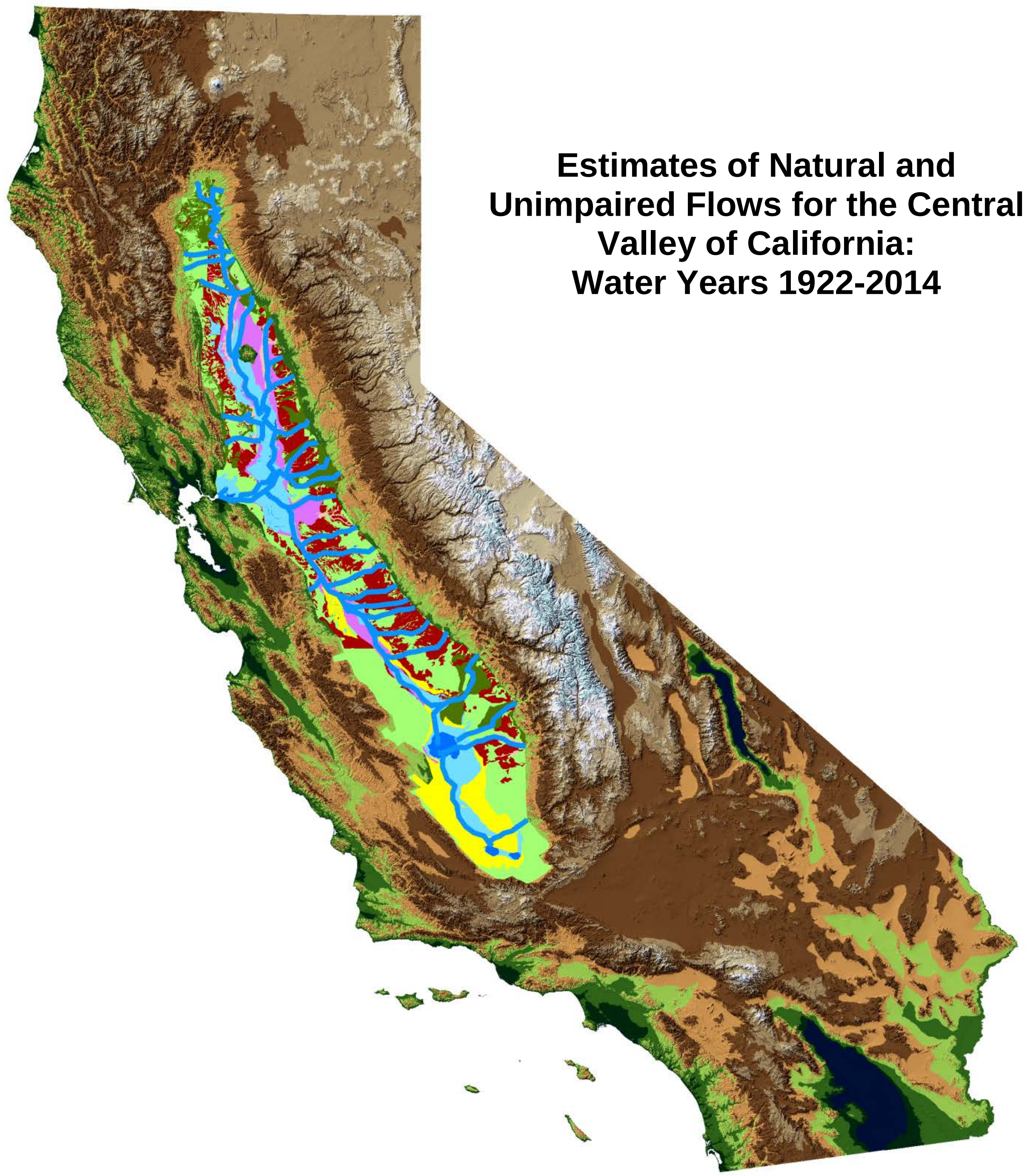
Estimates of Natural and Unimpaired Flows for the Central Valley of California: Water Years 1922-2014



March 2016 (DRAFT)

Department of Water Resources, Bay-Delta Office

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State of California
California Natural Resources Agency
DEPARTMENT OF WATER RESOURCES

Estimates of Natural and Unimpaired Flows for the Central Valley of California: WY 1922-2014

March 2016 – First Edition (DRAFT)

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Governor	**Secretary for Natural Resources**	**Director**
State of California	**California Natural Resources Agency**	**Department of Water Resources**

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FOREWORD

This report summarizes estimates of “natural” and “unimpaired” flows for all areas in the Central Valley tributary to the Sacramento – San Joaquin Delta (Delta) for the period spanning water years 1922-2014. A major objective of this report is to clarify the conceptual differences between natural and unimpaired flows. In spite of the Department’s previous attempts to distinguish between natural conditions and its calculation of theoretical unimpaired flows, unimpaired flow estimates have frequently been used as a surrogate measure of natural conditions, presumably because natural flow estimates were unavailable.

This report, which contains the Department’s first published estimates of natural flows in the Central Valley tributary to the Delta, builds upon a series of publications that chronicled the Department’s efforts to update estimates of unimpaired flow as new hydrologic data became available. The first edition, published in 1980, was titled *California Central Valley Natural Flow Data*. Subsequent editions in 1987, 1994, and 2007 were re-titled *California Central Valley Unimpaired Flow Data* in recognition of the conceptual differences between natural and unimpaired flows.

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EXECUTIVE SUMMARY

Purpose of Report

This report summarizes estimates of “natural” and “unimpaired” flows for all areas in the Central Valley tributary to the Sacramento – San Joaquin Delta (Delta) for the period spanning water years 1922-2014. A major objective of this report is to clarify the conceptual differences between natural and unimpaired flows. In spite of the Department’s previous attempts to distinguish between natural conditions and its calculation of theoretical unimpaired flows, unimpaired flow estimates have frequently been used as a surrogate measure of natural conditions, presumably because natural flow estimates were unavailable. This report contains the Department’s first published estimates of natural flows; these estimates are derived from complex simulation models and are based on published estimates of natural vegetation cover and associated evapotranspiration.

Summary of Findings

This report documents and compares a variety of natural and unimpaired flow estimates, including rim watershed inflows, valley floor water supply, and Delta inflows and outflows. Comparisons of Delta inflow and outflow estimates demonstrate that unimpaired estimates are consistently (and significantly) higher than natural estimates.

Annual average Delta outflow estimates are compared by 40-30-30 water year type, as well as over the long-term average, in Figure ES-1. For the long-term average, the annual unimpaired Delta outflow estimate (28.1 MAF) is 43 percent higher than the natural Delta outflow estimate of 19.7 MAF. Unimpaired outflow estimates are higher than natural flow estimates, primarily because the former estimates do not account for overbank flows and the resulting evapotranspiration associated with natural wetlands. The relative seasonal (i.e. monthly) distributions of unimpaired and natural Delta outflow estimates are not widely different. However, the relative distribution of unimpaired Delta outflow tends to be smaller in the winter (and larger in the other seasons) compared to natural Delta outflow. In sum, the findings of this report show that unimpaired flow estimates are poor surrogates for natural flow conditions.

Sensitivity analyses were conducted on several key model inputs and parameters. These analyses, supported by 30 model runs, suggested an uncertainty range of approximately ± 10 percent. Potential evapotranspiration from riparian and wetland vegetation was found to be the most sensitive model parameter.

Conceptual Differences between Natural and Unimpaired Flows

In this report, the term “unimpaired” flow is used to describe a theoretically available water supply assuming existing river channel conditions in the absence of (1) storage regulation for water supply and hydropower purposes and (2) stream diversions for agricultural and municipal uses. Unimpaired flow estimates are theoretical in that such conditions have not occurred historically. In pristine watersheds which have undergone little land use change, unimpaired flow estimates provide a fixed frame of reference to develop relationships between precipitation, runoff, and water supply based on long-term hydrologic records. For many years these relationships were based on the assumption of stationarity, i.e. that the past is a good indicator of the future. However, global warming now requires hydrologists and water resources managers to analyze non-stationary processes, requiring more sophisticated tools and techniques to quantify future water supplies. This report updates and extends the Department's previous published estimates of unimpaired flows for 24 Central Valley subbasins and the Delta. Monthly unimpaired flows are presented for water years 1922-2014.

The term "natural" flow is used in this report to describe the flows that would have occurred absent all anthropogenic influences and is considered to represent the period circa 1850 prior to significant landscape changes following the California Gold Rush. These influences have dramatically affected Central Valley flows, including inflows to the Delta. For example, changes in land use, including (but not limited to) the clearance and drainage of wetlands, have affected the amount and timing of surface runoff. Groundwater pumping has impacted groundwater elevations and groundwater inflows to streams and rivers. Flood control measures, including an extensive network of levees, have ended the natural cycle of bank overflows and detention storage.

The estimates of natural flow provided in this report are not to be confused with estimates of actual flows that occurred under Paleolithic or more recent conditions prior to European settlement. Rather, these estimates assume the contemporary precipitation and inflow pattern to the valley floor (i.e. water years 1922-2014) with the valley floor in a natural or undeveloped state: before flood control facilities, levees, land reclamation, irrigation projects, imports, etc.

Summary of Methods

Methods used to estimate natural and unimpaired flows are detailed in the main body of the report. While methods used to estimate unimpaired flows generally follow the approach established in previous Department publications, those used to estimate natural flows are new. This new methodology relies on two complex models to simulate hydrology of the Central Valley rim watersheds and floor:

- SWAT (Soil Water Assessment Tool), a precipitation-runoff model, was used to simulate stream flows for most rim watersheds. SWAT, which is a public domain model developed by the U.S. Department of Agriculture, provides a tool for evaluating future potential impacts of climate change.
- C2VSim, an integrated hydrologic model, was used to simulate groundwater and surface water hydrology on the Central Valley floor. C2VSim is a Central Valley application of the Department's IWFM model.

The new approach to estimate natural flow, which is based on published estimates of the region's natural vegetation cover and associated evapotranspiration, was designed to overcome information gaps that were identified in previous unimpaired flow publications:

First, the ground water accretions from the very large area of the Central Valley floor probably were considerably higher under natural conditions but no data are available. Second, the consumptive use of the riparian vegetation and the water surfaces in the swamps and channels of the Central Valley under a natural state could be significant but are difficult to estimate. Third, during periods of high flow, Central Valley rivers would overflow their banks and water could be stored in the valley for long periods of time and could interact with item two. Fourth, the outflow from the Tulare Lake Basin under natural conditions is difficult to estimate.

SWAT-based estimates of natural rim watershed flows are somewhat different from the values used to estimate unimpaired rim watershed flows. These differences, as discussed in the main body of the report, were found to be small and therefore do not bias conclusions regarding differences between natural and unimpaired flows.

Previous Unimpaired Flow Reports

This report, which contains the Department's first published estimates of natural flows in the Central Valley tributary to the Delta, builds upon a series of publications that chronicled the Department's efforts to update estimates of unimpaired flow as new hydrologic data became available. The first edition, published in 1980, was titled *California Central Valley Natural Flow Data*. Subsequent editions in 1987, 1994, and 2007 were re-titled *California Central Valley Unimpaired Flow Data* in recognition of the conceptual differences between natural and unimpaired flows.

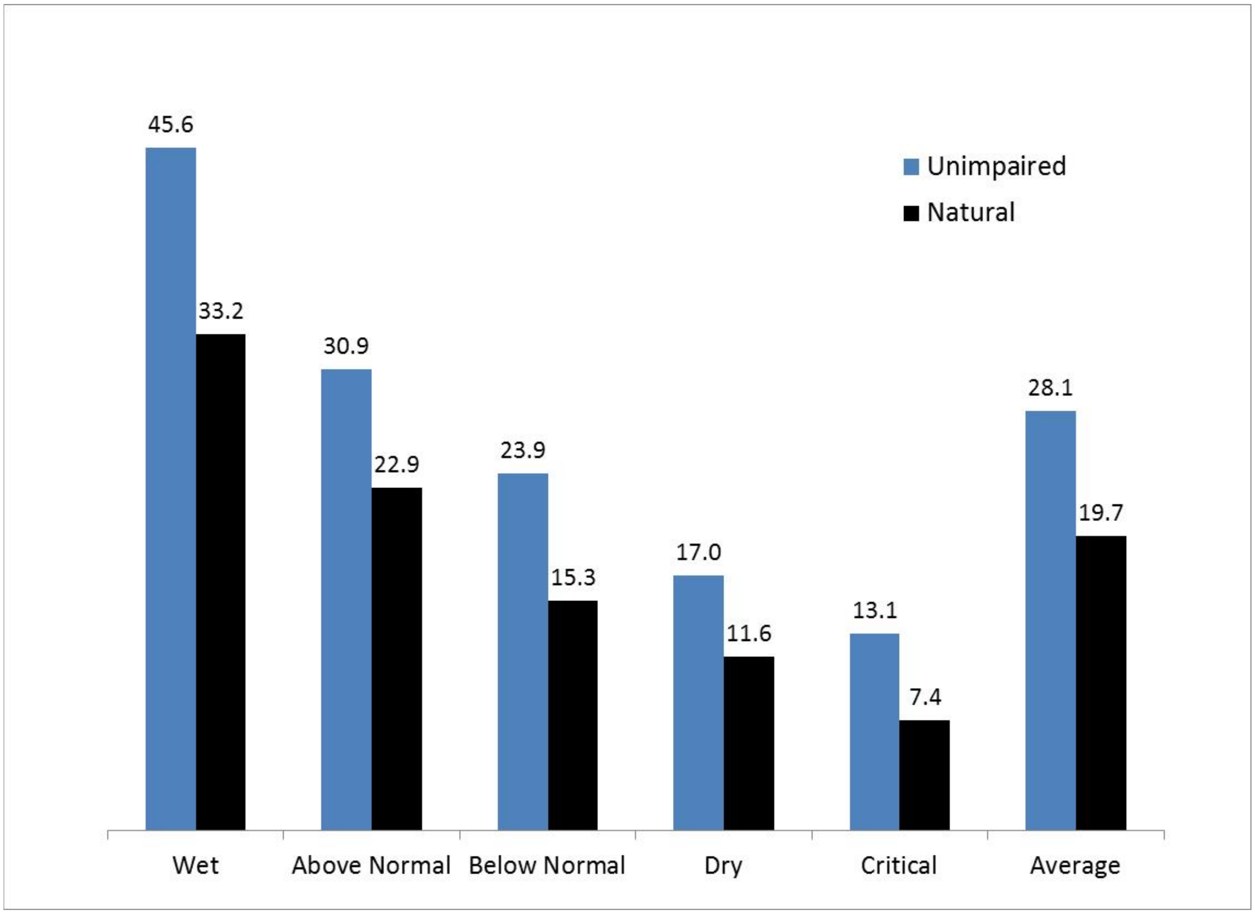

Figure ES-1. Average Annual Unimpaired and Natural Net Delta Outflow (MAF)

This chart compares annual average “unimpaired” and “natural” Delta outflow estimates (in units of million acre-feet) for the 93-year hydrologic period spanning water years 1922 through 2014. Comparisons are shown by 40-30-30 water year type as well as the full period average. This chart clearly shows that unimpaired flow estimates are significantly higher than natural flow estimates under all hydrologic conditions. Under average conditions, the annual unimpaired flow estimate is 43 percent higher than the natural flow estimate.

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ABBREVIATIONS AND ACRONYMS

AF	acre-foot
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
CSU Chico	California State University at Chico
DWR	California Department of Water Resources
ET	evapotranspiration
ET_c	Potential crop evapotranspiration
ET_o	Reference crop evapotranspiration
IWFM	Integrated Water Flow Model
MAF	million acre-feet
NF	natural flow
OWID	Oroville-Wyandotte Irrigation District
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
SWAT	Soil Water Assessment Tool
TAF	thousand acre-feet
UF	unimpaired flow
USGS	U.S. Geological Survey
WY	Water Year

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1. INTRODUCTION

Estimating regional water supplies that would have occurred absent human activities is a common practice in water resources planning. In this report, such theoretical water supply estimates are referred to as "unimpaired" flow. Since 1980, the Department of Water Resources (Department) has periodically published estimates of Central Valley unimpaired flows. In spite of the Department's previous attempts to distinguish between natural conditions and its calculation of theoretical unimpaired flows, unimpaired flow estimates have frequently been used as a surrogate measure of natural conditions, presumably because natural flow estimates were unavailable. A major objective of this report is to clarify the conceptual differences between natural and unimpaired flows.

In this report, the term "unimpaired" flow is used to describe a theoretically available water supply assuming existing river channel conditions in the absence of (1) storage regulation for water supply and hydropower purposes and (2) stream diversions for agricultural and municipal uses. Unimpaired flow estimates are theoretical in that such conditions have not occurred historically. In pristine watersheds which have undergone little land use change, unimpaired flow estimates provide a fixed frame of reference to develop relationships between precipitation, runoff, and water supply based on long-term hydrologic records. For many years these relationships were based on the assumption of stationarity, i.e. that the past is a good indicator of the future. However, global warming now requires hydrologists and water resources managers to analyze non-stationary processes, requiring more sophisticated tools and techniques to quantify future water supplies. This report updates and extends the Department's previous published estimates of unimpaired flows for 24 Central Valley subbasins and the Delta. Monthly unimpaired flows are presented for water years 1922-2014.

The term "natural" flow is used in this report to describe the flows that would have occurred absent all anthropogenic influences and is considered to represent the period circa 1850 prior to significant landscape changes following the California Gold Rush. These influences have dramatically affected inflows to the Delta. For example, changes in land use, including (but not limited to) the clearance and drainage of wetlands, have affected the amount and timing of surface runoff. Groundwater pumping has impacted groundwater elevations and groundwater inflows to streams and rivers. Flood control measures, including an extensive network of levees, have ended the natural cycle of bank overflows and detention storage.

The estimates of natural flow provided in this report are not to be confused with estimates of actual flows that occurred under Paleolithic or more recent conditions prior to European settlement. Rather, these estimates assume the contemporary precipitation and inflow pattern to the valley floor (i.e. water years 1922-2014) with the valley floor in a natural or undeveloped state: before flood control facilities, levees, land reclamation, irrigation projects, imports, etc.

The mountain and foothill watersheds that surround the Central Valley are relatively pristine. Land use changes have not dramatically affected the volume and timing of seasonal runoff in these watersheds. Furthermore, these watersheds have limited groundwater aquifers. Therefore, in these watersheds, unimpaired flows may be calculated relatively simply by adjusting observed gaged data to remove the effects of (1) upstream changes in surface water storage, (2) basin imports, and (3) basin exports. Given that anthropogenic impacts are relatively small in these upstream watersheds, unimpaired and natural flow estimates are likely to be similar, and for the purposes of this report are assumed to be the same.

The main body of this report, comprised of six chapters and references, provides conceptual differences between natural and unimpaired flow estimates, describes the methods used to develop these estimates, and presents summary results and conclusions. Details of the SWAT model, a model used as part of the natural flow methodology to estimate rim watershed contributions, are presented in A**ppendi**x A. Additional appendices summarize tables of monthly unimpaired and natural flow and differences between the two estimates.

2. CONCEPTUAL DIFFERENCES BETWEEN NATURAL AND UNIMPAIRED FLOWS

Full natural flow, natural flow, natural runoff and unimpaired flow are all phrases that have been used by the Department in various publications to represent the runoff from a basin that would have occurred had man not altered the flow of water in the basin. Of special interest here is a series of publications that reported updates to the Department's Central Valley unimpaired flow estimates. The first edition of this series was titled *California Central Valley Natural Flow Data*. Subsequent editions were re-titled *California Central Valley Unimpaired Flow Data* in recognition of the conceptual differences between natural and unimpaired flows.

The word "natural" connotes that the Central Valley landscape is in a pre-development or pristine state. The word "unimpaired", on the other hand, implies that certain items in the measured flows have been adjusted. Unimpaired flow could be synonymous with natural flow if all of the items in the unimpaired estimation procedure matched the natural flow estimation. In practice, this is not usually the case; it is customary to include only those items in the unimpaired flow estimation for which either reliable data are readily available or reasonable estimates can be made. In previous editions of the Department's *California Central Valley Unimpaired Flow Data* the data are better described as unimpaired data, primarily because of the difficulty in estimating four items of significance, as follows:

- First, groundwater accretions from the very large area of the Central Valley floor probably were considerably higher under natural conditions but no data are available.
- Second, the consumptive use of the riparian vegetation and the water surfaces in the swamps and channels of the Central Valley under a natural state were significant but are difficult to estimate.
- Third, during periods of high flow, Central Valley rivers would overflow their banks and water could be stored in natural low-lying basins for long periods of time, recharging groundwater and providing water for natural wetlands and perennial grasslands.
- Fourth, the outflow from the Tulare Lake Basin under natural conditions may have been significant in wet years, but are difficult to estimate.

The unimpaired flows in this report assume that the river channels of the valley are in their present configuration. Figure 2-1 shows the 24 subbasin boundaries established by the Department for reporting estimated monthly unimpaired flow time series data for the Central Valley beginning Water Year 1922 (DWR, 2007). The areas of the Central Valley (Figure 2-1) can be separated into three main regions: the upper watersheds of the Sierra Nevada and coastal mountain ranges (colored light blue in Figure 2-1); the valley floor, typically the areas below the 500-foot elevation contour, (shown in green in Figure 2-1); and the Delta. The Delta is part of the valley floor but for accounting purposes is identified separately (Area 24 in Figure 2-1). When referring to areas tributary to the Delta, the Tulare Basin (Area 23 and associated watersheds) contribute minimal surface water (flood flows from the Kings River to the San

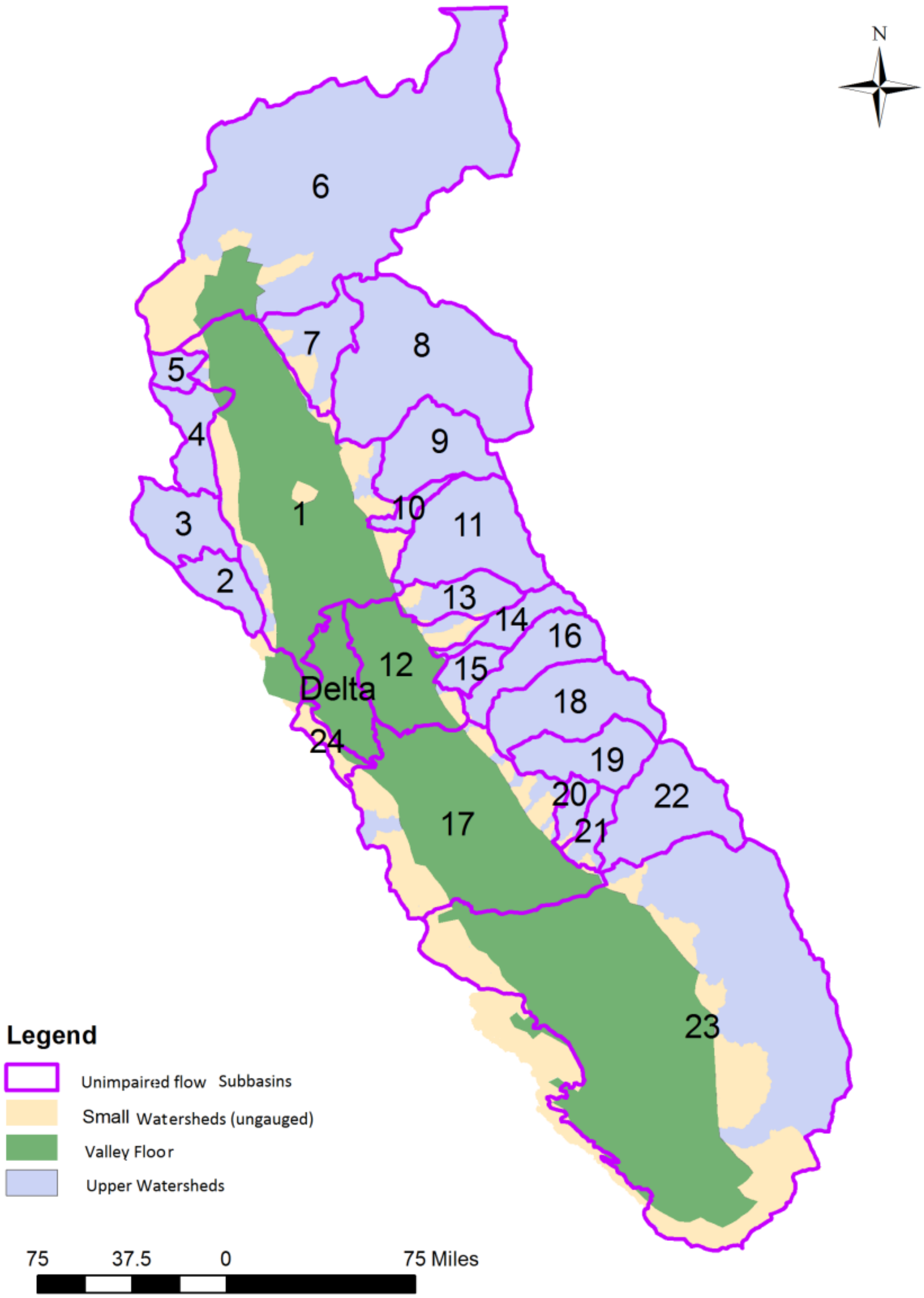

Figure 2-1. Unimpaired Flow Subbasins in the Central Valley

Joaquin River). However, the subsurface ground water system between the San Joaquin River Basin and Tulare Basin are connected.

