Appendix M

SACFEM2013 Manual

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SACFEM2013

Sacramento Valley Finite Element Groundwater Flow Model User's Manual

Prepared for

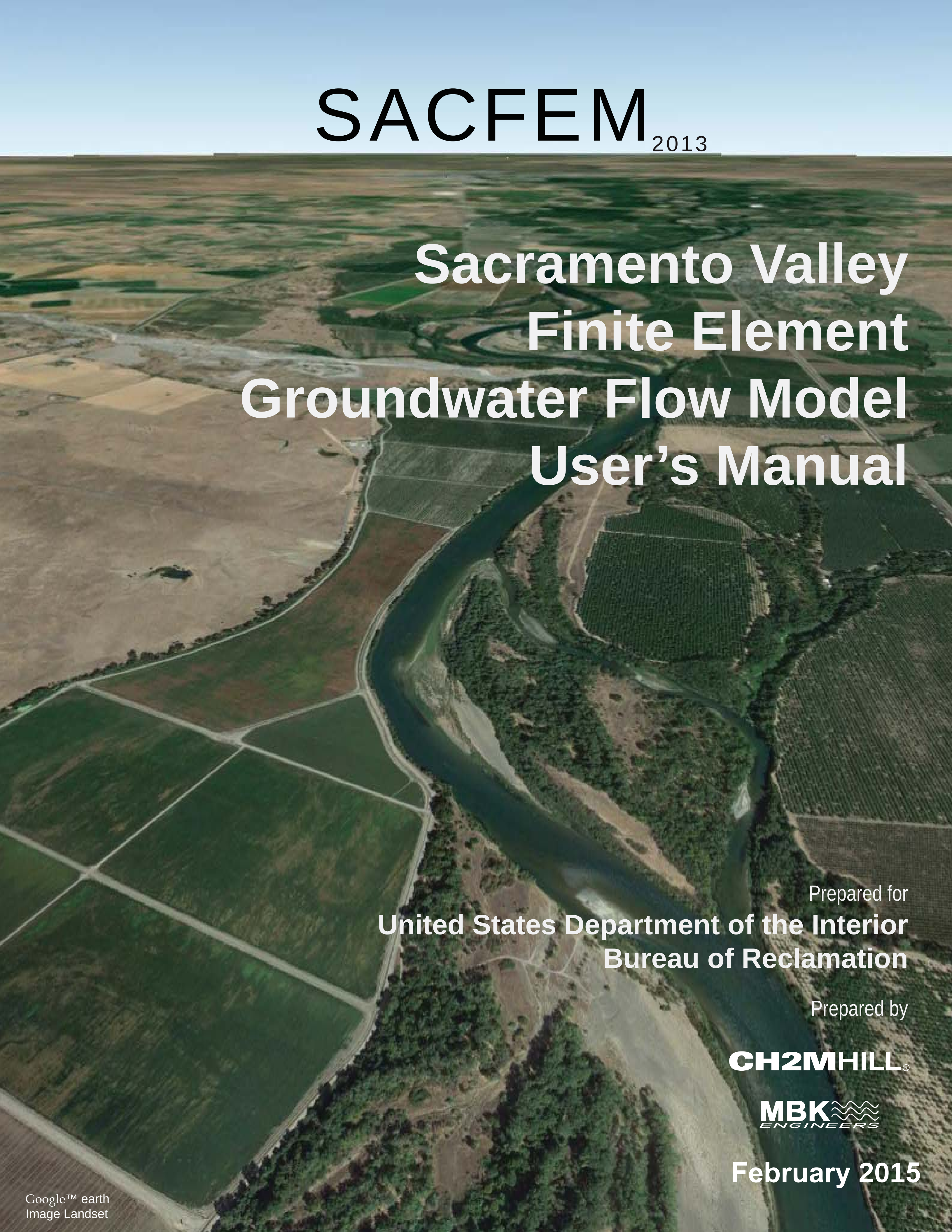
United States Department of the Interior
Bureau of Reclamation

Prepared by

CH2MHILL®

MBK ENGINEERS

February 2015



SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model User's Manual

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Acronyms and Abbreviations

*.fem file	MicroFEM Base-model
*.fpr	SACFEM2013 project file
40-30-30	Sacramento Valley Water Year Type
ac-ft/month	acre-feet per month
AVI	audio video interleave
AWD	applied water demand
bgs	below ground surface
CSM	conceptual site model
DEM	digital elevation model
DWR	Department of Water Resources
ET	evapotranspiration
GIS	geographic information system
gpm	gallons per minute
h1	upper aquifer
IDC	Integrated Water Flow Model Demand Calculator
Kh	horizontal hydraulic conductivity
m	meters
MAF	million acre-feet
ME	Mean error
R^2	Coefficient of determination
RMSE	Root mean squared error
RMSE/Range	RMSE divided by the range of target head values
SACFEM	Sacramento Valley Finite Element Groundwater Flow Model
SVGB	Sacramento Valley Groundwater Basin
USGS	U.S. Geological Survey
WBAs	water budget areas
wh1	user-specified stream stage
wl1	critical depth
WSE	water surface elevation
WY	water year

