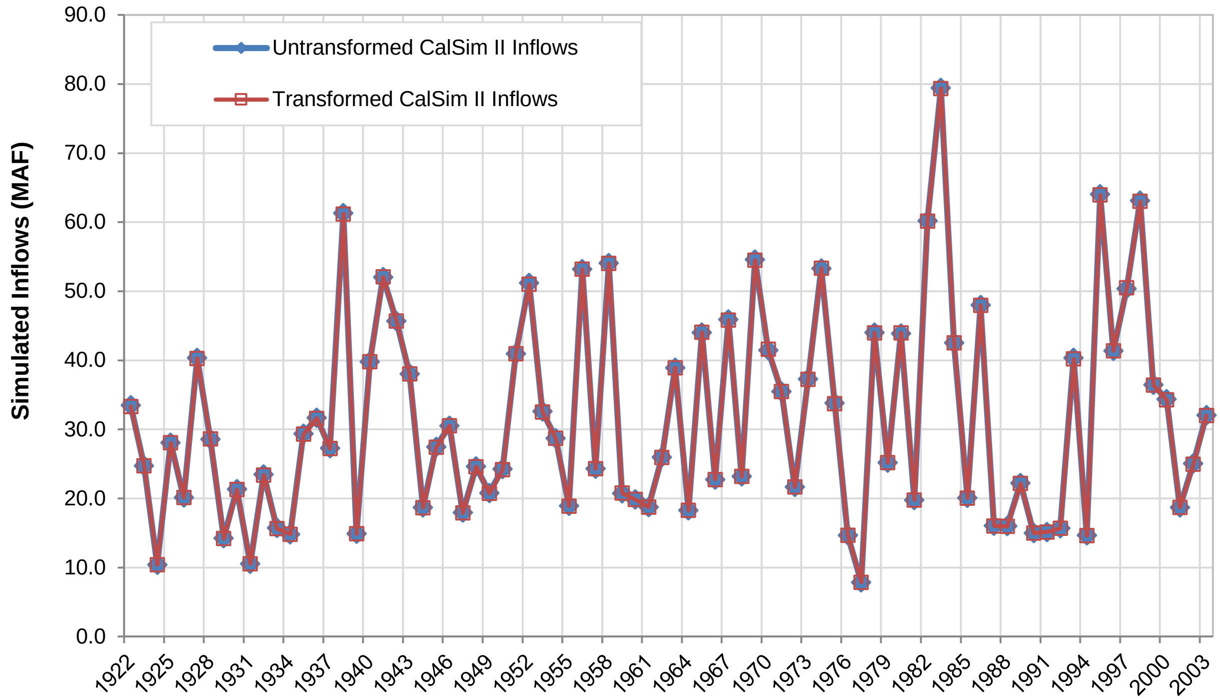

Figure 8-1. Effects of Climate Change on Annual Inflows from the Foothill and Mountain Watersheds for 2010 Level of Development

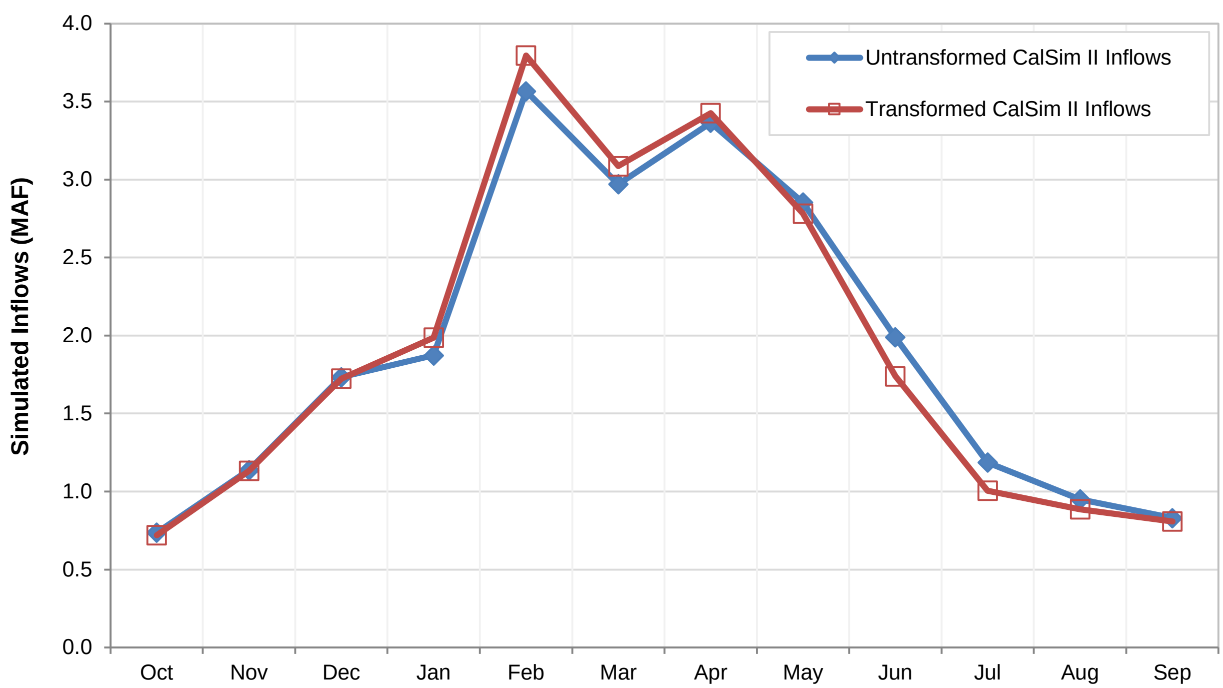

Figure 8-2. Effects of Climate Change on Seasonal Inflows from the Foothill and Mountain Watersheds for 2010 Level of Development, Water Years 1922-1931

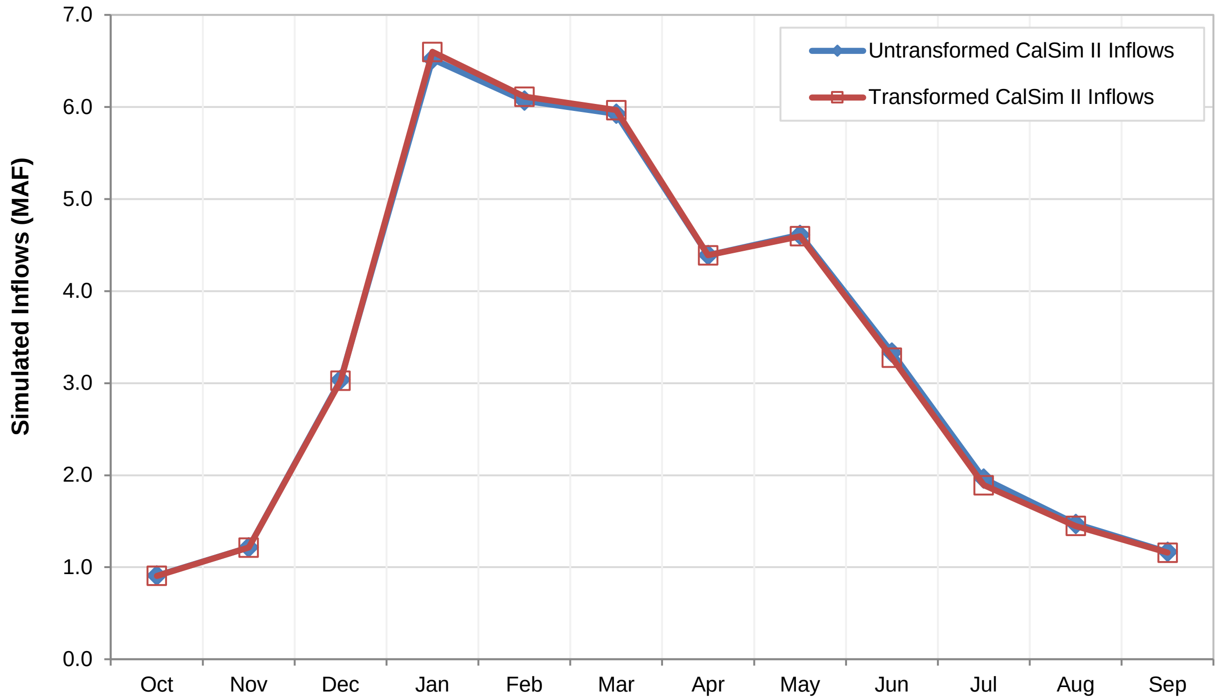

Figure 8-3. Effects of Climate Change on Seasonal Inflows from the Foothill and Mountain Watersheds for 2010 Level of Development, Water Years 1994-2003