The main source of natural water on any of the watersheds shown in Figure 2-1 is precipitation in the form of rainfall and snowfall. That precipitation is subjected to different physical processes (e.g., accumulation and melt for snowfall, runoff, soil moisture storage, deep percolation, evaporation and evapotranspiration). In addition, if the area is developed for agriculture and/or urbanized, streamflows from precipitation are subject to further modifications such as storage regulation, diversions and return flows. For general planning purposes and sometimes for regulatory needs, it is important to estimate the water supply generated in a watershed due to the precipitation that falls on that area prior to any human or anthropogenic development. One can approach this in two ways:

1. Start with a measured outflow (gaged) for an area, which represents impaired flow, and then "unimpair" (or modify) that flow for any anthropogenic impacts (e.g., diversions, return flows, imports into an areas, or exports from an area) to arrive at an estimate of unimpaired flow.
2. Use physically based computer models to simulate the outflow from the area under pre-development land use conditions to arrive at an estimate of natural flow.

How the unimpaired and natural flow estimates differ in magnitude and interpretation will depend on the degree of land use development (i.e., alteration of pre-development native conditions due to agriculture or urbanization). Figure 2-2 divides the major watersheds in the Central Valley tributary to the Sacramento – San Joaquin Delta into three distinct regions: the upper watersheds in the Sierra Nevada Mountains and Coastal Mountains (shown in green); the valley floor (shown in yellow); and the Delta (shown in red).

For the mountain watersheds, precipitation runoff (both rainfall and snowfall) is subject to changes in volume and timing as reflected in the watershed stream outflows. The causes for modifications to streamflows include vegetative evapotranspiration or consumptive use, sublimation, snow accumulation and snowmelt, overland and subsurface shallow flow, infiltration, and stream/groundwater interaction. Outflows from the upper watersheds become inflows to the Sacramento and San Joaquin Valley floor areas. Volumetrically most of these flows are surface streamflows (including shallow subsurface flows) while some are subsurface flows that feed the valley floor ground water systems. These outflows from the upper watersheds become inflows to the flat valley areas of the Central Valley. (Although the Tulare Basin contributes only a very small quantity of runoff to the Delta, selected flow estimates for this hydrologic region are included in this report for completeness.) Minimal runoff contributions to these upper watersheds are provided from areas outside of California.

For the valley floor, inflows from the upper watersheds along with local precipitation are modified in magnitude and timing before becoming inflow to the Delta. Causes of modifications include vegetative consumptive use (riparian, native vegetation, etc.), overbank flows from streams during high flow conditions, formation and disappearance of lakes and wetlands, stream/groundwater interaction, infiltration, runoff, return flows, and uptake from groundwater to meet vegetative consumptive water demands.

Within the Delta, outflows from the Sacramento Valley, Eastside Streams, and San Joaquin Valley are subject to further modifications due to in-Delta vegetative consumptive use, evaporation from open water surfaces, wetlands, and lakes, and stream-groundwater interaction, before flowing into the San Francisco Bay and Pacific Ocean as Delta outflow.

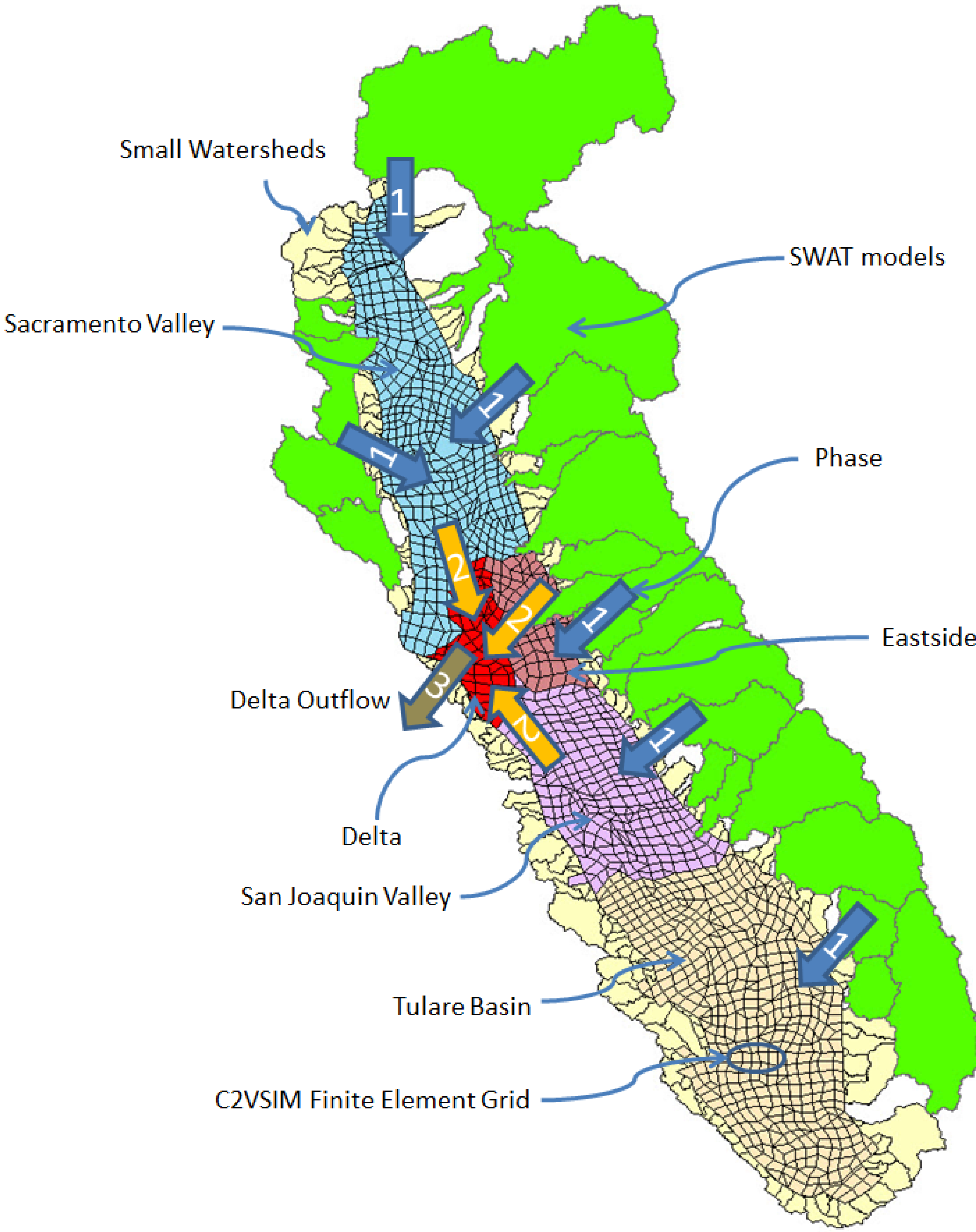

Figure 2-2. Three Major Phases Affecting Water Travel from the Upper Watersheds to Delta Outflow

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3. ESTIMATES OF UNIMPAIRED FLOWS

Introduction

The Department first published estimated unimpaired flows for 24 Central Valley subbasins and the Delta in a 1980 report titled Central Valley Natural Flow Data. The report presented monthly flows for water years 1920-1978. Data for October 1920 through September 1983 were published in a 1987 report titled California Central Valley Unimpaired Flow Data, Second Edition. The title of the second edition corrected the misuse of the term "Natural Flow." The extension of unimpaired flow data from October 1983 through September 1992 was published in August 1994 as the Third Edition. The Fourth Edition, published in 1997, added data for October 1992 through September 2003.

This chapter describes the extension of unimpaired flow data through water year 2014 of the 1921-2003 data found in the *California Central Valley Unimpaired Flow Data Fourth Edition - Draft* (DWR, 2007), prepared by the Bay-Delta Office. The text describing the procedures used to estimate the unimpaired flows is taken from the 2007 report (with minor editorial changes) and updated when necessary. The information below also explains any differences in calculations between the 2007 report and this report. For flow data taken directly from the Department's Snow Survey records, unimpaired flow estimation procedures are also provided where available.

The unimpaired flows as presented in this report are an extension in time of previous published values by the Department**. Appendix B contains tables of monthly unimpaired flows for each of the** 24 **subbasins in the Central Valley**. In addition, estimates are included of the total unimpaired inflow to the Delta, and the total unimpaired net Delta outflow.

Procedures Used to Estimate Unimpaired Flows

UF 1— Sacramento Valley Floor

These values represent the estimated unimpaired flow for the Sacramento Valley floor and the minor streams from the Stony Creek drainage area to the Cache Creek drainage area, from the Cache Creek drainage area to the mouth of the Sacramento River, and from the Feather River drainage area to the American River drainage area (Bulletin No. 1 areas 2-8, 2-9, 2-16, and 2-29). With Bulletin No. 1 mean seasonal runoff as a base, these minor streams were estimated to be 2.18 times the Bear River near Wheatland (776/356=2.18). In the unimpaired flow data published in the 1966 —Surface Water Hydrology of Yuba-Bear Rivers Hydrographic Unit office report, the 1911-1960 average runoff of the Bear River near Wheatland was 5.05 times that of Dry Creek near Wheatland. The resulting runoff for the 1921 through 1960 period was estimated by multiplying 11 (2.18 x 5.05) by the estimated monthly runoff of Dry Creek near Wheatland.

Unimpaired runoff for the 1961-1992 period was estimated as the product of 2.18 times the estimated unimpaired flow of the Bear River near Wheatland due to the discontinued Dry Creek record. Since this estimation showed abnormally high summer flows, the June flows were reduced by one-half and flows for July, August and September were made equal to zero.

The unimpaired flow data for the 1993 – 2003 period was estimated using similar procedure as that of the 1961 – 1992 period flow data. However, we note the rationale for reducing June flows by one-half and setting the July to September flows to zero as subjective that need to be revisited and verified in future updates. For the 2011-2014 period, the subjective reduction for June-September was not applied.

UF 2 — Putah Creek near Winters

The unimpaired flow for Putah Creek near Winters for water year 1921 was obtained from the 1964 DWR office report —Surface Water Hydrology of Putah-Cache Hydrographic Unit. The unimpaired flow of Putah Creek near Winters for the 33 year period (1922-1954) was assumed to be equal to the historical flow USGS gage 11454000, Putah Creek near Winters. Flows for the 1955-1992 period were obtained from USGS gage 11454000, adjusted for the changes in storage and evaporation from Lake Berryessa starting in January 1957. Flows for the 1993 to 2014 period were extended similarly.

UF 3 — Cache Creek above Rumsey

These flows represent the estimated unimpaired flow of Cache Creek above Rumsey. The 1921 unimpaired flow was based on the 1964 "Surface Water Hydrology of Putah-Cache Creeks Hydrographic Unit" office report and was calculated by adding together Table 18 (Cache Creek at Lower Lake, unimpaired flow), Table 21 (Bear Creek near Rumsey), Table 22 (North Fork Cache Creek near Lower Lake), and data from an incremental ungauged area equivalent to 0.41 times the flow of North Fork Cache Creek. The factor 0.41 was used in estimating historical outflow of depletion Study Area 16 (Cache Creek above Rumsey) in the 1966 joint DWR – U.S. Department of the Interior, Bureau of Reclamation (Reclamation) Central Valley depletion study.

Unimpaired runoff for the 1922 through 1960 water year period was obtained by adding the differences between Table 18 (Cache Creek at Lower Lake, unimpaired flow) and Table 20 (Cache Creek near Lower Lake, recorded flow) of the 1964 office report mentioned above to the historical outflow of Joint Depletion Study Area 16 (Cache Creek above Rumsey). The difference between Tables 18 and 20 corrects the historical flow for upstream depletion and regulation due to Clear Lake.

Unimpaired flows for 1961-1970 were calculated by the same method except that the computer program OUTFLOW (developed by the DWR Statewide Planning Branch) was used to find Cache Creek at Lower Lake unimpaired flow instead of Table 18. This program determined the unimpaired outflow of Clear Lake with a given net supply. The net supply for Clear Lake was calculated by adding together the historical outflow of Cache Creek near Lower Lake, (USGS water supply papers), the average lake evaporation (lake area at average monthly gage height times average monthly evaporation), and change in gage height times average lake area).

Beginning with water year 1971, the unimpaired flow of Cache Creek above Rumsey was estimated as the sum of the estimated unimpaired outflow of Clear Lake plus the flows from Bear Creek near Rumsey, North Fork Cache Creek near Lower Lake and the remaining area between the gages at those three locations and the Rumsey gage. For water years 1971 through 1973 and 1976 through 1978, the accretions were calculated as the difference in measured flow of Cache Creek above Rumsey and the three upstream gages. For water years 1974 and 1975, the accretions were estimated by graphical correlation with the unimpaired flow of North Fork Cache Creek near Lower Lake. The equation is:

Accretions = 0.47674 (North Fork) – 11,688 acre-feet

Adjustments for the estimated changes in storage and evaporation of Indian Valley Reservoir began in December 1974. For water years 1981 through 1983, the unimpaired flow was estimated as the sum of the historical flow of Cache Creek at Rumsey plus the net effects of Indian Valley Reservoir and Clear Lake.

Flows for 1984-1992 were estimated as the sum of historical flow of Cache Creek at Rumsey plus net effects of Clear Lake and Indian Valley Reservoir. The net effect of Clear Lake is estimated as:

Clear Lake outflow from the Cache HEC-3 Model minus historical Clear Lake flow near Lower Lake (Clear Lake historical outflow).

For the 1993 to 2003 period, similar procedure as the 1984 to 1992 period was used except that USGS gage (11451000) data for Clear Lake outflow was used instead of HEC-3 model output. It is assumed that the gage data are more representative than the HEC-3 model output.

For 2004 to 2014 period, unimpaired flow estimate was made as the sum of unimpaired North Fork Cache Creek near Clear Lake Oaks, unimpaired Cache Creek near Lower Lake, and Bear Creek above Holsten Chimney Canyon near Rumsey, a scale factor of 1.28 was applied for drainage area between Cache Creek above Rumsey and these three subbasins.

UF 4 — Stony Creek at Black Butte

These flows are the estimated unimpaired flows of Stony Creek at Black Butte Reservoir. Unimpaired flows for water year 1921 were obtained from the DWR office report —Surface Water Hydrology-Upper Sacramento Valley, January 1968. Runoff for 1922 through 1949 was obtained from Reclamation Appendix I —Hydrology on Black Butte Unit, Stony Creek Division, Central Valley Basin, February 1951. Extensions of the flows were made in about 1960 by Reclamation personnel to cover water years 1950 through 1957. The flows for the 1958-1992 period were estimated by adding together the historical outflow of Stony Creek at Black Butte (USGS water supply papers), historical export of South Diversion Canal, and the changes in storage and evaporation from Stony Gorge, East Park, and Black Butte Reservoirs. Flows for the 1993 to 2014 period were extended similarly.

UF 5 — Sacramento Valley West Side Minor Streams

These flows represent the estimated unimpaired flow of the west side area between the Red Bluff gage on the Sacramento River and the Stony Creek drainage area on the west side of the Sacramento Valley. The runoff for water year 1921 was derived by adding the historical outflows of the Redbank Creek group, Thomes Creek at Paskenta, Thomes Creek above 500-foot contour, and Elder Creek near Henleyville. Flows for the 1922-1954 period were derived by adding the historical outflow of Thomes and Elder Creeks (Joint Depletion Study Area 5, Elder Creek group) to Tables 33 (Redbank Creek group) and 36 (unmeasured area, Thomes Creek above 500-foot contour) of the 1957 Joint Hydrology Study. Estimated historical flows for Thomes Creek at Paskenta are from a DWR 1968 office report, —Surface Water Hydrology-Upper Sacramento Valley.

The annual flows for Redbank Creek group and Elder Creek near Henleyville were derived by correlation with Elder Creek near Paskenta as set forth in the 1968 —Surface Water Hydrology-Upper Sacramento Valley report. The data on annual flows for Elder Creek near Henleyville were then distributed according to the monthly flows of Elder Creek at Paskenta. Annual flow data for the Redbank Creek group were distributed according to the nine monthly flows of Thomes Creek at Paskenta.

Thomes Creek above the 500-foot contour was correlated to Thomes Creek at Paskenta to obtain the yearly flows, which were then distributed according to the monthly flows of the same creek.

Unimpaired runoff for the 1955-1983 period was derived by adding the outflow of the Redbank Creek group, Thomes Creek at Paskenta, Thomes Creek above 500-foot contour, and Elder Creek at Gerber.

Flows for Thomes Creek at Paskenta, Elder Creek at Paskenta, and Elder Creek at Gerber were obtained from the USGS water supply papers. The gage Elder Creek at Gerber was discontinued in 1979, and flows after that time were correlated with Elder Creek near Paskenta. Also, the gage Red Bank Creek near Red Bluff was discontinued in 1982 and later flows were estimated by correlation with Thomes Creek at Paskenta.

Annual flows (1955-1983) for Thomes Creek above 500-foot contour were obtained by correlation with Thomes Creek at Paskenta and distributed according to the monthly flows of Elder Creek at Gerber and Thomes Creek at Paskenta after Elder Creek at Gerber was discontinued.

Annual flows (1955-1959) for the Redbank Creek group were obtained by correlation with historical flows of Elder Creek near Paskenta and distributed according to the monthly flows of Elder Creek at Paskenta. Monthly flows (1960-1983) for the Redbank Creek group were estimated by multiplying Redbank Creek near Red Bluff by an area precipitation ratio of 1.88. Since there was negligible historical development within this area, historical flows were assumed to be unimpaired.

Unimpaired runoff for 1984 to 1992 was derived by adding the outflows of the Redbank Group; Thomes Creek at Paskenta; Thomes Creek above the 500-foot contour; and Elder Creek at Gerber. Unimpaired runoff for the 1993 to 2003 period was estimated using the same procedure used for the 1984 to 1992 period unimpaired flow calculation.

UF 6 — Sacramento River near Red Bluff (CDEC ID SBB)

Data were taken from the Department's Snow Survey records.

In 1969 USGS moved the Red Bluff gage upstream to a new site 3 miles above Bend Bridge. The new gage no longer measures Paynes Creek flows. To be consistent with pre-1969 Sacramento River near Red Bluff, the flows of Paynes Creek near Red Bluff are added to the unimpaired flows developed by the Department's Snow Surveys Branch.

In 1970 USGS discontinued the gage of Paynes Creek near Red Bluff. Therefore, Paynes Creek was estimated by graphical correlation with Mill Creek near Los Molinos, using measured data from 1950-1960.

Monthly unimpaired flows are calculated from measured flows reported by USGS gage 11377100, Sacramento River above Bend Bridge, then adjusting by:

1. Change in storage at Shasta and Whiskeytown reservoirs.
2. Adding evaporation (gross) at Shasta Reservoir reported by Reclamation.
3. Less import from the Trinity River at Judge Francis Carr powerhouse.
4. **Adding an estimate for change in storage, irrigation, and consumptive use upstream in the Pit River and Redding basins. The monthly pattern of the 315 thousand acre-feet (TAF) annual depletion adjustment is, in TAF:**

October	28.5	April	37.0
November	2.5	May	54.0
December	4.0	June	56.0
January	6.0	July	43.0
February	7.0	August	35.0
March	7.0	September	35.0

Before WY 1969 the Sacramento River flows were measured 10 miles downstream near Red Bluff. The older location included the small Paynes Creek drainage of 93 square miles.

UF 7 — Sacramento Valley East Side Minor Streams

This area is located on the east side of the Sacramento Valley between the Red Bluff gage (Sacramento River) and the Feather River drainage area. Runoff for the 10/21-9/80 period was estimated by adding the historical outflow of Joint Depletion Study Areas 6 (Antelope Creek Group), 7 (Mill Creek), 8 (Deer Creek Group), 9 (Big Chico Creek), and 14 (Minor East Side Tributaries, Big Chico to Feather). Runoff for the 10/20-9/21 period was estimated by correlation with Deer Creek near Vina.

Unimpaired runoff is equivalent to the historical runoff within these basins minus the historical import from the west branch of the Feather River. Import for the period 10/20-9/30 is estimated. Data for the period 10/30-9/83 is taken from USGS Water Supply Reports. The data are listed under —Butte Creek near Chico.

The flows for 1984-1992 were assumed to be the same as historical outflow of depletion areas 66 and 14, minus the import from the west branch of the Feather River. Flows for the 2003 to 2014 period were extended similarly.

UF 8 — Feather River near Oroville (CDEC ID FTO)

Data were taken from the Department's Snow Survey records.

The unimpaired flow at this site is calculated from:

1. Observed flow at the USGS station No. 114070, "Feather River at Oroville", which is just upstream from the fish barrier dam.
2. Add Thermalito Afterbay releases to the Feather River. (In recent years the State Water Project provides the sum of Items 1 and 2 as "Oroville Complex River Release".)
3. Add diversions at the Thermalito Complex into Western Canal, Richvale Canal, the PG&E lateral, and Sutter Butte Canal.
4. Change in storage of the complex: Thermalito Diversion Pool, Thermalito Forebay, and Thermalito Afterbay.
5. Add evaporation at Thermalito Afterbay from the Department of Water Resources, Northern District.
6. Lake Oroville change in storage.
7. Lake Oroville evaporation (gross).
8. Add Palermo and Bangor Canal diversions.
9. Add Oroville-Wyandotte Canal (aka Forbestown Ditch), Hendricks and Miocene Canal (diversions above Oroville Lake).
10. Change in storage at Lake Almanor, Mountain Meadows, Butt Valley, Bucks Lake, Frenchman, Antelope, Lake Davis, Little Grass Valley and Sly Creek reservoirs.
11. Add estimated evaporation for the reservoirs listed in item 11, taken as 1.4 times Lake Almanor evaporation, based on a monthly capacity – evaporation table from Great Western Power Company (PG&E predecessor). Summer amounts can easily be 300 cfs on Lake Almanor.
12. Subtract Slate Creek Tunnel import from the Yuba River basin.
13. Subtract Little Truckee River import into Sierra Valley. This has been taken to be 6.6 TAF in recent years on a pattern:

April	0.1	July	1.2
May	1.9	August	.2
June	3.1	September	.1

14. Add depletion for upstream irrigation and consumptive use of 75 TAF per year.

Some data on Little Truckee River imports are available in Northern District watermaster reports. It is recommended that this data be obtained and reviewed to see if the standard pattern is still reasonable.

The Oroville-Wyandotte Irrigation District (OWID) Canal annual diversion of 16.5 TAF per year were from about 1970 through August 2014. The closing of Woodleaf Lumber Mill in 1962 and other factors have reduced OWID Canal usage to around 6 TAF in recent years. The monthly upstream depletion amounts have apparently been taken as constant since about 1970.

The monthly distribution of depletion and the OWID Canal is as follows, TAF:

Month	Depletion	OWID	Month	Depletion	OWID
October	0.9	.74	April	1.3	1.0
November	.2	.29	May	7.5	.37
December	.1	.13	June	22.5	.71
January	.1	.07	July	21.3	1.11
February	0	.04	August	13.6	1.29
March	0	.05	September	7.5	1.19

Before the construction of Oroville Dam and the Thermalito Complex, the gage was upstream a few miles with 17 (out of 3,624) square miles less drainage area before July 1962. The estimations before completion of the Afterbay in 1967 did not include Thermalito complex releases because all the water being diverted flowed by the gage.

UF 9 — Yuba River at Smartville (CDEC ID YRS)

Data were taken from the Department's Snow Survey records.

These flows are taken as the measured flow of the Yuba River below Englebright Dam near Smartville, USGS Gage 11418000, (now measured by PG&E) plus Deer Creek near Smartville, Gage 11418500.

1. Plus diversions from PG&E's Drum Canal and South Yuba Canal, at Gage YB 31, Nevada Irrigation District's D-S Canal, Cascade Ditch, and in earlier years (pre Merle Collins Reservoir in 1963) Browns Valley Canal.
2. Plus exports to the Feather River via Slate Creek Tunnel.
3. Less imports to the Yuba from the Bear River in South Yuba Canal at Gage YB 34.

4. Change in storage at the Lake Spaulding South Yuba System (from PG&E), Bullards Bar, Englebright (Narrows), Bowman Lake, French Lake, Jackson Meadows, and Scotts Flat reservoirs.
5. Evaporation and consumptive use are neglected.

In earlier estimations prior to 1975, the estimations included small amounts in Nevada Irrigation District's Excelsior Ditch, which apparently ceased functioning in 1967 and Snow Mountain Ditch until summer 1974, when its flows were combined with and routed into Cascade Ditch.

UF 10 — Bear River near Wheatland

The unimpaired flow for the Bear River for the period 1921-58 were obtained from the DWR Nov. 1966 Office Report —Surface Water Hydrology of Yuba-Bear Rivers Hydrologic Unit. Flows for 1959-63 were obtained from the Department's Snow Surveys Branch. The period 1964-1983 was calculated by adding the following:

1. Historical flow of Bear River near Wheatland – USGS water supply papers.
2. South Yuba Canal – DWR Snow Surveys.
3. Boardman Canal – USGS water supply papers.
4. Towle Canal – DWR Snow Surveys, until 1971, after which it was neglected.
5. Gold Hill Canal – Depletion Study Area 56 historical export data.
6. Bear River Canal – Depletion Study Area 56 historical export data.
7. Camp Far West Diversion – (Includes Camp Far West North and South Canals and South Sutter Conveyance Canal).