SECTION 1

Introduction

Implementation of conjunctive water management within the Sacramento Valley is one strategy being used to enhance the reliability of the existing water supply, as well as potentially improve water quality, within the San Francisco Bay-Delta. However, operating conjunctive water management, or groundwater substitution projects, can result in adverse impacts on water resources within the Valley. The two most critical potential impacts of additional groundwater production are depression of local groundwater levels, with associated impacts on well yields from nearby water supply wells, and changes in the hydraulic relationship between the surface water and groundwater systems in the area. To support the evaluation of these potential impacts, a high-resolution, numerical groundwater modeling tool was developed to estimate the impacts of potential future conjunctive water management projects on surface water and groundwater resources within the Sacramento Valley. This model, known as the Sacramento Valley Finite Element Groundwater Flow Model (SACFEM2013), is described herein.

SECTION 2

Sacramento Valley Groundwater Basin Conceptual Site Model Overview

The following briefly summarizes the geology and hydrology of the Sacramento Valley Groundwater Basin (SVGB). The groundwater conceptual site model (CSM) is a theoretical construct that represents primary features of the physical system beneath the Sacramento Valley (Figure 1). The CSM is the primary basis for developing SACFEM2013.

2.1 Geologic Setting

The Sacramento Valley is located in the northern portion of the Great Valley physiographic region of California. The Great Valley is bounded by the Coast Ranges to the west, the Sierra Nevada to the East, and the Klamath Mountains and Cascade Range to the north. The Sacramento Valley is a north-northwestern trending asymmetrical trough filled with as much as 10 miles of both marine and continental rocks and sediment (Page, 1986). On the eastern side, the basin overlies basement bedrock that rises relatively gently to form the Sierra Nevada; on the western side, the underlying basement bedrock rises more steeply to form the Coast Ranges. Marine sandstone, shale, and conglomerate rocks that generally contain brackish or saline water overlie the basement bedrock. The more recent continental deposits, overlying the marine sediments, contain fresh water. These continental deposits are generally 2,000 to 3,000 feet thick (Page, 1986). The depth (below ground surface) to the base of fresh water typically ranges from 1,000 to 3,000 feet (Bertoldi et al., 1991). Three areas of bedrock outcrop are present within the interior of the Sacramento Valley; these include the Sutter Buttes, Black Butte, and the Dunnigan Hills. Descriptions of the major geologic units within the Sacramento Valley are listed in Table 1 (Page, 1986; California Department of Water Resources [DWR], 1978). Figure 2 presents a conceptual geologic section of the Central Valley.

2.2 Hydrogeology

The Sacramento Valley is part of the Sacramento River Hydrologic Region, which covers approximately 27,200 square miles in northern California (Figure 3) (DWR, 2003a). As shown on Figure 3, the Sacramento Valley includes the Redding Groundwater Basin (in the northern portion of the Valley) and the SVGB (in the southern portion of the Valley). The SVGB has been divided into 18 subbasins by DWR, as shown on Figure 3, based on groundwater characteristics, surface water features, and political boundaries (DWR, 2003a). However, from a hydrologic standpoint, these individual groundwater subbasins have a high degree of hydraulic interconnection because the rivers do not always act as barriers to groundwater flow. Therefore, the SVGB functions primarily as a single laterally extensive alluvial aquifer, rather than numerous discrete, smaller groundwater subbasins.

Fresh water in the SVGB is found within the continental deposits described in Section 2.1. Hydrostratigraphic units containing fresh water along the eastern portion of the basin (derived from the Sierra Nevada) are primarily the Tuscan and Mehrten Formations. In the southeastern portion of the SVGB, the Laguna, Riverbank, and Modesto Formations are important sources of fresh water. The primary hydrostratigraphic unit in the western portion of the SVGB is the Tehama Formation, which was derived from the Coast Ranges. As described above, these deeper hydrogeologic units are overlain by younger alluvial and floodplain deposits over the majority of the SVGB.

In the SVGB, surface water and groundwater systems are strongly connected and are highly variable spatially and temporally. Generally, the major trunk streams of the Valley (the Sacramento and Feather Rivers) act as drains and are recharged by groundwater throughout most of the year. The exceptions are areas of depressed groundwater elevations attributable to groundwater pumping (inducing leakage from the rivers) and localized recharge to the groundwater system. In contrast, the upper reaches of tributary streams flowing into the Sacramento River from upland areas are almost all losing streams (they recharge the groundwater system). Some of these transition to gaining streams (they receive groundwater) farther downstream, closer to their confluences with the Sacramento River. Estimates of these surface water/ groundwater exchange rates have been developed for specific reaches on a limited number of streams in the SVGB (U.S. Geological Survey [USGS], 1985), but a comprehensive Valley-wide accounting has not been performed to date.

Figure 4 presents a conceptual diagram of groundwater flow in the SVGB. Under current conditions, groundwater generally flows from the mountains toward the SVGB and then toward the Sacramento River in a southerly direction parallel to the river. Depth to groundwater throughout most of the SVGB averages about 30 feet below ground surface (bgs), with shallower depths along the Sacramento River and greater depths along the basin margins. Seasonal fluctuations in groundwater levels occur due to the recharge from precipitation and snowmelt runoff, associated fluctuations in river stages, and the pumping of groundwater to supply agricultural and municipal demands.