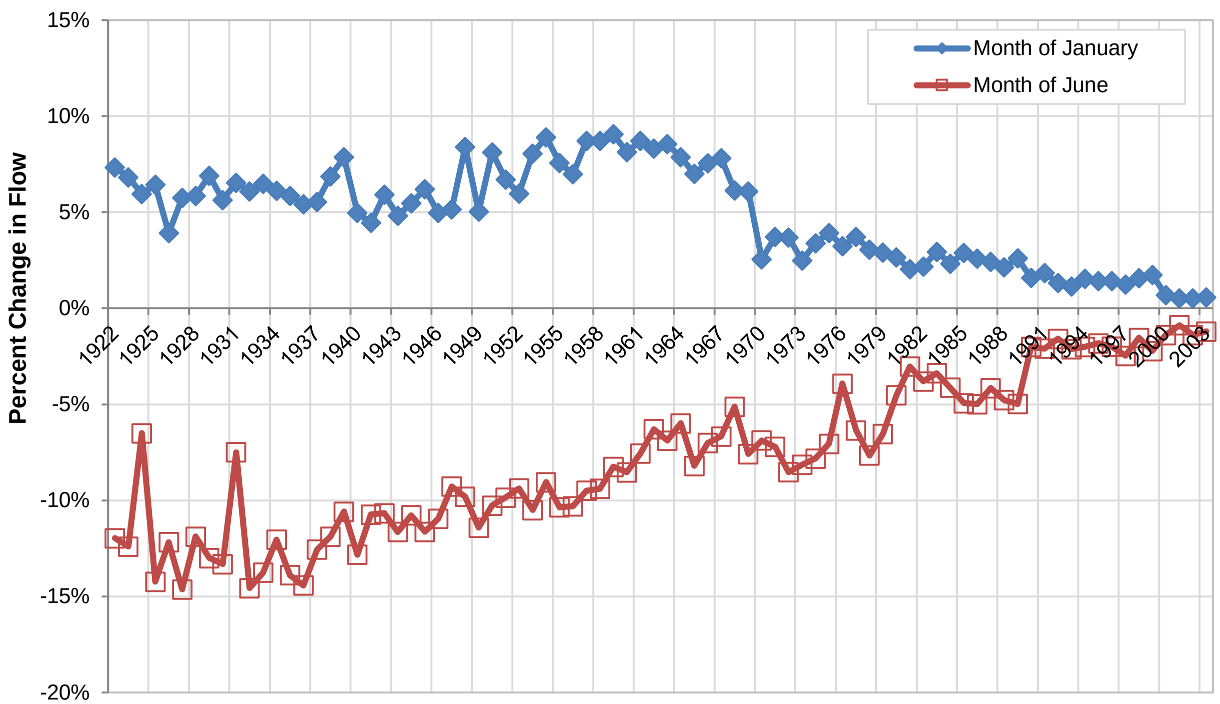

Figure 8-4. Effects of Climate Change on Monthly Inflows from the Foothill and Mountain Watersheds for 2010 Level of Development

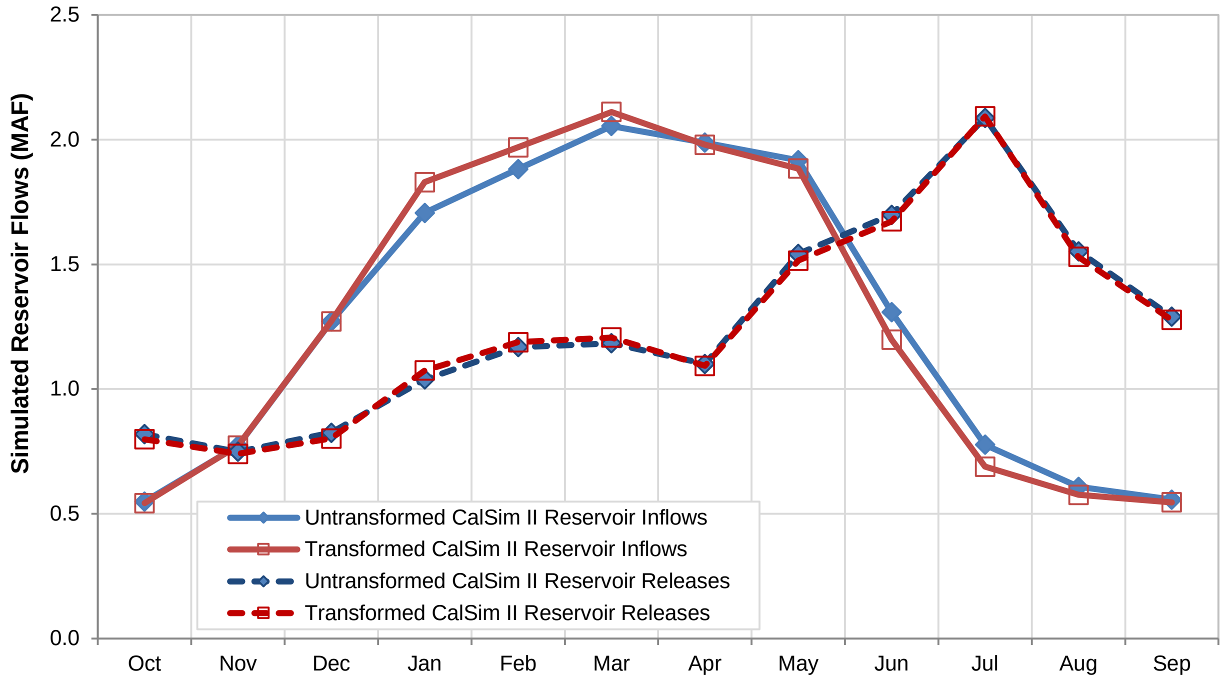

Figure 8-5. Seasonal Effects of Climate Change on Reservoir Inflows and Outflows for 2010 Level of Development

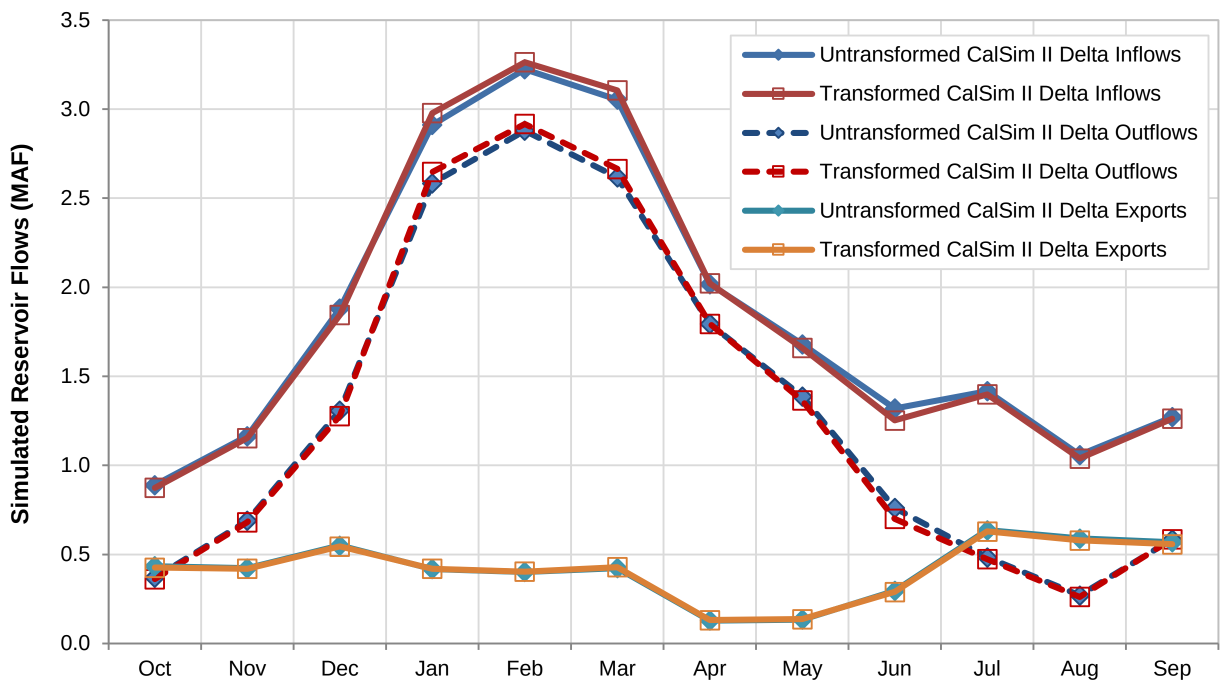

Figure 8-6. Seasonal Effects of Climate Change on Delta Inflows, Exports, and Outflows for 2010 Level of Development