And deducting the following items:

1. Drum Canal – DWR Snow Surveys
2. Lake Valley Canal – Depletion Study Area 22 historical export data.
3. South Yuba Canal – DWR Snow Surveys
4. D-S. Canal to Bear River via Greenhorn Creek – DWR Snow Surveys.

Plus the changes in storage of the following reservoirs:

1. Camp Far West (1921-1958) – DWR Snow Surveys; (1959-1983) – USGS water supply papers.
2. Rollins – USGS water supply papers.
3. Combie – DWR Snow Surveys.

Unimpaired runoff for 1984 to 1992 was calculated by adding the following:

1. Unimpaired Bear River flow at the Van Trent gage (1922-29); flow at the gage near Wheatland (1929-92)
2. Evaporation from Camp Far West Reservoir
3. Evaporation from Combie Reservoir
4. Evaporation from Rollins Reservoir
5. Change in storage at Camp Far West Reservoir
6. Change in storage at Combie Reservoir
7. Change in storage at Rollins Reservoir
8. Total exports above Camp Far West Reservoir
9. Camp Far West Water District South Canal diversion
10. Camp Far West Water District North Canal diversion
11. South Sutter Water District diversion
12. Historical depletion

And deducting the following items:

1. Consumptive use of replaced native vegetation
2. Total imports above Camp Far West

Flows for the 2003 to 2014 period were extended in the same manner as that of the 1993 to 2003 extension.

UF 11 — American River at Fair Oaks (CDEC ID AMF)

Data were taken from DWR Snow Survey records.

The calculations of unimpaired flow start with observed flow of USGS station 11446500 then:

1. Add Lake Valley Canal diversion
2. Add diversion from the Folsom Lake pumps (old North Fork and Natomas Ditches.
3. Subtract imports from Echo Lake Flume (1.5 TAF per year estimate) and via South Canal (YB-90) from the Bear River Canal.
4. Change in storage at Folsom Lake, French Meadows, Hell Hole, Lake Valley, Caples Lake, Silver Lake, Ice House, Loon Lake, Union Valley, Slab Creek, Stumpy Meadows, and Lake Natoma.
5. Add Folsom Lake evaporation as estimated by Reclamation.
6. Add a constant estimate of depletion above Folsom Dam of 11.4 TAF per year on this pattern:

October	.4	April	.2
November	.2	May	.6
December	.2	June	2.1
January	.2	July	2.5
February	.2	August	2.6
March	.2	September	2.0

7. Add diversion through the American River Pump station near the site of the once-proposed Auburn Dam.

UF 12 — San Joaquin Valley East Side Minor Streams

These flows represent the estimated unimpaired runoff on the valley floor east of the Delta for the minor streams that lie between the Stanislaus River and the American River drainage areas. The runoff was estimated by multiplying the area precipitation ratio of 3.85 by the monthly runoff of Dry Creek near Galt.

UF 13 — Consumnes River at Michigan Bar (CDEC ID CSN)

Data were taken from DWR Snow Survey records.

Unimpaired monthly flows at this station consist of the observed flow of USGS station No. 11335000, Cosumnes River at Michigan Bar, adjusted by adding Camino Conduit diversions (shown as part of the Camp Creek near Somerset records), and adding change in storage at Jenkinson Lake. Data for both adjustments are provided by the Eldorado Irrigation District.

UF 14 — Mokelumne River at Pardee Reservoir (CDEC ID PAR)

Data were taken from DWR Snow Survey records.

The estimated unimpaired flow at this location is the total outflow from Pardee Reservoir plus change in storage at Pardee, and PG&E's Salt Springs and Lower Bear River reservoirs, and several small old upstream reservoirs (Upper Bear, Upper Blue, Lower Blue, Twin, and Meadow lakes). Pardee Reservoir outflows include:

1. Controlled releases through the powerplant and sluice valves.
2. Uncontrolled releases over the spillway overflow.
3. Estimated leakage.
4. Releases to Jackson Valley Irrigation District
5. Releases into the Mokelumne Aqueduct to the East Bay area.
6. Evaporation at Pardee Reservoir

The natural flow figures are estimated by East Bay Municipal Utility District and furnished to DWR Snow Surveys. Sometime prior to 1971, the estimated flows were developed by taking the measured flow at the USGS Station 11319500 "Mokelumne River near Mokelumne Hill", adding Amador Canal diversions to the Jackson area, and adjusting for upstream PG&E storage. The exact time, prior to 1971, when the transition in methods took place is unknown.

UF 15 — Calaveras River at Jenny Lind

The unimpaired runoff of the Calaveras River at Jenny Lind was estimated to be the measured flow plus the change in storage and net evaporation of Old and New Hogan reservoirs. Occasional estimated negative flows were assumed to be zero. The estimated unimpaired flow for the 1921 to 1948 period of the Calaveras River above Jenny Lind was assumed to be equal to the historical outflow of Joint Depletion Study Area 32 (Calaveras River above Jenny Lind). Historical upstream depletions were considered to be negligible and probably offset by small imports from the Mokelumne River. Adjustment for the effect of Old Hogan Reservoir was made for the period January 1949 to December 1963. Before 1949, no records were kept on the storage of Old Hogan Reservoir. Since there were no gates prior to 1949 with which to regulate Hogan Reservoir, the only effect on the runoff was a short-term delay in heavy flood runoff. Unimpaired runoff of the Calaveras River then was assumed to be the same as the measured flow. Old Hogan Reservoir was inundated in the fall of 1963. No records of Old Hogan storage operation could be found from November 1, 1962 to December 1963. To determine the impairment during this period, the inflow to Hogan Reservoir was estimated from measured releases and estimates of net reservoir evaporation and storage changes. Inflow from November 1962 through December 1963 was estimated to be the sum of measured flow in the Calaveras River below Hogan Dam (159,360 acre feet (AF)) plus estimated net reservoir evaporation of 1,700 AF, plus the gain in storage at the end of December 1963 (1,240 AF in New Hogan Dam less the TAF in Old Hogan Dam on November 1, 1962). Thus, total inflow was 161,300 AF. The total inflow consisted of the sum of the North and South Forks of the Calaveras River plus Calaveritas Creek (all USGS stations) at 133,060 AF and an unmeasured accretion calculated to be 28,240 AF by difference. The monthly pattern of the unmeasured accretion was assumed to be distributed on the average of the pattern of the three upper stations and the pattern of Cosgrove Creek near Valley Springs.

After December 1963, unimpaired runoff was estimated by adjusting the Calaveras River flows for changes in storage in, evaporation from, and precipitation on New Hogan Reservoir. Storage and evaporation were reported in USGS water supply papers. Precipitation was estimated by multiplying precipitation at the Hogan Dam station times New Hogan Reservoir area. The surface area was based on the storage-capacity table in the 1972 USGS water supply paper.

The Calaveras at Jenny Lind station was discontinued in 1966. The Jenny Lind station was extended by adding estimated accretions between Jenny Lind and New Hogan to the runoff of Calaveras River below New Hogan Dam. The accretions were estimated to be 1.42 times those of Cosgrove Creek near Valley Springs. The factor 1.42 is the ratio of the drainage area (30 square miles) of the Jenny Lind to New Hogan Reach to that of Cosgrove Creek near Valley Springs (21.1 square miles).

Flow for 1984-2003 was estimated as the sum of historical flow of the Calaveras River below New Hogan Dam plus the net effects of New Hogan Dam, historical gross evaporation of New

Hogan Reservoir and accretions to Calaveras River between Jenny Lind and New Hogan Dam. Flows for the 2003 to 2014 period were extended similarly.

UF 16 — Stanislaus River at Melones Reservoir (CDEC ID SNS)

Data were taken from DWR Snow Survey records.

Estimations begin with the USGS gage No. 113020 of the same name which has been operated since 1957. To the observed flow are added Tuolumne Canal near Long Barn, Oakdale Canal, and South San Joaquin Canal diversions. (Diversions to the Central Valley Project contractors in eastern San Joaquin County via the new Stockton East tunnel at Goodwin Dam are currently being made and included, but did not start until after 1994.)

Adjust for change in storage at New Melones (Old Melones prior to November 1978) Relief, Strawberry, Lyons, Donnell, Beardsley, Tulloch, Spicer Meadows (since 1989) and, prior to 1989, the Utica system reservoirs. The Utica system includes Lake Alpine (4.1 TAF) and Union (3.1 TAF) Reservoirs and also the old 4 TAF capacity Spicer Meadows reservoir. When the Utica System was accounted for, the storage change for a month was considered the same each year as follows: units are TAF:

October	-3.2	April	11.6
November	-0.8	May	0
December	0	June	-1.7
January	0	July	-3.0
February	0	August	-2.0
March	0	September	-0.9

The estimated evaporation from New Melones Reservoir is added. Before completion of New Melones Reservoir an estimate of monthly evaporation was used which was based on a curve of storage verses evaporation.

UF 17 — San Joaquin Valley Floor

These figures represent the estimated unimpaired valley-floor flows of the minor streams from the San Joaquin River at Friant to San Joaquin River at Vernalis, and the west side of the San Joaquin Valley above the valley floor tributary to the San Joaquin River. With Bulletin No. 1 mean seasonal runoff as a base, these minor streams were found to be 2.615 (238,500/91,300) times the Chowchilla River flows at Buchanan Dam site. The 1922-1954 average runoff for the Chowchilla River at the gage was 66 TAF. Comparable minor-stream 1922-1954 runoff was 172,400 AF. Runoff from Joint Depletion Study

Area 43 (Chowchilla River above Buchanan Dam site) was 67,600 AF, slightly higher than the gage because some adjacent drainage area was included. The resulting monthly runoff for the minor streams was estimated by multiplying a factor of 2.55 (172,400/67,600) by the historical outflow of Joint Depletion Study Area 43.

Flow for 1984-1992 was estimated by multiplying the factor 2.55 by the sum of the historical outflow of DA43 Chowchilla River above Buchanan Dam site plus net effect of Eastman Lake.

Flows for the 2003 to 2014 period were extended similarly.

UF 18 — Tuolumne River at Don Pedro Reservoir (CDEC ID TLG)

Data were taken from DWR Snow Survey records.

The estimations begin with the measured flow at the USGS gage 11289650 “Tuolumne River below La Grange Dam” and add:

1. Diversions by the City and County of San Francisco through the Hetch Hetchy Aqueduct.
2. Change in storage at Hetch Hetchy, Lake Eleanor, and Lake Lloyd (Cherry Valley) reservoirs.
3. Estimated net evaporation of 2.0 feet per year at Hetch Hetchy, Lake Eleanor, and Lake Lloyd based on surface area. This is summed from daily estimations based on a fixed monthly rate and combined surface reservoir area.
4. Change in storage at New Don Pedro Reservoir beginning in November 1970 and at the Old Don Pedro Reservoir prior to then.
5. Evaporation at Don Pedro reservoir, estimated at 50.2 inches per year net, estimated from daily reservoir area and an average monthly rate, varying by month.
6. Diversion into Modesto and Turlock Canals near La Grange.

The natural flows at La Grange Dam are estimated by Turlock Irrigation District and provided to the Department.

UF 19 — Merced River at Exchequer Reservoir (CDEC ID MRC)

Data were taken from DWR Snow Survey records.

Estimated unimpaired flows start with measured flow at the above station, USGS gage 11270900, and add:

1. Diversions in the North Side Canal.
2. Change in storage at Lake McClure (Exchequer), enlarged in 1967, and McSwain Reservoir.
3. Estimated monthly average evaporation at Lake McClure and McSwain.

Estimated annual evaporation is 22.45 TAF and is listed below, by month, in TAF:

October	1.55	April	1.60
November	1.00	May	2.60
December	.60	June	3.25
January	.50	July	3.85
February	.70	August	3.30
March	1.30	September	2.20

UF 20 — Chowchilla River at Buchanan Reservoir

The estimated unimpaired flow for the Chowchilla River at Buchanan Reservoir was assumed to be equal to the historical outflow of Joint Depletion Study Area 43 (Chowchilla River above Buchanan Dam site). Historical upstream depletions and imports were considered to be negligible.

Flow for 1984-1992 was estimated as the sum of the historical outflow of DA43 Chowchilla River above Buchanan Dam site plus net effect of Eastman Lake. Flows for the 2003 to 2014 period were extended similarly.

UF 21 — Fresno River near Daulton

The estimated unimpaired flow for the Fresno River near Daulton was assumed to be equal to the historical outflow from Joint Depletion Study Area 45 (Fresno River). Historical upstream depletions and imports were considered to be negligible. Flow for 1984-1992 was estimated as the sum of the historical outflow of DA45 plus net effect of Hensley Lake (Hidden Dam). Flows for the 2003 to 2014 period were extended similarly.

UF 22 — San Joaquin River at Millerton Reservoir (CDEC ID SJF)

Data were taken from DWR Snow Survey records, as furnished by Reclamation. Unimpaired flow of the San Joaquin River is calculated from the observed flow of USGS gage 11251000 San Joaquin River below Friant and adding the following:

1. Diversions from Millerton Lake to the Friant-Kern and Madera canals.
2. Change in storage at Millerton Lake.
3. Evaporation from Millerton Lake, as determined by Reclamation.
4. **Change in storage at upstream reservoirs: Florence, Thomas A. Edison, Huntington, Shaver, Mammoth Pool, Redinger, Crane Valley (Bass Lake), and Kerckhoff reservoirs.**

UF 23 — Tulare Lake Basin Outflow

The amounts of unimpaired flow originating in the Tulare Lake Basin that would reach the Delta are subject to considerable conjecture. The historical outflow of Joint Depletion Study Area 60

(Tulare Lake Basin) was considered to be a reasonable estimate for present purposes. The outflow is measured by USGS gage 11253500, James Bypass (Fresno Slough) near the San Joaquin River. Gaged data were not adjusted for the effects of Pine Flat Dam on Kings River flows north to the Mendota Pool.

UF 24 — San Joaquin Valley West Side Minor Streams

The estimated unimpaired flows for the minor streams on the west side of the San Joaquin Valley that are tributary to the Delta were assumed to be equal to the historical outflow of Joint Depletion Study Area 51 (west side minor streams, south Delta). This consisted of the estimated historical flow of Marsh Creek near Byron.

Sacramento Valley Unimpaired Total Outflow

Flows for 1921-2014 were estimated as the sum of UF 1 through UF 11.

East Side Streams Unimpaired Total Outflow

Flows for 1921-2014 were estimated as the sum of UF 12 through UF 15.

San Joaquin Valley Unimpaired Total Outflow

Flows for 1921-2014 were estimated as the sum of UF 16 through UF 24.

Delta Unimpaired Total Inflow

Flows for 1921-2014 were estimated as the sum of:

1. Sacramento Valley Unimpaired Total Outflow
2. East Side Streams Unimpaired Total Outflow
3. San Joaquin Valley Unimpaired Total Outflow

Delta Unimpaired Net Use

Delta water use was estimated as the sum of Delta uplands net water use and Delta lowlands net water use. Delta net water use under unimpaired conditions assumes that existing Delta levees and islands would remain in-place.

In previous reports net use in the lowlands is estimated as the sum of water surface evaporation, consumptive use of riparian vegetation, and seepage from Delta channels, minus the precipitation on the lowland channels and riparian vegetation areas. Precipitation on the islands and seepage from the lowland channels are assumed to be fully depleted. The DOP Consumptive Use Model was used to estimate water surface evaporation and evapotranspiration of riparian vegetation. Seepage losses were estimated using data from Chapter 4 of the Appendix to DWR Bulletin 76 (1962).

In previous report net use in the uplands was estimated as the sum of the consumptive use of native vegetation, consumptive use of riparian vegetation, and evaporation from the water surfaces, minus the precipitation on the entire uplands. In the uplands, all historical irrigated agriculture and urban areas were replaced with native vegetation. Consumptive use of native vegetation is limited to precipitation and stored soil moisture, whereas a full water supply is assumed available for riparian vegetation. Consumptive uses for the uplands were estimated using the Bay-Delta Office Consumptive Use Model.

In this report Delta net use was estimated as:

Delta net use = Delta Uplands net use + Delta Lowlands net use

Where:

Delta Uplands net use = Delta Uplands consumptive use – Delta uplands total precipitation

Delta Lowlands net use = Delta Lowlands consumptive use +
Delta seepage -Delta lowlands total precipitation

Delta Unimpaired Total Outflow

Flow for 1921-1992 was estimated as the Delta Unimpaired Total Inflow minus the Uplands Net Use (DA55) minus the Lowlands Unimpaired Net Use (DA54). Flows for the 1993 to 2013 period were extended similarly.

4. SIMULATION OF NATURAL FLOWS

Introduction

As described in the previous California Central Valley Unimpaired Flow Report (DWR 2007), natural flow represents streamflows that would have occurred under a pre-development or pristine landscape. In contrast, unimpaired flows are theoretical values based on measured flows that have been adjusted to remove the influences of upstream diversions, storage, and exports and imports from other basins. A series of modeling tools and extensive input data have to be used in estimating natural flow conditions. Daily simulations of natural flows from October 1, 1921 through September 30, 2014 were developed using precipitation-snowmelt-runoff models for the upper watersheds that are tributary to the California Central Valley. Subsequently, these flows are routed through the Central Valley floor area using a modified version of the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) for water years 1922 through 2014. Natural Delta inflows and natural net Delta outflow are estimated for the 93-year period.

Upstream Watersheds

A precipitation-runoff simulation model provides two important advantages over the use of the upper watershed unimpaired flows described in Chapter 3. First, such a model facilitates the use of a daily time step, which is important in routing flood flows across the flood plain and determining overbank spills. Second, such a model can be readily applied to assess future potential impacts of global warming and climate change.

The Central Valley drainage area consists of upstream watersheds and the valley floor. Upstream watersheds include major river watersheds above designated stream gauging stations and/or foothill reservoirs and ungauged small watersheds (Figure 4-1). The upstream watersheds include subbasins UF2-UF11, UF13-16, and UF18-24 (Figure 4-2). The precipitation-runoff model tool, SWAT (Soil Water Assessment Tool), was the Department’s choice to simulate the daily stream outflow time series data for most rim watersheds. SWAT is a public domain, generic, semi-distributed precipitation-runoff model developed by U.S. Department of Agriculture Agricultural Research Service (Arnold et al. 2012). Twenty-three SWAT models were developed and calibrated to match available unimpaired observed streamflow data at watershed outlets. For some watersheds, an area ratio factor was also applied to consider rainfall-runoff from small local drainage areas located between a SWAT watershed outlet and its corresponding C2VSim stream inflow node location. The SWAT models are based on existing land use conditions, land surface elevations, and stream geomorphology.

There are 36 stream inflows locations in the C2VSim model of the valley floor. SWAT simulated daily flow time series data provide over 90 percent of these model boundary inflows. Observed USGS stream gage data are used for several inputs, since SWAT models have not been developed for a few smaller watersheds such as Cottonwood Creek and Cow Creek.

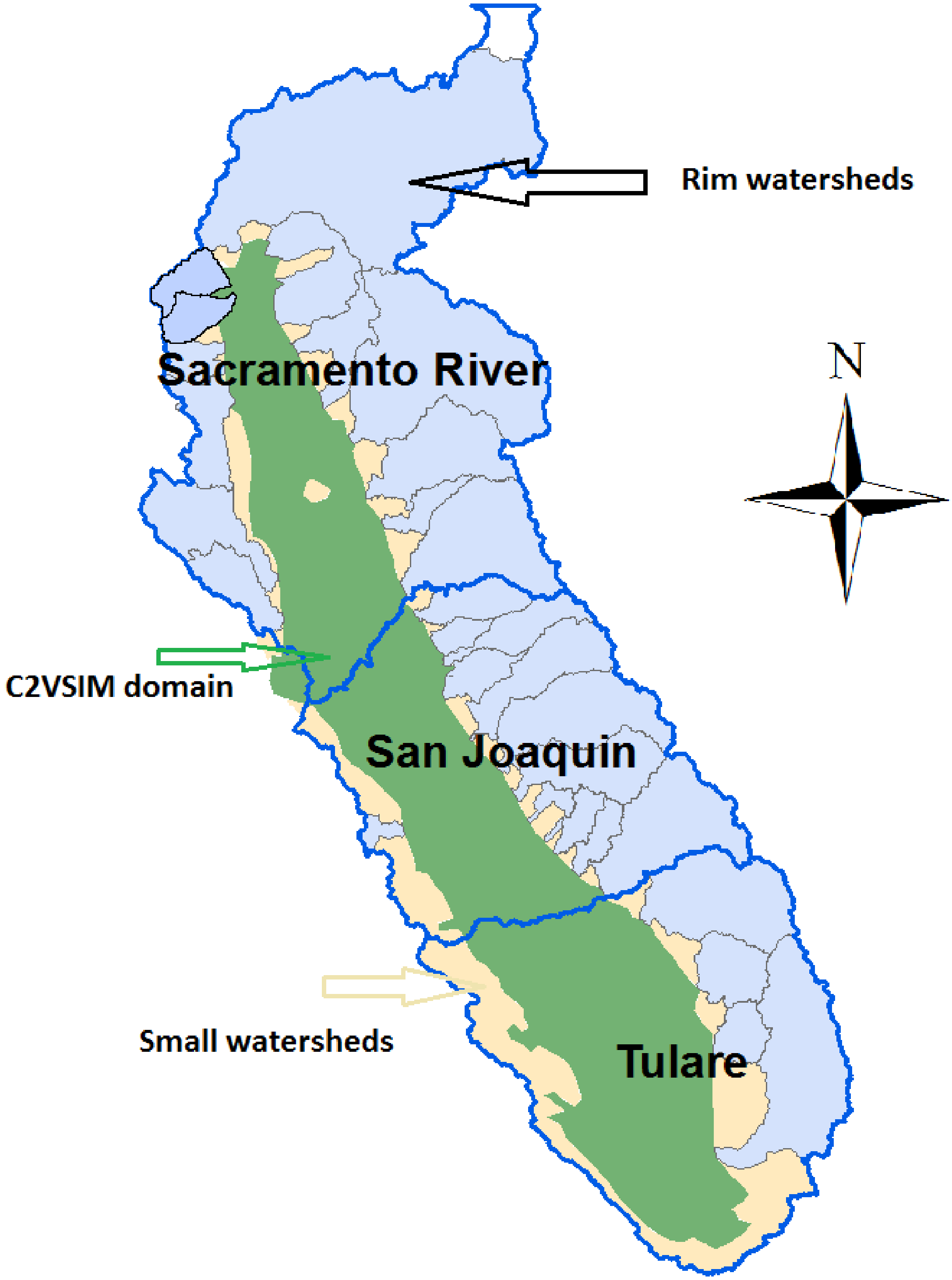


Figure 4-1. Drainage Area of the Central Valley and Natural Flow Model Sub Domains

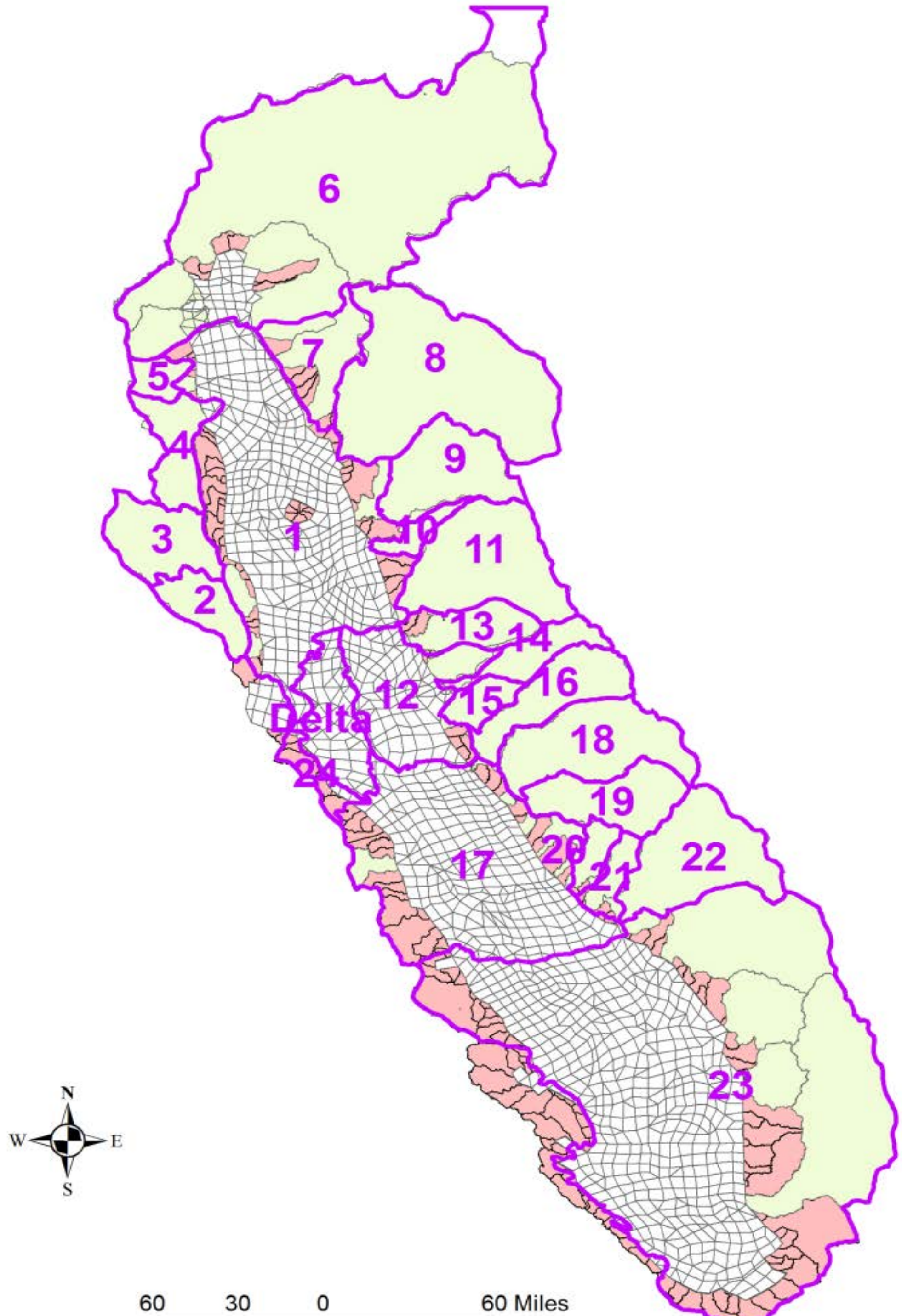


Figure 4-2. Comparison of the 24 Unimpaired Flow Subbasins and Natural Flow Modeling Domain

Sacramento Valley Rim Inflows

There are 19 stream inflow locations in the Sacramento Valley. They correspond to unimpaired subbasins UF2-UF11 (see Figure 4-2). UF1- Sacramento Valley Floor is mostly part of the C2VSim model domain. UF6 includes five separate stream inflows (Sacramento River at Shasta, Cow Creek, Battle Creek, Paynes and Seven Mile Creeks, and Cottonwood Creek) and a few small watersheds with a portion of Valley Floor rainfall-runoff in Subregion 1. Table 4-1 and Figure 4-3 compare average monthly simulated flows to unimpaired observed flows over the period of simulation (Water Years 1922-2014). A more detailed comparison for each subbasin is provided in Chapter 5.