Groundwater level fluctuations reflect changes in the amount of groundwater stored in the aquifer system, which is driven by variability in the magnitude and timing of aquifer recharge and discharge. The primary components of groundwater inflow to the SVGB include the following:

- Groundwater recharge from precipitation
- Groundwater recharge from applied irrigation water
- Groundwater recharge from river, bypass, or lake leakage
- Groundwater recharge along the margin of the basin (mountain front recharge)

The primary components of groundwater outflow from the SVGB include the following:

- Groundwater discharge to land surface (including evapotranspiration, discharge to low-lying stream riparian areas, and discharge to low-lying areas such as the Butte Sinks in the Sutter Basin)
- Groundwater discharge to rivers
- Groundwater discharge to wells

In dry years, groundwater levels gradually decline in many areas because more water is extracted than recharged. During wet years, groundwater levels in the SVGB typically recover because more water is recharged than extracted (DWR, 2003b).-

Except during drought periods, groundwater levels recover to pre-irrigation-season levels each spring. In other words, no extensive areas of depressed groundwater levels exist in the basin except for localized conditions as described below. Historical groundwater level hydrographs suggest that even after extended droughts, groundwater levels in this basin recovered to pre-drought levels within 1 or 2 years after the return of normal rainfall.

As agricultural land use and water demands have intensified over time, groundwater levels in some areas have declined because increases in pumping have exceeded the quantity of local recharge to the groundwater system. This imbalance between pumping and recharge in portions of the Valley has been the motivating force developing supplemental surface water supplies in several areas during the past 30 to 40 years. Examples include Yolo County's construction of Indian Valley Dam on the North Fork of Cache Creek, South Sutter Water District's construction of Camp Far West Reservoir on the Bear River, and Yuba County's construction of New Bullards Bar Dam and Reservoir on the North Yuba River.

Currently, groundwater levels are generally in balance Valley-wide, with pumping matched by recharge from the various sources annually. Some locales show the early signs of persistent declines in groundwater level, including northern Sacramento County, areas near Chico, and on the far west side of the Valley in Glenn County, where water demands are met primarily, and in some locales exclusively, by groundwater.