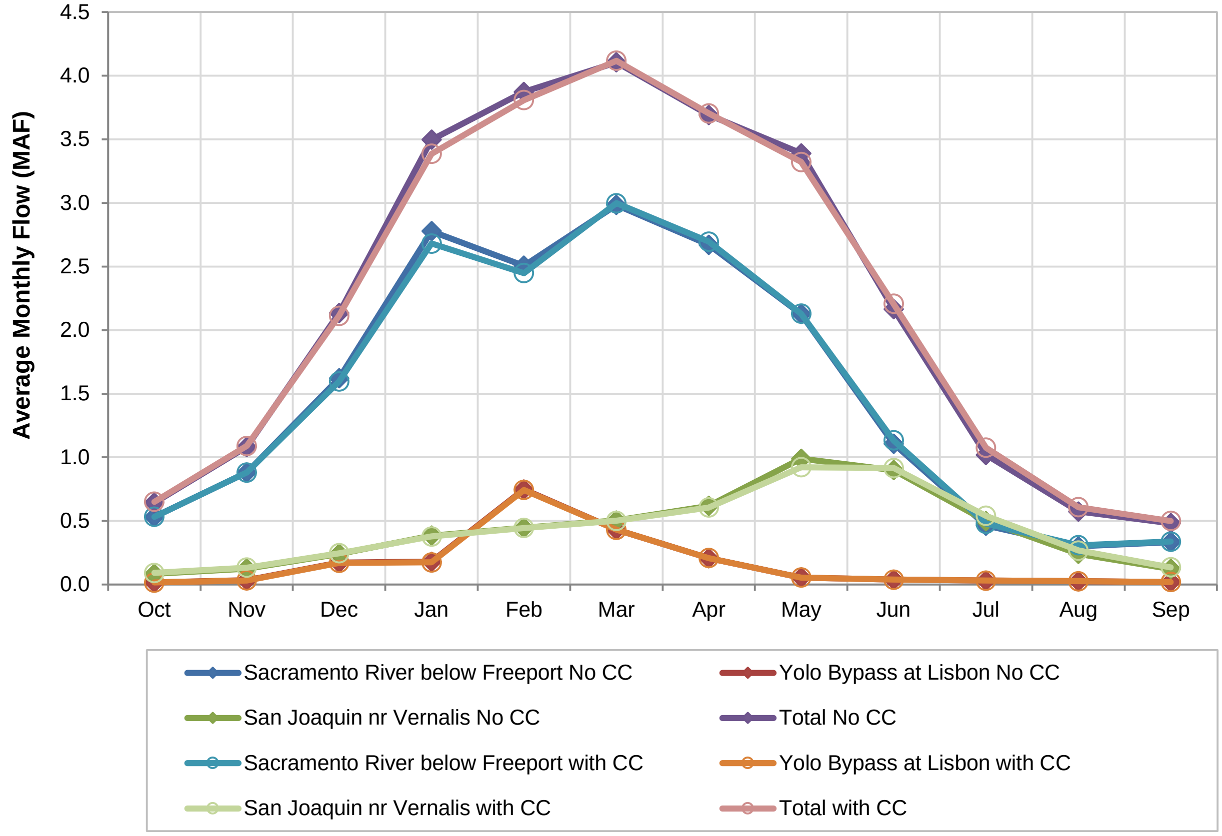

Figure 8-7. C2VSim Simulated Delta Inflow, 1920 Level of Development
CC = Study with Climate Change Transformed Inflows

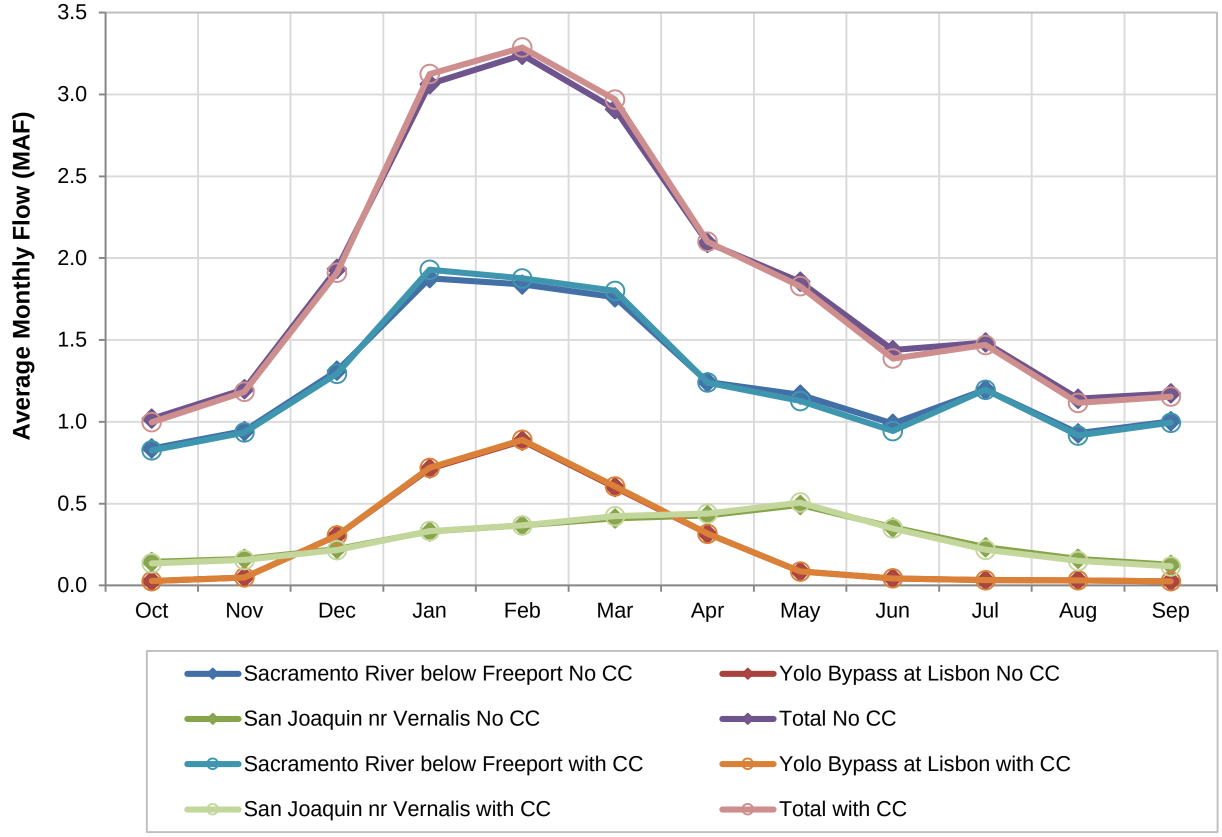

Figure 8-8. C2VSim Simulated Delta Inflow, 2010 Level of Development

CC = Study with Climate Change Transformed Inflows

Chapter 9
Conclusions

The *Historical Level of Development Study* provides a set of model results that assist understanding both how and why streamflows in the Sacramento and San Joaquin valleys has changed over a 115-year span, beginning in 1900. By using a fixed level of development approach, the influence of hydrology is separated from that of human actions. The integrated surface water groundwater model (C2VSim) used for the analysis incorporates a complete simulation of the hydrologic cycle of the valley floor, including rainfall-runoff, land-use based evaporative demands, stream diversions, groundwater pumping, return flows, and stream-groundwater interaction.

Model results are presented as annual flows and average monthly flows by water year type. Presentation of model results focuses on Delta inflows and net Delta outflow. However, model results include timeseries of streamflows for many locations along the Sacramento and San Joaquin rivers and their tributaries. Simulation of the early levels of development before the construction of the major flood control dams (e.g., Shasta Dam, Friant Dam) is complicated by the significant inundation of the floodplain that probably occurred during high flow events. This flooding may have significantly increased evaporative losses and groundwater recharge. Additional depletion losses were added to the 1900, 1920, and 1940 LOD models to indirectly account for these losses. Further study is required to confirm whether these additional losses are correct.

The major conclusions of the study are as follows:

- Long-term average annual streamflows and Delta inflows decline steadily from the 1900 LOD to 1980 LOD, and thereafter stay relatively constant (**Figure 7-2**). The decline in flows before 1980 are observed across both the Sacramento and San Joaquin valleys and are primarily caused by agricultural development.

- For the Sacramento River, the largest declines in Delta inflows occur from February through May. These declines are partially offset by increased Delta inflows from July to September after the construction of the CVP and SWP, as simulated in the later levels of development. (**Figure 7-3**).

- For the San Joaquin River, the decline in Delta inflows is most marked for May and June, and the adjacent months of April and July (**Figure 7-4**).

- The shift in timing of Delta inflows is most noticeable in critical years during which July to September Delta inflows are considerably greater in the later levels of development (**Figure 7-10**).

- Long-term average annual net Delta outflow declines at an accelerating rate from 1900 LOD to 1980 LOD because of the demands of irrigated agriculture in the upstream watersheds. The steepest decline in outflow between 1960 and 1980 also is associated with CVP and SWP export pumping in the south Delta. There is a modest recovery in net Delta outflow for the 2010 LOD (**Figure 7-2**).

- Because of the hydraulic connection between surface waters and groundwater, additional groundwater pumping is converted to a similar reduction in streamflows. The stream-groundwater interaction has changed significantly over the last 9 decades. Groundwater inflows that sustained streamflows in the summer and fall have diminished and in some instances become negative as groundwater levels have fallen over the 20th century. Additionally, stream seepage losses in the winter months have increased. Falling groundwater levels are largely attributed to increased pumping for agricultural and municipal purposes (**Figure 7-18 and 7-19**).

Chapter 10
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Appendix A
Electronic Files

This appendix briefly describes the files delivered to MWD under the *Hydrology Development (Delta Flow and Salinity Trends Support)* Task Order (Agreement # 143875, Task Order 1). The sections below refer to folders within the electronic deliverables.