Table 4-1. Sacramento Valley Simulated Rim Inflows and Corresponding Unimpaired Observed Flows

	UF2-UF11 basins: Average Monthly Flows 1922-2014 (TAF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Unimpaired	521	941	2,032	2,781	3,061	3,222	2,880	2,510	1,383	649	444	417	20,842
SWAT	563	1,176	2,215	2,664	2,868	3,110	2,704	2,284	1,379	707	448	364	20,482

Key:
SWAT = Soil Water Assessment Tool
TAF = thousand acre-feet
UF = unimpaired flow

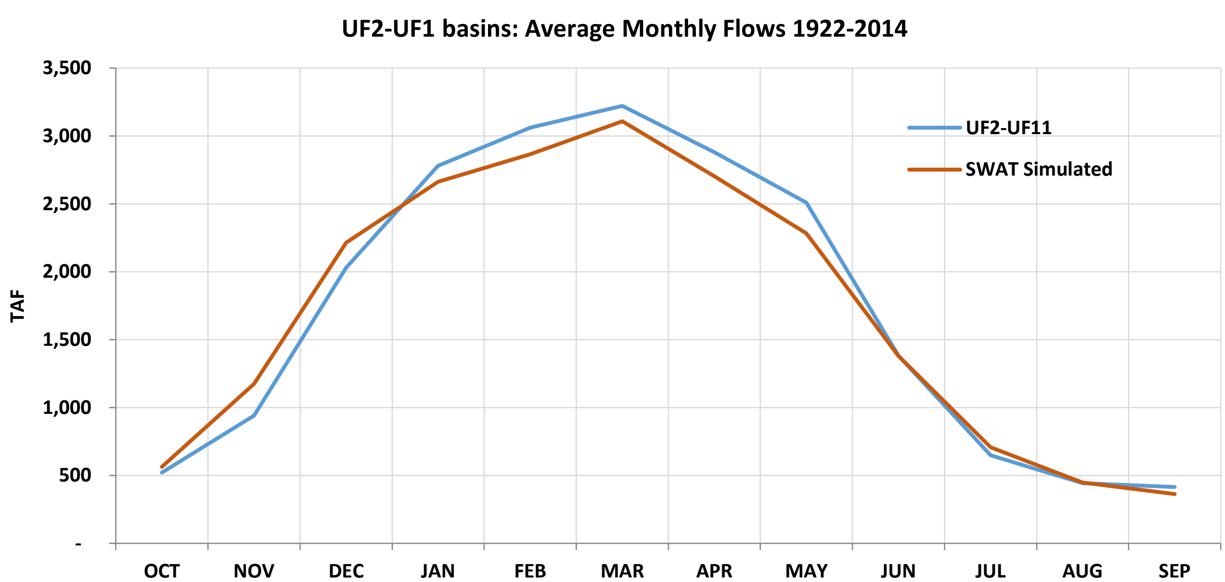


Figure 4-3. Sacramento Valley SWAT Simulated Rim Inflows and Corresponding Unimpaired Estimated Flows

East Side Streams

East side streams rim inflows include Cosumnes River, Mokelumne River, Calaveras River and Dry Creek at Galt. This corresponds to unimpaired flow subbasins UF12-15. About three quarters of UF12 is within the C2VSim model domain. A small portion of UF12 is considered in stream inflow (Dry Creek at Galt). Table 4-2 and Figure 4-4 compare average monthly simulated flows to unimpaired observed flows over the period of simulation (Water Years 1922-2014). A more detailed comparison for each subbasin is provided in Chapter 5.

Table 4-2. Eastside Streams SWAT Simulated Rim Inflows and Corresponding Unimpaired Observed Flows

	UF12-UF15 basins: Average Monthly Flows 1922-2014 (TAF)												
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
Unimpaired	20	55	119	147	176	216	224	252	148	25	4	7	1,394
SWAT	9	33	95	161	190	220	228	247	139	32	7	4	1,364

Key:
SWAT = Soil Water Assessment Tool
TAF = thousand acre-feet
UF = unimpaired flow

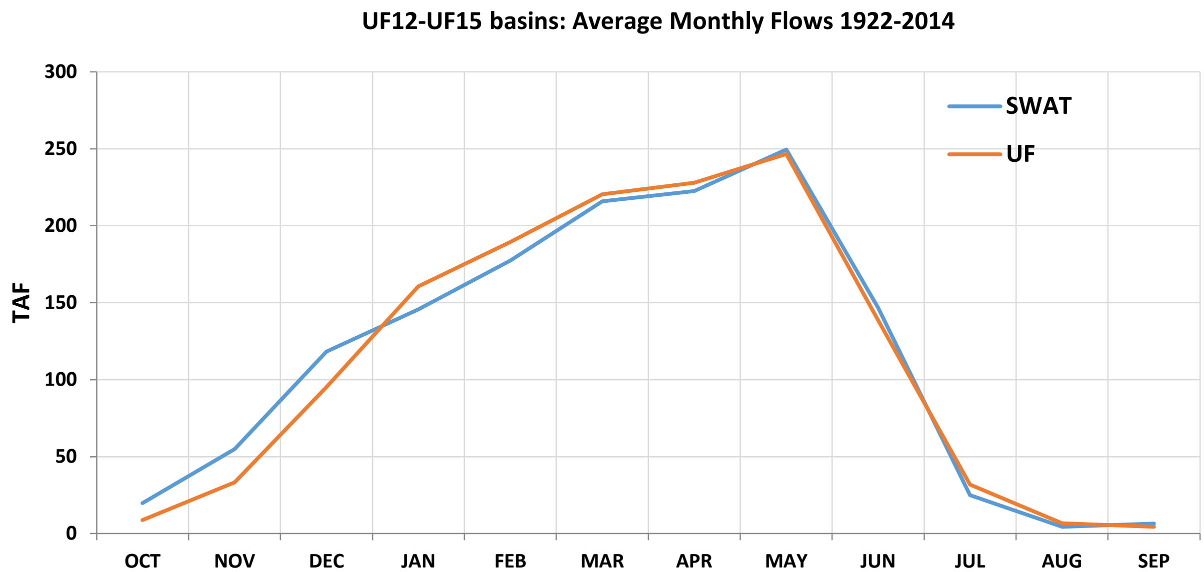


Figure 4-4. Eastside Streams SWAT Simulated Rim Inflows and Corresponding Unimpaired Estimated Flows

San Joaquin Valley

The San Joaquin Valley covers unimpaired flow subbasins UF16, and UF18-UF22. UF17 is a valley floor area that consists of a mix of C2VSIM elements, small watersheds and drainage area of stream inflows. And UF24 is for ungauged small watersheds draining into the Delta region. Table 4-3 and Figure 4-5 compare average monthly simulated flows to unimpaired observed flows over the period of simulation (Water Years 1922-2014). A more detailed comparison for each subbasin is provided in Chapter 5.

Table 4-3. Simulated San Joaquin Valley Rim Inflows and Corresponding Unimpaired Observed Flows

	UF 16, UF18-UF22 basins: Average Monthly Flows 1922-2014 (TAF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Unimpaired	59	131	268	390	469	629	911	1,460	1,113	412	104	48	5,993
SWAT	98	223	372	426	539	753	965	1,324	1,010	407	94	51	6,263

Key:
SWAT = Soil Water Assessment Tool
TAF = thousand acre-feet
UF = unimpaired flow

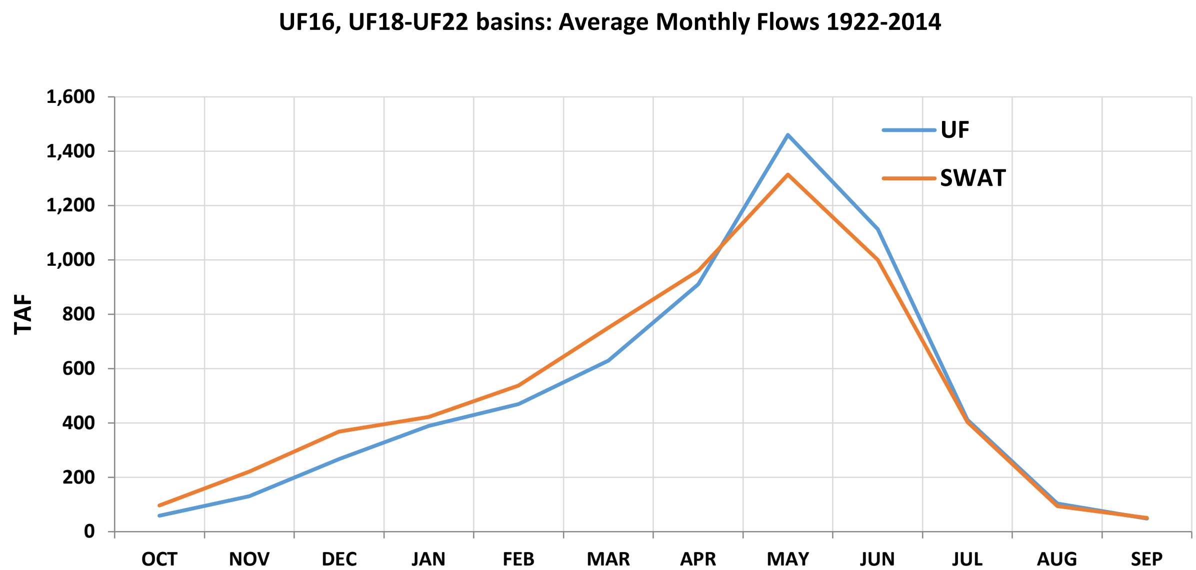


Figure 4-5. San Joaquin Valley SWAT Simulated Rim Inflows and Corresponding Unimpaired Estimated Flows

Tulare Lake Basin

The Tulare Lake Basin (UF23) is also fully simulated (see Figure 4-2). The Valley Floor rainfall-runoff is part of the Valley Floor integrated hydrologic modeling (UF1, UF12 and UF 17).

Valley Floor

Description of C2VSim Natural Flow Model Set up

The C2VSim is an integrated numerical model that simulates water movement through the linked land surface, groundwater and surface water flow systems in California's Central Valley. Valley floor hydrology is modelled with a natural flow version of C2VSim based on the Integrated Water Flow Model (IWFM) Version 2015 (DWR 2015). Although calibrated hydrologic parameters and main model framework are retained as in C2VSim-historical model from Brush et al. (2013), model inputs are substantially different.

The C2VSim natural flow model was run on a daily time step with a coarse finite element grid of 1,392 elements ranging from 1,366 acres to 21,379 acres. Daily historical precipitation, potential evapotranspiration, natural vegetation, and stream inflows spanning water years 1922-2014 were the main time series input data. The CAL-SIMETAW (California Simulation of Evapotranspiration of Applied Water) 4km × 4km grid based dataset (Orang et al. 2013) was used to prepare precipitation and reference potential evapotranspiration (ET_o). Since the CAL-SIMETAW dataset was not updated to Water Year 2014, we extended precipitation with PRISM data (PRISM Climate Group 2015) and ET_o with USGS Basic Characterization Model 270 meters × 270 meters grid data (Alan and Lorraine Flint, personal communication, 2015).

In C2VSim, the valley floor was subdivided into 21 subregions and the water balance was grouped into five hydrologic regions: Sacramento Valley, Eastside Streams, San Joaquin Valley, Tulare Lake, and Delta. The consumptive use of native vegetation was simulated with daily root zone soil water routing, allowing for groundwater uptake to root zone, and stream water contribution to the riparian vegetation. Stream overflow through natural levees to the flood basins were also considered. Permanent wetlands in the flood basins were simulated with the IWFM Lake option, thereby facilitating overflow from streams using a flow rating table/curve, wetland-groundwater interaction, and flood basin storage. Potential evapotranspiration of permanent wetlands was used for lakes/wetlands since wetland vegetation is assumed to cover the lakes, not just the water surface.

Native Vegetation Types and Spatial Distribution

Pre-development land cover classifications and spatial distribution was compiled and developed from best available sources. California State University at Chico (CSU Chico, 2003) produced a pre-1900 historic vegetation map of the Central Valley based on hundreds of historic maps and collections (Figure 4-6). Kuchler (1977) provides vegetation mapping for the whole California that shows potential or pristine land cover before European-American settlement and the part of Central Valley is reproduced in Figure 4-7. Fox et al. (2015) conducted the latest extensive study of Central Valley native vegetation and provide further details on flood plains vegetation and vernal pools combining information from the CSU Chico base map, Kuchler's map and early soil survey data, but the final spatial extent is limited to Sacramento and San Joaquin Valleys (Figure 4-8). We used the Fox et al. (2015) mapping data for overlapping common area within the C2VSim boundary, and applied their methodology for the Tulare Lake basin and any other missing area gaps using the CSU Chico and Kuchler geographic information system maps (Figure 4-9). A summary of the vegetation types and acreage is listed in Table 4-4. The area of each vegetation type was specified for each element (grid cell) in order to simulate surface water flow processes: rainfall-runoff, infiltration, soil moisture, deep percolation and evapotranspiration. From comparison of the three above mentioned maps, (rain fed) grassland in the current simulation and CSU Chico (2003) relates to California prairie, and permanent wetland (large stand wetland) is tule marsh in the Kuchler map. The category of "Other floodplain habitat" in the CSU Chico map has been further identified and classified in Fox et a. (2015).

As stated in CSU Chico (2003), the confidence in identifying specific native vegetation under pre-development condition varies significantly for different vegetation types. Pre-development conditions is usually referred to period before the 1850s, however, the earliest source map is dated 1894. No early maps identified specific location of native grasslands; vernal pool locations are even more uncertain. Fox et al. (2015) used early soil survey data to infer vernal pool locations. On the other hand, riparian forest and wetlands along major streams have more reliable historic map data (Figure 4-10). Since riparian and permanent wetlands are the major source of stream water depletion, this actually reduces uncertainties for natural flow estimation. Finally, different vegetation types have different sources of water supply and potential evapotranspiration, as follows:

- Grassland, hardwoods, seasonal wetland, vernal pool, saltbush and chaparral can only utilize soil water and groundwater uptake.
- Riparian forest can access nearby stream water to meet potential evapotranspiration after using up soil water and groundwater uptake.
- When flood plains are emulated with the lake option (Figure 4-11), the lake elements are assigned with potential evapotranspiration of permanent wetlands, and any predefined vegetation set up for the lake elements are ignored. Lakes can receive stream water from main stream channel overflowing into them and also small creeks direct inflows.

Table 4-4. Area Distribution of Vegetation Types (Acres)

Valley	Subregion	Water Surface	Chaparral	Seasonal Wetlands	Vernal Pools	Grasslands	Hardwood	Riparian	Saltbush	Permanent Wetlands
Sacramento	1	-	-	-	7,808	88,240	198,754	33,476	-	-
	2	5,401	-	2,415	63,287	306,557	179,675	140,424	-	253
	3	3,321	-	27,302	228,734	246,112	60,453	53,147	-	70,039
	4	5,183	-	41,443	211	225	2,399	109,236	-	192,878
	5	5,318	-	232,900	79,483	40,891	104,192	137,254	-	13,718
	6	12,564	-	15,581	108,825	220,624	88,927	54,173	-	157,170
	7	5,324	-	34,455	115,461	30,862	95,474	26,011	-	42,271
Delta	9	21,226	-	58,361	31,608	99,388	481	3,276	-	511,115
San Joaquin	8	2,298	61	150,753	264,734	148,709	246,739	71,130	-	11,110
	10	2,516	369	139,218	159,519	235,025	-	2,483	102,335	26,608
	11	2,186	-	24,939	173,680	170,047	3,220	33,564	-	4,906
	12	1,273	-	14,092	118,518	163,300	3,731	32,373	-	7,050
	13	4,464	-	49,686	583,563	313,335	367	18,201	20,850	47,173
Tulare Lake	14-21	163,740	-	55,320	485,000	2,104,121	414,336	40,808	1,105,854	655,931
TOTAL		234,814	430	846,465	2,420,431	4,079,196	1,199,994	722,080	1,229,039	1,740,222

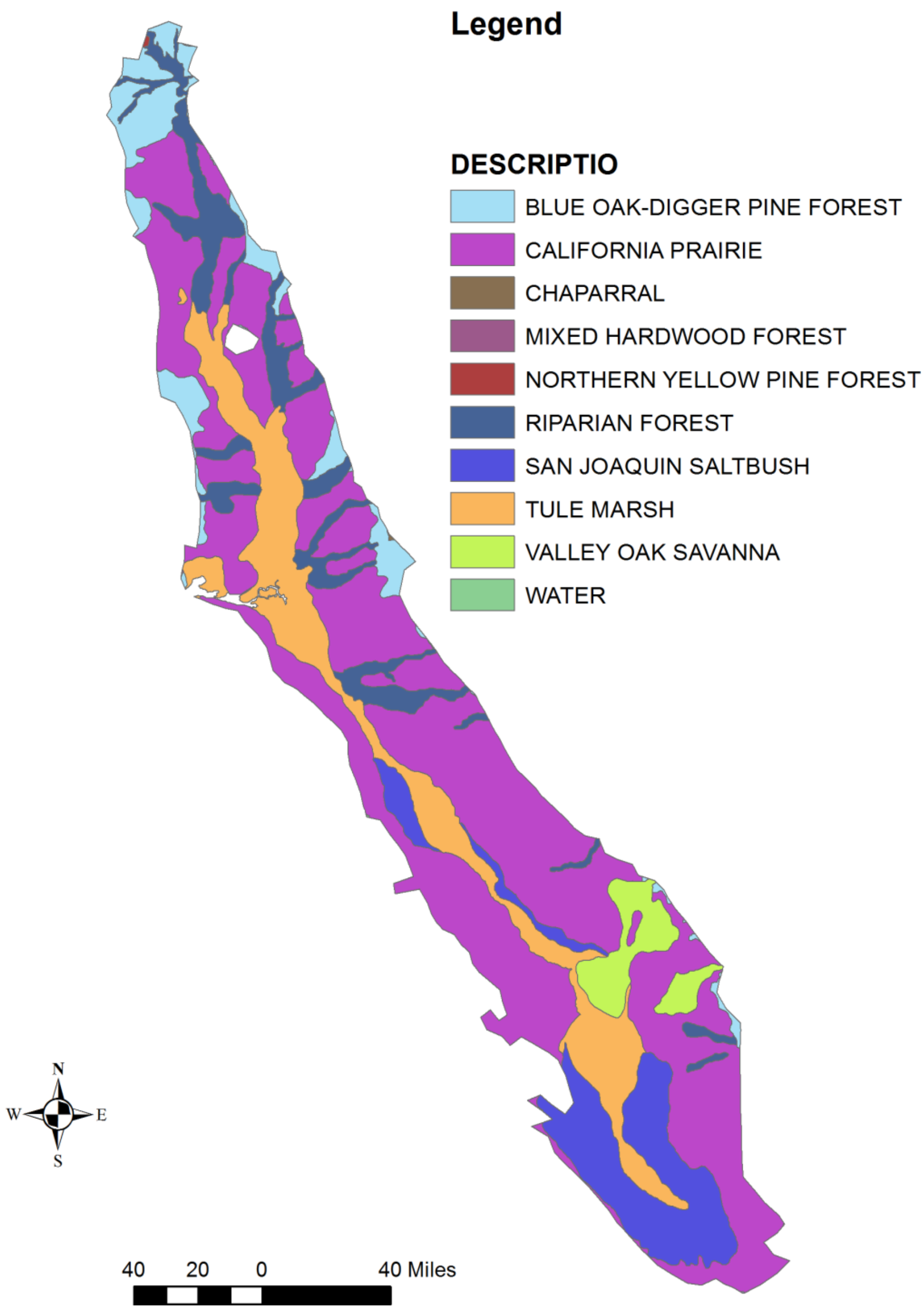


Figure 4-6. Valley Floor Native Vegetation from Kuchler (1977)

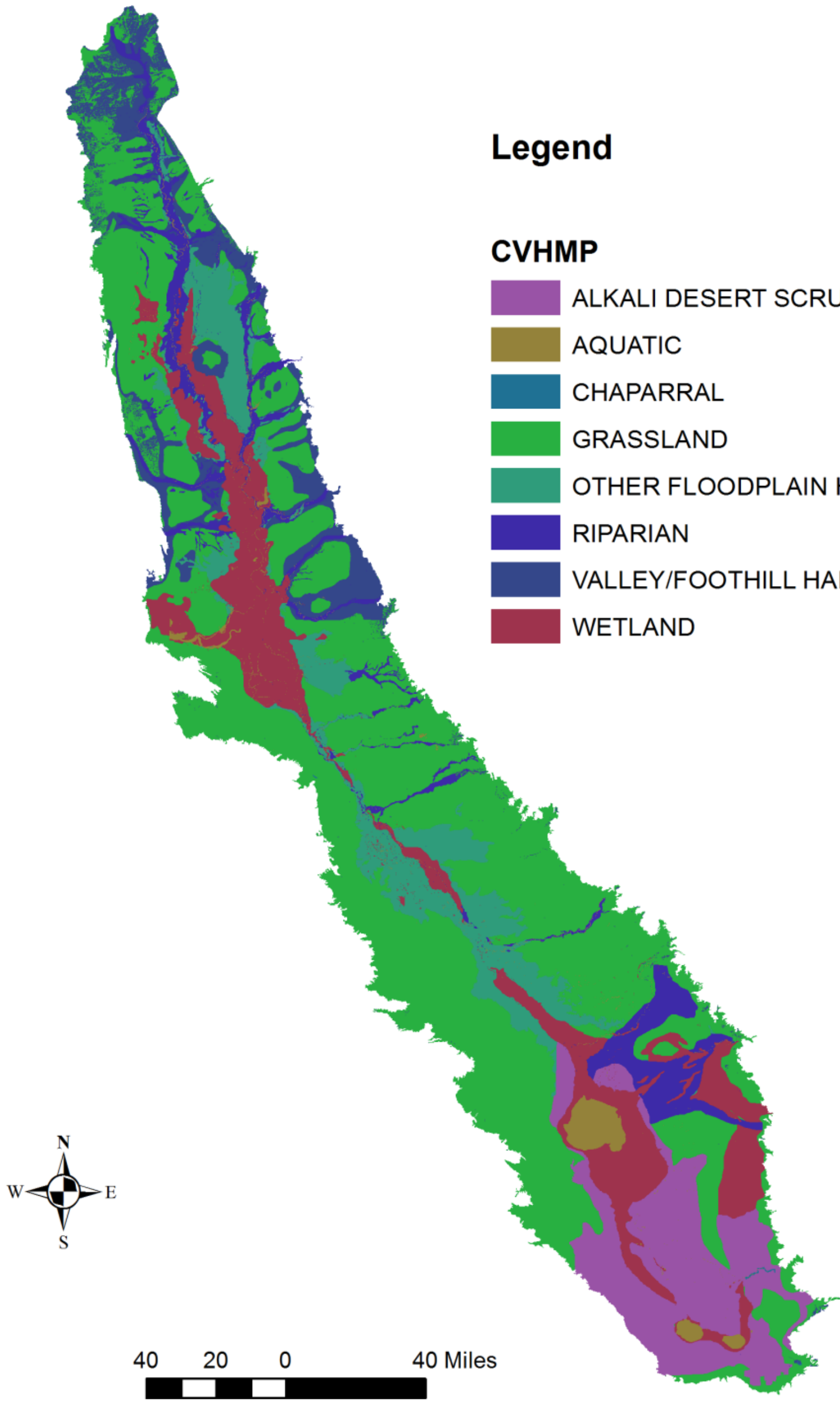


Figure 4-7. Valley Floor Vegetation from CSU Chico (2003)