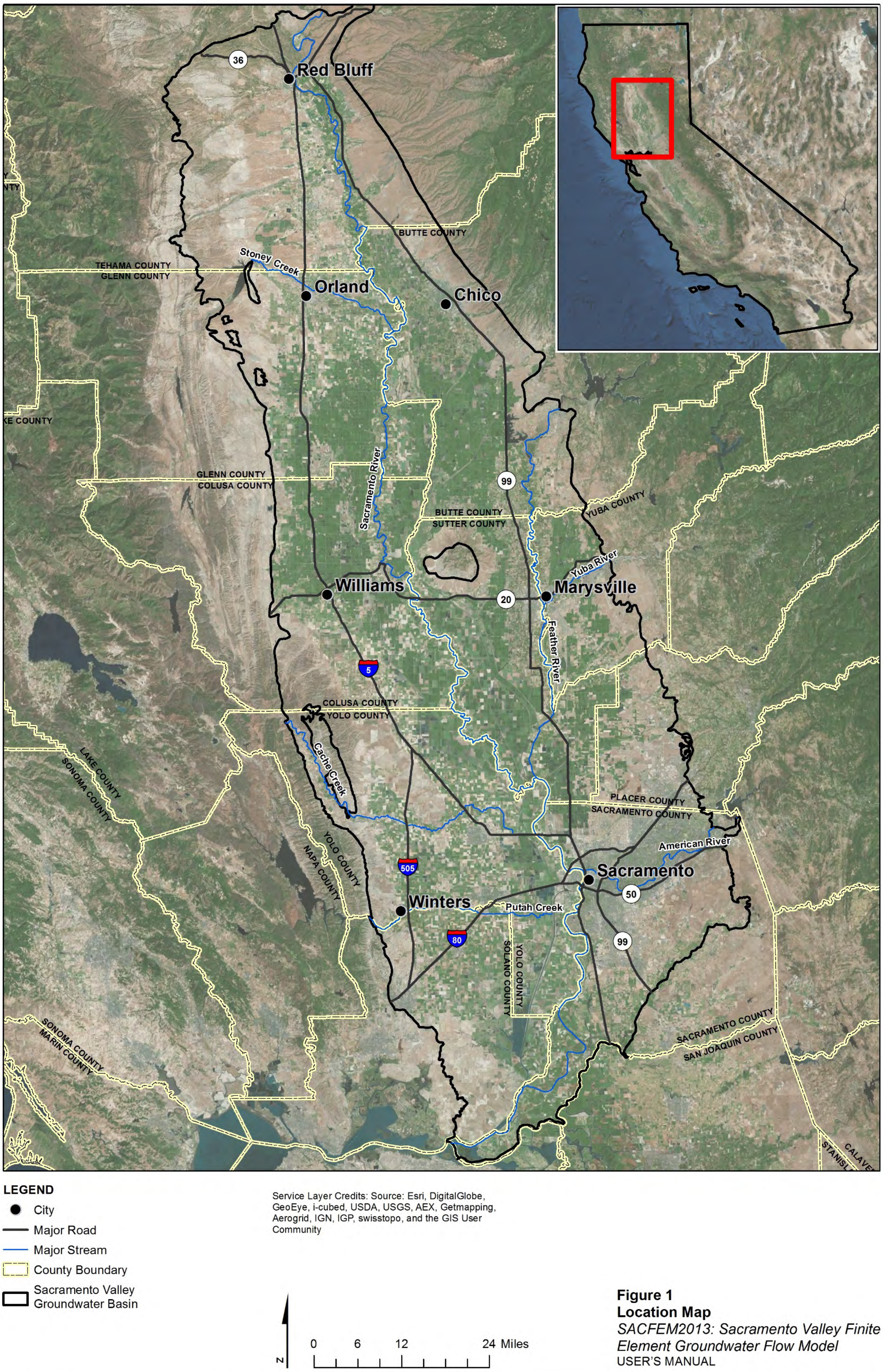

Figure 1
Location Map
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

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TABLE 1
Major Lithologic Units of the Sacramento Valley
SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Geologic Unit	Geologic Age	Description	Water-Bearing Properties
Alluvium	Quaternary (Holocene)	Alluvial deposits not included as fans or flood basin deposits are found throughout the Sacramento Valley and consist of stream channel, natural levee, and floodplain deposits. Alluvium consists primarily of sands and gravel with minor amounts of silt and clay. Large, coarse-grained deposits are associated with larger streams in the Valley.	Stream channel deposits have high yields.
Flood Basin Deposits	Quaternary (Holocene)	Flood basin deposits are found in five distinct basins along the Sacramento River. During flood conditions, silts, clays, and fine sands were deposited in low-lying areas between the natural levees of streams and the alluvial plains on the Valley sides.	Insufficient data, but yields expected to be low given the fine-grained nature of the deposits.
Alluvial Fan Deposits	Quaternary (Pleistocene-Holocene)	Alluvial fan deposits are found along the western side of the Sacramento Valley from Stony Creek southward. Alluvial fans along the eastern side of the Valley are limited to the Chico area. Coalescing fans comprise materials ranging from clay to gravel. Alluvial fans in the Stony Creek and Chico areas contain a high proportion of coarse-grained materials.	Coarse-grained alluvial fans (Stony Creek) have reported yields up to 4,000 gpm. Alluvial fans dominated by finer-grained materials have lower yields.
Victor Formation	Quaternary (Pleistocene)	The Victor Formation is present on the eastern side of the Sacramento Valley where it forms a broad plain. The unit was deposited on a plain of aggradation by shifting streams draining the Sierra Nevada. The Victor Formation consists of stream channel sand and gravel deposits that grade laterally and vertically to silts and clays with a thickness up to 100 feet.	Important water-bearing unit for domestic and shallow irrigation wells. Limited data are available for wells completed entirely in the Victor Formation; yields up to 1,900 gpm are estimated for channel deposits of sand and gravel.
Arroyo Seco Gravel South Fork Gravels Red Bluff Formation	Quaternary (Pleistocene)	Small gravel deposits that form caps to the low hills and dissected uplands along the eastern and western sides of the Sacramento Valley. Gravel deposits are associated with glaciation of the Sierra Nevada and Coast Ranges and are generally either cemented or contain hardpan soils.	Not important water-bearing units, generally found above the regional water table, where units are saturated; well yields are generally low.
Fanglomerate	Quaternary (Pleistocene)	This unnamed geologic unit is restricted to the northeastern portion of the Sacramento Valley (north of Chico). The unit consists of coalescing alluvial fans derived from erosion of outcrops of the Tuscan Formation. The fanglomerates consist predominantly of cemented sand and gravel with large amounts of clay.	Estimated to have low to moderate yields.
Laguna Formation Fair Oaks Formation	Tertiary-Quaternary (Pliocene to middle-Pleistocene)	The Laguna Formation outcrops along the eastern margin of the basin and consists of westward-thickening deposits of silt, clay, and sand with gravel lenses. The Laguna Formation was deposited by streams draining the Sierra Nevada, with primarily granitic and metamorphic mineralogy (little/no volcanics). In portions of Sacramento County, deposits are referred to as the Fair Oaks Formation.	Finer-grained portions of the formation have low well yields. Well sorted sand units have reported well yields up to 1,750 gpm.
Tehama Formation	Tertiary-Quaternary (Pliocene to middle-Pleistocene)	The Tehama Formation occupies entire western portion of the Sacramento Valley and consists of predominantly fine-grained materials (silts and clays) with thin/ discontinuous lenses of sand and gravel derived from erosion of the Coast Ranges and the Klamath Mountains. The relative proportion of coarse-grained materials varies	The Tehama Formation is a principal water-bearing unit in the Sacramento Valley with reported well yields up to 4,000 gpm.