Reservoir Operations Models

The *Reservoir Operations Models* folder contains spreadsheet-based models that provide input (inflows and selected diversions) to C2VSim under without- and with- climate change conditions. **Table A-1** lists, in the left-hand column of the table, the file names of models without climate change. Corresponding climate change models are labeled with "_CC" appended to the filename. For each model, **Table A-1** presents the C2VSim location and the levels of development for which the model provides inputs. A "c" denotes that C2VSim inputs are derived from CalSim II studies.

Table A-1. Reservoir Operations Models

File Name	C2VSim Input Location	1900 LOD	1920 LOD	1940 LOD	1960 LOD	1980 LOD	2000 LOD	2010 LOD
MWD1_1_18_32_Shasta_Folsom_Millerton_1960 LOD.xlsx	Sacramento River				x			
MWD1_1_ShastaOperations.xlsx	Sacramento River	x	x	x		c	c	c
MWD1_2_CowCreek.xlsx	Cow Creek	x	x	x	x	x	x	x
MWD1_3_BattleCreek.xlsx	Battle Creek	x	x	x	x	x	x	x
MWD1_4_CottonwoodCreek.xlsx	Cottonwood Creek	x	x	x	x	x	x	x
MWD1_5_PaynesSevenmile.xlsx	Paynes and Sevenmile Creek	x	x	x	x	x	x	x
MWD1_6_AntelopeCreek.xlsx	Antelope Creek Group	x	x	x	x	x	x	x
MWD1_7_MillCreek.xlsx	Mill Creek	x	x	x	x	x	x	x
MWD1_8_ElderCreek.xlsx	Elder Creek	x	x	x	x	x	x	x
MWD1_9_ThomesCreek.xlsx	Thomes Creek	x	x	x	x	x	x	x
MWD1_10_DeerCreek.xlsx	Deer Creek Group	x	x	x	x	x	x	x
MWD1_11_StonyCreekOperations.xlsx	Stony Creek	x	x	x	x	x	x	x
MWD1_12_BigChicoCreek.xlsx	Big Chico Creek	x	x	x	x	x	x	x
MWD1_13_ButteAndChicoCreek.xlsx	Butte & Chico Creek	x	x	x	x	x	x	x
MWD1_14_FeatherRiverOperations.xlsx	Feather River	x	x	x	x	c	c	c
MWD1_15_BullardsBar_1920-1960.xlsx	Yuba River	x	x	x	x			
MWD1_15_BullardsBar_1980-2010.xlsm	Yuba River					x	x	x
MWD1_15_MiddleForkYubaOperations.xlsx	Yuba River	x	x	x	x	x	x	x
MWD1_15_SimulationofCamptonvilleTunnel.xlsx	Yuba River					x	x	x
MWD1_15_SimulationofSlateCreekTunnel.xlsx	Yuba River					x	x	x
MWD1_15_SouthForkYubaOperations.xlsm	Yuba River	x	x	x	x	x	x	x
MWD1_16_BearRiverOperations.xlsx	Bear River	x	x	x	x	x	x	x
MWD1_17_ClearLakeOperations.xlsx	Cache Creek	x	x	x	x	x	x	x
MWD1_18_AmericanRiverOperations.xlsx	American River	x	x	x		c	c	c
MWD1_19_LakeBerryessaOperations.xlsx	Putah Creek	x	x	x	x	x	x	x
MWD1_20_CosumnesRiver.xlsm	Cosumnes River	x	x	x	x	x	x	x
MWD1_21_DryCreek.xlsx	Dry Creek	x	x	x	x	x	x	x
MWD1_22_MokelumneRiver.xlsx	Mokelumne River	x	x	x	x	x	x	x
MWD1_23_NewHoganOperations.xlsx	Calaveras River	x	x	x	x	x	x	x
MWD1_24_MelonesOperations.xlsx	Stanislaus River	x	x	x	x	c	c	c
MWD1_25_NewDonPedroOperations.xlsx	Tuolumne River	x	x	x	x	c	c	c
MWD1_26_OrestimbaCreek.xlsx	Orestimba Creek	x	x	x	x	x	x	x
MWD1_27_LakeMcClureOperations.xlsx	Merced River	x	x	x	x	x	x	x
MWD1_28_BearCreekGroup.xlsx	Bear Creek Group	x	x	x	x	x	x	x
MWD1_29_DeadmansCreek.xlsx	Deadman Creek	x	x	x	x	x	x	x
MWD1_30_ChowchillaRiver.xlsx	Chowchilla River	x	x	x	x	c	c	c
MWD1_31_FresnoRiver.xlsx	Fresno River	x	x	x	x	c	c	c
MWD1_32_37_38_39_41_Millerton & FKC Operations.xlsx	San Joaquin River, Friant-Kern Canal	x	x	x	x	x	x	x
MWD1_33_PineFlatOperations.xlsx	Kings River	x	x	x	x	x	x	x
MWD1_34_KaweahOperations.xlsx	Kaweah River	x	x	x	x	x	x	x
MWD1_35_LakeSuccessOperations.xlsx	Tule River	x	x	x	x	x	x	x
MWD1_36_IsabellaOperations.xlsm	Kern River	x	x	x	x	x	x	x
MWD1_40_CVCtoKern.xlsx	Cross Valley Canal					c	c	c
MWD1_42_ClearCreek.xlsx	Clear Creek	x	x	x	x	x	x	x

Note: ‘x’ denotes input from spreadsheet-based model; ‘c’ denotes input from CalSim II study.
Key: LOD = level of development

CalSim II Studies

The *CalSim II Studies* folder contains the output HEC-DSS files from various CalSim II simulations. These output files are listed in **Table A-2**.

Table A-2. CalSim II Output Files.

Filename	Description
1980LOD_NoCC_DV.dss	1980 level of development, no climate change
2000LOD_NoCC_DV.dss	2000 level of development, no climate change
2010LOD_NoCC_DV.dss	2010 level of development, no climate change
1980LOD_CC_DV.dss	1980 level of development, with climate change
2000LOD_CC_DV.dss	2000 level of development, with climate change
2010LOD_CC_DV.dss	2010 level of development, with climate change

C2VSim Input Development

Files included in the *C2VSim* folder are used to develop the inflow and diversion input data for C2VSim by reading data from the reservoir operations models and the CalSim II input and output files. These data are subsequently stored in HEC-DSS. **Table A-3** lists the filenames and their respective functions (corresponding files for climate change scenarios are labeled with the suffix "_CC").

Table A-3. C2VSim Input Development Files

File Name	Description
__ReadAllDiversionDatatoDSS_C2VSim.xlsm	Reads data into the C2VSim diversion. HEC-DSS input file, based on a list of source files contained in this file
__ReadAllInflowDatatoDSS_C2VSim.xlsm	Reads data into the C2VSim inflow. HEC-DSS input file, based on a list of source files contained in this file
_MWD1_CalSimOutput_to_C2VSim_1980_2000_2010_Diversions.xlsx	Develops diversion inputs to 1980, 2000, and 2010 C2VSim simulations based on CalSim results and historical C2VSim diversion data
_MWD1_SAC_SJR Adjustments.xlsm	Calculates correction factors to adjust the C2VSim models based on discrepancies between the historical simulation and historical gaged flows, input to the model as additional diversions
_MWD1_SourceofDivData_DSS.xlsx	Calculates diversions input to the 1900 through 1960 level of development simulations, using average diversions from the historical C2VSim simulation for the 10-year period centered around each level of development

C2VSim Models

The *C2VSim* folder contains a series of subfolders, each containing a set of C2VSim models. These subfolders are as follows:

- Historical
- No Climate Change

- Climate Change

Historical

C2VSim models that simulate historical flows for water years 1922 – 2009 are used stored in the *Historical* subfolder. These models are used as a baseline for developing the fixed level of development models.

Models include:

- **Historical_ wClearCreek** – C2VSim model released by DWR in 2013 (C2VSim-CG_R374), modified to include Clear Creek inflows to the Sacramento River.[31]
- **Historical_wClearCreek_Revised** – C2VSim model released by DWR in 2013 (C2VSim-CG_R374), modified to include Clear Creek inflows to the Sacramento River and depletions in the form of additional diversions to improve model agreement with gaged flows for the Sacramento River at Freeport and the San Joaquin River near Vernalis.[32] Modified files are listed below.

No Climate Change

C2VSim models that simulate fixed level of development scenarios without climate change are stored in the *No Climate Change* subfolder. These C2VSim models were modified to read input flow and diversion data from the HEC-DSS files listed in **Table A-4**.

Table A-4. C2VSim Input Files for Timeseries Data

File Name	Description
C2VSim_LOD_Diversions.dss	Diversion data for each fixed level of development scenario, referenced by the CVdiversions.dat file in each C2VSim fixed level of development model
C2VSim_LOD_Inflows.dss	Inflow data for each fixed level of development scenario, referenced by the CVinflows.dat file in each C2VSim fixed level of development model

The C2VSim models for the fixed level of development simulations are provided in the following sub folders: 1900 LOD, 1920 LOD, 1940 LOD, 1960 LOD, 1980 LOD, 2000 LOD, and 2010 LOD. Modified files for each fixed level of development model are listed in **Table A-5**. The remaining files are common to all levels of development.