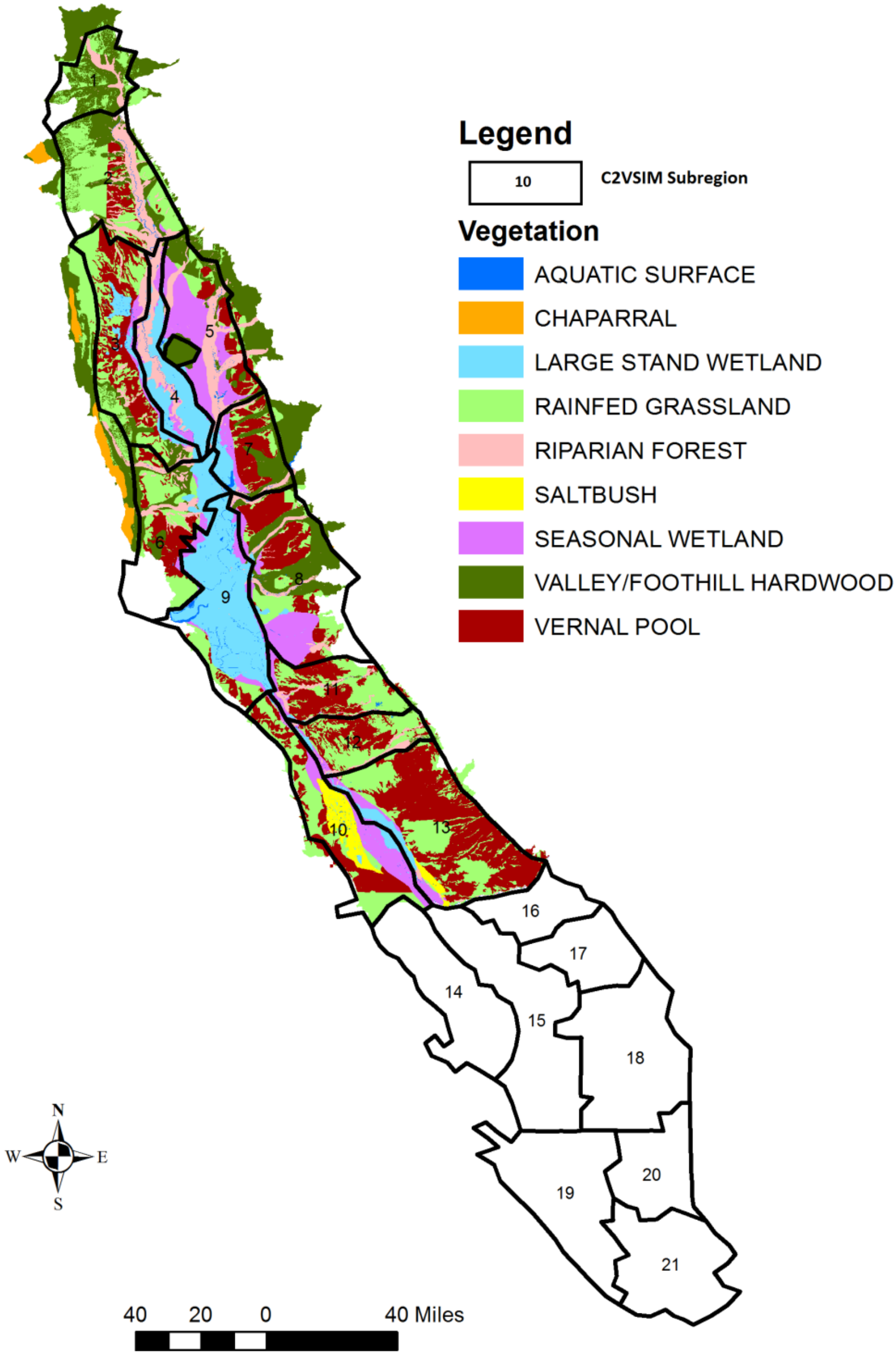


Figure 4-8. Valley Floor Vegetation from Fox et al. (2015)

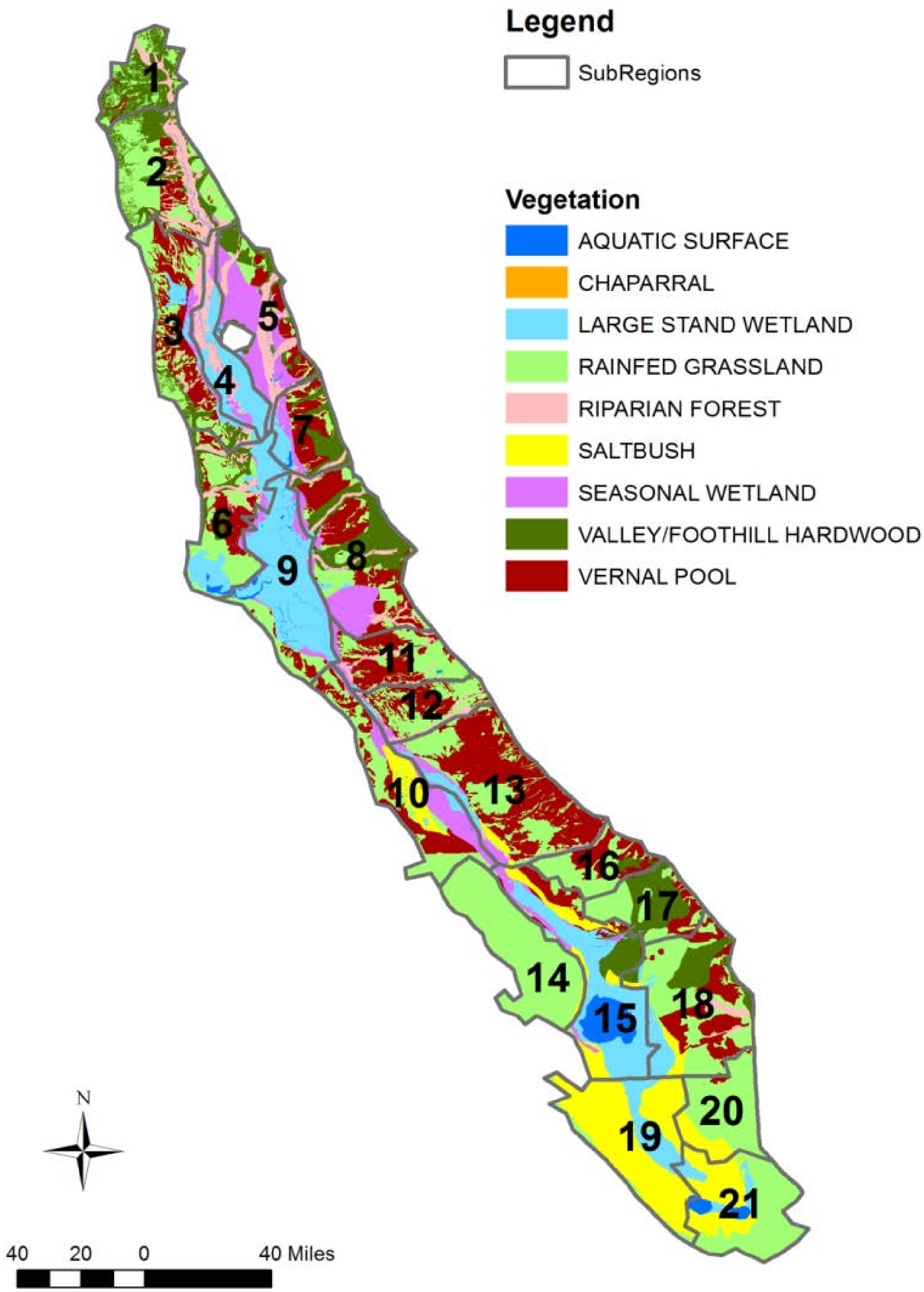
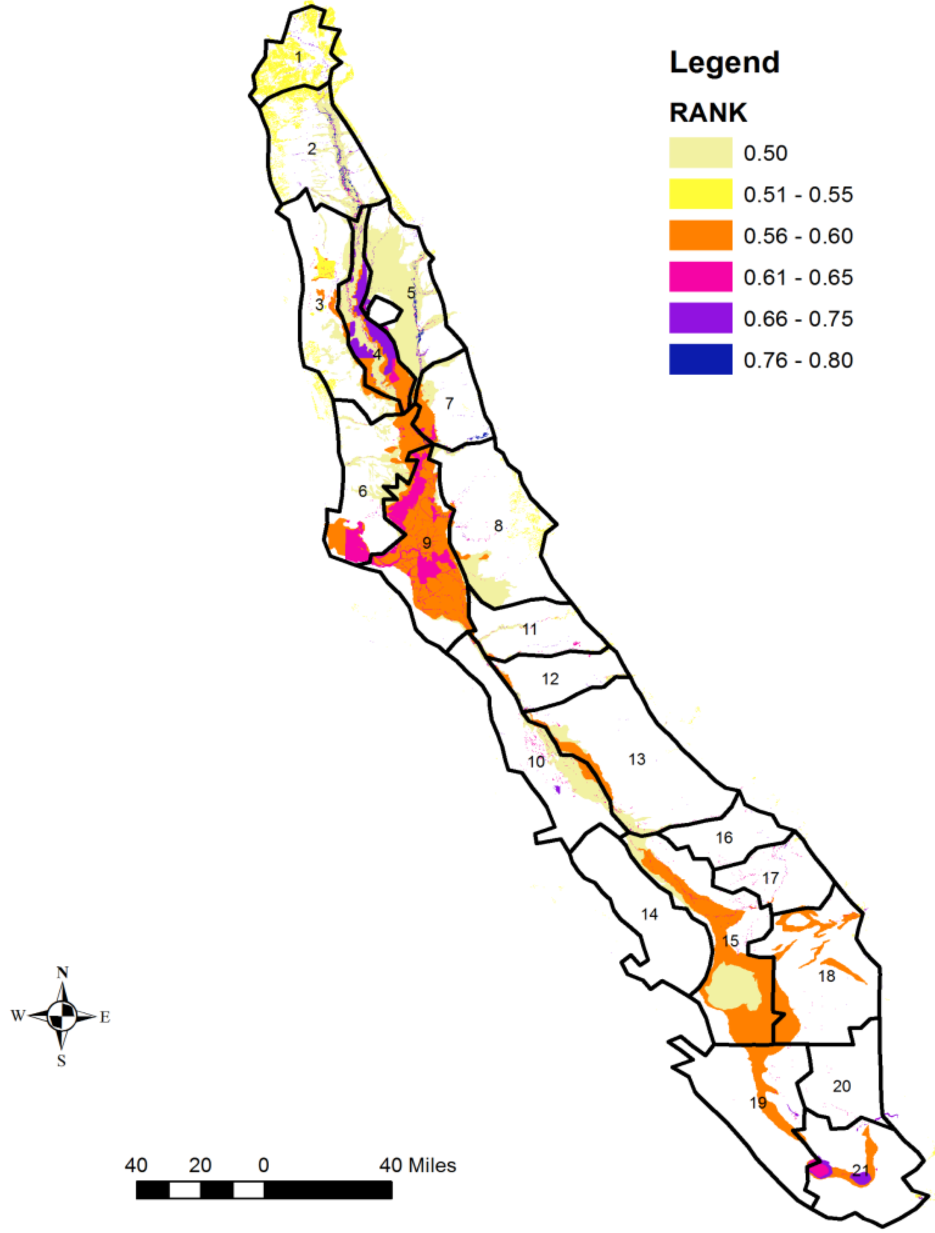


Figure 4-9. Native Vegetation Distribution under Pre-Development Condition Used in Natural Flow Simulations



Rank	Original Scale	Date Relevance to Time Period	Source Topic	Original Values
0.1 (Low)	<1:500,000	Potential, historic	Extremely unrelated	Extreme difference
0.3	>=1:500,000	+/- 100 years	Moderately unrelated	Significant difference
0.5	>=1:250,000	+/- 50 years	Equal target	Moderate difference
0.7	>=1:100,000	+/- 10 years	Significant target	Similar value
0.9 (High)	>=1:24,000	+/- 5 years	Exact target	Exact value

NOTES:
-Source topic refers to focus or intention of the map
-Original values are classifications used on the original data

Figure 4-10. Distribution of Mapping Source Ranking (>0.5) by CSU Chico (2003)

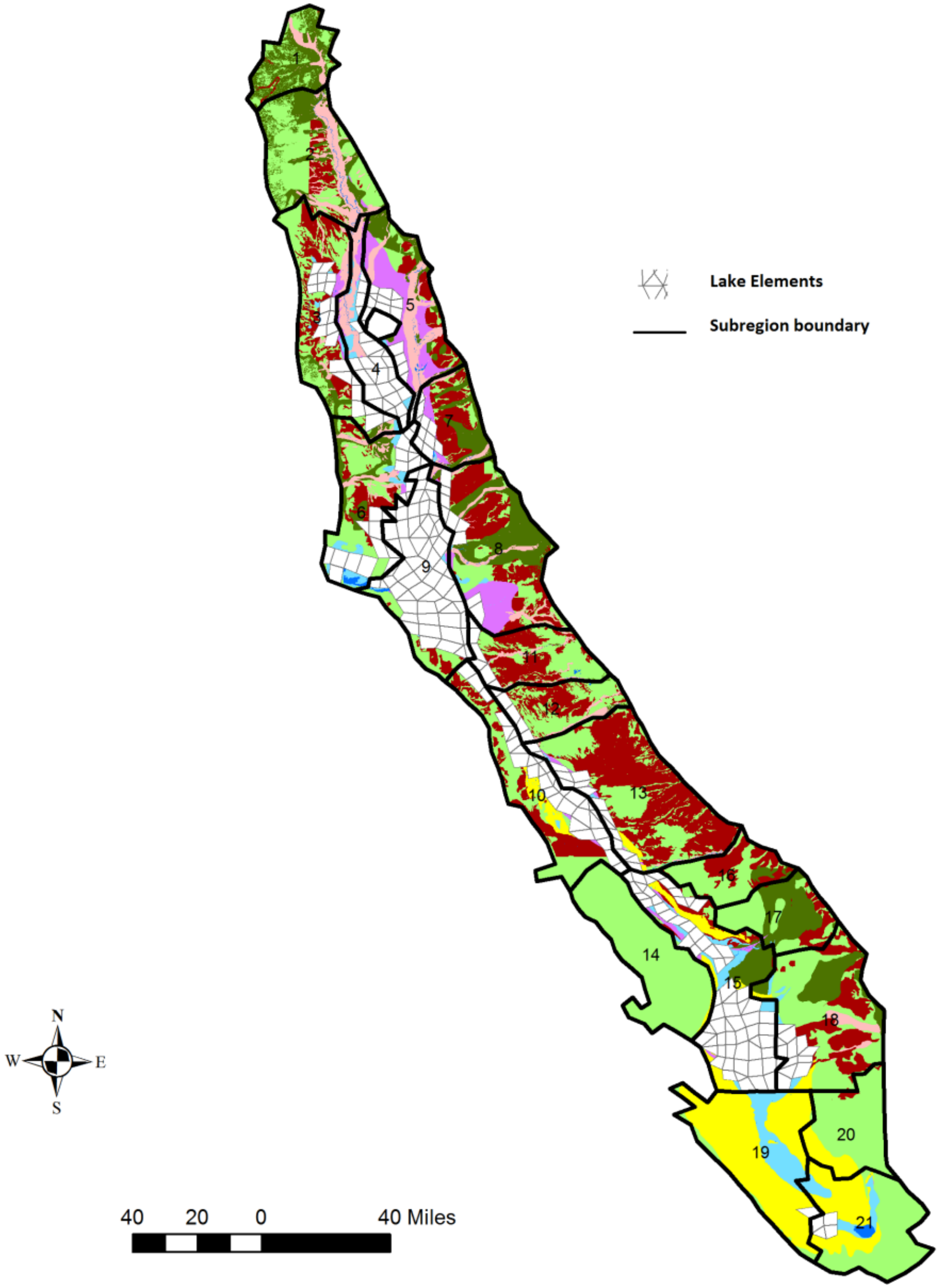


Figure 4-11. Permanent Wetlands and Some Vernal Pools are Represented as Lake Elements

Potential Evapotranspiration

Howes et al. (2015) is the best available data for evapotranspiration from natural vegetation in the Central Valley. We used their estimated monthly vegetation coefficients (Kc) with the grass reference crop evapotranspiration (ET_o) to estimate daily potential evapotranspiration ($ETc=Kc*ET_o$) for each vegetation type. Daily ET_o for each of 21 subregions was estimated from the CAL-SIMETAW model 4-km grid dataset (Orang et al. 2013). Actual evapotranspiration for all vegetation types is internally computed within C2VSim based on local water supply and ETc for each vegetation type at daily time step. Therefore, grassland, hardwoods, vernal pools, seasonal wetlands, saltbush, and chaparral all used potential evapotranspiration as evaporative demand input (Table 4-5).

Table 4-5. Monthly Vegetation Coefficients (Kc)

Vegetation	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain fed Grassland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vernal Pool	1.00	1.00	1.00	1.00	1.05	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Permanent Wetland	0.70	0.70	0.80	1.00	1.05	1.20	1.20	1.20	1.05	1.10	1.00	0.75
Hardwood	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Seasonal Wetland	0.70	0.70	0.80	1.00	1.05	1.10	1.10	1.15	0.75	0.80	0.80	0.75
Riparian Forest	0.80	0.80	0.80	0.80	0.90	1.00	1.10	1.20	1.20	1.15	1.00	0.85
Saltbush	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chaparral	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Aquatic Surface	0.65	0.70	0.75	0.80	1.05	1.05	1.05	1.05	1.05	1.00	0.80	0.60

Valley Floor Evapotranspiration and Delta Inflows

For long term averages under natural conditions, storage changes are negligible, and primary loss of water is through evapotranspiration. Actual evapotranspiration from each vegetation type is summarized in Table 4-6 with sources of water supply for Sacramento and San Joaquin Valleys and Eastside Streams regions, all draining into the Delta area. Soil water is derived from rainfall and groundwater uptake is limited by maximum root depths.

Since evapotranspiration demand peaks in the summer months, simulations reveal that seasonal storage changes play a key role in meeting the demand. As shown in Figure 4-12, for permanent wetlands, winter rainfall and overflowed flood waters fill up the flood basins before May, and then stored water will be used to meet evapotranspiration from June through October. As for riparian forest, stream water is consumed most during the summer months (Figure 4-13).

The overall long term water balance under natural condition for the Central Valley can be seen in Table 4-7 and Figure 4-14. From Figure 4-14, water supply sources (ignoring the Delta and Tulare Lake Basin) include rim stream inflows (28.1 MAF), ungauged small watersheds (2.6 MAF) and Valley Floor rainfall (9.7 MAF). However, 18.4 MAF was lost to evapotranspiration, and only 21.7 MAF reached the Delta boundary.

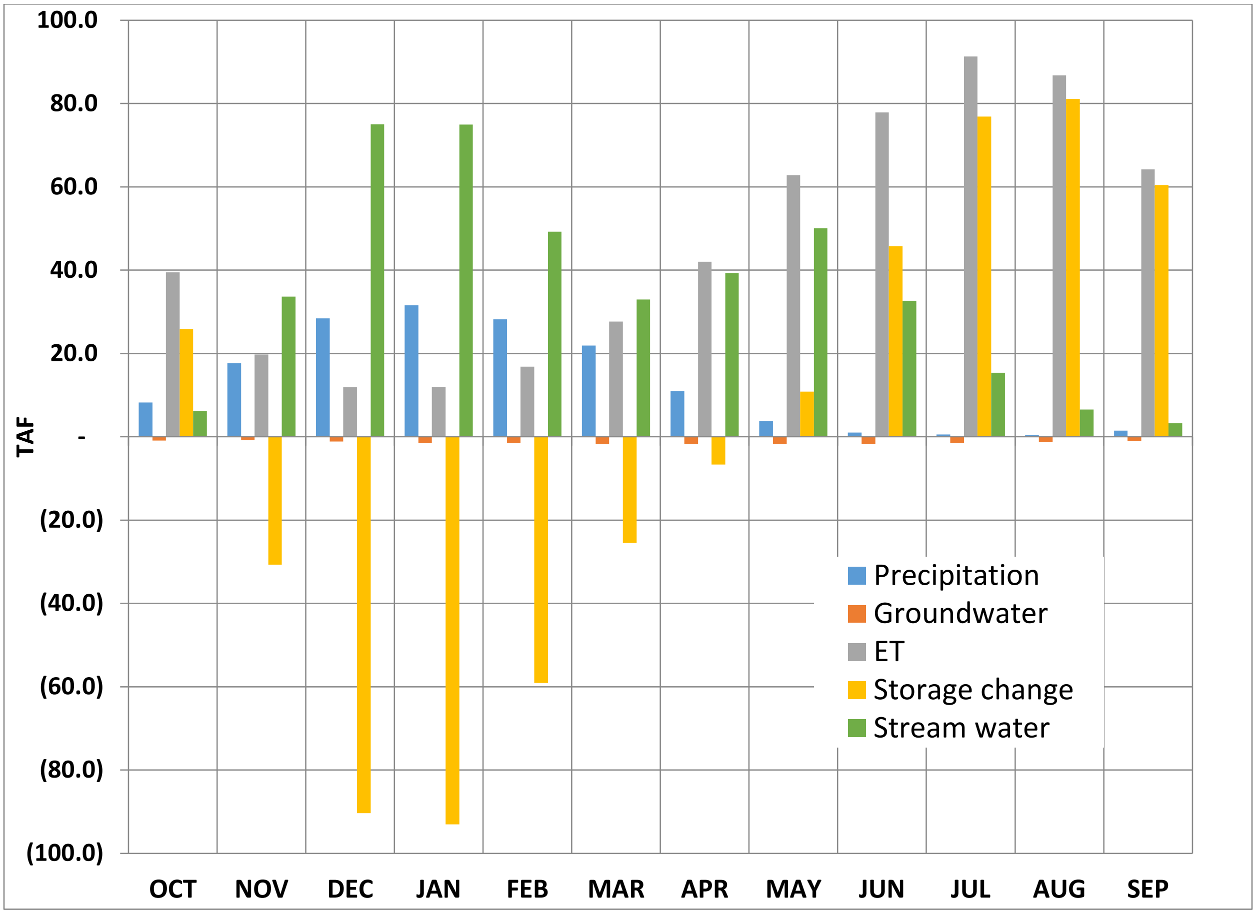


Figure 4-12. Stream Water Stored in the Wetlands/Lakes (negative yellow bar) and Used for Summer Month Evapotranspiration (positive yellow bar)

Table 4-6. Source of Simulated Water Supply for Different Native Vegetation Types

	Average Annual Evapotranspiration: 1922-2014 (TAF)[1]								
	Chaparral	Seasonal Wetlands	Vernal Pools	Grasslands	Hardwood	Riparian	Saltbush	Wetlands /Lakes[1]	Total
Soil water	0.3	419.4	773.1	1,992.4	1,555.3	1,929.2	44.7	0.0	6,714
Groundwater	0.0	194.1	53.5	367.1	1,235.4	430.8	59.8	-496.8	1,844
Stream water	0.0	0.0	0.0	0.0	0.0	3,688.8	0.0	4,220.1	7,909
Rainfall								1,570	1,570
Total	0.3	613.5	826.5	2,359.5	2,790.7	6,048.8	104.6	5,293.3	18,037

Notes:

[1] Excludes the Sacramento-San Joaquin Delta and the Tulare Lake Basin

[2] Riparian elements include vernal pools adjacent to streams. Lake elements are mainly permanent wetlands. Near the lake boundary, it could contain a small portion of seasonal wetlands, San Joaquin saltbush, and water surface or riparian forest.