TABLE 1
Major Lithologic Units of the Sacramento Valley
SACFEM2013, Sacramento Valley Finite Element Groundwater Model, User's Manual

Geologic Unit	Geologic Age	Description	Water-Bearing Properties
Tehama Formation (cont'd)		spatially within the unit. The Tehama Formation extends eastward from the Valley margin and interfingers with the Tuscan and Laguna Formations at depth beneath the central portion of the Valley. The average thickness of the unit beneath the western half of the Sacramento Valley is approximately 2,000 feet.	
Mehrten Formation Tuscan Formation	Tertiary (Pliocene)	The Mehrten Formation is a volcanic unit that outcrops primarily along the southeastern margin of the Sacramento Valley. The formation is divided into two units: an upper fluvatile unit of interbedded black sands and blue to brown clay and a lower unit consisting of dense tuff-breccia. The formation dips and thic kens to the southwest. The Tuscan Formation outcrops in the east/northeastern portion of the Sacramento Valley and dips westward. The formation underlies approximately 900 square miles of the Valley. The Tuscan Formation is a wedge-shaped unit that thins from approximately 1,000 to 1,600 feet in the eastern outcrop areas to approximately 300 feet beneath the Valley center where it interfingers with the Tehama Formation. The unit consists of stream-deposited black volcanic sands, tuffaceous clay, and gravel.	The black sands of the Valley Springs Formation yield large quantities of fresh water to wells. The Tuscan Formation is an important water bearing unit in the Sacramento Valley, with reported well yields up to 3,000 gpm.
Valley Springs Formation	Tertiary (Miocene)	The Valley Springs Formation outcrops primarily along the southeastern margin of the Sacramento Valley. The unit consists of southwestward-dipping sequence of rhyolitic ash, clay, sand, and gravel deposited by streams with thickness up to approximately 200 feet.	Fresh water-bearing unit; low yields due to presence of fine-grained materials.
Marine and Continental Deposits (Includes Ione Formation)	Tertiary (Eocene)	Mixed marine and continental sediments deposited in a semi-isolated basin during and following uplift of the Coast Range. With transgression and regression of seas, some deposits contain both marine and sedimentary materials. Ione formation was deposited in a marsh-like environment in the east/southeastern portion of the Sacramento Valley and in fluvatile to marine environments in other portions of the Central Valley. The unit outcrops along the eastern margin of the Sacramento Valley and dips southwestward. The Ione Formation consists of clay, sand, sandstone, and conglomerate up to 400 feet thick.	Largely non-water bearing or saline. Where deposited in near-shore environment, the Ione Formation yields small quantities of fresh water to wells (up to 50 gpm).
Volcanics (Includes Sutter Buttes)	Tertiary	Andesitic and rhyolitic volcanics within interior of the Sacramento Valley.	Primarily non-water-bearing.
Marine Rocks (Includes Chico Formation)	Cretaceous	Outcrop primarily along the western side of the Sacramento Valley. Sedimentary rocks consisting primarily of eastward-dipping (and thickening) sandstones and shales.	Generally contain connate water or yield small volumes.
Basement Rocks	Pre-Tertiary	Igneous and metamorphic rocks that underlie the sedimentary deposits. Outcrops are limited to the eastern portion of the Valley, in the Sierra Nevada, and slope southwest. Igneous rocks include granitics with some mafic intrusions. Metamorphic rocks include metasedimentary, metavolcanic, and undifferentiated metamorphics.	Primarily impermeable boundary at base of groundwater basin; fractures and joints yield small quantities of water.

Notes:

Lithologic descriptions from DWR (1978) and Page (1986)
gpm = gallons per minute

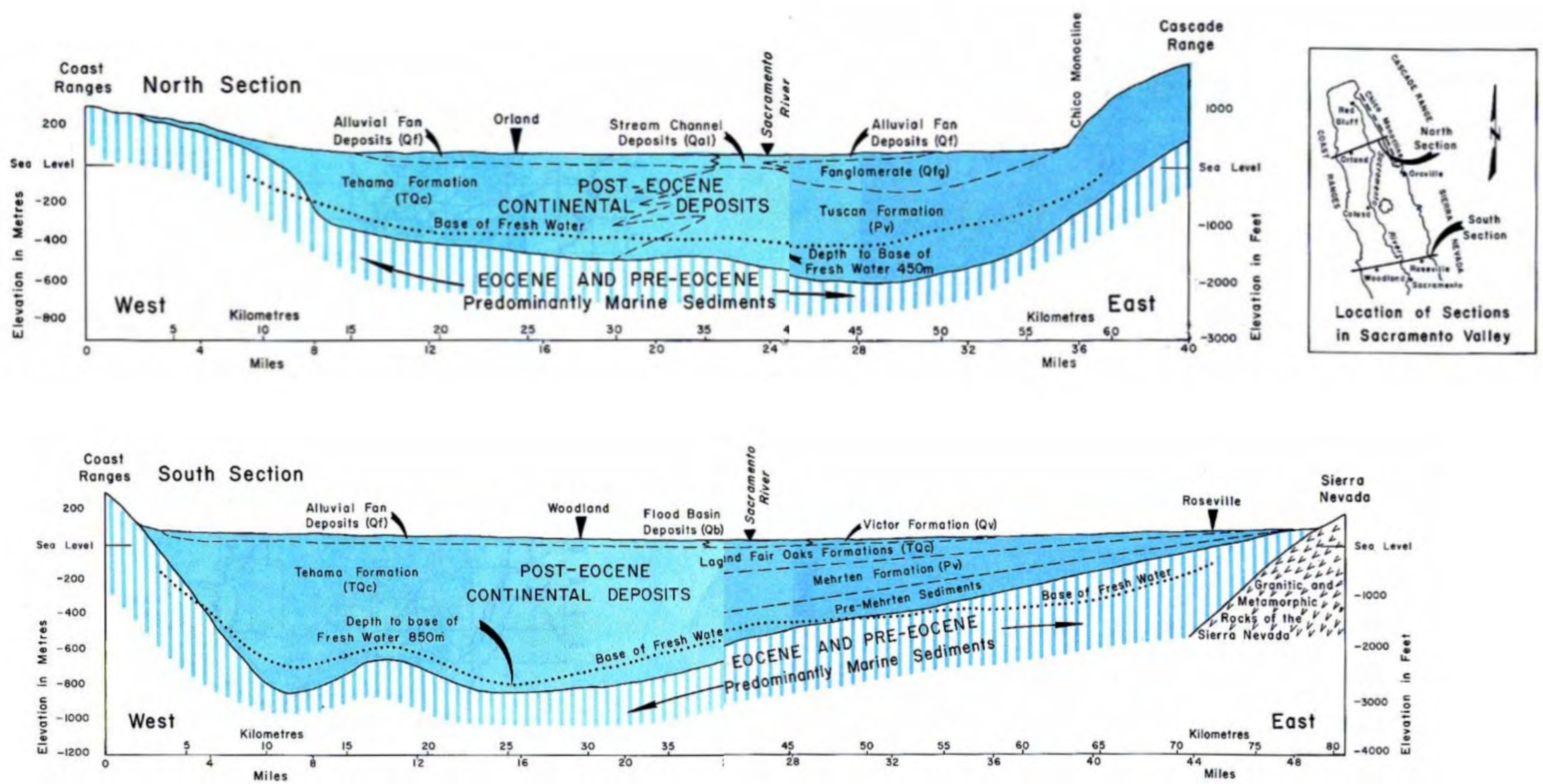
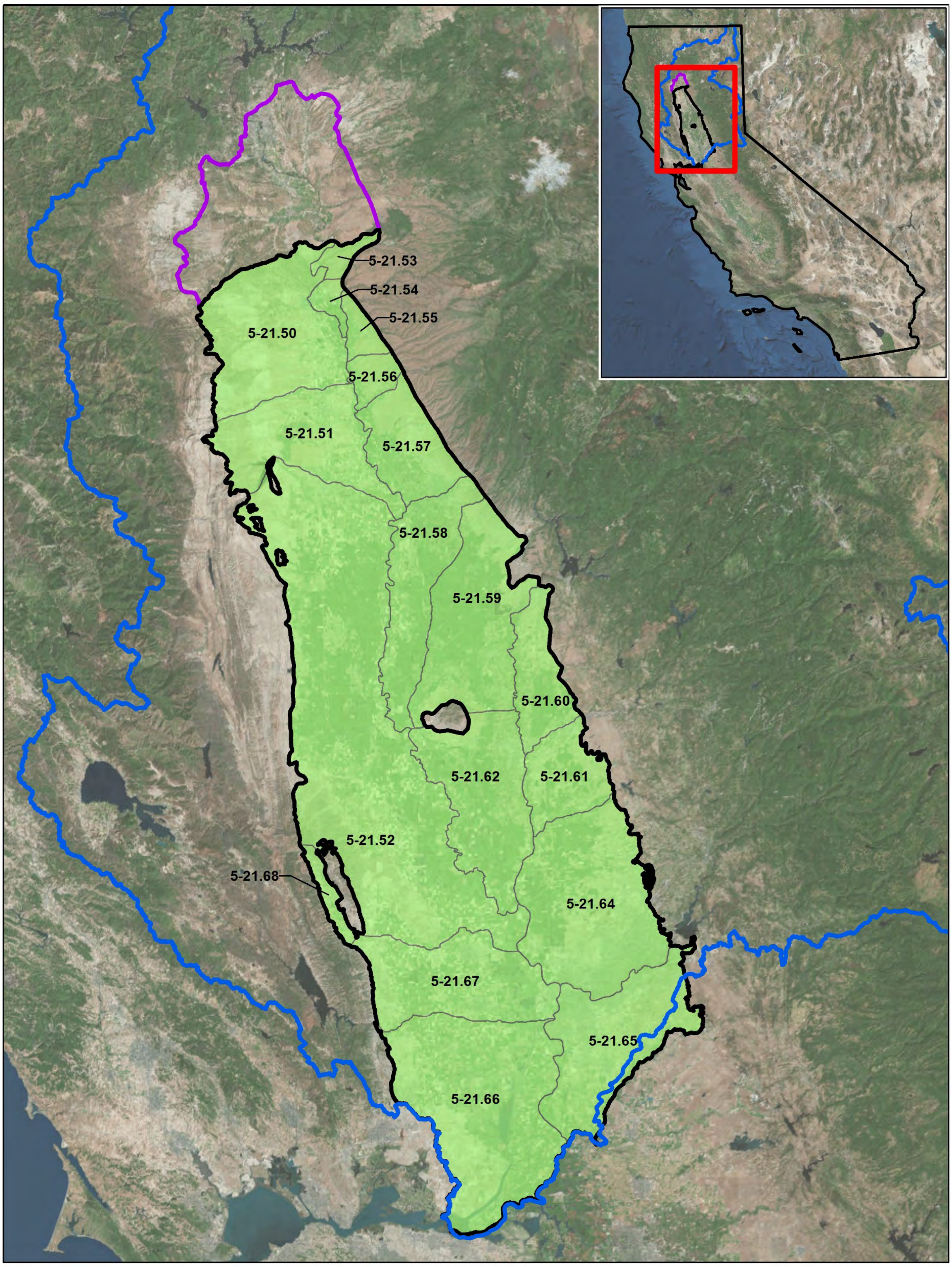