With Climate Change

C2VSim models that simulate fixed level of development scenarios *with* climate change are used stored in the *Climate Change* subfolder. These C2VSim models were modified to read input flow and diversion data from the HEC.DSS files listed in **Table A-6**.

The C2VSim models for the fixed level of development simulations are provided in the following sub folders: 1900 LOD_CC, 1920 LOD_CC, 1940 LOD_CC, 1960 LOD_CC, 1980 LOD_CC, 2000 LOD_CC, and 2010 LOD_CC. Modified files for each fixed level of development model are similar to those listed in **Table A-5**.

[31] The input file CVInflows.dat was modified to include Clear Creek inflows to the Sacramento River, as inflow #42.

[32] The input file CVdiversions.dat was modified to include additional depletions, applied as diversions #247 and #248. The input file CVdivspec.dat was modified to include specifications for these diversions.

Table A-5. C2VSim Modified Input Files for Fixed Level of Development Simulations

File Name	Description
CVcropacre.dat	Modified to apply the historical crop acreage data from the year corresponding to the given level of development (from the C2VSim historical model) to all years in the model simulation
CVdiversions.dat	Modified to read data from the .dss file containing diversions for each fixed level of development (C2VSim_LOD_Diversions.dss), and to include diversions that apply flow adjustment factors (diversions #247 and #248)
CVdivspec.dat	Modified to include specifications for diversions that apply flow adjustment factors (diversions #247 and #248)
CVinflows.dat	Modified to read data from the .dss file containing inflows for each fixed level of development simulation (C2VSim_LOD_Inflows.dss)
CVinit_1921.dat	Modified to apply the simulated historical groundwater heads (at each layer) at the end of the year corresponding to the given level of development (simulated historical heads from the modified C2VSim historical model) as the initial groundwater heads
CVlanduse.dat	Modified to apply the historical land use data from the year corresponding to the given level of development (from the C2VSim historical model) to all years in the model simulation
CVprint.dat	Modified to output surface water flows at additional stream nodes
CVurbandem.dat	Modified to apply the historical urban demands from the from the year corresponding to the given level of development (from the C2VSim historical model) to all years in the model simulation

Table A-6. C2VSim Input Files for Climate Transformed Timeseries Data

File Name	Description
C2VSim_LOD_Diversions_CC.dss	Diversion data for each fixed level of development scenario under climate change, referenced by the CVdiversions.dat file in each C2VSim fixed level of development model
C2VSim_LOD_Inflows_CC.dss	Inflow data for each fixed level of development scenario under climate change, referenced by the CVinflows.dat file in each C2VSim fixed level of development model

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Appendix B
CalSim II Models

This appendix briefly describes additional CalSim II simulations that were conducted at the request of MWD to support the *Delta Flow and Salinity Trends* analysis being conducted by the agency. These additional studies include the following:

- **D1485**, analysis of water operations in the Sacramento and San Joaquin valleys under existing land use conditions and State Water Board requirements specified in D-1485 (SWRCB, 1978), but with CVP and SWP South-of-Delta contract amounts[33] fixed at the 1980 LOD. Demands upstream of the Delta are at the existing level of development.

- **D1641**, analysis of water operations in the Sacramento and San Joaquin valleys under existing land use conditions and State Water Board requirements specified in D-1641 (SWRCB, 2000), but with CVP and SWP South-of-Delta contract amounts fixed at the 1980 LOD. Demands upstream of the Delta are at existing level of development.

- **BO**, analysis of water operations in the Sacramento and San Joaquin valleys under existing land use conditions, State Water Board requirements specified in D-1641, and CVP and SWP operations conforming to the RPAs specified in the USFWS (2008) and NMFS (2009) biological opinions. Demands upstream of the Delta are at existing level of development, but CVP and SWP South-of-Delta contract amounts are fixed at the 1980 LOD.

The purpose of this attachment is to document changes to model input files so that the work may be reproduced, or possibly revised and/or extended in the future.

Background

In January 2015, Reclamation completed an initial analysis to support a new cost allocation for the CVP. The study, when completed, will apportion project costs among the project's seven congressionally-authorized purposes (water supply, power, flood control, fish and wildlife, recreation, navigation, and water quality). As part of the study, CalSim II models were developed to show how the CVP, under a near future condition (nominally 2020), would be operated under past regulatory environments. CalSim II models that were developed include:

- D1485
- D1641 without Trinity ROD
- D1641 with Trinity ROD
- Pre-BO

[33] In CalSim II modeling, SWP contractors are assumed to request their full contract amount.

- BO (Benchmark)

Although the final results of the Cost Allocation Study are not yet available, the CalSim II models are available from Reclamation. Reclamation's D1485, D1641 with Trinity ROD, and Benchmark BO models form the basis of the additional MWD analysis described in this Attachment.

Model Revisions

The Reclamation models described in the previous section were modified to reflect existing rather than future land use conditions.

Existing Conditions

Timeseries data for existing conditions were taken from the 2013 SWP Delivery Reliability Report Study (DRR2013_Existing_FullDem_082313). However, timeseries data for 10 additional variables needed to be defined because of differences in structure between Reclamation's studies and the 2013 SWP Delivery Reliability Report study. Timeseries data for these additional variables were taken from Reclamation's 2020 models. It is assumed that these data also are appropriate for existing land use conditions. These data are listed in **Table B-1**.

Table B-1. Timeseries Data from Reclamation Cost Allocation Studies

Variable		Description
B-Part	C-Part	
DEM_D162A_WR_ANN	DEMAND-NP-MI	Annual water rights for Sacramento Suburban Water District from proposed diversion on the Sacramento River
DEM_D162B_WR_ANN	DEMAND-NP-MI	Annual water rights for Placer County Water Agency from proposed diversion on the Sacramento River
DEM_D162D_WR_ANN	DEMAND-NP-MI	Annual water rights for Placer County Water Agency from proposed diversion on the Sacramento River
DEM_D162E_WR_ANN	DEMAND-NP-MI	Placer County WA sales to Sacramento Suburban WD and City of Roseville
DEM_D7C_DCMP	DEMAND-SWP-DECOMP	Rice straw decomposition demands for the Feather River Service Area
DEM_D8H_WR_ANN	DEMAND-NP-MI	Annual water rights for Placer County Water Agency from Folsom Lake
NP_DR58	DEMAND	Non-Project water demands in DSA 58
PRJ_DR58	DEMAND	Project water demands in DSA 58
R135C_DCMP	RETURN-FLOW	Return flows from fields flooded for rice straw decomposition in the Feather River Service Area
RF_58_PIMI	RETURN-FLOW	Return flows from wastewater treatment plants in DSA 58

Table B-2 lists wresl files that were modified so as to reflect existing (2010) infrastructure, operations, and demands, rather than future conditions, as defined for the **2013 SWP Delivery Reliability Report**. In additions to the files listed, the "main.wresl" file was revised so as to remove simulation of the San Joaquin River Restoration Program.

Table B-2. Modified WRESL Files

File Name	Description
.\common\CAAFramework\LCPSIM\LCPSIM_Adjustments.wresl	Minor modification to prevent division by zero for Table A amounts that are set to zero for 1980 LOD
.\common\swp_dellogic\Allocation\swp_contractor_perdel_B.wresl	Minor modification to prevent division by zero for Table A amounts that are set to zero for 1980 LOD
.\common\swp_dellogic\Allocation\carryover_allocation.wresl	Minor modification to prevent division by zero for Table A amounts that are set to zero for 1980 LOD
.\common\SanJoaquin\Tuolumne\Tuolumne_dems.wresl	Minor adjustment to prevent runtime error and LP infeasibility in some months
.\common\hydrology\DEMANDS\demands_70.wresl	Revised representation of Placer County Water Agency's demands at the American River Pump Station
.\common\NorthOfDelta\American\FolRuleCurv.wresl	Revised representation of Placer County Water Agency's demands at the American River Pump Station
.\common\Freeport\SCWA\scwa.wresl	Sacramento County Water Agency demand at Freeport set to zero for consistency with 2013 SWP Delivery Reliability Report
.\common\Freeport\EBMUD\ebmud.wresl	East Bay Municipal Water District demand at Freeport set to zero for consistency with 2013 SWP Delivery Reliability Report
.\common\Delta\SoDeltaChannels\SoDeltaChannels.wresl	Flows at Head of Old River
.\common\CCWD\UserInput.wresl	Capacity of Contra Costa Water District's Victoria Canal intake set to zero for consistency with 2013 SWP Delivery Reliability Report and capacity of Los Vaquero Reservoir set to 100,000 acre-feet
.\common\SanJoaquin\SanJoaquinCore_noSJRR.wresl	Simulation of the City of Stockton's Delta Water Supply Project removed for consistency with 2013 SWP Delivery Reliability Report
.\common\SHORTAGE\shortage_cvp_n.wresl	Placer County Water Agency's American River Pump Station included in summary totals for CVP deliveries and shortages
.\common\System\SystemTables_ALL\Channel-table.wresl	Capacity of South Bay Aqueduct changed from 430 to 300 cfs for consistency with 2013 SWP Delivery Reliability Report
.\common\wsi_di_gen\CVP\tot_del_CVP_n.wresl	American River Pump Station included in CVP demands for consistency with 2013 SWP Delivery Reliability Report
.\common\B2Actions\B2VampCommon.wresl	Exports capped during the pulse period as per the San Joaquin River Group Agreement for consistency with 2013 SWP Delivery Reliability Report
.\common\Delta\Ann\ExportEstimate1_B2.wresl	Estimate of Delta exports under USFWS and NMFS BO revised.
.\common\SanJoaquin\Delta\COSMA_dmd.wresl	Minor modification to prevent division by zero for City of Stockton's Delta demands that are set to zero

1980 South of Demand Project Contract Amounts

Table B-3 lists the CalSim II input files which were modified to reflect 1980 LOD South-of-Delta CVP and SWP demands. Modified files include CalSim II lookup tables and CalSim II HEC-DSS files.