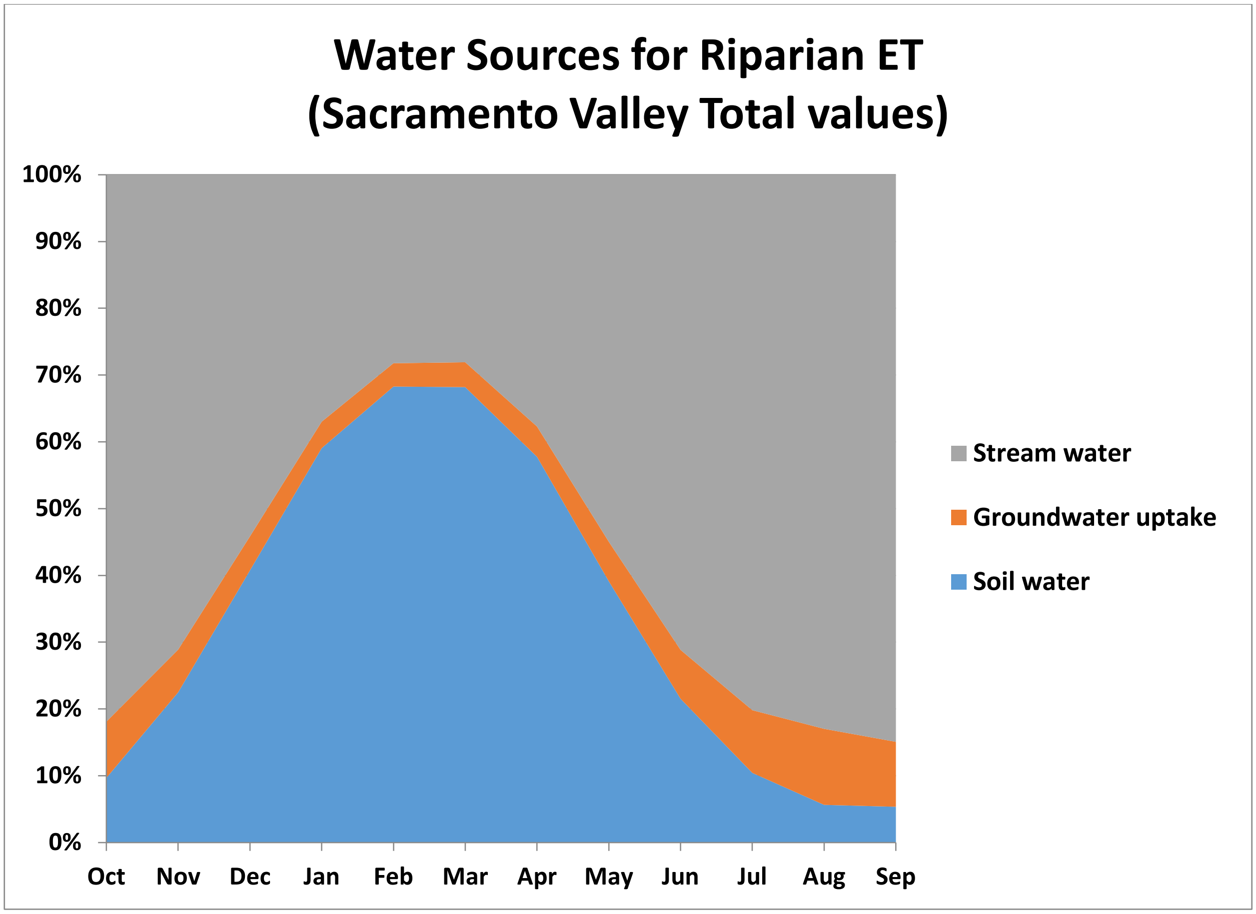
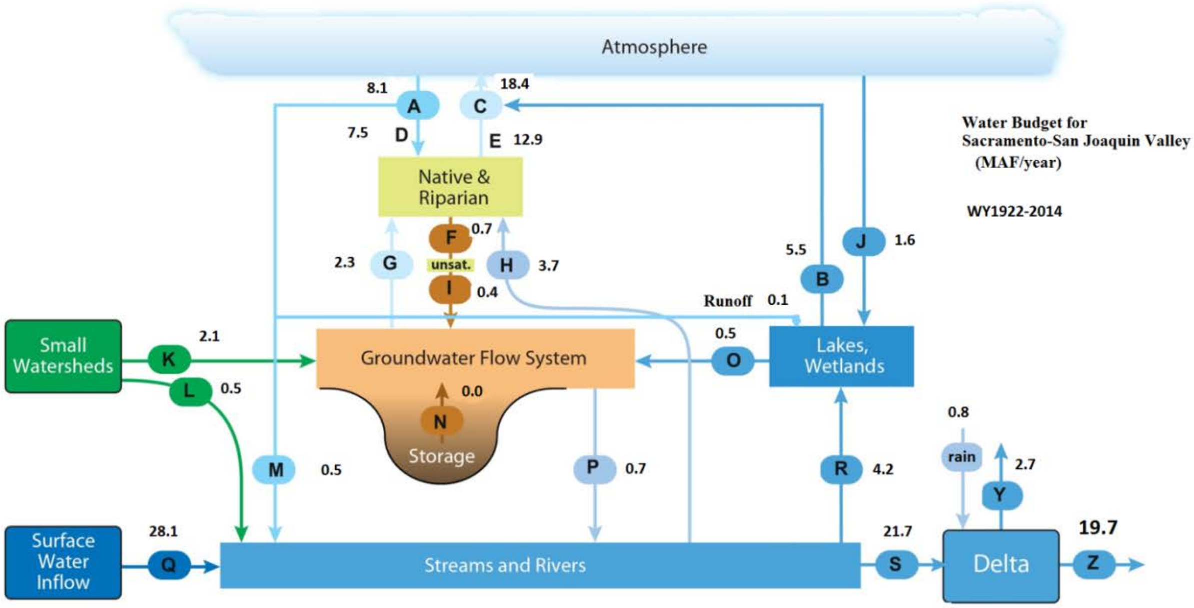


Figure 4-13. Partition of Water Sources for Riparian Evapotranspiration (Soil Water, Groundwater Uptake and Stream Water)

Table 4-7. Average Annual Water Budgets for Water Years 1922-2014 under Natural Conditions

Hydrologic Region	Area (sq. mile)	Average Annual Volumes: 1922-2014 (TAF)					
		Precipitation	Stream inflows	Small watershed inflows	Total Water Supply	Stream Outflows	Evapo-transpiration
Sacramento Valley	5,763	6,179	20,482	2,204	28,865	17,212	11,001
Eastside Streams	1,399	1,195	1,394	227	2,816	986	1,841
San Joaquin Valley	3,842	2,413	6,263	209	8,885	3,334	5,216
Subtotal	11,004	9,787	28,139	2,640	40,566	21,533	18,058
Delta	1,134	804	21,533	92	22,429	19,708	2,969
Tulare Lake Basin	7,852	3,310	2,438	350	6,098	41	6,057
Central Valley Total	19,990	13,901	30,577	3,083	46,664	19,708	27,169

Note:
Groundwater flows between boundaries are not significant.



Note: Tulare Lake Basin outflow toward the Delta is only 41 TAF

A Precipitation

B Evaporation from lakes and wetlands

C Total evapotranspiration and evaporation

D Precipitation to native and riparian Vegetation (N&RV) areas

E Evapotranspiration from N&RV areas

F Deep percolation below root zone from N&RV areas

G Ground water uptake to N&RV areas

H Stream flow to riparian vegetation

I Net deep percolation from N&RV (unsaturated zone to ground water)

J Precipitation on lakes and wetlands

K Boundary small watersheds to valley floor ground water

L Boundary small watersheds to valley floor streams

M Precipitation runoff to streams

N Increase in ground water storage

O Net deep percolation from lakes and wetlands

P Stream – ground water interaction

Q Major Stream inflows to valley floor (upper watersheds SWAT model outflows)

R Overbank flows from streams to lakes and wetlands

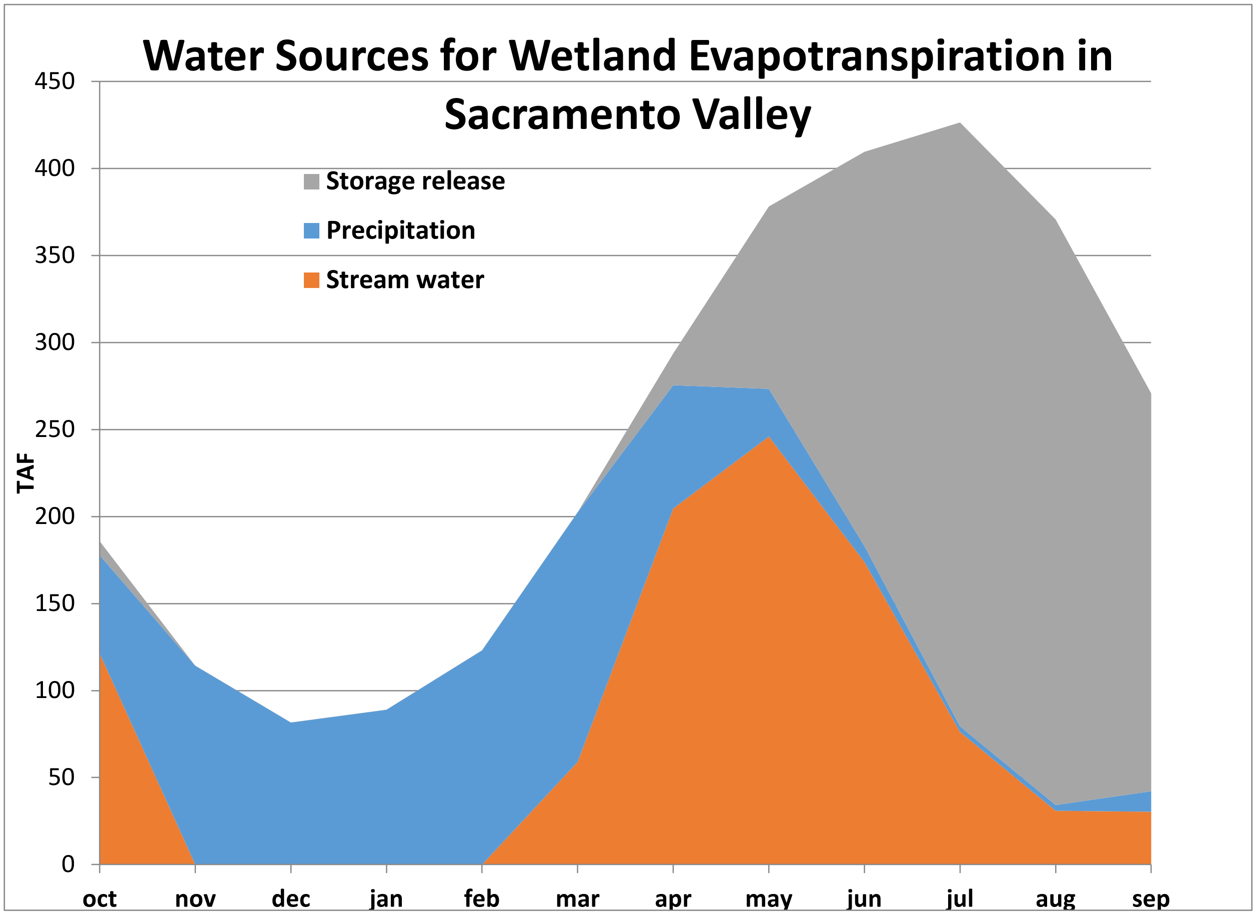
S Delta inflow

Y Delta depletion

Z Delta outflow

Key: MAF = million acre-feet SWAT = Soil Water Assessment Tool TAF = thousand acre-feet

Figure 4-14. Schematic of Central Valley Overall Water Budget



Note: Rainfall and overflowed stream water in the winter months fills up wetlands/lakes storage.

Figure 4-15. Stacked Area Plot of Monthly Water Supply Components for Wetlands (lakes) Evapotranspiration in Sacramento Valley

Sacramento-San Joaquin Delta Inflows and Outflows

Sacramento-San Joaquin Delta Inflows

Delta inflows consist of stream outflows at the Delta boundary from the Sacramento Valley, Eastside Streams, and San Joaquin Valley (Table 4-8 and Figure 4-16). Sacramento Valley inflow peaks in March while the peak flows in Eastside Streams and San Joaquin Valley are in May.

Because of evapotranspiration, the net stream depletion from natural rim inflows to Delta inflows actually peaks in May, comparing to unimpaired rim inflows, outflows from Eastside streams, and especially San Joaquin Valley have been greatly decreased, and as a result, the flow peak in May shown in unimpaired flows disappears from Delta Inflows (Figure 4-17).

Table 4-8. Estimated Natural Delta Inflows

Flow Items	Average Monthly Flows: 1922-2014 (TAF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Sacramento Valley	262	792	1,860	2,490	2,727	2,966	2,525	1,973	1,028	348	131	111	17,212
Eastside Streams	14	40	86	106	125	148	149	182	115	15	2	5	986
San Joaquin Valley	35	90	197	263	307	426	522	701	516	196	52	30	3,334
Total Delta Inflows	312	922	2,142	2,859	3,159	3,539	3,195	2,856	1,659	559	185	145	21,533
Natural Rim Inflows	700	1,455	2,689	3,227	3,567	4,043	3,881	3,876	2,559	1,151	559	437	28,144
Net Stream depletion	388	532	547	368	408	504	686	1,020	900	592	373	292	6,611

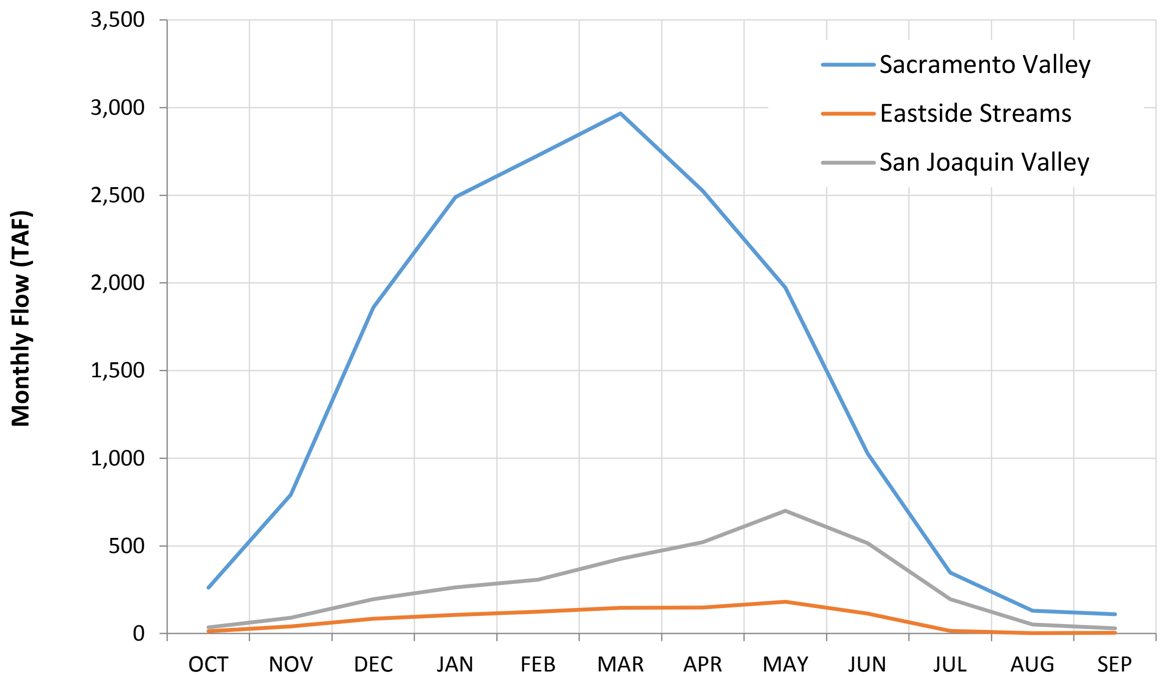


Figure 4-16. Estimated Natural Delta Inflows

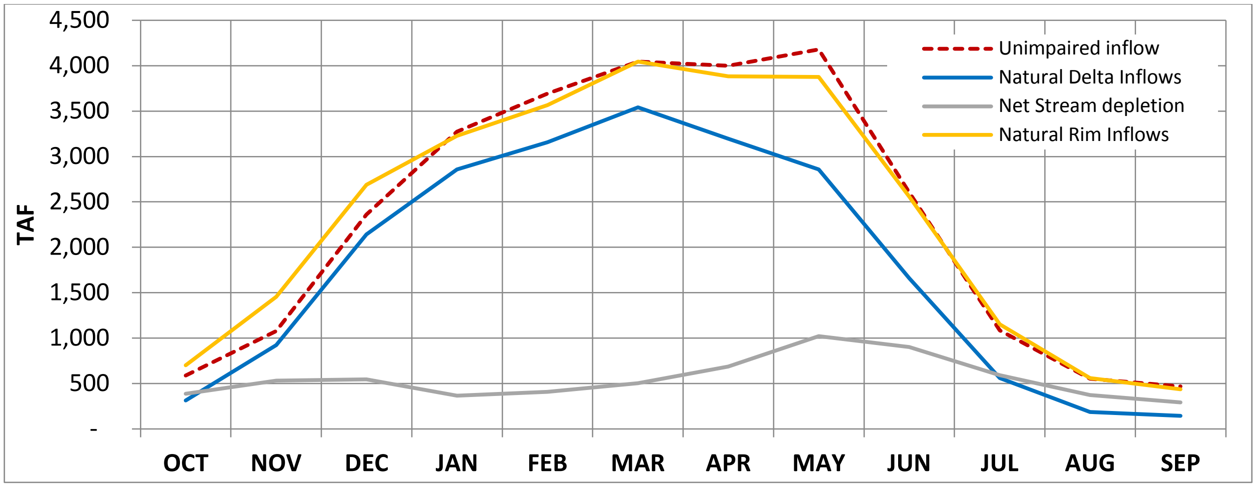


Figure 4-17. Natural Delta Inflows, and Natural/Unimpaired Rim Inflows Monthly Distribution

Sacramento-San Joaquin Delta Consumptive Use

Under natural conditions, about 86 percent of Delta area is covered with permanent wetlands or water surface. Of the remaining Delta area, riparian forest accounts for 4 percent and non-riparian native vegetation accounts for 10 percent. As shown in Table 4-9, at nearly 3 MAF, Delta evapotranspiration is significant. As shown in Table 4-10, this demand is effectively met by depletion of stream water (2.2 MAF) and rainfall (0.8 MAF).

Table 4-9. Delta Actual Evapotranspiration

	Average Annual Volumes: 1922-2014 (TAF)			
	Riparian ET	Non-riparian Native Vegetation ET	Wetlands/Lakes ET	Total
Delta	129	70	2,778	2,977

Table 4-10. Sources of Delta Water Supply for Evapotranspiration

Water Supply	Average Annual Volumes: 1922-2014 (TAF)	
	Wetlands	Root Zone (Including Riparian)
Stream water	2,138	109
Rainfall	709	96
Groundwater	(59)	10
Storage change	(10)	0
Total	2,778	215

Sacramento-San Joaquin Delta Outflows

Natural net Delta outflows equal Delta inflows minus Delta evapotranspiration. The baseline estimated net Delta outflow is 19.7 MAF. The water year 1922-2014 monthly distribution is listed in Table 4-11 and plotted in Figure 4-18. Compared to unimpaired outflow estimates, natural Delta outflow is lower, particularly in the dry season. Under natural condition, riparian forests use stream water mostly in the dry season and wetland water storage in the flood plains is used for wetland evapotranspiration, with stream accretion occurring in the winter months.

Table 4-11. Average Monthly Natural Net Delta Outflow

	Average Monthly Flow: 1922-2014 (TAF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Delta Outflow	280	760	1,859	2,634	3,012	3,406	3,012	2,567	1,414	467	164	133	19,708

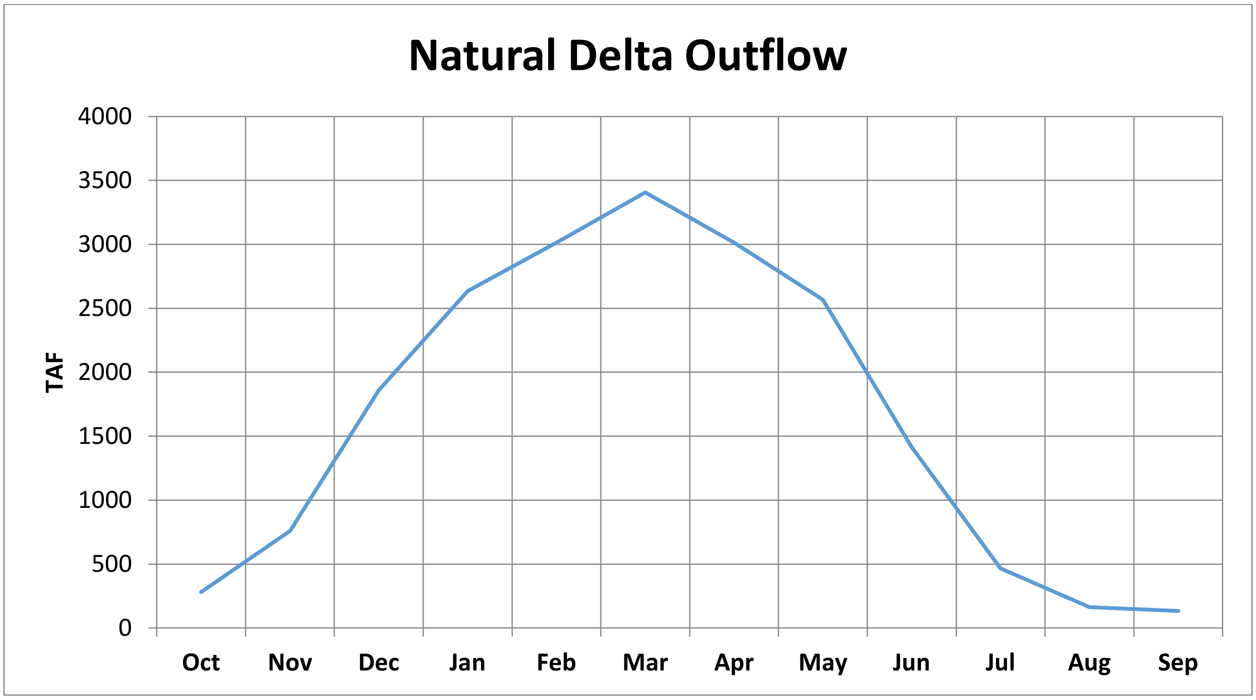


Figure 4-18. Estimated Natural Delta Outflow

Tulare Lake Basin

The Tulare Lake Basin water budget was simulated in detail as part of the Valley Floor. Tulare Lake Basin outflow into the Delta is through a stream reach (Fresno Slough) connecting to the San Joaquin River. The Kings River was assumed to generally flow south into Tulare Lake and spill into Fresno Slough only when Tulare Lake water levels exceed 206 feet elevation. Historically, Tulare Lake basin has been considered to be a closed basin.

Simulation results show that Tulare Lake Basin outflow into the Delta is very small; it averages only 41 TAF per year for the period spanning water years 1922-2014. The Kings, Kaweah, Tule and Kern River stream inflows are evaporated and transpired by riparian forest and wetlands (Tulare Lake and Buena Vista Lake). With all available stream inflows draining into Tulare Lake before it can overflow to Fresno Slough, the lake rarely fills to the maximum water level (Figure 4-19). This demonstrates the very high evapotranspiration demand in the Tulare Lake Basin compared to its limited water supply under natural conditions.

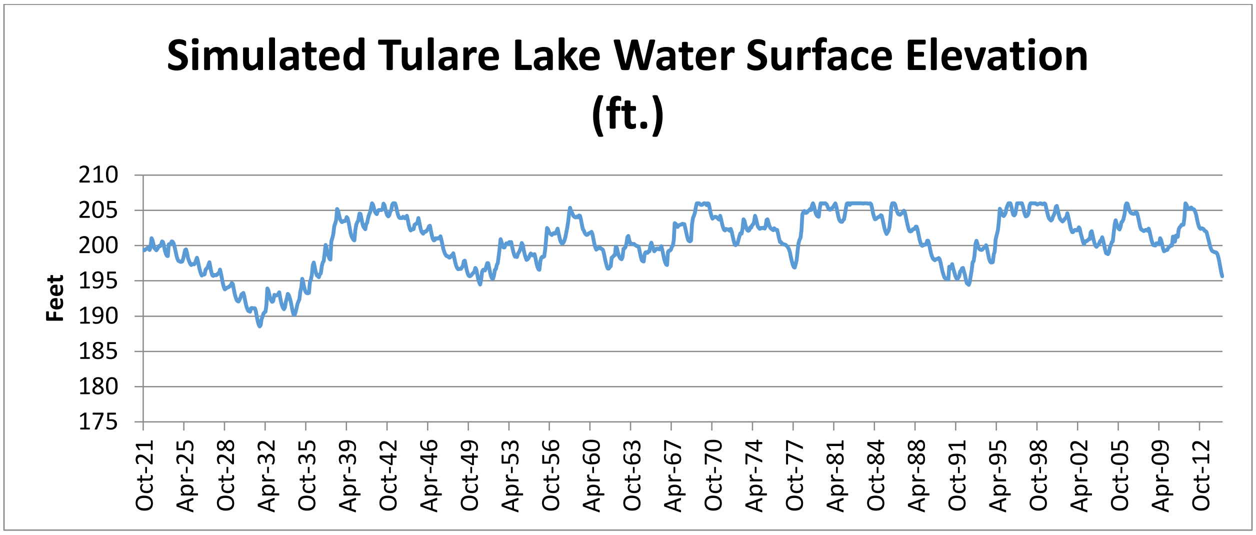


Figure 4-19. Simulated Tulare Lake Water Levels (WY1922-2014)

Delta Outflow ranges due to Model Input and Parameter Sensitivity and Uncertainties

Natural Delta outflow is fresh water that discharges into San Francisco Bay after Valley Floor and Delta evapotranspiration. Therefore, the main model simulation factors affecting Delta outflow are parameters for evapotranspiration (especially those for riparian vegetation and wetlands that have direct access to stream water), lake-groundwater interaction parameters, vegetation spatial distribution and the way each vegetation type is simulated, and extinction depth for groundwater uptake.