Figure 2
Generalized Geologic Section of the Sacramento Valley
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
USER'S MANUAL

Note:
Figure reproduced from DWR (1978).



LEGEND

- Redding Groundwater Basin
- Sacramento Valley Groundwater Basin
- Sacramento River Hydrologic Region
- Groundwater Subbasin

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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Figure 3
Sacramento Valley Groundwater Basin
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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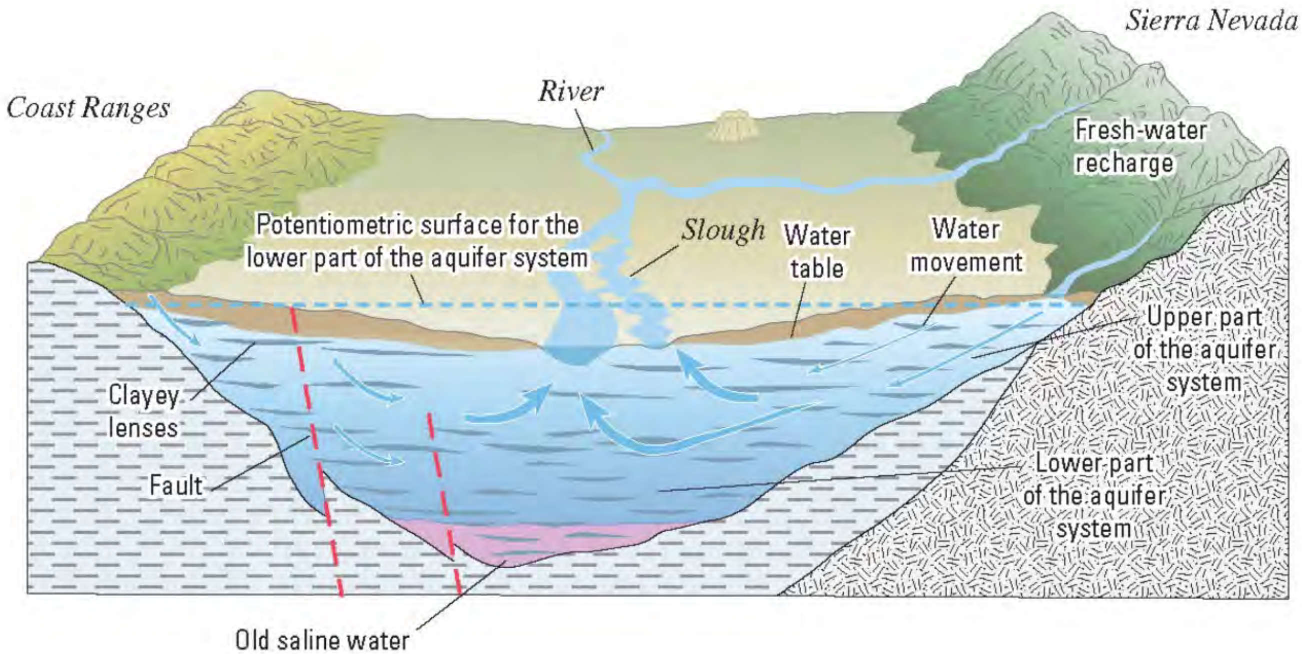

Note:
Figure reproduced from USGS (2009).

Figure 4
Conceptual Diagram of Groundwater Flow in the Sacramento Valley Groundwater Basin
SACFEM2013: Sacramento Valley Finite Element Groundwater Flow Model
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2.3 Regional Hydrology

The SVGB is an area of approximately 3.6 million acres on the Valley floor (Figure 3). The Sacramento River is the main surface water feature in the SVGB. It has several major tributaries draining the Sierra Nevada, including the Feather, Yuba, and American Rivers. Stony, Cache, and Putah Creeks drain the Coast Range and are the main westside tributaries to the Sacramento River. The westside tributaries contribute significantly less stream flow than those on the eastside. The Sacramento River flows south through the center of the Valley before heading west to flow to Suisun Bay.