Central Valley Project

The source of the revised inputs for CVP SOD contract amounts is the Excel file MWD1_CVP_SOD_Inputs_1980LOD.xlsx. The CVP full contract amounts was reduced from 2.4 MAF to 1.8 MAF. The higher contract amount for the 2010 LOD compared to the 1980 LOD is caused by: (a) Barcellos Judgement in 1986 awarding an additional 0.250 MAF to Westlands WD , (b) the Cross Valley Canal, which was completed in 1987, with an associated contract amount of 0.128 MAF, and (c) the passage of the CVPIA in 1992, which resulted in CVP contracts for the supply of 0.27 MAF Level 2 water to refuges south of the Delta. Simulated CVP refuge demands for the 1980 LOD are equal to the ‘existing supplies’ described in the *Report on Refuge Water Supply Investigations* (Reclamation, 1989a).

State Water Project

The source of the revised inputs for SWP SOD contract amounts is the Excel file MWD1_SWP_SOD_1980_03.01.15.xlsm. Table A amounts were reduced from 4.169 MAF to 2.193 MAF. Table A amounts were taken from the *California State Water Project – Current Activities and Future Management Plans*, Bulletin 132-81 (DWR, 1981) for year 1980.

Table B-3. Input Files for 1980 South-of-Delta Contract Amounts

File Name	Description
SWP Contract Demands	
TableA.table	Table A amount set to 2.193 MAF, excluding Plumas County and California Aqueduct conveyance losses.
AnnualReqDel_swp.table	Table A amount set to 2.193 MAF for every year of simulation.
SWP_Table_A.table	Table A amounts for 28 long-term SWP contractors revised to be in agreement with DWR Bulletin 132-81 for year 1980. Table A amounts for Castaic Lake Water Agency and Kern County Water Agency subdivided into agricultural and M&I water use.
SWP_3_TableA.table	Table A requests for 3 levels of water allocations (30%, 50%, and 100%). Assumes 2.193 MAF for 30% and 50% allocations and 2.071 MAF for 100% allocation.
SWP_3pattern_demands	Table A monthly demand pattern for 3 levels of water allocations (30%, 50%, and 100%). Monthly fraction of annual demand assumed to be equal to existing level of development.
WSIDI\SWP_3_TableA.table	File used for retraining WSI:DI curve. Table A requests for 3 levels of water allocations (30%, 50%, and 100%). Retraining assumes that 30% and 50% requests are the same as 100% allocation request.
WSIDI\SWP_3pattern_ demands.table	File used for retraining WSI:DI curve. Table A monthly demand pattern for 3 levels of water allocations (30%, 50%, and 100%). Retraining assumes that 30% and 50% demand patterns are the same as 100% allocation request.
SWP_Carryover.table	Article 56 demands for 3 levels of water allocations (30%, 50%, and 100%). Assumes 0.122 MAF at 100% allocation and zero demand for 30% and 50% allocations.
SWP_3Pattern_SLRule.table	San Luis Reservoir rule curve from May to September for 3 levels of allocations.
SV timeseries data	Timeseries data for Article 21 demands (DEM_D810_PIN, DEM_D814_PIN, DEM_D815_PIN, DEM_D821_PIN, DEM_D846_PIN, DEM_D848_PIN, DEM_D849_PIN, DEM_D859_PIN, DEM_D868_PIN, DEM_D877_PIN, DEM_D883_PIN, DEM_D884_PIN). Timeseries data for North Bay Aqueduct losses.
CVP Contract Demands	
SV timeseries data	Timeseries data for upper Delta-Mendota Canal demands (dem_d700_pag, dem_d701_pag, and dem_d702_pls)
SV timeseries data	Timeseries data for San Felipe Division demands (dem_d700_pag, dem_d701_pag, dem_d702_pls, dem_d710_pag, dem_d711_pmi)
SV timeseries data	Timeseries data for lower Delta-Mendota Canal demands (dem_d706_pag, dem_d707_pex, dem_d708_prf)
SV timeseries data	Timeseries data for Mendota Pool and Sack Dam demands (dem_d607a_pag, dem_d607b_pex, dem_d607c_prf, dem_d607d_pls, DEM_D608B_PEX, DEM_D608C_PRF)
SV timeseries data	Timeseries data for San Luis Canal demands (dem_d833_pag, dem_d834_pls, dem_d835_pag, dem_d836_pag, dem_d837_pag, dem_d838_pls, dem_d839_pag, dem_d840_pls, dem_d841_pag, dem_d843_pag, dem_d842_pls, dem_d844_pmi, dem_d845_pls)
SV timeseries data	Timeseries data for Cross Valley Canal demands and Tulare Basin refuges (dem_d855_pag, dem_d856_prf)
SV timeseries data	Timeseries data for demands by water use type (Total_SOD_CVP_AG, Total_SOD_CVP_MI, Total_SOD_CVP_EX, Total_SOD_CVP_RF, Total_SOD_CVP_LS, Total_SOD_CVP_PRJ)

Comparative Analysis D1485 vs D1641

Input TimeSeries Data

The two studies have identical input timeseries data (file: 2005A01A_1980SOD_SV.dss) and initial conditions (file: 2005A01AINIT.dss).

Input Relational Data

The two studies, D1485 and D1641, have different sets of relational data as defined by table files (*.table) in the lookup directory. **Table B-4** summarizes the differences between the two sets of table files.

Table B-4. Comparison of D1485 and D1641 Relational Input Data

File Name	Description
Files Unique for D1485 Analysis	
KeswickMin.table	Minimum flow requirements below Keswick Dam
Salinity_std_aww.table	D1485 EC standard for Striped Bass at Antioch Waterworks Intake on the San Joaquin River (1.5 µS/cm)
WYtypeD1485.table	D1485 water year types
NdoBass.table	D1485 net Delta outflow requirement for Striped Bass
WYtypeSnow.table	D1485 water year types – years of subnormal snowmelt
NdoBassSnow.table	D1485 net Delta outflow requirement for Striped Bass in years of subnormal snowmelt.
Salinity_std_chs.table	D1485 salinity requirements at Chipps Island for fish and wildlife
WYtypeDefic.table	D1485 water year types – years of project deficiencies
Files Containing Different Data	
wsi_di_swp	
wsi_di_cvp_sys	
Stan_yr.table	Operational criteria for New Melones Reservoir and downstream demands
Dltidx_expidx_cvp_s.table	Export index – part of CVP South of Delta allocation logic
Xchanneldays.table	Requirements for closure of Delta Cross Channel
Clear_ck_min.table	Clear Creek minimum flow requirement
Trinitymin.table	Trinity River flow requirements
BanksLimits.table	Permit capacity for Banks Pumping Plant
RioVista.table	Flow requirements at Rio Vista
TracyLimits.table	Permit Capacity for Jones Pumping Plant
VAMP_Req.table	VAMP flow requirements – no VAMP requirement for D1485

Operational Logic

The two studies have different sets of operational logic (i.e., weights and constraints) as defined by the WRESL files (*.wresl). **Table B-5** lists WRESL files that exist for the D1485 analysis, but are not needed for the D1641 analysis.