Potential Evapotranspiration (ET_c)

When the ET_c input is uniformly changed by a constant factor with other parameters and inputs held constant at the base case values, the effect on the natural Delta outflow estimate is summarized in Table 4-12. Actual evapotranspiration from non-riparian vegetation (e.g. grassland and hardwoods) is water supply limited. Thus, when ET_c for these vegetation classes is perturbed by -10 percent to +20 percent, the resulting change in Delta outflow is small (2 percent). However, when ET_c for riparian forest and permanent wetlands is perturbed by the same amounts, changes in actual evapotranspiration are more significant and result in greater changes in Delta outflow.

Table 4-12. Changes in Delta Outflow Due to Potential Evapotranspiration Values

	Changes in Potential Evapotranspiration-ET_c		
Changes in actual ET and Delta Outflow	-10%	10%	20%
Non-riparian	-2%	1%	2%
Riparian	-7%	6%	13%
Permanent wetlands	-8%	7%	13%
Delta Outflow	7%	-6%	-11%

Simulating Permanent Wetlands as Lakes

In the C2VSim natural flow model, 26 lakes are defined for major historical flood basins (Butte, Sutter, Colusa, Yolo, American, and Sacramento Basins), known lakes (Tulare Lake) and minor local seasonal wetlands or vernal pools (Figure 4-20). Lake parameters include conductance of lake bed materials that controls lake-groundwater interaction, maximum lake elevation defining lake surface wetted area and outflow volume and timing and rating for stream overflow into lakes.

Lakebed conductance values have significant impact on lake-groundwater interaction. Under natural flow condition, a very small conductance of 0.003 is used to constrain the interaction flux. If a larger value is used (0.3~3.0), water in the lakes would easily be drained through groundwater interaction and show up in the Delta as groundwater inflow, with corresponding reduced stream inflow. Large groundwater flux from the Valley Floor to the Delta was considered to be unrealistic.

Overflow rating tables are defined and adjusted to have reasonable maximum stream flow rates in the main stream channels. For example, maximum daily flows at the Sacramento River below Verona cannot exceed 120,000 cubic feet per second. Overflow rating into Yolo Basin is adjusted to meet this requirement. Stream water into flood basins (lakes/wetlands) flow back into streams or downstream lakes when maximum lake elevation is reached.

Maximum lake elevation is determined by GIS map boundary of permanent wetlands. If a lake element node has a land elevation higher than the maximum lake elevation, it would be dry throughout the simulation process.

Figure 4-20. Distribution of Lakes/Wetlands

Vernal Pools

A significant portion of native vegetation is designated as vernal pools. Vernal pool hydrology is more complex than rain fed grassland. In addition to soil water and groundwater uptake, local runoff, perched groundwater, and flood water from local streams and creeks can supply water to vernal pools. The current model configuration and algorithm only allows riparian vegetation to have access to stream water. Therefore, without any special treatment in the C2VSim model, water available to vernal pools is limited to soil water and groundwater uptake (similar to grassland and hardwood vegetation classes).

For the base case, vernal pools in elements next to river reaches are treated as riparian vegetation and can access stream water when there is stream water available. This special treatment implicitly takes into account the small watersheds and local rainfall-runoff draining into nearby vernal pools. A sensitivity model run restricting water availability to vernal pools results in a long term annual average Delta outflow of 21.2 MAF, which is 1.5 MAF more than the baseline value of 19.7 MAF.

In Howes et al. (2015) and Fox et al. (2015), vernal pool water use in the San Joaquin Valley is about 2.2-2.9 feet per year or about 3.5 MAF. Our analysis does not support such a high overall water use, because San Joaquin Valley Floor non-lake land surface precipitation is 1.9 MAF (shared with grassland, hardwoods, etc. in the area), and there is very little local rainfall-runoff or small watersheds runoff. Furthermore, rim stream water inflows concentrate at a few major streams: San Joaquin River above Millerton, Merced River, and Stanislaus River (Figure 4-21). Vernal pools adjacent to smaller rivers such as Fresno River, Chowchilla, and Calaveras Rivers would have very limited water supply. Element level water balance is an advantage of this distributed, integrated modeling approach. It is possible that total vernal pool area in the San Joaquin Valley may have been overestimated. Instead of a continuous area distribution, the vegetation could be distributed more sporadically. Vernal pool area definition should be limited to pool surface.

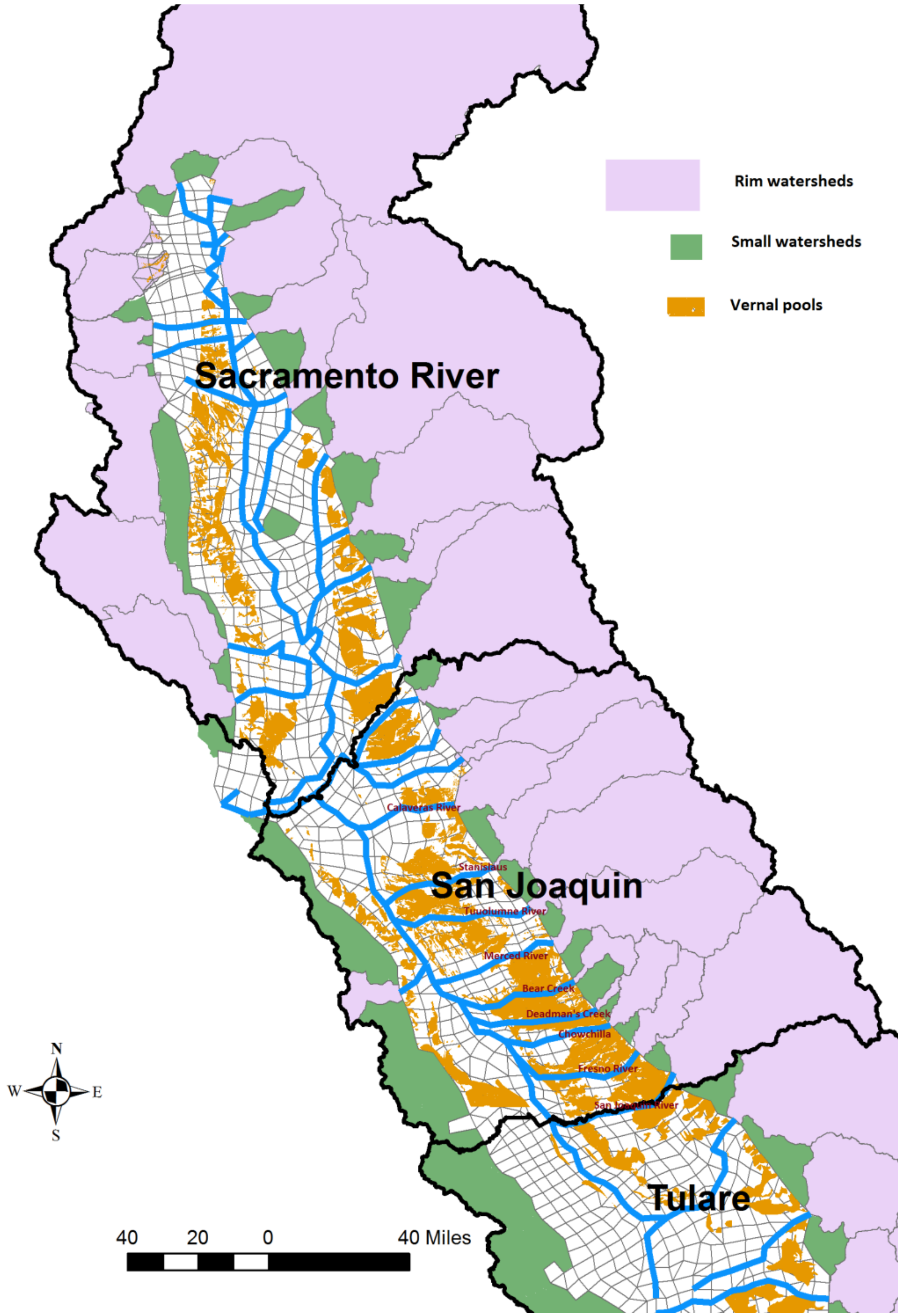


Figure 4-21. Location of Vernal Pools, Streams, Small and Rim Watersheds

Groundwater Uptake

Even though the area of hardwood vegetation is only 24 percent of the total non-riparian vegetation, groundwater uptake from this class exceed 50 percent of total groundwater uptake in the Valley Floor. Almost all of this is located in the Sacramento Valley and Eastside Streams regions. The volume of groundwater uptake is determined by groundwater tables and the maximum rooting depth. Canadell et al. (1996) reviewed maximum rooting depth of vegetation types in the scientific literature. Root depths of large trees and some shrubs can be as deep as 50-100 feet. The ranges vary greatly by species and locations. Doubling the maximum rooting depths of all vegetation classes results in a 1.2 MAF decrease of Delta outflow relative to the base case. On the other hand, reducing maximum rooting depths by 50 percent will increase Delta outflow by 0.6 MAF.

Uncertainties from Combination of Impact Factors

When major model parameters and inputs are perturbed within certain ranges simultaneously, one would expect a distribution for range of natural Delta outflows. We used the PEST (Doherty 2015) package tool to do random samplings of five screened major factors with predefined ranges:

- Scale factor for ET_c: (0.9, 1.2)
- Lakebed conductance (0.001, 0.006)
- Extinction depths of groundwater uptake for riparian forest (10,40) and hardwoods (20, 160)
- Partition parameter of surface runoff and groundwater flow in small watersheds (0.0, 20.0).

Because the clock time for a model run on a current PC is about 2.5 hours, only 30 model runs were conducted. The results (Figure 4-22) are still revealing. The estimated Delta outflow range is between 17.1 and 21.5 MAF, with the most sensitive parameter being ET_c (Figure 4-23). Figures 4-24 and 4-25 show the sensitivity of simulated Delta outflow to vegetative crop coefficients and unit evapotranspiration.

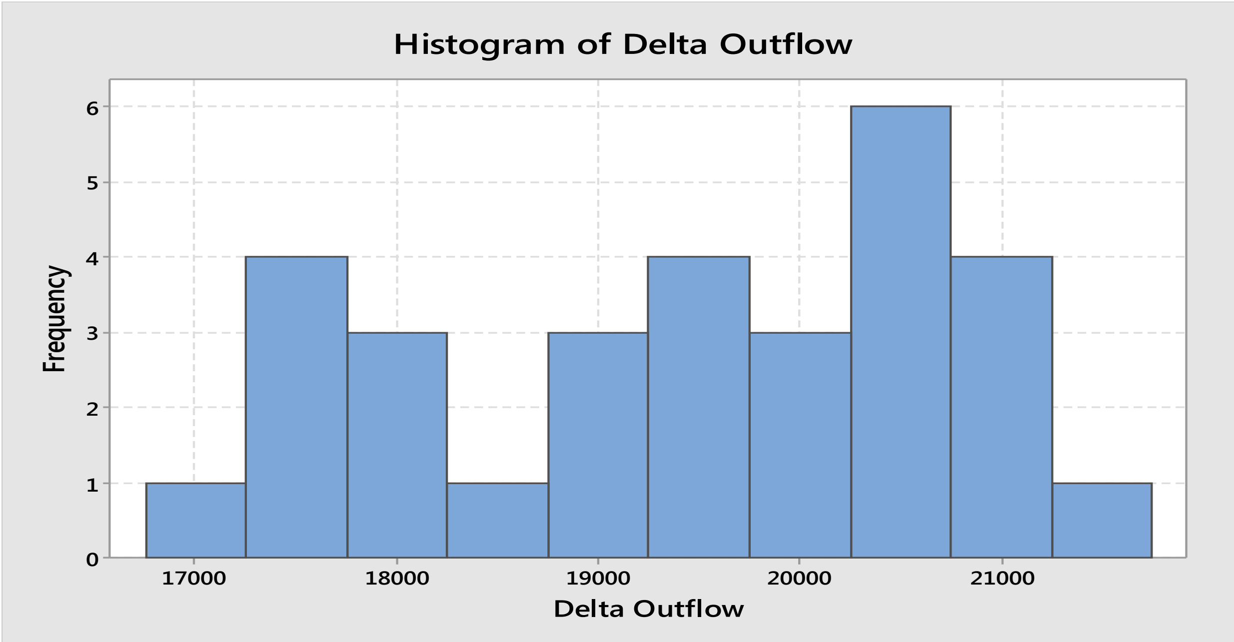


Figure 4-22. Histogram of Estimated Delta Outflows with 30 Sampling Combinations of Major Model Parameters and Inputs

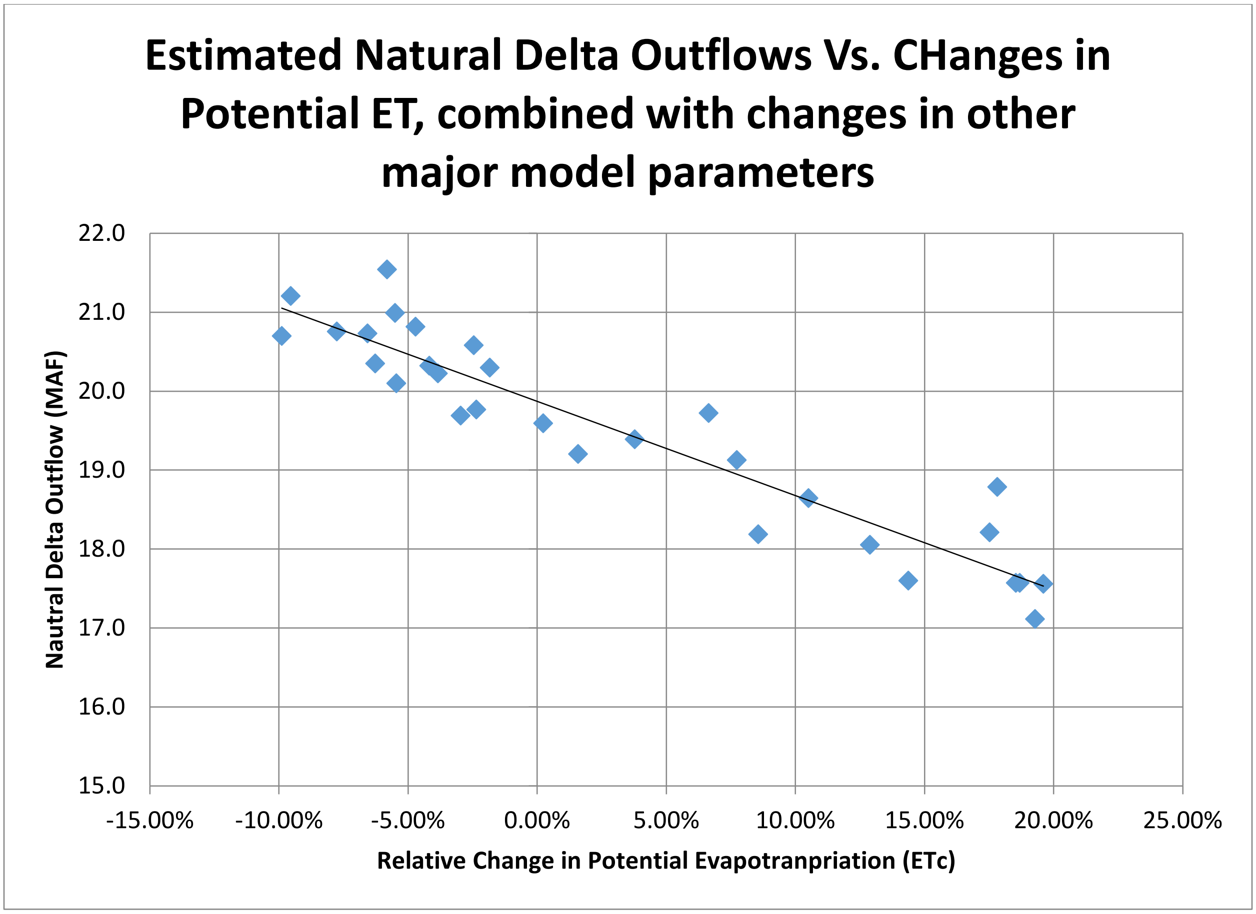


Figure 4-23. Sensitivity of Delta Outflow to Model Inputs and Parameters

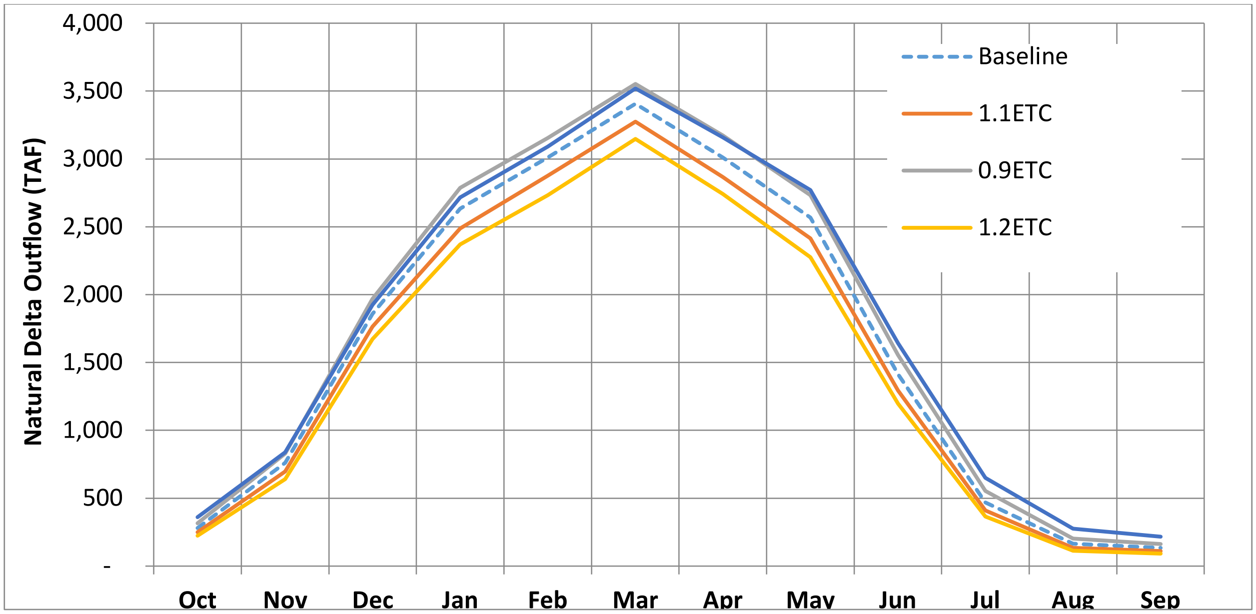


Figure 4-24. Monthly Distribution of Estimated Delta Outflow under Different Assumptions

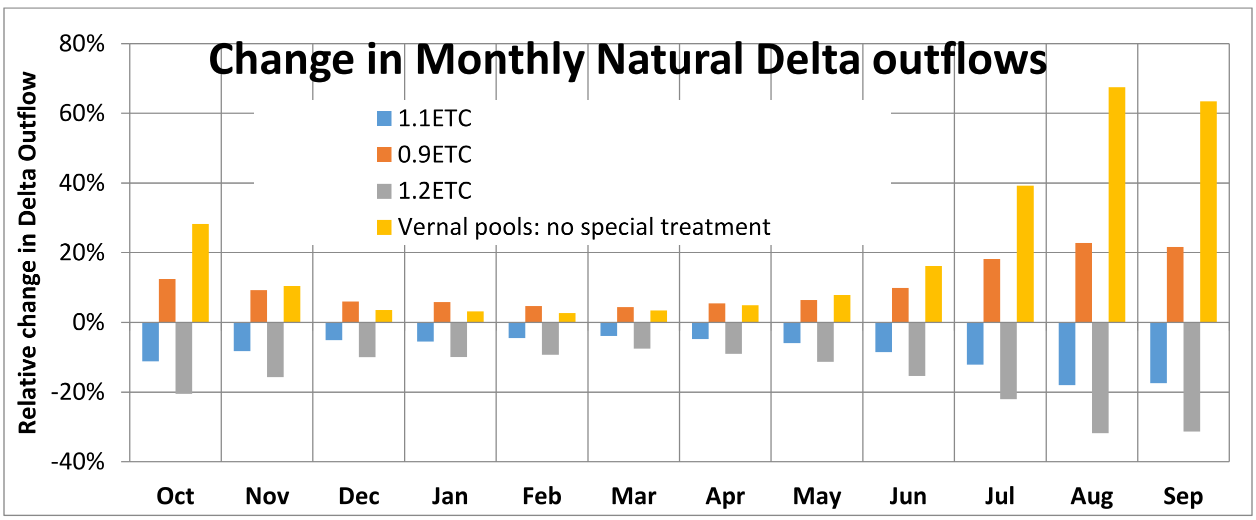


Figure 4-25. Changes in Monthly Delta Outflows for Different Sensitivity Model Runs

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5. COMPARISON BETWEEN NATURAL FLOWS AND UNIMPAIRED FLOWS

Estimated unimpaired flows reaching the Delta (i.e. Delta inflows) assume current channels and levees and, as a result, do not consider depletions or accretions on the valley floor other than depletions of valley floor rainfall runoff. The unimpaired flows estimates do not account for depletions from riparian vegetation, stream-groundwater interaction, and bank overflow to the flood plains and associated depletions from wetland vegetation. The natural flow estimates presented in this report, on the other hand, take into account all these depletions and accretions. The remainder of this chapter provides comparisons between natural and unimpaired flow estimates for rim watersheds, the valley floor and Delta inflow, and Delta outflow.

Rim Watershed Outflows

Upper rim watersheds, located in the foothill and mountain regions of the Sierra Nevada and California Coast Ranges, are relatively undeveloped. Precipitation-runoff processes are assumed to be assumed unchanged from natural condition for a given climate. Therefore, simulated natural outflows from these watersheds should be similar to estimates of unimpaired flows. As discussed in Chapter 4, the SWAT models used to simulate the upper rim watersheds were calibrated to match unimpaired flows. Table 5-1 compares SWAT simulated natural flows at unimpaired flow subbasin locations with unimpaired flow estimates for Water Years 1922-2014.

Unimpaired rim inflows entering the Valley Floor were not routed through main channels and bypasses. In the Delta, estimated natural inflows from Putah and Cache Creeks are very close numerically to estimated unimpaired flows but stream depletions or accretions from riparian vegetation and stream-groundwater interaction still applied before they directly entered the Yolo basin. Sacramento Valley, Eastside streams and San Joaquin Valley Delta inflows are significantly impaired after flowing through the valley floor before entering the Delta.

Table 5-1. Comparison of Natural and Unimpaired Average Monthly Flows

	Average Monthly Flows (thousand acre-feet)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
UF 2 – Putah near Winters													
SWAT	2	8	47	81	78	61	37	23	14	9	5	3	368
Unimpaired	2	11	55	87	98	68	34	11	4	2	1	0	373
UF 3 – Cache above Rumsey													
SWAT	3	20	58	94	105	90	64	44	26	16	8	3	532
Unimpaired	5	11	52	93	120	109	68	39	23	15	10	6	551
UF 4 – Stony at Black Butte													
SWAT	4	23	75	103	93	81	45	19	7	3	1	1	454
Unimpaired	2	11	50	89	97	77	49	27	9	1	0	0	412
UF 5 – Sacramento Valley West Side Minor Streams													
Elder	1	3	11	14	13	11	5	2	1	0	0	0	61
Thomes	3	8	28	38	41	37	24	14	9	7	5	3	217
SWAT Total	4	12	39	52	55	47	29	16	10	7	5	3	278
Unimpaired	3	15	51	78	90	81	65	40	13	3	1	1	441
UF 6 – Sacramento River near Red Bluff													
Cow	7	23	66	86	86	78	51	33	13	4	2	2	450
Paynes	1	3	8	12	12	9	4	2	1	0	0	0	52
Cottonwood	7	18	72	120	123	111	67	39	18	7	4	4	591
Battle	16	21	33	40	40	41	38	36	27	18	14	14	338
Sacramento at Shasta	233	395	593	635	721	791	630	447	322	263	218	187	5,434
SWAT Simulated	263	459	772	892	983	1029	791	557	380	292	239	208	6,865
Unimpaired Flow	308	441	844	1134	1244	1251	975	704	443	303	259	262	8,168
UF 7 – Sacramento Valley East Side Minor Streams													
Deer	9	26	53	65	67	65	43	28	12	5	3	3	379
Big Chico	3	9	22	28	30	28	19	14	6	2	1	1	162
Butte and Chico	18	28	61	83	95	98	86	65	37	22	18	15	627
Mill	6	18	34	40	39	36	27	20	10	5	3	3	241
SWAT Simulated	36	81	170	216	231	228	175	126	65	34	25	22	1,410
Unimpaired Flow	35	59	128	169	181	182	155	123	72	41	31	28	1,204
UF 8 – Feather River near Oroville													
SWAT Simulated	105	206	393	504	570	710	667	543	318	171	99	72	4,357
Unimpaired Flow	105	184	375	480	539	658	678	627	325	152	101	86	4,310
UF 9 – Yuba River at Smartville													
SWAT Simulated	63	152	262	268	277	310	334	377	200	40	14	15	2,312
Unimpaired Flow	32	87	200	256	285	330	361	404	207	57	23	19	2,261
UF 10 – Bear River near Wheatland													
SWAT Simulated	6	22	45	55	65	62	40	17	5	3	2	2	323
Unimpaired Flow	5	13	41	57	66	61	39	18	7	3	1	2	313

Table 5-1. Comparison of Natural and Unimpaired Average Monthly Flows contd.