The Sacramento River and its major tributaries are the main water supply source for much of the area and provide water for urban, agricultural, and environmental uses. The flow of the major rivers and tributaries is managed by reservoir operations of the Central Valley Project, State Water Project, and locally operated projects. Groundwater pumping has been developed in much of the Valley to supplement surface water sources, and in some areas, it is the only source of water. Stream flow data for streams throughout the SVGB are collected at gaging stations operated by California DWR[1] and USGS[2].

The SVGB experiences a Mediterranean climate characterized by cool, wet winters and warm, dry summers. The average annual precipitation on the Valley floor is approximately 22 inches and varies considerably. The majority of the precipitation comes in the winter months from November through March with typically only minimal amounts from June through September. Figure 5 presents a plot of the Sacramento Valley water year[3] (WY) index between WY1970 and WY2010. The WY index is a function of the unimpaired runoff in the hydrologic region and is used to illustrate climatic variability. As shown on Figure 5, the SVGB has experienced prolonged droughts (such as WY1976-WY1977 and WY1987-WY1992) and extremely wet periods (such as WY1982-WY1984 and WY1995-WY1999).

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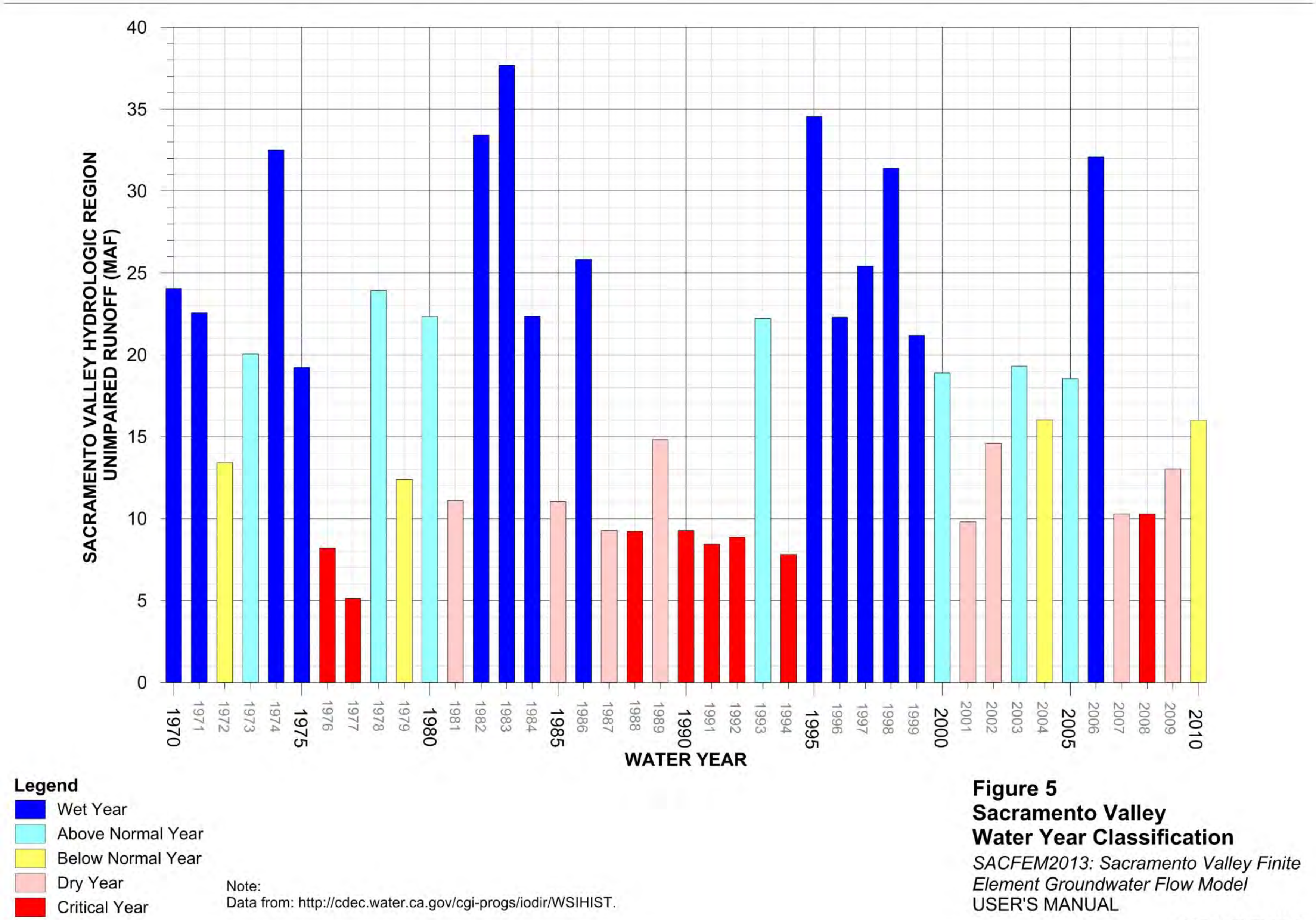
[1] http://cdec.water.ca.gov/

[2] http://waterdata.usgs.gov/nwis

[3] A water year runs from October 1 of the previous calendar year through September 30 of the current calendar year (for example, water year 1970 includes the period of October 1, 1969, through September 30, 1970).



Note:
Data from: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

Figure 5
Sacramento Valley
Water Year Classification
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