Table B-5. Comparison of D1485 and D1641 Operational Logic

File Name	Description
Files Unique for D1485 Analysis	
.\common\Delta\Xchannel\xc-gates_D1485Setup.wresl	Delta Cross Channel gate operation under D1485
.\common\ReOperations\Wheeling\PB_wheelfixes.wresl	D1485 payback wheeling at Banks Pumping Plant
.\common\ReOperations\Wheeling\wheelD1485.wresl	D1485 payback wheeling at Banks Pumping Plant
Files Containing Different Logic	
.\CONV\Run\mainCONVWSI.wresl	
.\common\SanJoaquin\Stanislaus\stan_FW_min.wresl	
.\CONV\Run\CycleOutput\cycle_output.wresl	
.\common\Delta\Xchannel\xc-gates.wresl	
.\CONV\Run\mainCONV_SA.wresl	
.\common\SanJoaquin\Stanislaus\stan_FW_pulse.wresl	
.\common\SanJoaquin\Stanislaus\Stan_defs.wresl	
.\common\ReOperations\Wheeling\wheelcap.wresl	
.\common\Freeport\SCWA\scwa_excess_last_DELTA.wresl	
.\common\Freeport\SCWA\scwa_excess_ last_TRANSFERS_STAGE2.wresl	
.\common\Freeport\SCWA\scwa_excess_last_WHEELCVC.wresl	
.\common\NorthOfDelta\Sacramento\setnodminflows.wresl	
.\common\NorthOfDelta\Sacramento\keswickmin.wresl	
.\common\SanJoaquin\Stanislaus\Stan_defs_D1485.wresl	
.\CONV\Run\System\SystemTables_ALL\Weight-table.wresl	
.\common\Delta\Mrdo\Final-mrdo\final-mrdo.wresl	
.\common\Export_Ops\april_may_maxexport.wresl	
.\common\SanJoaquin\Vernalis\vernalis_min_D1485.wresl	
.\common\Export_Ops\exportratio.wresl	
.\common\NorthOfDelta\Trinity\Trinitymin.wresl	
.\common\Wytypes\wytypes.wresl	
.\common\Delta\Ann\ExportEstimate1.wresl	
.\common\cvp_dellogic\cvp_dellogic_s\exp_based\exp_based_del_cvp_s.wresl	
.\common\Delta\Ann\ExportEstimate1_PRESETUP.wresl	
.\common\Export_Ops\BanksSplit.wresl	
.\common\Delta\IsolatedFacility\Split_IFTD.wresl	
.\common\Delta\Ann\NegCarriageOpsLimit.wresl	
.\common\Delta\Ann\JerseyPoint_data.wresl	
.\common\Delta\Ann\Collins_data_reduced_calls.wresl	
.\common\Delta\Ann\Antioch_data.wresl	

Table B-5. Comparison of D1485 and D1641 Operational Logic contd.

.\common\Delta\Delta_ANN_Reduced_Calls.wresl	
.\common\Delta\Delta_ANN.wresl	
.\common\Delta\Ann\RockSlough_est.wresl	
.\common\Delta\Ann\ExportEstimate2.wresl	
.\common\Delta\Ann\Emmaton_data.wresl	
.\common\Delta\Ann\Collins_data.wresl	
.\common\Delta\Ann\Chipps_data_reduced_calls.wresl	
.\common\Delta\Ann\Chipps_data.wresl	
.\common\Delta\Ann\Antioch_data_reduced_calls.wresl	
.\common\Delta\Ann\AnnSacFlow.wresl	
.\common\Delta\Ann\ANN_COA_MRDO.wresl	
.\common\ReOperations\Wheeling\WheelCore.wresl	
.\CONV\Run\COA\coa.wresl	
.\common\Delta\Mrdo\Delta-outflow\delta-outflow.wresl	

Comparative Analysis D1641 vs Benchmark BO

Input TimeSeries Data

The two studies have identical input timeseries data (file: 2005A01A_1980SOD_SV.dss) and initial conditions (file: 2005A01AINIT.dss).

Input Relational Data

The two studies, D1485 and D1641, have different sets of relational data as defined by table files (*.table) in the lookup directory. **Table B-6** summarizes the differences between the two sets of table files.

Table B-6. Comparison of D1641 and Benchmark BO Relational Input Data

File Name	Description
Files Unique for D1641 Analysis	
Stan_yr_dems.table	Information merged into Stan_yr.table for Benchmark BO model.
wytypeSJR_Rest.table	Legacy code. Data is not used in D1641 model and could be deleted.
Files Containing Different Data	
wsi_di_swp.table	Relationship between water supply index and delivery index for the SWP
wsi_di_cvp_sys.table	Relationship between water supply index and delivery index for the CVP
Merced_GP570_ann_demand.table	Defines annual groundwater pumping for Merced ID. 25 TAF for existing, 45 TAF for future LOD.
FMP_Trigger.table	American River flow management standard
stan_yr.table	Information from Stan_yr_dems.table merged into Stan_yr.table for Benchmark BO model.
ExportEstimate_SWP.table	Estimate of export capability under regulatory environment used to determine SWP allocations
stan_pulse_rpa.table	NMFS BO flow requirements below Goodwin Dam
stan_monfish.table	STnislaus River fishery flow requirements

Operational Logic

The two studies have different sets of operational logic (i.e., weights and constraints) as defined by the WRESL files (*.wresl). **Table B-7** lists WRESL files that exist for the D1485 analysis, but are not needed for the D1641 analysis.

Table B-7. Comparison of D1641 and Benchmark BO Operational Logic

File Name	Description
Files Unique for D1641 Analysis	
.\common\SanJoaquin\Friant\SJRR_Rest_BUFF.wresl	
Files Containing Different Logic	
.\CONV\Run\mainCONVWSI.wresl	
.\CONV\Run\mainCONV_SA.wresl	
.\common\SanJoaquin\SanJoaquinCore_Alt_B.wresl	
.\common\SanJoaquin\SanJoaquinCore_D1485.wresl	
.\common\NorthOfDelta\American\FMStandard.wresl	
.\common\System\SystemTables_ALL\return-table.wresl	Benchmark BO has more sophisticated routine for calculating winter return flows from flooded rice fields based on any shortages in deliveries.
.\common\hydrology\RETURNS\returns_nod.wresl	
.\CONV\Run\System\SystemTables_ALL\Weight-table	
.\common\SanJoaquin\Stanislaus\Stanislaus_dems.wresl	
.\common\Wytypes\wytypes.wresl	
.\CONV\Run\DeliveryLogic\delcar_swp.wresl	
.\common\swp_dellogic\WSI_DI\delcar_swp.wresl	
.\common\ReOperations\Transfers\Transfers_Capacity_Limits .wresl	
.\CONV\Run\CycleOutput\cycle_output.wresl	
.\common\SanJoaquin\Stanislaus\stan_FW_pulse.wresl	
.\common\SanJoaquin\Stanislaus\stan_FW_min.wresl	
.\common\NorthOfDelta\Sacramento\setnodminflows	
.\common\SanJoaquin\PurchasedWater\InstreamFromOID	
.\common\SanJoaquin\Various\definitions\SJR_restrict.wresl	
.\common\B2Actions\Repeat\B2ActConditionsFix.wresl	
.\CONV\Run\BaseStudyResults\BaseStudyResults.wresl	
.\common\SanJoaquin\Vernalis\vernalis_min.wresl	
.\common\SanJoaquin\SanJoaquinAddCyc6.wresl	
.\common\SanJoaquin\Stanislaus\Stan_NMFS_RPA.wresl	
.\common\hydrology\WEIRS\weir_steps_monthops.wresl	
.\common\hydrology\WEIRS\weir_steps_dailyops.wresl	
.\CONV\Run\DeliveryLogic\delcar_cvp_s.wresl	
.\common\B2Actions\B2Action3.wresl	
.\common\hydrology\DEMANDS\demands_69.wresl	Benchmark BO allows delivery shortages for winter flooding of rice fields in the Feather River Service Area.
.\CONV\Run\B2Actions\B2Action1Repeat.wresl	
.\common\Export_Ops\OMR\OMR_constraint.wresl	
.\common\Export_Ops\EXP_constraint.wresl	
.\common\Delta\Xchannel\xc-gates.wresl	
.\common\Delta\Mrdo\X2\X2days_FWS.wresl	

Appendix C
State Water Project Demands

This appendix describes how water demands for SWP long-term contractors were developed for the 1980 level of development.

Table A Amounts

The initial SWP long-term contracts defined annual entitlement as the amount of water to be made available to a contractor as defined in Table A of the contract. Table A entitlements typically increased each year before reaching the maximum annual entitlement. Originally, the State envisaged an expansion of SWP facilities so that Table A entitlements could be met in full. The ultimate minimum yield of the SWP was planned to be equal to the sum of all contractors maximum annual entitlement. However, in 1978 DWR acknowledged that the ability of existing project facilities to deliver entitlement water was quickly approaching the dry period yield (1928-34) of these facilities and that in the event of a dry period, shortages in entitlement water deliveries could occur as early as 1982 (DWR, 1978). Before the Monterey Agreement, shortage provisions required that the State reduce deliveries to contractors using water for agriculture, up to a shortage of 50 percent in any one year, and up to 100 percent in any seven years, before reducing deliveries of project water to all contractors. Table A annual entitlements and contractors request for Table A water from 1976 to 1985 are presented in **Table C-1** and **Figure C-1**.