	Average Monthly Flows (thousand acre-feet)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
UF 11 – American River at Fair Oaks													
SWAT Simulated	49	136	256	289	290	364	416	477	301	101	28	16	2,724
Unimpaired Flow	25	82	203	288	316	387	441	493	265	67	16	12	2,595
UF 13 – Cosumnes River at Michigan Bar													
SWAT Simulated	3	15	37	47	58	71	66	49	14	3	1	0	364
Unimpaired Flow	2	9	30	54	64	75	65	43	16	4	1	1	364
UF 14 – Mokelumne River at Pardee Reservoir													
SWAT Simulated	15	29	42	43	61	92	116	179	128	21	4	6	734
Unimpaired Flow	6	18	37	51	59	82	125	189	117	26	5	3	718
UF 15 – Calaveras River at Jenny Lind													
SWAT Simulated	1	7	26	40	40	31	21	8	1	0	0	0	176
Unimpaired Flow	1	4	16	31	39	36	22	7	2	1	0	0	159
UF 16 – Stanislaus River at Melones Reservoir													
SWAT Simulated	20	38	52	58	90	145	215	283	174	53	11	10	1,149
Unimpaired Flow	10	26	54	80	93	130	193	279	173	53	12	7	1,110
UF 18 – Tuolumne River at Don Pedro Reservoir													
SWAT Simulated	44	91	155	173	191	248	283	368	270	80	16	18	1,937
Unimpaired Flow	18	46	89	122	142	192	276	444	348	122	26	12	1,837
UF 19 – Merced River at Exchequer Reservoir													
SWAT Simulated	10	32	54	60	78	117	155	213	168	68	9	3	967
Unimpaired Flow	8	19	43	66	82	102	148	240	170	56	13	6	953
UF 20 – Chowchilla River at Buchanan Reservoir													
SWAT Simulated	1	4	12	17	23	23	11	3	1	0	0	0	95
Unimpaired Flow	0	1	6	12	17	17	11	4	1	0	0	0	69
UF 21 – Fresno River near Daulton													
SWAT Simulated	1	6	14	20	28	29	17	5	1	0	0	0	120
Unimpaired Flow	0	2	6	11	16	19	15	9	5	2	0	0	85
UF 22 – San Joaquin River at Millerton Reservoir													
SWAT Simulated	19	45	73	84	113	169	252	403	355	187	54	18	1,772
Unimpaired Flow	20	33	60	83	100	144	237	431	371	167	51	23	1,720

Notes:

[1] In C2VSim, UF 5 includes two separate stream inflows, Thomes Creek and Elder Creek. Furthermore, the Red Bank group and ungauged runoff in UF5 are part of small watersheds in C2VSim.

[2] UF6 includes five separate stream inflows: 1, Sacramento River (Shasta Lake), 2, Cow Creek, 3, Battle Creek, 4, Paynes and Seven mile Creek, 5, Cottonwood Creek, and a few small watersheds with a portion of Valley Floor rainfall-runoff in Subregion 1. Therefore, the sum of C2VSim stream inflows does not add up to unimpaired flow UF6.

[3] UF7 includes separate stream inflows from Mill Creek, Deer Creek and Big Chico Creek and adjacent ungauged runoff.

Key: SWAT = Soil Water Assessment Tool, UF = unimpaired flow

Valley Floor Water Supply and Delta Inflows

The valley floor water supply includes stream inflows from the major rim mountainous watersheds, inflows from the minor small watersheds, and valley floor rainfall. Water supply to the valley floor can be assumed to be the same for natural and unimpaired conditions. However, as previously discussed, natural Delta inflows are significantly reduced from rim inflows because of evaporative use of water from riparian forests, grasslands, and wetlands. Comparisons between natural and unimpaired Delta inflow estimates are provided in Table 5-2.

Table 5-2. Comparison of Natural and Unimpaired Delta Inflows

Flow Items	Average Annual Flows: 1922-2014 (TAF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
	Natural Flow Estimates												
Sacramento Valley	262	792	1,860	2,490	2,727	2,966	2,525	1,973	1,028	348	131	111	17,212
Eastside Streams	14	40	86	106	125	148	149	182	115	15	2	5	986
San Joaquin Valley	35	90	197	263	307	426	522	701	516	196	52	30	3,334
Total Delta Inflows	312	922	2,142	2,859	3,159	3,539	3,195	2,856	1,659	559	185	145	21,533
	Unimpaired Flow Estimates												
Sacramento Valley	526	938	2,092	2,870	3,187	3,333	2,937	2,515	1,375	646	443	416	21,278
Eastside Streams	10	39	119	205	251	278	263	257	140	33	7	5	1,607
San Joaquin Valley	58	133	282	416	509	667	934	1,457	1,102	409	104	48	6,119
Total **Delta Inflows**	594	1,110	2,492	3,492	3,947	4,278	4,134	4,230	2,617	1088	554	469	29,003
Total Difference	-282	-188	-350	-633	-788	-739	-939	-1374	-958	-529	-369	-324	-7,472

Delta Outflow

Table 5-3 compares average annual and monthly natural and unimpaired Delta outflow estimates for the period spanning water years 1922-2014. Average annual estimates are significantly lower for natural conditions (19.7 MAF) relative to unimpaired conditions (28.2 MAF). Figures 5-1 displays a comparison between natural and unimpaired annual values by 40-30-30 water year type. Similarly, Figures 5-2 through 5-7 display comparison between natural and unimpaired monthly values by water year type.

The annual and monthly natural and unimpaired Delta outflow estimates for the period spanning water years 1922-2014 were also compared by plotting exceedance curves. These charts are provided in Appendix D.

Table 5-3. Comparison of Natural Delta Outflow and Delta Outflow in Unimpaired Flow Report

	Average Annual Flows: 1922-2014 (TAF)												
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Natural Net Delta Outflow	280	760	1,859	2,634	3,012	3,406	3,012	2,567	1,414	467	164	133	19,708
Unimpaired Net Delta Outflow	511	1,051	2,450	3,468	3,902	4,198	4,032	4,111	2,492	961	438	369	28,050

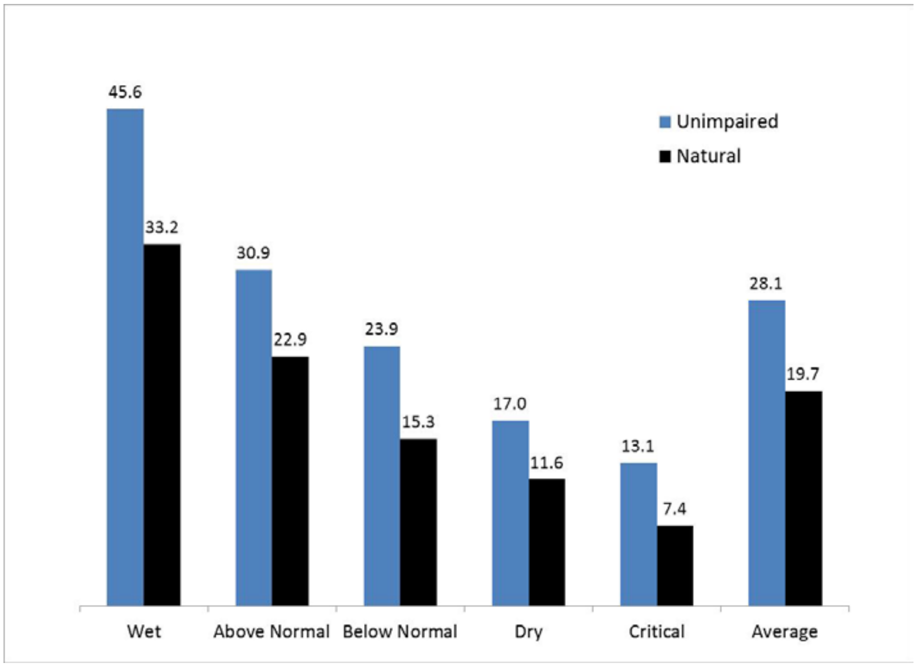

Figure 5-1. Comparison of Annual Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Averages (in MAF)

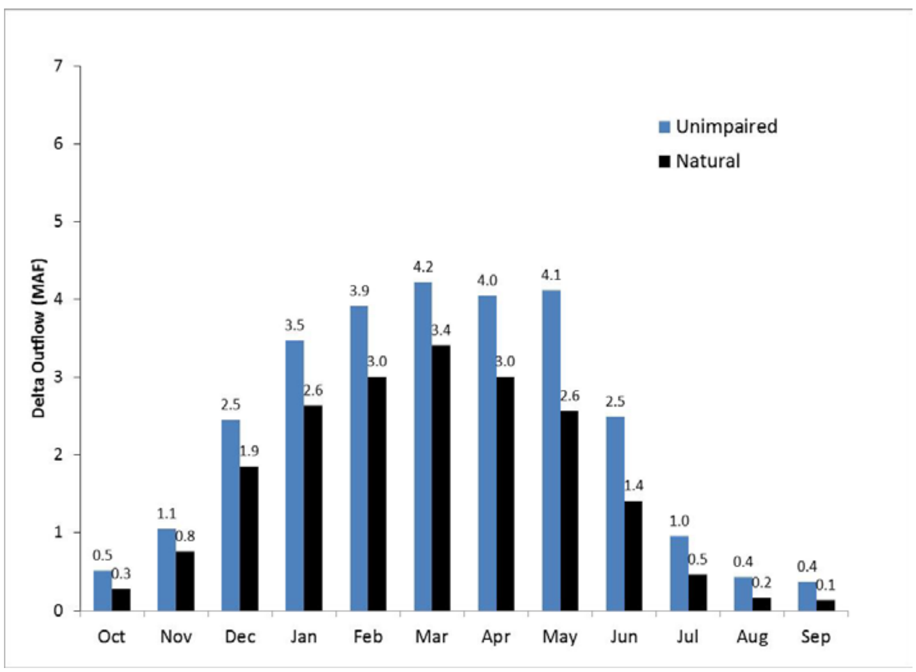

Figure 5-2. Comparison of Monthly Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Averages

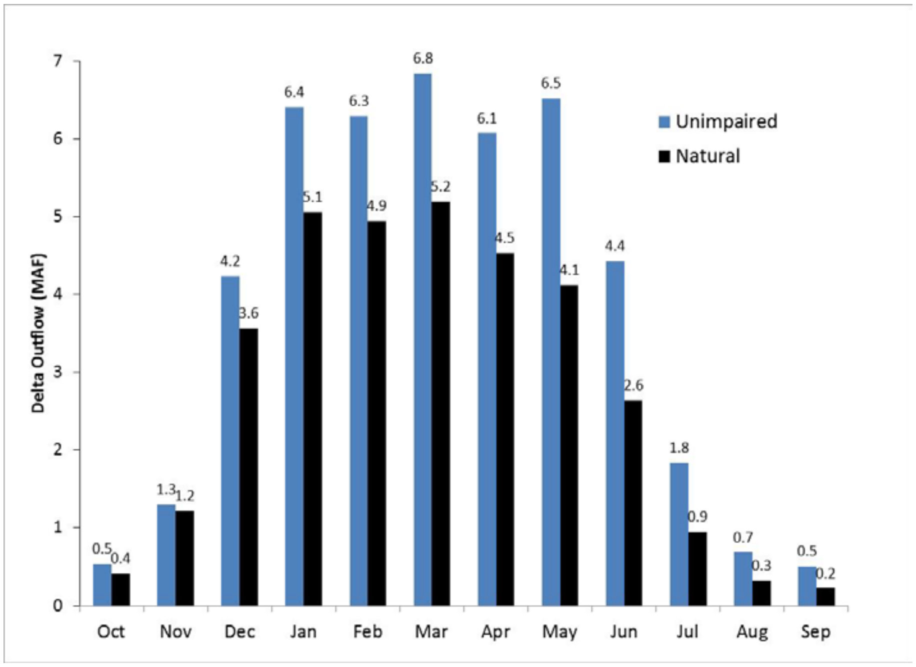

Figure 5-3. Comparison of Monthly Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Wet Year Averages

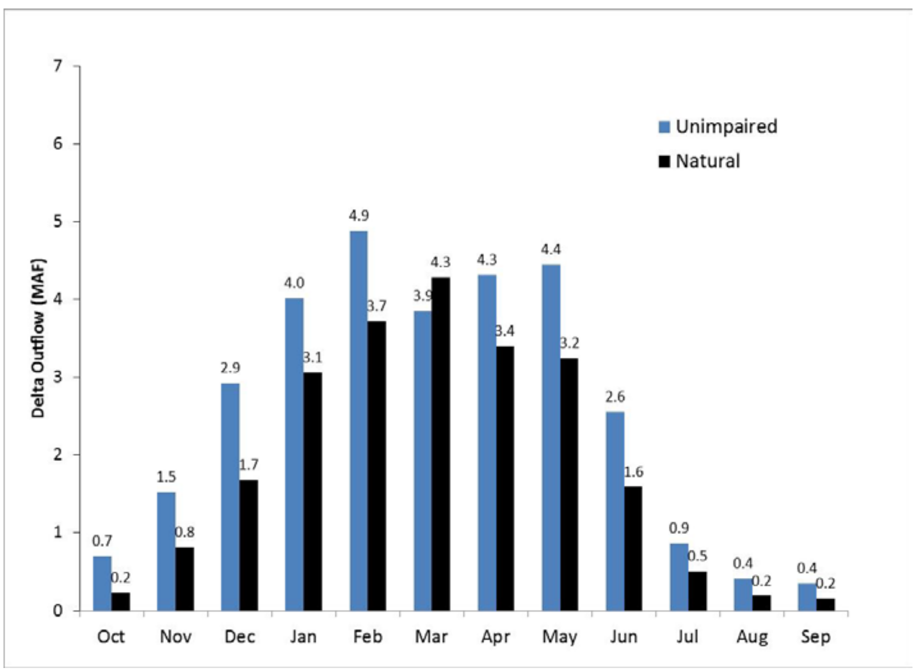

Figure 5-4. Comparison of Monthly Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Above Normal Water Year Averages

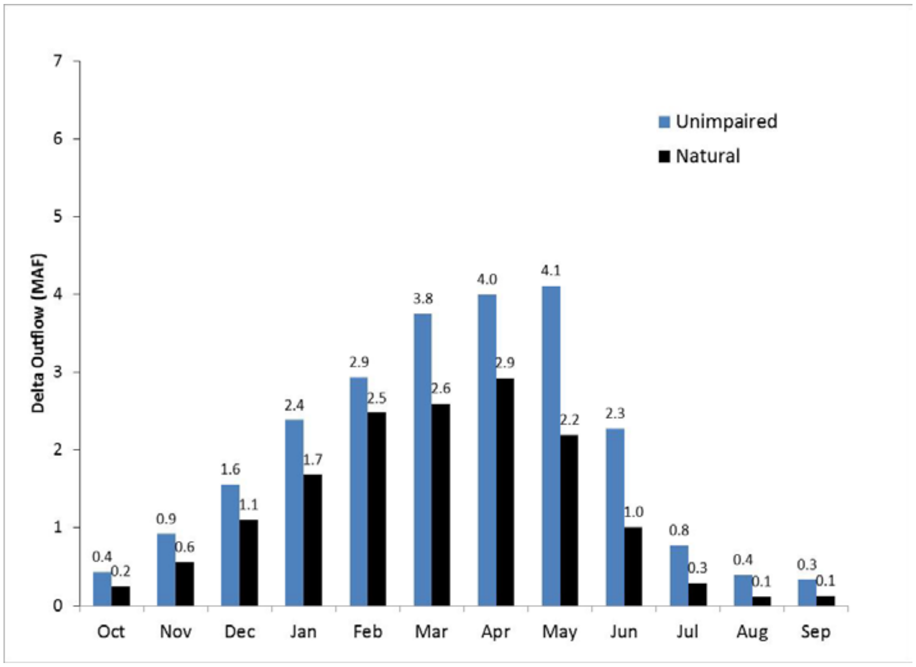

Figure 5-5. Comparison of Monthly Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Below Normal Water Year Averages

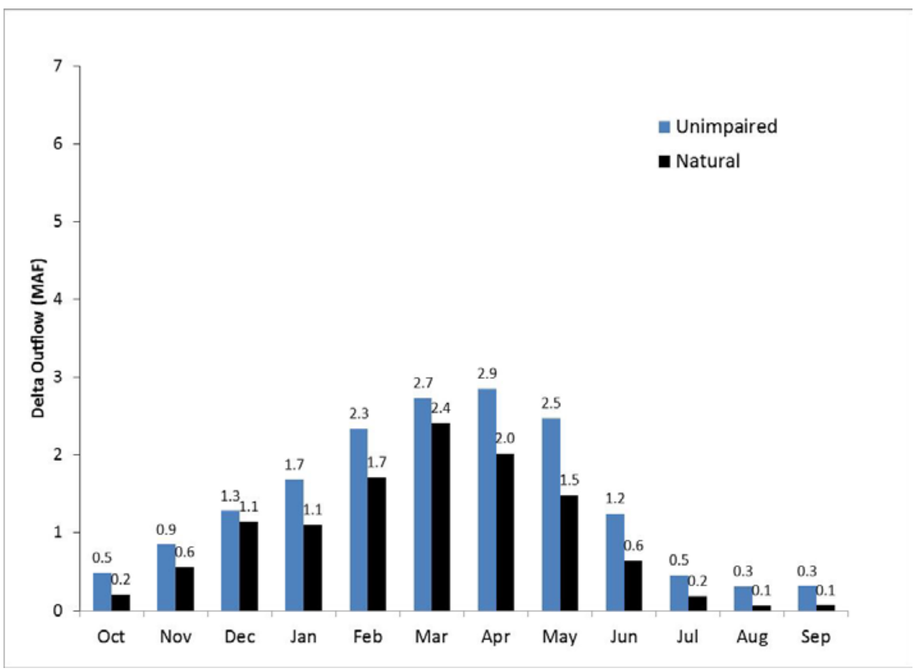

Figure 5-6. Comparison of Monthly Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Dry Water Year Averages

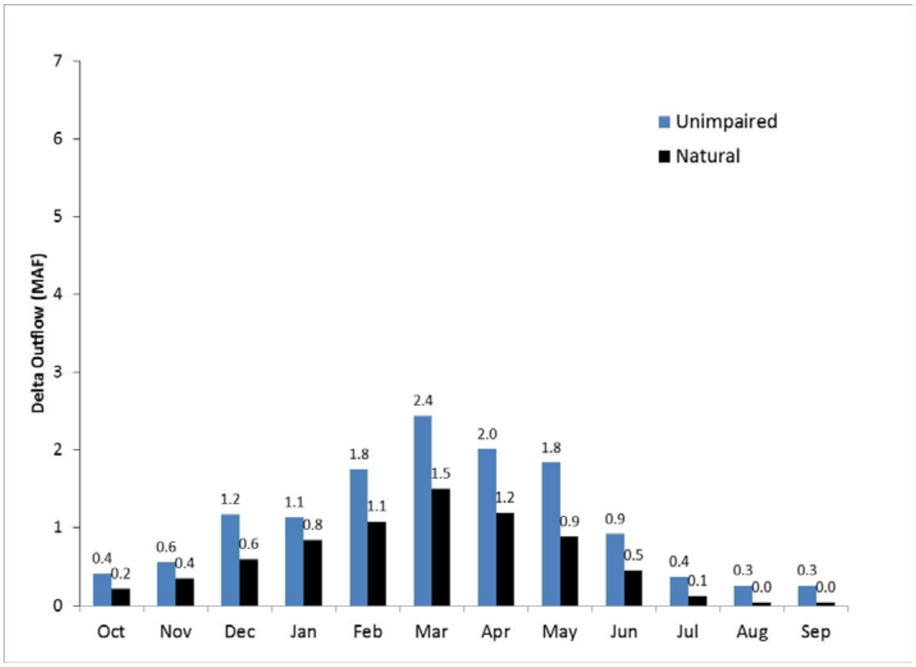

Figure 5-6. Comparison of Monthly Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Critical Water Year Averages

6. SUMMARY

This report documents and compares a variety of natural and unimpaired flow estimates for the hydrologic period spanning water years 1922-2014, including rim watershed inflows, valley floor water supply, and Delta inflows and outflows. The natural flow estimates, the first to be published by the Department, were derived from complex simulation models (SWAT and C2VSim) and were based on published estimates of natural vegetation cover (Fox et al. 2015) and associated evapotranspiration (Howes et al. 2015). Methods used to estimate unimpaired flows generally followed the approach established in previous Department publications; the last update was published in 2007 (DWR 2007).

Comparisons of Delta inflow and outflow estimates demonstrate that unimpaired estimates are consistently (and significantly) higher than natural estimates. This difference is primarily the result of the unimpaired estimates not accounting for overbank flows and the resulting evapotranspiration associated with natural wetlands. The relative seasonal (i.e. monthly) distributions of unimpaired and natural Delta outflow estimates are not widely different. However, the relative distribution of unimpaired Delta outflow tends to be smaller in the winter (and larger in the other seasons) compared to natural Delta outflow. In sum, the findings of this report show that unimpaired flow estimates are poor surrogates for natural flow conditions.

To further evaluate the resulting annual average natural Delta outflow estimate of 19.7 MAF, sensitivity analyses were conducted on potential evapotranspiration, lakebed conductance, extinction depths of groundwater uptake (for riparian forest and hardwoods), and surface runoff and groundwater flow partition parameters. The sensitivity analyses, supported by 30 model runs, suggested an uncertainty range of approximately ± 10 percent. Potential evapotranspiration from riparian and wetland vegetation was found to be the most sensitive model parameter.

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7. REFERENCES

Arnold, J.G., D.N. Moriasi, P.W. Gassman, K.C. Abbaspour, M.J. White, R. Srinivasan, C. Santhi, R.D. Harmel, A. van Griensven, M.W. Van Liew, N. Kannan, M.K. Jha. 2012. SWAT: Model Use, Calibration, and Validation. Transactions of the ASABE. Vol. 55(4): 1491-1508.

Brush, C.F., E.C. Dogrul, and T.N. Kadir. 2013. Development and Calibration of the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG. June.

California State University Chico (CSU Chico). 2003. The Central Valley Historic Mapping Project, Dept. of Geography and Planning and Geographic Information Center, California State University, Chico, California.

Canadell J, R.B. Jackson, J.R. Ehleringer, H.A. Mooney, O.E. Sala, and E.D Schulze. 1996. Maximum rooting depth of vegetation types at the global scale. Oecologia 108:583–595.

Doherty, J. 2015. Calibration and Uncertainty Analysis for Complex Environmental Models. Watermark Numerical Computing, Brisbane, Australia. ISBN: 978-0-9943786-0-6.

DWR. 1980. California Central Valley Natural Flow Data (First Edition). Department of Water Resources, Division of Planning, Sacramento. April.

DWR. 1987. California Central Valley Unimpaired Flow Data (Second Edition). Department of Water Resources, Division of Planning, Sacramento. February 1987.

DWR. 1994. California Central Valley Unimpaired Flow Data (Third Edition). Department of Water Resources, Division of Planning, Sacramento. August 1994.

DWR. 2007. California Central Valley Unimpaired Flow Data (Fourth Edition). Department of Water Resources, Bay-Delta Office, Sacramento. May.

DWR. 2015. Integrated Water Flow Model IWFM -2015 revision 369 Theoretical Documentation. Department of Water Resources, Bay-Delta Office, Sacramento. June.

Fox, P., and L. Sears. 2014. Natural Vegetation in the Central Valley of California, Technical Rep., State Water Contractors and San Luis and Delta-Mendota Water Authority, Los Banos, California.

Fox, P., P.H. Hutton, D.J. Howes, A.J. Draper, and L. Sears. 2015. Reconstructing the Natural Hydrology of the San Francisco Bay-Delta Watershed. Hydrol. Earth Syst. Sci., 19, 4257-4274.

Howes, D., P. Fox, and P. Hutton. 2015. Evapotranspiration from Natural Vegetation in the Central Valley of California: Monthly Grass Reference-Based Vegetation Coefficients and the Dual Crop Coefficient Approach. J. Hydrol. Eng., 10.1061/(ASCE)HE.1943-5584.0001162, 04015004.

Küchler, A.W. 1977. Natural vegetation of California. Terrestrial vegetation of California, J. Major and M.G. Barbour, eds., Wiley, New York.

Orang, M.N., et al. 2013. California simulation of evapotranspiration of applied water and agricultural energy use in California. J. Integr. Agric., 12(8), 1371–1388.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed on July 17, 2015.

Williamson, A.K., D.E. Prudic, and L.A. Swain. 1989. Ground-water flow in the Central Valley, California. Professional Paper 1401-D, U.S. Geological Survey, Reston, Virginia.