Table C-1. State Water Project Table A Requests and Deliveries

Year	Table A Requests and Allocations (TAF)				Deliveries (TAF)		
	Table A Entitlement	Contractor' Requests	Request as Percentage of Table A	Approved Allocation	Table A	Article 12(d)	Article 14(b)
1976	1,508	1,368	91%	1,368	1,373	0	0
1977	1,667	1,157	69%	1,157	596	0	0
1978	1,818	1,829	100%	1,829	1,291	139	0
1979	2,028	1,834	90%	1,834	1,452	201	7
1980	2,215	1,570	71%	1,570	1,536	0	0
1981	2,392	1,580	66%	1,580	1,930	0	0
1982	2,575	2,064	80%	2,064	1,753	0	0
1983	2,701	2,022	75%	2,022	1,187	0	0
1984	2,884	1,568	54%	1,568	1,592	0	0
1985	3,056	1,892	62%	1,892	1,996	0	0

State Water Project Article 21

During the initial years of SWP operations, it was recognized that project facilities would be able to deliver water in excess of full Table A requirements. Article 21 of the water supply contracts provides that in "any year the supply of project water, after appropriate allowance for holdover storage, exceeds the total of annual entitlements of all contractors for that year, the State shall offer to sell and deliver such surplus water for periods expiring not later than the end of such year". The long-term contracts included provisions for providing surplus water service for agricultural use and groundwater replenishment. These provisions, added, in 1963, aimed to reduce the overall cost of water to agricultural contractors. The special provisions for agricultural contractors were amended in 1974 to provide a more restrictive definition of when surplus water would be available. The 1974 amendment required that full Table A amounts be scheduled before any surplus water be scheduled. Additionally, a contractor may not receive water in excess of its Table contract amount for that year until the annual entitlement is above 75 percent of the maximum entitlement.

Table C-1 presents historical SWP Article 21 requests and deliveries for the decade centered on 1980. Contractor requests for Article 21 water are submitted in September of the previous year, before water conditions are known. Initial schedules for delivery of Article 21 deliveries are formulated in December. Initial requests may be revised as water supply conditions evolve. Surplus water deliveries began in 1968. From 1968 to 1975, deliveries varied from 72 TAF acre-feet to 580 TAF. Between 1976 and 1985, Article 21 deliveries varied from zero (in 1977) to 647 TAF (in 1979).

An extra-surplus water program was developed in 1980 as a result of contractor requests. Extra-surplus water is available when Delta water supplies and aqueduct delivery capability exceed that needed to meet scheduled water deliveries and other SWP requirements. Extra-surplus water is scheduled one week in advance, in accordance with extra-surplus water contracts. Extra-surplus water is also known as unscheduled water. The water must be used primarily for groundwater replenishment, agricultural water use in-lieu of groundwater pumping, and pre-irrigation.

Table C-2. State Water Project Article 21 Requests and Deliveries

Year	Surplus Water Initial Requests[g] (TAF)	Article 21 Deliveries (TAF)		Article 21 Deliveries by Region (TAF)			
		Surplus Water	Unscheduled Water	South Bay Aqueduct	San Joaquin Valley	Southern California	Other
1976	790	580	N/A	32	548	0	0
1977	1,305	0	N/A	0	0	0	0
1978	907[a]	17	N/A	0	16	0	<1
1979	734	647[b]	N/A	16	631	0	0
1980	901	330[c]	72	14	388	0	0
1981	832	633	275	19	889	<1	0
1982	779	48[d]	168	1	215	0	0
1983	660	13[e]	0[f]	0	13	0	0
1984	246	263	0[f]	0	0	0	0
1985	384	302	0[f]	10	292	0	<1

Notes:

(a) Contractor requests for Article 21 for 1978 were revised downwards following a very wet spring to 17 TAF.

(b) Excludes 20 TAF of Emergency Relief Water.

(c) Excludes 3 TAF acre-feet of Emergency Relief Water, includes 'extra surplus water'.

(d) Delivery of surplus water was limited due to repairs to San Luis Reservoir. Agricultural water demands were reduced due to heavy storms in April and May and heavy crop damage.

(e) A wet spring resulted in low demands; water supplies exceeded demand.

(f) No unscheduled water was delivered as enough surplus water was available to meet all demands.

(g) Initial requests for surplus water are made by contractors in September before water conditions for the coming conditions are known. Requests may be revised following spring precipitation.

For modeling purposes, demands for surplus water were developed by establishing a relationship between historical SWP surplus deliveries and the Tulare Basin Precipitation index. This relationship is presented in **Figure C-1**.

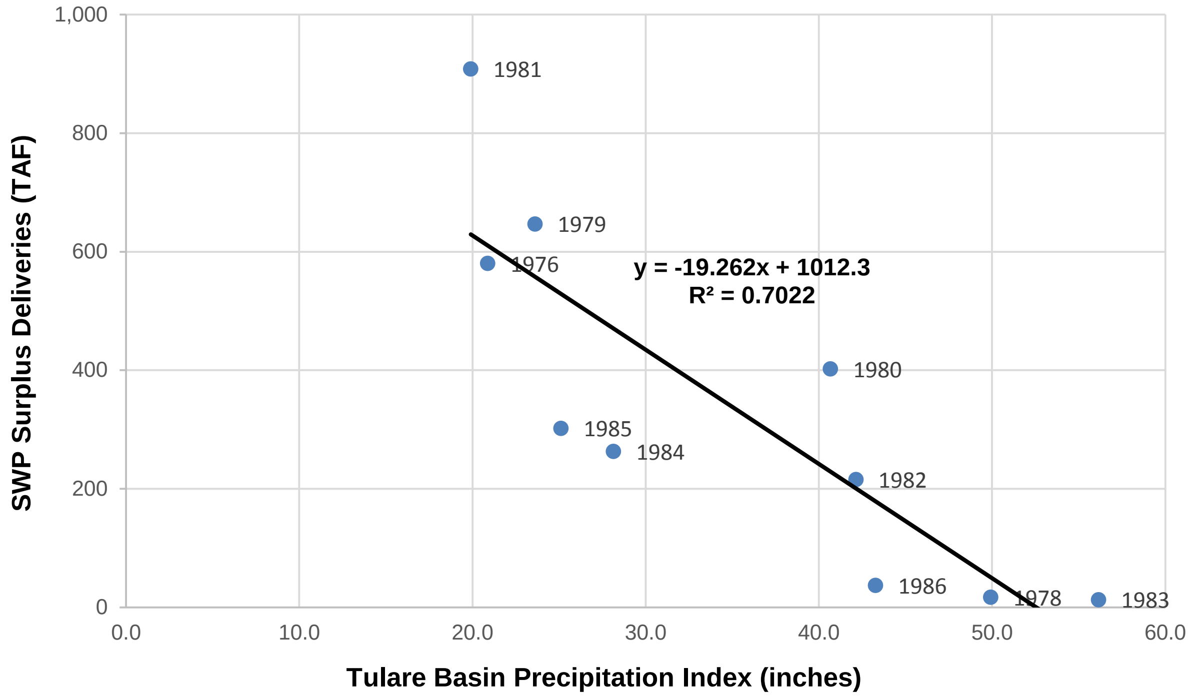

Figure C-1. State Water Project Surplus Deliveries as a Function of Precipitation

State Wheeling of Federal Water

In 1975, DWR and Reclamation signed a two-party contract for wheeling of CVP water through the California Aqueduct for delivery to Cross Valley Canal contractors. Initially, delivery contracts were signed with five San Joaquin Valley water agencies. A sixth contract was added early in 1976. The maximum contract amount was 82,704 acre-feet. Wheeling and deliveries began in January 1976. Additional contracts and contract amendments signed in 1976 and 1977 increased the maximum contract amount to 125,832 acre-feet.

Before the adoption of Water Rights Decision 1485 (D-1485), wheeling of federal water through the California Aqueduct was limited to water for the Cross Valley Canal contractors. D-1485, adopted in 1978, limited exports at Banks and Jones pumping plants during May, June and July.[34] for the protection of striped bass. D-1485 authorized DWR to wheel CVP water through State facilities to make up for federal pumping curtailments. Wheeling of this Federal water began in May 1980.

SB 200, which was passed in January 1980, limited wheeling of CVP water through SWP facilities. The Bill permitted DWR to convey CVP water through SWP facilities: (a) under existing contracts, (b) in accordance with State Water Board requirements, and (c) for the CVP San Felipe Unit, in accordance with agreements between Santa Clara Valley WD and DWR. Any additional wheeling was to be curtailed

[34] The July curtailment did not impose a limitation on existing Federal pumping capability.

until the federal government agreed to operate the CVP in compliance with State Water Board water quality standards.[35] This provision of SB 200 was rejected by the State voters in 1982.

In 1980, DWR signed an interim agreement with Reclamation to wheel water to Westlands WD that the CVP was unable to deliver due to maintenance of the Delta-Mendota Canal. In 1981, DWR signed an additional interim agreement to wheel water to supply temporary CVP contractors. In these agreements, Reclamation agreed to limit exports in accordance with D-1485 and provide its share of water to meet Delta water quality standards. In 1985, DWR signed an agreement to wheel 28,000 acre-feet of CVP water through SWP facilities for wildlife habitat purposes in the Grasslands area.

[35] Reclamation maintained that compliance with State Water Board water quality standards was voluntary.